3.4　Mahe島における上水道設備を活用したPV導入量拡大の可能性

3.4.1 検討目的

セーシェルの小規模電力系統において、PVの導入が進んだ場合、PVの出力変動に起因する系統周波数への影響等の問題が顕在化することが予想され、セーシェルが再生可能エネルギー導入に関する最終的な目標として掲げる「2030年までに再生可能エネルギー導入率15%」を達成することを妨げる要因となることが懸念される。よって、今後、セーシェルがPVの導入促進を図るためには、PVの出力変動が系統に及ぼす影響を緩和することが必要となる。

また、セーシェルと同様の島嶼地域である沖縄県では、上記の対策の一つとして、宮古島において貯水タンクと揚水ポンプからなる揚水ポンプ制御システムでのPV出力変動抑制手法を実証試験にて確立しており、セーシェルにおいてもPUCが運営・管理する上水道設備のポンプを用いて、PV出力変動を抑制する効果的な仕組みを構築し、PV導入拡大に寄与できる可能性がある。

これらを背景に、沖縄県宮古島の実証試験結果を基に、セーシェルにおける上水道設備を活用したPV出力変動抑制手法を確立した場合の効果について検討した。

3.4.2 宮古島における揚水ポンプ制御システムの概要

沖縄県宮古島にて行われた実証試験にて構築された揚水ポンプ制御システムの概略図を図3.4.2-1に示す。構成される主な機器は、PVアレイ、パワーコンディショナ(PCS)、揚水ポンプ、制御インバータ等であり、制御コントローラーにて、貯水タンクの時間ごとの目標水位を確保しながらPVの出力変動を揚水ポンプの出力変化にて抑制するシステムである。

当該実証試験の報告書では、揚水ポンプ制御システムを宮古島の主要な上下水道設備及び農業用揚水ポンプに導入した場合、ある前提条件下において、沖縄電力㈱が公表している短周期制約によるPV連系可能量を約1.38MW拡大することが可能であると推定している。

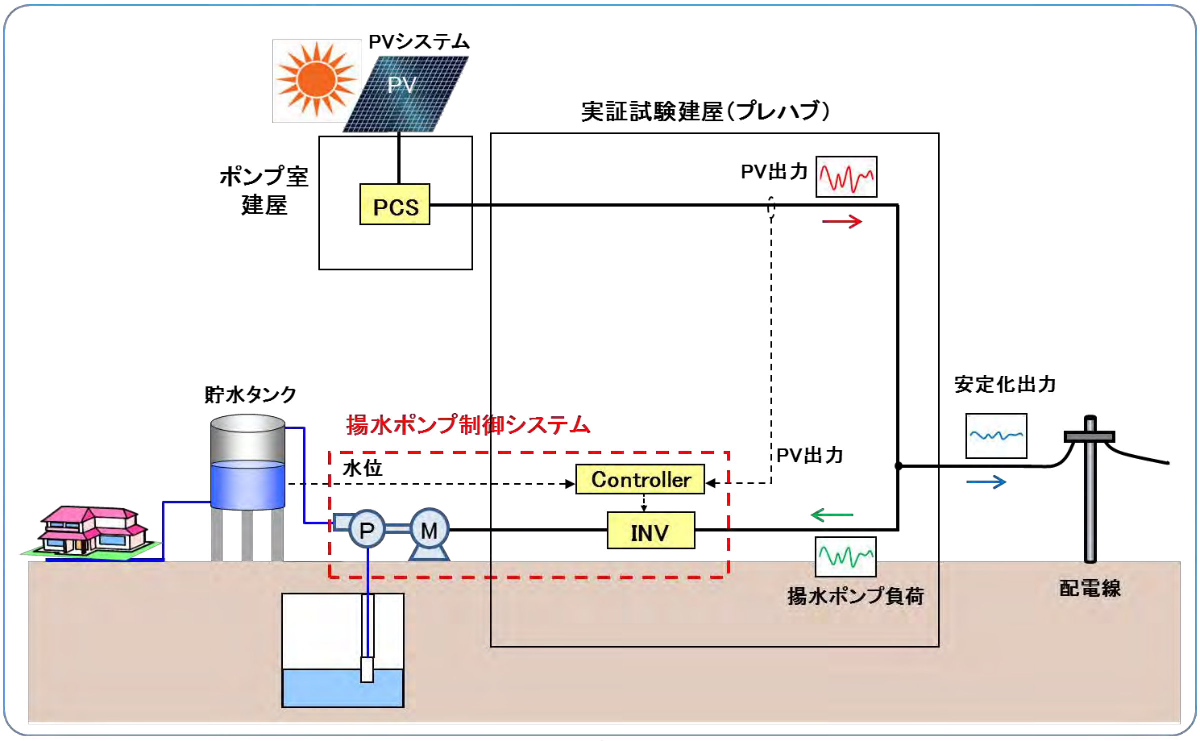

図3.4.2-1. 揚水ポンプ制御システム

表3.4.2-1. 宮古島PV連係可能量試算結果

①	ポンプの容量(MW)	9.10
②	ポンプの可制御容量(MW)	7.28
③	PV連系可能量(MW)(沖縄電力㈱公表値)	9.83
④	PV連系可能量(MW)(ポンプ活用後)	11.21
⑤	PV連系拡大量(MW)	1.38

3.4.3 Mahe島での揚水ポンプ制御システムの活用可能性調査

3.4.3.1 現地調査

沖縄県宮古島の揚水ポンプ制御システムのMahe島における導入可能性を検討するために、上水道設備を管理するPUCから設備情報を提供していただくとともに現地調査を実施した。

Mahe島では、河川を利用したダムが2箇所あり、ダムの水を浄化して自然流下にて貯水池へ送水している。貯水池からは、送水ポンプを用いて中継タンクへ送水し、タンクからは自然流下やポンプを用いて各地域へ送水している。このように、Mahe島では、基本的に高地の水を自然流下で送水しており、送水ポンプは、自然流下できない貯水池から中継タンクへの送水用や各地域への送水用に使用され、Mahe島内に小容量(1.1～30kW)で分散設置されている状況であった。また、これらのポンプで送水するタンクについても満杯に近い状態を維持する運用としているため、ポンプは24時間ほぼ休みなく稼動していた。

これらの状況を勘案すると、Mahe島の上水道設備は、ポンプ容量が小さいとともに多くのポンプが常時稼動している状況であるため、PVの出力抑制用として活用することは難しいと考える。

図3.4.3-1に現地調査状況写真、表3.4.3-1、図3.4.3-2にMahe島における上水道設備の一覧及び島内位置を示す。

現地調査状況写真①　ダム放水口

現地調査状況写真②　貯水池

現地調査状況写真③　送水ポンプ

現地調査状況写真④　PUC聞き取り

図3.4.3-1 現地調査状況写真

表3.4.3-1 Mahe島の上水道設備一覧

Sr No	Pump Station	No of Pumps	Capacity m³/hr per Pump	Pump Details(CR)	Motor Size(kW)	Total Motor Size(kW)	Present Operation
1	Glasis Cemetry	2	45	CR45-6	22	44	02Duty
2	L'llot Glacis	2	3	CR3-19	1.5	3	01 duty 01 Stabdby
3	Carana(Machabee)	2	16	CR16-10	11	22	01 duty 01 Stabdby
4	North East Point (Gopal)	2	16	CR 16-70	7.5	15	01 duty 01 Stabdby
5	NEP Bonta	2	15	CR15-8	7.5	15	01duty 01 stand by
6	North East Point (Village)	2	20	CR 20-8	11	22	02 Duty
7	N.E. Point La Retraite	2	32	CR 32-7	15	30	02 Duty
8	La Retraite(Booster)	2	17	TPD 100-200	5.5	11	01 duty 01 Stabdby
9	La Gogue Village	2	10	CR 10-12	4	8	01 duty 01 Stabdby
10	Maldive Upper	2	15	CR15-9	7.5	15	01 duty 01 Stabdby
11	Maldive Lower	2	32	CR32-8	15	30	01 duty 01 Stabdby
12	Quincy Village	2	64	CR64-6	30	60	01 duty 01 Stabdby
13	Mont Buxton	2	32	CR 32-8	15	30	01 duty 01 Stabdby
14	Mont Signal upper	2	5	CR 5-20	4	8	01 duty 01 Stabdby
15	Dan Lenn	2	8	CR8-8	3	6	01 duty 01 Stabdby
16	Sorento Glacis	2	4	CR4-9	4	8	01 duty 01 Stabdby
17	Mare Anglaise/La Batie	2	32	CR 32-10	18.5	37	01 duty 01 Stabdby
18	Mare Anglaise/Creve Coeur	2	10	CR 10-12	4	8	01 duty 01 Stabdby
19	Mont Simpson/Le Niol	2	10	CR 10-14	4	8	02 Duty
20	Mt Simson Raw water transfer	2	32	CR 32-9	15	30	02 Duty
21	Danzilles(Dan Bernard)	2	8	CR 8-14	5.5	11	01 duty 01 Stabdby
22	Dan Gala Le Niol	2	8	CR8-10	4	8	01 duty 01 Stabdby
23	Le Niol Treatment Works	2	5	CR5-18	3	6	02 Duty
24	Rochon Treatment	3	45	Caprari	30	90	02 duty 01 Stabdby
25	Salazie Pump Stn	3	54	Caprari	75	225	02 duty 01 Stabdby
26	Port Glaud- Foret noire)	1	16	CR16-7	7.5	7.5	01 Duty
27	Port Launay Pressure Filter Station	4	64	CR 64-3	18.5	74	03 Duty 01 standby
28	Port Glaud/Mahe Beach	3	64	CR64-5	30	90	03 Duty
29	Beoliere(upper)	2	5	CR5-18/CR3-15	3/1.1	4.1	02 Duty
30	Beoliere Lower1	2	5	CR5-20	4	8	01 duty 01 Stabdby
31	Beoliere Lower2/Beoliere Upper	2	32	CR32-7	15	30	02 Duty
32	La Misere Satellite	2	64	CR64-5	30	60	01 duty 01 Stabdby
33	Fairview Lower/Satalite	2	20	CRN20-7	7.5	15	01 duty 01 Stabdby
34	Fairview Lower/Upper	2	8	CR8-50	2.2	4.4	02 Duty
35	Fair view Upper	2	10	CR10-9	3	6	01 duty 01 Stabdby
36	Basin Rouge	2	32	CR32-7	15	30	01 duty 01 Stabdby
37	Basin Bleu	2	32	CR32-7	15	30	01 duty 01 Stabdby
38	Copolia Pumping Station	2	10	CR10-14	5.5	11	01 duty 01 Stabdby
39	Barbaron Land Bank	2	16	CR16-5	5.5	11	01 duty 01 Stabdby
40	Hermitage	3	64	CR64-4	22	66	3 Duty
41	Cascade(cemetery)	2	32	CR32-7	15	30	01 duty 01 Stabdby
42	Cascade(UPPER)	1	4	CR4-16	3	3	01 Duty
43	Anse Des Genets	2	15	CR15-9	7.5	15	01 duty 01 Stabdby
44	Point La Rue(Nageon Estate)	2	45	CR45-6	22	44	02 Duty
45	Point La Rue Upper(Dan Santol)	2	10	CR10-9/CR20	4/7.5	11.5	02 Duty
46	Bodamier Lower(Dan Tol)A/s Pin	2	20	CR20-8	11	22	01 duty 01 Stabdby
47	Dan Bodamier upper A/s aux Pin	1	30	CR30-8	15	15	01 Duty
48	Anse Royal Treatment/Mt Plaisir	1	45	CR45-4	18.5	18.5	01 Duty
49	Les Cannelle	2	64	CR64-6	30	60	01 duty 01 Stabdby
50	Santa Maria	3	64	CR64-4	22	66	03 Duty
51	Bougainville	2	8	CR8-8	3	6	01 duty 01 Stabdby
52	Fairy land	2	8	CR8-14	5.5	11	01 duty 01 Stabdby
53	Anse Forban Pump Stn	3	32	CR32-6	11	33	01duty 01 stand by
54	Intendence(Takamaka)	2	16	CR16-10	11	22	02 duty
55	Val D'endor Pressure Filter	2	32	CR32-7	15	30	01duty 01 stand by
56	Baie Lazare /Anse Soleil	1	32	CR32-6	11	11	01 duty
57	Baie Lazare	2	8	CR 8-16	5.5	11	02 Duty
58	Dam Le Roi/Au Sed	2	4	CR4-12	2.2	4.4	01duty 01 stand by
59	Dam Le va	2	10	CR10-14	5.5	11	01duty 01 stand by
60	Quatre Bornes Treatment Works	2	16	CR16-10	11	22	02 Duty
61	Ex Hunt	2	15	CR15-10	11	22	01duty 01 stand by
62	Ex Albert	2	20	CR20-7	7.5	15	02 Duty
63	Anse Louis	2	32	CR32-8	15	30	01duty 01 stand by
64	Mt Posee 1	2	15	CR15-9	7.5	15	01duty 01 stand by
65	Mt Posee 2	2	15	CR15-8	7.5	15	01duty 01 stand by
66	Mt Posee 3 (Prison)	1	32	CR32-6	11	11	01duty 01 stand by
67	Montange Posse	2	15	CR15-9	7.5	15	01duty 01 stand by
68	Tar Plant	2	15	CR 15-8	7.5	15	01duty 01 stand by
69	Maconstance/Hanga	2	5	CR5-24	4	8	02 Duty
70	Caiman raw water	2	45	CR45-7	30	60	01duty 01 stand by
71	Laurencine(STA)	2	15	CR 15-12	11	22	01duty 01 stand by
72	Muscat/La Misere	1	20	CR 20-4	5.5	5.5	01 Duty
73	La Misere/New Filter Pstn	1	5	CR 5-20	4	4	01 Duty
74	Providence/Cascarde	3	60	Lowra	30	90	03 Duty
75	Ill Persiverence/Quincy 1000lts tank	3	45	CRN45-7	30	90	03 Duty
76	Macabee/Bowse unload	1	45	CR 45-3	11	11	01 Duty
77	Belombre Desalination	3	24	Lowra	11	33	03 Duty
78	Sava Sava Farm	1	10	CR45-4	15	15	01 Duty
79	Roche Bois	2	10	CR10 -14	7.5	15	01duty 01 stand by
80	Mont Signal Lower	2	8	CR8-11	5.5	11	01duty 01 stand by
81	Anse aux Pin Treatment	1	20	CR 20-14	11	11	01 Duty
82	Rochon/ Sans Souci	2	8	CR 8-6	2.2	4.4	01duty 01 stand by
83	Sailfish	2	2	CR 2-18	2.2	4.4	01duty 01 stand by
84	Calvert	1	3	CR 3-8	4	4	01 Duty
					total	2,170	

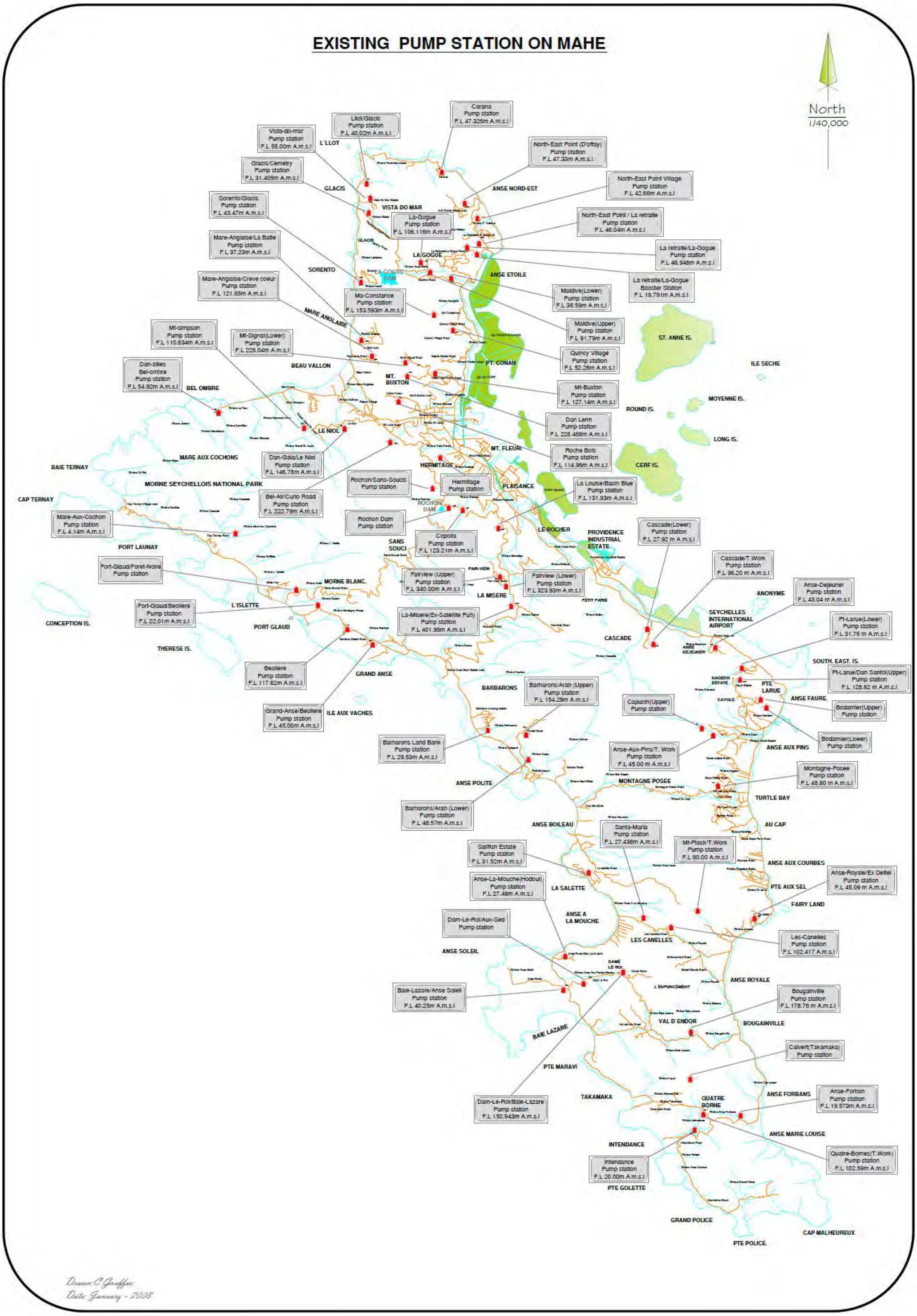

図3.4.3-2 Mahe島の上水道設備位置図

3.4.3.2　PV拡大量試算

現地調査において、Mahe島のポンプは、設備容量が小さいとともに常時稼動しているため、揚水ポンプ制御システム用として活用することは困難である状況であったが、仮にこれらのポンプが当該システム用として活用できる場合を想定し、表3.4.3-1のポンプのうち、比較的容量が大きい定格容量30kWのポンプ20基(総容量600kW)を活用することと仮定し試算を行った。

【試算条件(前提条件)】

①PUCが運営・管理する8箇所の上水道用ポンプ(30kW×20基＝600kW)を活用する。
②揚水ポンプ制御システムは、原則、PVの発電出力を取込む。
③ポンプのモータは、すべて可変速モータ(インバータ化)である。
④水運用についての制約は考慮しない。(PV出力変動抑制のためのみに活用)
⑤試算に用いる縮小率は、宮古島の実証試験結果の値(PVとポンプ揚水容量比に対する縮小率を線
形近似)を代用する。

【試算結果】

試算結果を表3.4.3-2に示す。Mahe島において上下水道用ポンプを揚水ポンプ制御システム用として活用した場合、第3章の「3.1.3.5代数的手法によるRE連系許容量算定結果」で算定した短周期制約におけるPV連系可能量を約0.12MW引き下げることとなり、PV導入拡大に寄与できない結果となった。

表3.4.3-2 Mahe島PV接続可能量試算結果

ポンプ容量(MW)	Prated	0.6
可制御容量(MW)	Pactive	0.48
PV連系可能量ー短周期制約(MW)	K	1.60
線形近似係数	α	0.62
	β	-27.99
ポンプ活用後のPV連系可能量(MW)	PpV	1.48
PV拡大量(MW)	ΔPpv	-0.12

➢各種計算式

・出力変動縮小率 Rm＝$\dfrac{(PV出力変動幅－系統出力変動幅)}{PV出力変動幅}\times 100$

＝αX＋β　・・・①　※線形近似（図3.4.3-3）

（X：PV容量に対する過制御負荷容量比率　α：線形近似係数　β：　）

・Mahe島ポンプ容量合計 Prated　（0.6MW）

・可制御容量 Pactive＝0.8×Prated　・・・②

・PV連系可能量（短周期制約）K

（※第3章 3.1.3.5代数的手法によるRE連系許容量算定結果 参照）

・ポンプ活用後のPV連系可能量 Ppv＝$\dfrac{K}{100-Rm}\times 100$　・・・③

①、②、③式より

$$\therefore\ \ \mathrm{Ppv} = \frac{K+0.8\alpha P_{rated}}{100-\beta}\times 100$$

図3.4.3-3ではPVの出力変動率が小さい場合は系統に与える影響が小さいと想定されることからPV出力変動が10%以下、20%以下は除外する2パターンのデータにより線形近似を行っている。表3.4.3-2の試算ではPV出力変動が10%以下を除外したパターンを採用した。

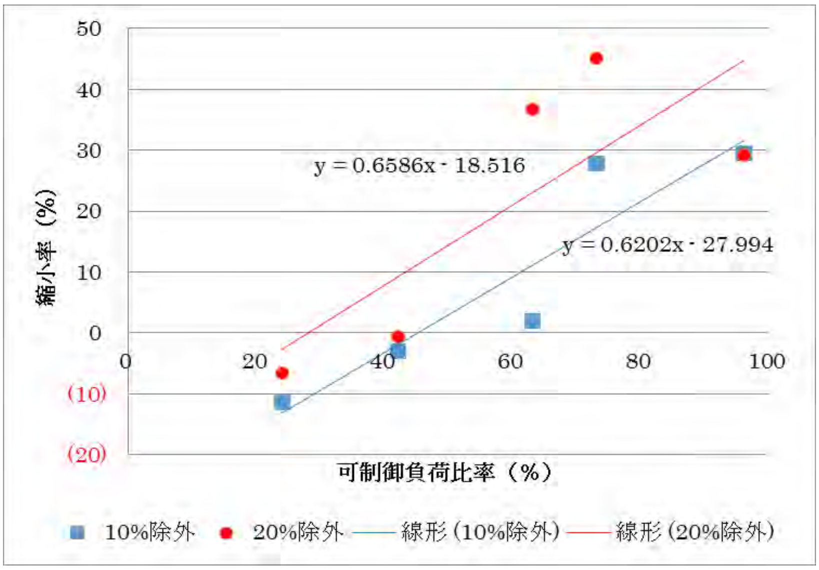

図 3.4.3-3　縮小率と可制御負荷比率の関係（線形近似）（宮古島実証試験結果）

3.4.3.3 まとめ

Mahe島においては、沖縄県宮古島にて行われた実証試験にて構築された揚水ポンプ制御システムの導入は、現地調査及び試算結果から困難であることが分かった。

さらに、揚水ポンプ制御システムは、システムへのPV発電出力の取込みが必要であるため、島内の当該システムに活用するポンプそれぞれの近傍に適当容量のPVを分散設置することとなり、敷地確保の問題や設備導入費用が高額となることが想定される。

また、図3.4.3-4に示す通り、Mahe島において揚水ポンプ制御システムでPV連系量を拡大させるためには、約0.90MWを超えるポンプ容量が必要となる。現在のMahe島における上水道設備の全ポンプの総容量は、2.17MW(表3.4.3-1)であり0.90MW以上の容量を有しているが、設備単体の容量が小さいことや稼動状況を考慮すると、現状では揚水ポンプ制御システム用として活用することは難しく、今後、水需要が増加したり、分散した上水道設備を集中させたり(ポンプ単体容量増大化)するなど、現状が大きく変化した場合に導入可能となると考える。

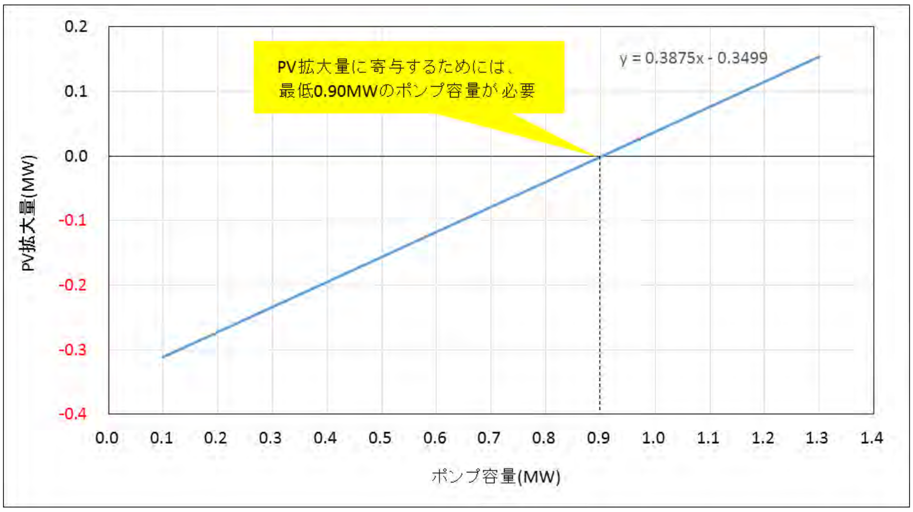

図3.4.3-4 Mahe島 ポンプ容量に対するPV拡大量

3.5 離島マイクログリッド安定運用に係る制度整備支援

3.5.1 系統連系ガイドライン

送配電系統に分散的に接続された発電システムが、系統側に電力を供給（逆潮流）する場合には、分散型電源の故障や発電量、さらには発電された電力の品質が、電力系統とその系統から電力供給を受けている他の需要家に影響を及ぼすことになる。従って、分散型電源の設置や運転については、所定の基準を守り、公共の安全確保はもとより発電電力の品質確保に努める必要があり、そのために系統連系ガイドラインというものが制定されることになる。

3.5.1.1 系統連系ガイドラインの主な要件

(1) 対象設備

連系する系統の電圧階級・設備構成、一カ所当りの最大容量、連系する発電設備の種類(インバータ、同期/誘導発電機)、逆潮流の有無などにより詳細は異なるが、基本的な要件を以下に示す。

(2) 電圧管理

配電系統においては、系統各所の需要家受電電圧は一定の幅をもった所定の値(日本の場合は 101±6V、202±20V)に維持しなければならない。これは配電用変電所の送り出し電圧の調整を負荷状態に合わせて行なうことで実現されているが、逆潮流を有する分散電源が配電線に接続されると、潮流が変電所方向に流れ、配電線の途中から線路電圧が上昇することになり、線路末端部分で規定電圧を逸脱することもある。このような恐れがある場合には、「進相無効電力制御機能」や「出力制御機能」などの自動電圧調整装置等が必要となる。また、瞬時電圧変動や電圧フリッカの発生についても対策が求められる。

(3) 単独運転検出

分散型電源が無い場合、事故発生時には、配電用変電所の送り出し側遮断器を開放して、配電線を無電圧状態にすることで、事故対応時の電気火災や感電事故の防止を図ってきた。しかし、配電線に分散型電源が接続されると、系統側の事故時にも分散型電源が単独で運転継続する恐れがあり、本来無電圧であるべき範囲が充電された状態となる。この事態を避けるために、系統側遮断と自らの単独運転を検出し、系統から自動的に解列する機能が必要となる。単独運転の検出は、系統から切り離された部分系統内で発電出力と負荷の平衡状態が大きく崩れていれば、過電圧・不足電圧・周波数上昇・周波数低下を検出することで行なえるが、発電出力と負荷がおおむね平衡している場合のために単独検出運転検出機能も別途必要となる。

(4) 力率

電力系統では有効電力だけでなく無効電力も管理する必要があるが、無効電力が多くなる(負荷力率が悪くなる)と、電流が増え、電力損失が増大する。分散型電源設備についても負荷と同様に、受電点における力率を一定以上とすること、かつ系統側からみて進み力率にならないことを求める必要がある。

(5) 高調波

高調波により系統電圧が歪むと、機器の誤動作や、場合によっては電力用コンデンサの焼損ということにもなる。太陽光発電設備の交直変換器(Power Conversion System, PCS)はパワー・エレクトロニクス機器であり、高調波電流発生源となりやすい。電流ひずみ率に関する規定が必要となる。

(6) 保護協調

以下の４つの基本的要求を実現する保護機能が求められる。

- 自らの故障に対しては、その影響を系統に波及させないために、発電設備を即時に系統から解列すること。
- 系統事故に対しては、迅速かつ確実に自らを解列して、単独運転を生じないこと。
- 系統事故の自動再閉路時に、発電設備が確実に系統から解列されていること。
- 連系された系統以外の事故や、系統側の瞬時電圧低下などに対し、発電設備を解列しないで運転継続または自動復旧できるシステムであること。

3.5.1.2 他国事例

(1) 日本

日本の「系統連系ガイドライン」は、昭和 61 年 8 月に資源エネルギー庁公益事業部長通達として定められたが、平成 16 年 10 月に「電気設備技術基準の解釈」と「電力品質確保に係る系統連系技術要件ガイドライン」に再整理され公表された。この二つの指針における分散型電源の系統連系に係る必要部分を中心に、分散型電源を系統に連携する際に遵守すべき事項を、日本電気技術企画委員会がまとめたものが「系統連系規定(JEAC9701-2012)」である。そこでは、通則や用語の定義から始まり、連系に必要となる設備対策として、共通事項、低圧配電線(600V 以下)、高圧配電線(600～7kV)、スポットネットワーク配電線、特別高圧配電線路(7kV 以上)などとの連系要件、電力会社との事前協議やそれに必要となる資料等がまとめられている。

図 3.5.1-1 JET 認証

なお、一般家庭に設置される出力 20kW 未満の太陽光発電設備の保護装置については、(財)電気安全環境研究所(Japan Electrical Safety & Technical Laboratories)において、ガ

イドライン､電気設備基準･解釈および電気用品の技術基準に基づく認証を行なっている[1]。(図 3.5.1-1 参照)

(2) 米国

米国の電力セクターは、

- 送電系統と配電系統とで管轄主体が異なっている[2]
- 電気事業者の数が非常に多い[3]

という特徴があり、系統連系ガイドラインは管轄主体により微妙に異なるが、多くが米国電気電子学会(Institute of Electric and Electronics Engineers, IEEE)1547 シリーズ規格、IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, 28 July, 2003 を基本として定めている。これは系統連系に係る性能、運用、試験、安全そして保守に係る要求を定めたものであり、以下のような 4 つの関連規格がある。

(a) 1547.1-2005, IEEE Standard Conformance Test Procedures for equipment Interconnecting Distributed Resources with Electric Power Systems
(b) 1547.2-2008, IEEE Application Guide for IEEE Standard 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
(c) 1547.3-2007, IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected With Electric Power Systems
(d) 1547.4-2011: IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

この IEEE1547 シリーズをベースに、米国の電力管轄主体は自らの系統連系ガイドラインを制定している。なお、日本の JET 認証と同様のものとして、UL1741 という認証規格がある。米国での系統連系では、この UL1741 を取得しているインバータ[4]であれば、特に詳細なチェックもなく連系が認められる場合が多い。

(3) 英国

英国では、ガス会社、送電会社、配電会社が 2003 年 10 月 1 日に設立したエネルギーネットワーク協会（ENA: Energy Networks Association）が、分散型電源の系統連系に関連する技術推奨（Engineering Recommendation: ER）を定めている。これは技術基準的な意味合いに近い位置付けを持つ文書であり、法的拘束力は持たないが事実上の連系要件として配電事業者等により採用されている。

系統連系に関係する技術推奨として以下の三つがある。

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[1] http://www.jet.or.jp/products/protection/
[2] 系統の管轄主体は、大まかには、送電系統(州境をまたぐもの)は連邦政府、配電系統(州境をまたがないもの)は各州政府となっている。
[3] 私営(public）、地方公営（municipal public）、連邦営（federal public）、協同組合営(cooperative）を合わせると、3000 以上になる。
[4] http://database.ul.com/cgi-bin/XYV/cgifind.new/LISEXT/1FRAME/index.html で、UL Category Code に QIKH を入れて検索すると UL1741 を取得しているインバータが表示される。

(e) EREC G83/2[5]: 低圧連系の小型電源（SSEG）向け（16A/相以下）

(f) EREC G59/3[6]: それ以上の発電設備（20kV 以下の系統への連系でかつ出力 5MW 以下）

(g) EREC G75: 5MW 以上を対象

(4) オーストラリア

太平洋島嶼国に大きな影響力をもつオーストラリアでは、系統連系に関係する規格として以下の三つがある。

(a) AS 4777.1: Grid connection of energy systems via inverters – Installation requirements
(b) AS 4777.2: Grid connection of energy systems via inverters – Inverter requirements
(c) AS 4777.3: Grid connection of energy systems via inverters – Grid protection requirement

そして実務的には、Clean Energy Council が、PV に関連して、認証を得た機器、小売店、施工業者をウェッブサイト上で公表している[7]。

3.5.1.3 島嶼国

以下に、セーシェル国と同様、島国で人口も少なく系統規模の小さい国々における系統連系ガイドラインの現状と概要を示す。

(1) モルディブ

モルディブは 298km^2 の国土、約 30 万人の人口で、1,006.7/km^2 の人口密度である。GDP は 22.2 億ドル、一人当たり GDP は 6,567 ドルである[8]。

"Guidelines on Technical Requirements for Photovoltaic Grid-connection[9]" が 2013 年 2 月に公表され、以下の事項について連系上の仕様が定められた。

- メーターリング方法
- 力率
- 電圧変動（常時、瞬時)
- 保護リレー
- 単独運転検出(静的、動的)
- 自動復帰機能
- 自動負荷制限と発電出力抑制

[5] https://www.ofgem.gov.uk/sites/default/files/docs/2012/08/er-g83-2-_v5--the-master-09-07-12-inc-ofgem-comments---clean-version_0.pdf
[6] http://www.amps.org.uk/static/assets/downloads/DraftG5931_170914updatev1280115trackchangev4.pdf?attach
[7] http://www.solaraccreditation.com.au/
[8] なおセーシェル国は、455km^2、 9.0 万人、人口密度 197.6/km^2、GNI 1.8 億ドル、一人当り GNI PPP (current international $) は 24,320 ドル、一人当たりの一次エネルギー消費量は 2,410.8kgoe（2007）である（2013 年)。
[9] http://www.energy.gov.mv/v1/wp-content/files/lawsandregulations/Guideline_for_Grid-connected_PV_System_-_Feb_2013.pdf

また、モルディブ電力庁(Maldives Energy Authority, MEA)は "Manual for Photovoltaic Grid-connection Application[10]" を 2013 年 2 月に公表し、対象や手続きについて定めている。その主な項目を以下に示す。

- 系統連系 PV 導入にあたっての申請手続きとフローチャート
- 申請書類、審査、検査シート
- 対象は 1φ 230V, 3φ 400V, 3φ 11kV
- 逆潮防止リレーは設置してもしなくてもよい
- OVR, UVR, OFR, UFR, 単独運転保護装置(能動/受動)

さらに、"POWER PURCHASE AGREEMENT[11]" が 3φ 11kV に対して準備されているが、まだ最終ドラフトの段階である。

(2) トンガ

トンガは 720km² の国土、約 10.5 万人の人口で、145.8/km² の人口密度である。GNI は 3.7 億ドル、一人当たり GNI は 3,580 ドル、一人当たりの一次エネルギー使用量は 567kgoe である。

"POLICY FOR THE CONNECTION OF EMBEDDED GENERATION[12]" が 2013 年 3 月にトンガ電力(Tonga Power Limited , TPL)により公表された。双方向メーターを用いたネット・メーターリングが適用され、10kW 以下とそれより大きな RE について申請手続きとフローチャートがそれぞれ示されている。なお、以下の規格基準類を参照した上で、50Hz +/-1.5% と 230V +/-10%を求めている。

- AS/NZS 3000 Wiring Standards
- AS/NZS 5033 Installation of Photovoltaic (PV) Arrays
- IEEE 1547, Standards for Interconnecting distributed Resources with Electric Power Systems
- EN50160 in regards to power quality
- IEC 61000-6-2 (EMC Immunity) and -4 (EMC Emission)
- AS 4777.1 Grid connect – Installation
- AS/NZS 1768 Lightning Protection
- IEC 61730 PV modules
- Pricing methodology

(3) ソロモン

ソロモンは 28,900km² の国土、約 55.0 万人の人口で、19.0/km² の人口密度である。GDP は 10 億ドル、一人当たり GDP は 1,130 ドル、一人当たりの一次エネルギー使用量は 130kgoe である。

ソロモン電力庁(Solomon Islands Electricity Authority, SIEA) が、"Solar System Connection Manual: Policies, Processes and Forms"を公表しており[13]、その中で系統連系

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10 http://www.energy.gov.mv/v1/wp-content/files/downloads/Manual_for_PV_Grid-connectin_Application_-_Feb_2013.pdf
11 http://www.mea.gov.mv/v1/wp-content/files/downloads/Draft_Standard_Power_Purchasing_Agreement.pdf
12 http://www.tongapower.to/Portals/2/Docs/TPL%20Net%20Billing/TPL%20Net-Billing%20Policy.pdf
13 http://www.siea.com.sb/sites/default/files/Regulatory/SIEA Solar PV System Connection Manual.pdf

上の技術要件を示している。主な事項としては以下のものがある。

- 1φ 230V <=10kVA, 3φ 400V <=30kVA
- 蓄電池利用は基本的になし
- 豪州基準(AS)を参照
- インバータ:は AS4777 に準拠したもので、AS5033 に従って保守
    - 豪州 Clean Energy Council のウェッブサイトに掲載されている製品
    - 設計者・供給業者は豪州 Clean Energy Council ウェッブサイトに掲載されているもの
    - SIEA の申請書類フォームシート
- 単独運転検出
- 210V, 255V (1φ) 440V, 370V (3φ), 54Hz, 46Hz でトリップ
- メーターリングにおける調整

SIEA はまた、"Photovoltaic Inverter Network Connection Agreement, For Connection to SIEA Grid"のドラフト(version 0.5, 2013 年 10 月 20 日)も準備している。Standby Charge を課金する点が特徴的であり、また、系統に逆潮流された電力に対して対価を支払わないことも明言している。

(4) マルタ

マルタは 316km² の国土、約 41.0 万人の人口で、1297.5/km² の人口密度である。GDP は 84.15 億ドル、一人当たり GDP は 19,740 ドル、一人当たりの一次エネルギー使用量は 2,057.9kgoe である。

マルタ政府は太陽光エネルギーの普及拡大に熱心であり、"The Network Code[14], Enemalta, Approved by the Malta Resources Authority, Version 1, October 2013"という明解なガイドラインをもっている。そこでは以下の事項に関する連系要件が示されている。

- 保護と設置上の要求
- 電圧制御
- 短絡容量
- 電圧変動
- 単独運転・待機用発電機
- メーターリング
- 需要予測(適切であれば)
- デマンド・コントロール
- 安全上の協調

(5) モーリシャス

モーリシャスは 2,045km² の国土、約 130.0 万人の人口で、635.7/km² の人口密度である。GNI は 103.4 億ドル、一人当たり GDP は 8,040 ドル、一人当たりの一次エネルギー使用量は 947.3kgoe である。

モーリシャスには、サトウキビの製糖工場が多くあり、バガスを用いたバイオマス発電が昔から系統連系されてきた。現在、中央電力委員会(Central Energy Board, CEB)は、

[14] http://www.enemalta.com.mt/index.aspx?cat=2&art=5&art1=71

“CEB, Grid Code for Small Scale Distributed Generation (SSDG), 9 Dec 2010”、“Customer Guidelines for Grid Connection of Small Scale Distributed Generators (SSDG) up to 50 kW, 9 Dec 2010”、“CEB, SSDG Application Form” and “CEB, SSDG Connection Agreement”[15]などの文書を公表している。小規模分散電源のガイドラインでは、以下のような事項について規定されている。

- LV, <17kW (1φ, 3φ), 50kW> <17kW (3φ)
- 総枠は 2MW or 200 サイト, 一般家庭は 1MW 上限
- 230/400V +/-6%, 50Hz +/-1.5%
- 保護上の要求
- 単独運転、再並列
- 電力品質、力率
- 安全とメーターリング

[15] http://ceb.intnet.mu/grid_code/project.asp

3.5.1.4 PUC の現行連系技術要件

Net Metering 申請時に PUC が求めている SSDG 連系上の技術要件を表 3.5.1-1 に、申請の承認プロセス・フローを図 3.5.1-2 に示す。なお、技術要件はモーリシャスのものをそのまま用いている。

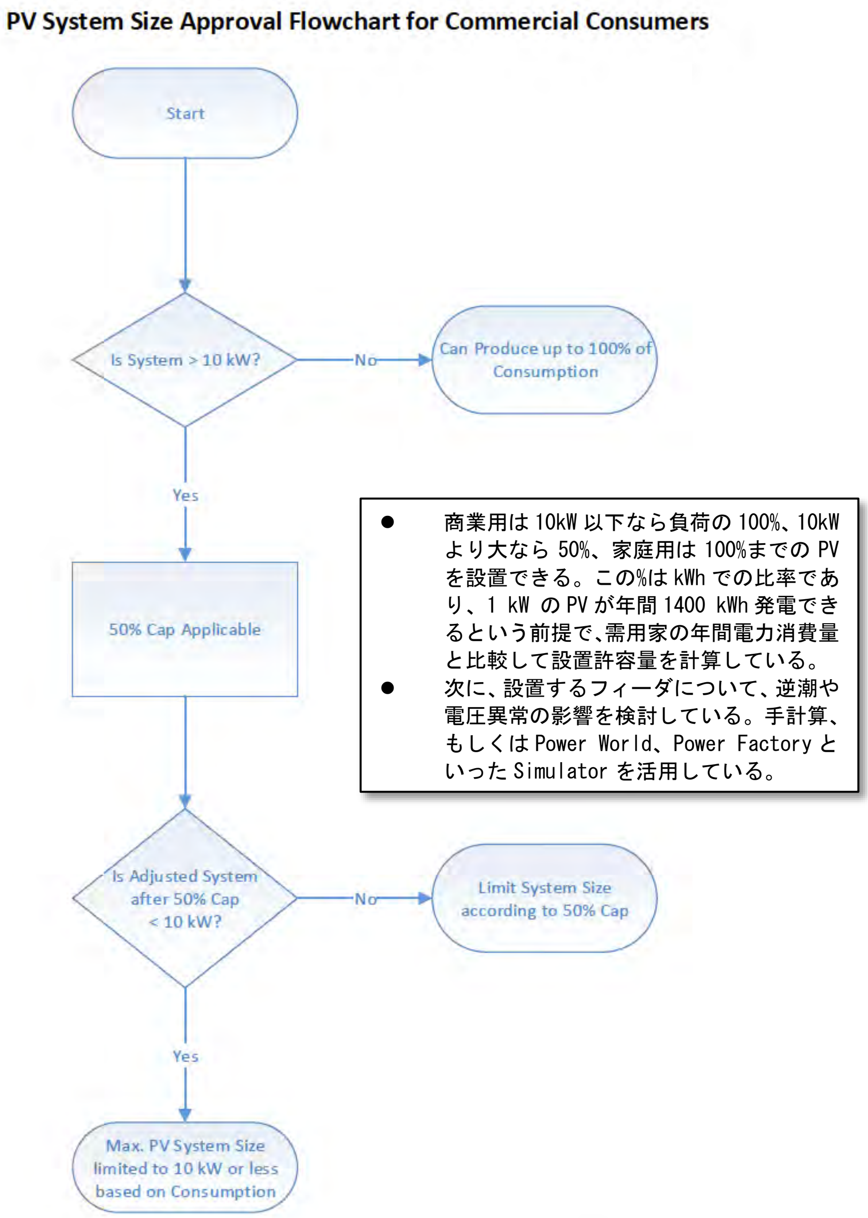
PV 設置のかかわる現在までの申請数は 217 件。うち 115 件の申請が認められたが、全てが設置されている訳ではなく、未設置のものもある。設置の可否は 1 ヶ月程度で結論をだしているようである。

表 3.5.1-1 PUC の現行連系技術要件

	Parameters	PUC Requirement	
1	Inverter Type	Central Inverter Or Micro Inverter	
2	Capacity of Inverter	To be specified by Applicant	
3	Protection Parameters Settings	Trip Setting	Clearance Time
3a	Over Voltage[1] (230 + 10%)	253V	0.2s
3b	Over Voltage (230V + 6%)	243.8V	1.5s
3c	Under Voltage (230 - 6%)	216.2V	1.5s
3d	Over Frequency[2] (50Hz + 1%)	51Hz	0.5s
3e	Under Frequency (50Hz – 1.5%)	49.25Hz	0.5s
3f	Loss of Mains (df/dt – Vector Shift)	2.5Hz/s 10 degrees	0.5s
4	Islanding Detection	Yes	
5	Isolated Generation possible	Optional	
6	Reconnection time	3 minutes	
7	Max. DC Current injection to grid	To be specified by Applicant	
8	Rated AC output current per phase	To be specified by Applicant	
9	Total Harmonics Distortion (Voltage)	To be specified by Applicant	
10	Total Harmonics Distortion (Current)	To be specified by Applicant	
11	Surge Withstand Capability	To be specified by Applicant	
12	Power Factor (Leading and Lagging)	0.95	
13	Will 1st Switch after meter have visible contacts?	Yes	
14	Will 1st Switch after meter have lock facilities in OPEN Position?	Yes	
15	Will Production Meter be installed?	Yes	
16	Will Earthing System be TNCS?	Yes	
17	Will Batteries be installed?	Optional	

[1] *If the SSDG can generate higher voltage than the trip setting, this (step 2 over voltage) is required.*

[2] *The trip setting for over frequency is set lower than the maximum operation operating frequency of 50Hz + 1.5% in order to avoid contribution of the SSDG to rising frequency.*



Notes:

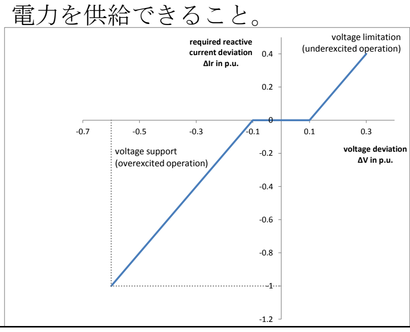
- Flowchart based on Net Metering Program Press Release from January 2014, which states:
  "... there will be a cap of 50% of energy consumption for only Commercial customers above 10kW, in other words, installation capacity should meet only 50% of their energy consumption. Whereas, Commercial customers 10kW and below, they can install PV system to cover 100% of their electricity consumption."
- At adjustment, if the potential PV system is calculated to be less than 10 kW, then the maximum size which could be installed is 10 kW, as long as a 10 kW system does not produce more than 100% of the applicant's consumption.

図 3.5.1-2 ネットメータリング承認プロセスフロー

3.5.1.5 Energy Nautics による系統連系ガイドライン

Energy Nautics により示されたグリッドコードの主要技術要件を表 3.5.1-2 に示す。

表 3.5.1-2 PUC の現行連系技術要件

<table>
<tr><th></th><th>Parameters</th><th>PUC Requirement</th></tr>
<tr><td>SGC5</td><td>Energy sources and generator technology</td><td>風力、PV、水力、バイオマス、廃棄物発電</td></tr>
<tr><td>SGC8</td><td>System Voltage Level Limit</td><td rowspan="2">230V、400V、11kV、33kV、 +/-10%【EN50160】</td></tr>
<tr><td>SGC13</td><td>System Voltage</td></tr>
<tr><td>SGC11</td><td>Short Circuit Power – Sk</td><td>同期発電機は発電機定格電流の８倍、誘導発電機は６倍、インバータは１倍</td></tr>
<tr><td>SGC12</td><td>Frequency Rating and Limits</td><td rowspan="2">50Hz -5% +3% (47.5 – 51.5Hz)。 以下の条件内では解列しないこと。2Hz/秒の変化に耐えること。
・ 47.0 Hz – 47.5 Hz: for 20 seconds
・ 47.5 Hz – 49.0 Hz: for 90 minutes
・ 49.0 Hz – 51.0 Hz: unlimited
・ 51.0 Hz – 51.5 Hz: for 90 minutes
・ 51.5 Hz – 52.0 Hz: for 15 minutes</td></tr>
<tr><td>SGC18</td><td>Maximum Frequency Gradient</td></tr>
<tr><td>SGC14</td><td>Steady-state active/reactive power capability chart (PQ-chart)</td><td rowspan="2">同期発電機で 0.85、インバータで 0.9</td></tr>
<tr><td>SGC24</td><td>Power factor control mode</td></tr>
<tr><td>SGC15</td><td>Flicker</td><td>Plt =< 0.5</td></tr>
<tr><td>SGC16</td><td>Harmonics</td><td>【IEC61000】【VDE-AR-N4105】に準拠</td></tr>
<tr><td>SGC17</td><td>Phase symmetry</td><td>単相は 5kW 以下、３相の相間差は 5kW 以下【VDE-AR-N4105】</td></tr>
<tr><td>SGC19</td><td>Reconnection after tripping</td><td>電圧・周波数が 15 分以上定格を保ってから再閉路【VDE-AR-N4105】</td></tr>
<tr><td>SGC20</td><td>Start-up and shut down ramp rates</td><td rowspan="3">有効電力を制御できる発電機は、起動停止の再には 10%/分で行なうこと。100kW 以上のものは、PUC の指示で、出力を制御できること。また、出力増加率の制御を 10 秒以内に行なえること。</td></tr>
<tr><td>SGC21</td><td>Active power limitation control mode</td></tr>
<tr><td>SGC22</td><td>Active power gradient control mode</td></tr>
<tr><td>SGC23</td><td>Limited frequency sensitive mode – overfrequency [LFSM-O]</td><td>出力制御可能なものは、50.2Hz 以上の周波数で有効電力を抑制でき、52.0Hz で解列すること。出力制御できないものは、50.2 52.0Hz 間でランダムに解列すること。【ENTSO-E NC RfG】【VDE-AR-N4105】</td></tr>
<tr><td>SGC25</td><td>Fault ride-through</td><td>10kW 以上のものに対し【BDEW】に沿って規定</td></tr>
<tr><td>SGC26</td><td>Network support during voltage dips</td><td>100KW 以上の非同期発電機は、瞬時電圧低下に対し無効電力を供給できること。

</td></tr>
<tr><td>SGC27</td><td>Description of system protection</td><td>保護に関する要求は下表の通り。10KW 以下のものは、U<と U>で解列すること。【BDEW】
<table>
<tr><th>Protection against</th><th>Name</th><th>Limit</th><th>Disconnection Time</th></tr>
<tr><td>Under voltage</td><td>U<</td><td>0.8 p.u.</td><td>1.5…2.4 s*</td></tr>
<tr><td>Over voltage (1)</td><td>U></td><td>1.1 p.u.</td><td>1 min</td></tr>
<tr><td>Over voltage (2)</td><td>U>></td><td>1.15 p.u.</td><td>100 ms</td></tr>
<tr><td>Under frequency</td><td>f<</td><td>47.0 Hz</td><td>100 ms</td></tr>
<tr><td>Overf requency</td><td>f></td><td>52.0 Hz</td><td>100 ms</td></tr>
</table></td></tr>
<tr><td>SGC28</td><td>Priority Order</td><td>保護・制御に関する要求が矛盾する場合は、以下の優先順位で作動すること。
1. 系統と発電機の保護　2. 周波数制御 (LFSM-O)
3. 有効電力抑制モード　4. 変化率抑制モード</td></tr>
</table>

SGC29 SGC30		100kW 以上は、監視制御のための通信機能を具備すること。
SGC32		100kW 以上は、DigSILENT のシミュレーションモデルを提出すること。
SGC37		受電（kWh, kVA）、売電用（kWh）の２つのメータを具備すること。

3.5.1.6 系統連系ガイドラインの原案

SEC および PUC と協議･検討の上まとめた系統連系ガイドラインの原案を以下に示す。

Version 0.01

19 March, 2016

Grid Code for Seychelles

1. Purpose of the Grid Code

The following interconnection standards are intended to provide general technical guidelines and procedures to facilitate the interconnection and parallel operation of distributed generating facilities of capacity less than 100kW with Public Utilities Corporation's (PUC) electrical distribution system. These technical interconnection requirements have been established to maintain safety, reliability, and power quality standards for all utility customers and personnel under the objectives described below:

The criteria and requirements in this document are applicable to the following distributed resource technologies, interconnected to PUCs at typical secondary distribution voltages.

- Photovoltaic (PV)
- Wind turbine (WT)

This standard does not prescribe generating facility self-protection or all operating requirements for generating facility units.

2. Interconnection Requirements

2.1 Interconnection Facility Characteristics

The generating facility is connected to the PUC's Low Voltage distribution line.

- 400V 3ϕ

- 230V 1ϕ

2.2 Interconnection Facility Design Parameters

The generating facility shall have the following design parameters. The generating facility has to functions and protects itself within the following range of the voltages, currents and frequencies existing in the PUC grid.

Table 1: Normal operating parameters of the PUC grid

Description	Range
Statutory Voltage range (LV)	400V +/-10% 3ϕ 230V +/-10% 1ϕ
Normal Frequency	50Hz
Operating frequency range	50Hz±1.5%

2.3 Protection Requirements

2.3.1 Availability of Protection

The generating facility shall, at a minimum, provide adequate protective devices, which include over/under voltage trip, over/under frequency trip, reverse power relay (for non-export generating facilities), and a means for automatically disconnecting the generating facility from PUC distribution system whenever a protective device initiates a trip. Based upon the results of the Initial Technical Review and/or Supplemental Review by PUC, additional protective devices may be required.

As for photovoltaic generating systems, inverters with certificate such as UL1741, may be appropriate.

Applicable circuit breakers or interrupting devices at the generating facility must be capable of interrupting the maximum available fault current at the site, including any contribution from the generating facility. For generating facilities, the interrupting device must be accessible to PUC personnel at all times.

2.3.2 Loss of Protection

Failure of the generating facility interconnection protection equipment, including loss of control power, shall result in the automatic disconnection of the generating facility from PUC distribution system until such time that the interconnection protection equipment has been restored. Such failure shall initiate a signal to trip a generating facility circuit breaker or shutdown an inverter.

2.3.3 Prohibition of Reverse Power Flow

PUC may not allow to flow back reverse power from generation facility to PUC grid. For such a system, Reverse Power Flow Relay (32R) shall be equipped.

2.3.4 Trip Settings

2.3.4.1 Instantaneous Voltage Regulation

The generating facility shall be equipped with protective equipment designed to automatically disconnect the generating facility from PUC distribution system for voltages outside the normal operating range within the clearing time as indicated in Table 2 below, and remain disconnected until the voltage and frequency have stabilized (see Section 4). The protective equipment shall measure the RMS (root-mean-square) voltage at the Point of Interconnection.

Table 2: Interconnection system response to abnormal voltage

Protection against	Voltage		Clearing Time (s)
Under voltage	230V -6%	216.2V	1.5
Over voltage 1	230V +6%	243.8V	1.5
Over voltage 2	230V +10%	253V	0.2

2.3.4.2 Fault ride-through

Generators above 10 kW nominal power must not disconnect from the grid due to voltage drops above the blue line in the following figure, representing the smallest line-to-line voltage at the generator terminals. (Refer to Figure 1.)

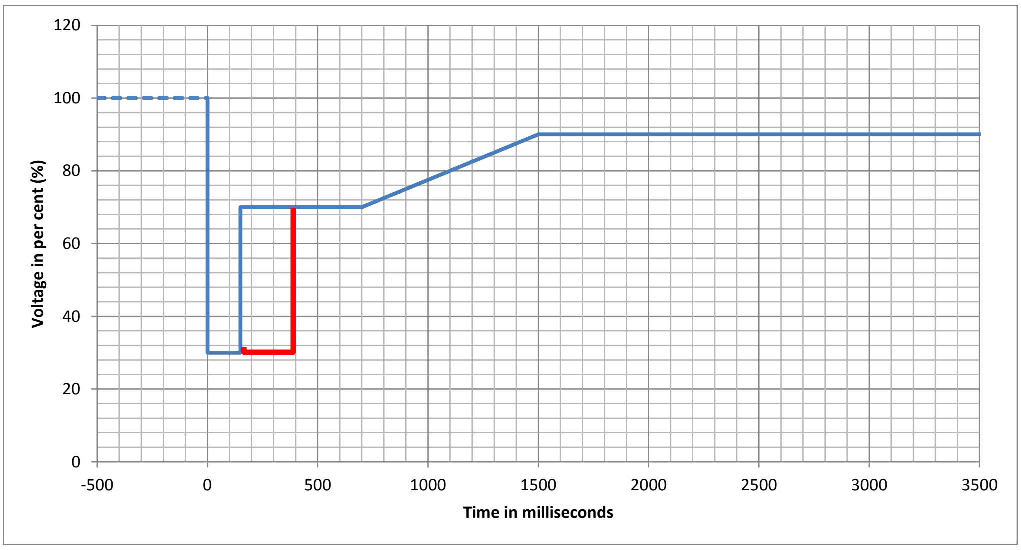


Figure 1: Fault ride-through

2.3.4.3 Frequency

When the system frequency is in a range given in Table 3, the generating facility shall cease to energize PUC grid within the clearing time as indicated. Clearing time is the time between the start of the abnormal condition and the generating facility ceasing to energize PUC grid.

Table 3: Interconnection system response to abnormal frequencies

Protection against	Frequency range		Clearing Time (s)
Under frequency	50Hz -1.5%	50,75Hz	1.5
Over frequency	50Hz +1.5%	49.25Hz	1.5

2.3.4.4 Maximum Frequency Gradient

Generators shall withstand frequency gradients of up to 2.0 Hz per second in either direction without tripping as long as the steady state frequency limits are not exceeded.

2.4 Unintentional Islanding

2.4.1 Detection of Unintentional Islanding

For an unintentional island in which the generating facility energizes a portion of PUC grid, the generating facility interconnection system shall detect the island

and cease to energize the PUC grid within two seconds of the formation of an island.

Both active and passive islanding detection mechanism are recommended to be equipped.

2.4.2 Re-connection and Synchronization

The generating facility shall be equipped with automatic means to prevent reconnection of the generating facility with PUC distribution system until PUC service voltage and frequency are within PUC tariff normal operating ranges and stable for at least 3 minutes, unless earlier directed by PUC.

Upon connection, the generating facility shall synchronize with PUC distribution system. Synchronization means that at the Point of Interconnection, the frequency difference shall be less than 0.2 Hz from rated frequency, the voltage difference shall be less than 5% of nominal voltage, and the phase angle difference shall be less than 10 degrees.

2.4.3 Grounding Requirements

The electrical installation of all consumers connected at low voltage shall be protected by a TN-C-S System (unless otherwise advised). Consumers are not permitted to combine the neutral and protective functions in a single conductor in the consumer's installation (e.g. TN-C). The neutral conductor is earthed at the LV winding of MV to LV transformers. Multiple earthing of the neutral conductor is permitted.

The grounding scheme of the generating facility interconnection shall not cause over voltages that exceed the rating of the equipment connected to the PUC grid and shall not disrupt the coordination of the ground fault protection on the PUC grid.

2.4.4 Surge Withstand Capability

The interconnection system shall have a surge withstand capability, both oscillatory and fast transient, in accordance with IEC 62305-3, the test levels of 1.5 kV. The design of control systems shall meet or exceed the surge withstand capability requirements of IEEE C37.90.

2.4.5 Short circuit capacity

The short circuit rating of the generator system owner's equipment at the connection point shall not be less than the design fault level of the distribution system as indicated by PUC. 6 -8 kA for low voltage

3. Power Quality

3.1 Power Factor

The generating facility shall not adversely impact the power factor at the Point of Interconnection. Generating facilities shall operate at a power factor minimum 0.9 (lagging).

3.2 DC Injection

The generating facility and its interconnection system shall not inject dc current greater than 0.3% of the full rated output current at the point of interconnection.

3.3 Flicker

The generating facility shall not create objectionable flicker for other customers on PUC grid.

3.4 Harmonics

When the generating facility is serving balanced linear loads, harmonic current injection into PUC grid at the point of common coupling (PCC) shall not exceed the limits stated below in Table 4. The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in PUC grid without the generating facility connected.

Table 4: Maximum harmonic current distortion in percent of current

Individual harmonic order	3.0
Total harmonic distortion (THD)	3.0

4. Safety Aspects

4.1 Safety, Isolation and Switching

The generating facility shall not energize PUC when PUC is de-energized.

4.2 Isolation Device

The generating facility shall have a manual isolation device that has a visible break to isolate their generating facility from PUC distribution system. The isolation device shall either be a disconnect switch or a breaker with rack-out capability. The device must be accessible/visible to PUC personnel and be capable of being locked by utility personnel in the open position. For generating facilities that do not have a circuit breaker or interrupting device, the isolation device must be capable of interrupting load.

4.3 Disconnection of Generating Facility for PUC Reasons and Safety

Upon providing prior notice, PUC may require the generating facility to temporarily disconnect from PUC's system when necessary for PUC to construct, install, maintain, repair, replace, remove, investigate, test, or inspect any of its equipment or other PUC customer's equipment, or any part of its system. The generating facility shall not energize a de-energized PUC line under any circumstances, but may operate isolated from PUC system with an open tie point.

PUC may disconnect the generating facility from PUC's system, without prior notice to the customer: (a) to eliminate conditions that constitute a potential hazard to PUC's personnel or the general public; (b) if pre-emergency or emergency conditions exist on PUC system; (c) if a hazardous condition relating to the generating facility is observed by PUC's inspection; (d) if the generating facility interferes with PUC's equipment or equipment belonging to other utility customers (including non-PUC generating equipment); or (e) if the customer or a party with whom the customer has contracted for ownership and/or operation of the generating facility has tampered with any protective device. The generating facility shall remain disconnected until such time as PUC is satisfied that the endangering condition(s) has been corrected, and the utility shall not be obligated to allow parallel operation of the generating facility during such period.

5. Commissioning

The generator system owner shall provide the required conformance proofs to PUC prior to commissioning. The date of commissioning shall be agreed upon between the generator owner and PUC. The following steps shall be taken during commissioning:

- Visual inspection of the generator

- Comparison of the generator setup with the submitted planning scheme
- Comparison of the metering setup with the requirements
- Function check of metering equipment
- Function check of circuit breaker/main switch mechanism and control
- Function check of operation at required power factor
- Function check of communication equipment (if applicable)

6. Metering

Metering refers to the measurement of consumed and/or produced electrical energy and/or power for accounting and billing purposes. Metering is necessary for all consumers and producers. It is independent from any measurements taken for the purposes of power system monitoring, supervision and control.

Meters for generator systems at customer installations shall be connected according to the specified scheme by PUC (Refer to ANNEX 2-4):

7. ANNEX

7.1 ANNEX 1 – PV System Connection Application Procedure

7.2 ANNEX 2 – General arrangement solar PV feed into PUC grid

7.3 ANNEX 3 - Solar Photovoltaic (PV) Power Supply System

7.4 ANNEX 4 - Single line diagram of PV metering connection to grid with Cut Out

系統連系ガイドラインは、一般的な技術要件を示すものである。しかしながら、セーシェルにおいては、既に以下のような課題を抱えている低圧配電線が存在しており、これらについては個別例外的に検討せざるを得ない面もある。

- 課題のある低圧配電線は、南部で４、北部で９～10、中央部で７本ある。
- 一つの課題は、PV 導入以前に PUC が解決しておくべきものであるが、配電線末端の電圧低下である。Anse Aux Pine Water Pump（Ref: 740, Size: 100 k.v.a. 3φ）では、電圧低下によりインバータが頻繁にトリップする。
- 一般家庭に供給している配電線では、その日負荷曲線は図 3.5.1-3 に示すように、系統全体のプロファイルとは大きく異なり、18-23 時以外は負荷が小さい。従って、このフィーダに数 kW の PV がいくつか入ると、日中に逆潮流が発生し、電圧上昇、過負荷などが発生する。Ex-Deltel Landbank (Size: 50 k.v.a 3φ Ref:

858）では、周りに需要がないところに 20kW PV の設置を希望しており、電圧上昇の恐れがある。

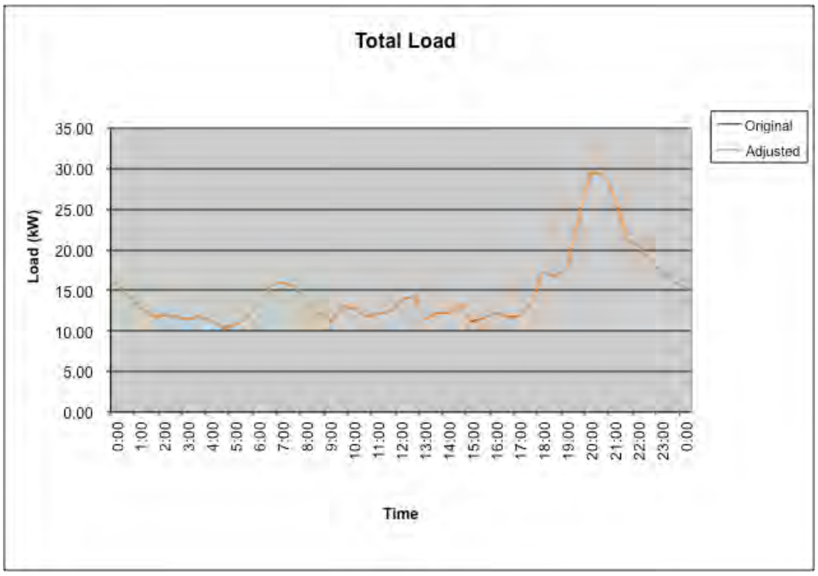


図 3.5.1-3 Brillant 線の日負荷曲線（2007/12/12）

逆潮を小さくするためには、On-Site Consumption を多くさせればよい。そのための技術的手段は電池併設であるが、今までのところ電池併設 PV は存在しない。ある申請で大きめの PV＋電池という提案があったが、電池が満充電となった状態を想定すれば、やはり逆潮が大きくなることが想定され、PUC は却下しているようだ。

3.5.2 再生可能エネルギー普及促進方策

より幅広い RE 活用を進めるためには、民間セクターによる RE 発電設備の設置が求められ、そのためのインセンティブを政府が提供する必要がある。以下では、世界で実施されている施策についてその概要を、特に島嶼国での取り組みに注意を払いまとめる。

3.5.2.1 各種方策の概要

エネルギーコスト面からみた助成の目的は、図 3.5.2-1 に示すように、予め RE 活用によりエネルギー・インフラの改造に投資して、化石燃料によるコスト増大リスクを和らげることにある[16]。

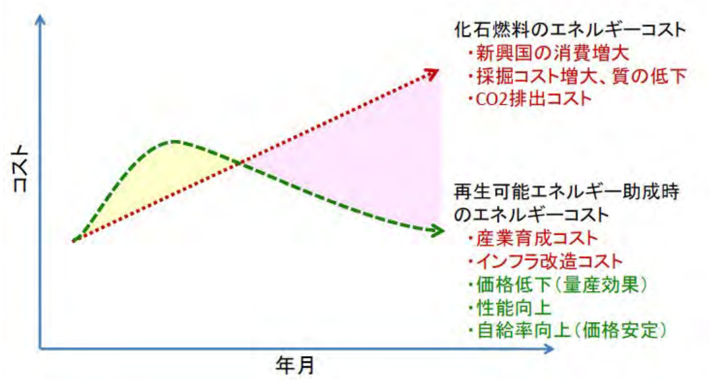


図 3.5.2-1 エネルギーコストからみた助成目的

化石燃料は、新興国の消費増大、採掘コスト増大、質の低下、CO2 排出コストなどが懸念され、このままでは長期的には上昇傾向を止めることは難しい。そこで、初期コストは高くなっても、将来的なエネルギーコストが下がるように、インフラを更新・改造していく方策が必要となる。

様々な普及促進策があるが、表 3.5.2-1 に示すように、運転支援施策には、大きくは価格ベースのものと普及量ベースの二つがある。前者は FIT（Feed-in Tariff）が代表的なものであるが、固定価格や電気料金にプレミアムを上乗せして、電力を買い取る制度である。後者は、Renewable Portfolio Standard (RPS) に代表されるように導入量を義務付けたり、入札を活用する方策である。発電電力量に応じて税額控除される発電税額控除(Production tax credit, PTC)や、投資額の一定比率を税額控除する投資税額控除(Investment tax credit, ITC)などの設置支援施策と組み合わせて支援が行なわれる。実際には複数の手法を組み合わせて実施できるため、表 3.5.2-1 はわかり易く分類した表と考えていただきたい。

[16] 櫻井啓一郎，2011，固定価格買取制入門：再生可能エネルギー：普及の切り札
http://ksakurai.nwr.jp/R/slides/WhyFIT/WhyFIT-v5.pdf

表 3.5.2-1 主な普及促進策の分類

<table>
<tr><td colspan="4">導入促進策の種類</td><td colspan="2">概要</td></tr>
<tr><td rowspan="4">設置支援施策</td><td rowspan="2">税額控除
Tax Credit</td><td colspan="2">発電税額控除（PTC）</td><td colspan="2">発電電力量に応じて税額控除</td></tr>
<tr><td colspan="2">投資税額控除（ITC）</td><td colspan="2">投資額の一定比率を税額控除</td></tr>
<tr><td colspan="3">補助金</td><td colspan="2">設備等の設置コストへの補助</td></tr>
<tr><td colspan="3">低金利融資</td><td colspan="2">設置への低金利融資</td></tr>
<tr><td rowspan="5">運転支援施策</td><td rowspan="3">価格ベースの支援策</td><td rowspan="2">固定価格買取制度（FIT）</td><td>Fixed 型（FIT）</td><td rowspan="2">再生可能エネルギーを 10～20 年程度の長期間にわたり一定の価格で買い取ることを系統運用者に義務付ける制度</td><td>買取価格の総額を固定する方式</td></tr>
<tr><td>Premium 型（FIP）</td><td>電力料金に上乗せするプレミアムを固定する方式（総額は固定されず、電力料金の変動に応じて変動する）</td></tr>
<tr><td colspan="2">ネットメータリング（NEM）</td><td colspan="2">電力消費量を太陽光発電システムの発電量で「相殺」する仕組み</td></tr>
<tr><td rowspan="2">普及量ベースの支援策
Quota 型</td><td>割当制度
Quota Obligation</td><td>RPS</td><td colspan="2">政府が消費者やエネルギー供給者に一定割合の再生可能エネルギーを導入することを義務付ける制度（通常クレジット取引制度も併設）</td></tr>
<tr><td colspan="2">入札（Tender）</td><td colspan="2">特定技術から供給するエネルギー量を入札にかけ、最も安価な価格を提示した事業者から買い取る制度</td></tr>
</table>

注） PTC: Production Tax Credit　ITC: Investment Tax Credit　FIT: Feed-in Tariff
FIP: Feed-in Premium　NEM: Net Metering　RPS: Renewable Portfolio Standard

3.5.2.2 価格ベースの支援策

(1) Feed-in Tariff (FIT)

FIT は民間投資の資金回収を確実なものとするために、RE 導入時に、その後一定期間(10～20 年間)の買い取り額を固定とするものである。全量買取が基本である。

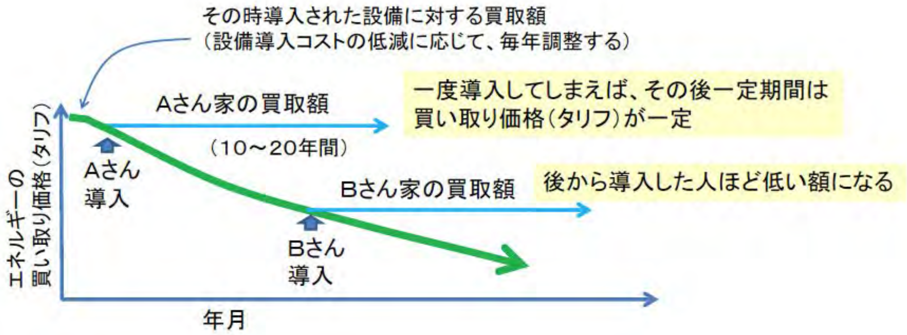


図 3.5.2-2 FIT の仕組み

導入ペースを調整可能とするために、一般的には、買い取り額は導入量が多くなるにつれ下げられる。図 3.5.2-2 において、導入が遅れた B 氏の価格は A 氏よりも安いものとなる。助成額の引き下げは導入済みの A 氏の設備には適用されないため、A 氏は当初の買取額で投資回収を一定期間続けられることが保証される。また、FIT の制度設計においては、国や地域固有の事情を勘案して、さまざまなオプションが組み込まれるが[17]、ここでは割愛

[17] Toby D. Couture, Karlynn Cory, Claire Kreycik and Emily Williams, 2010, A Policymaker's Guide to Feed-in Tariff Policy Design　http://www.nrel.gov/docs/fy10osti/　44849.pdf

する。

次節では、運転段階での支援施策について紹介する。

(2) Net Metering (NEM)

NEM は、分散型発電設備の所有者に対する電力料金の算定手法である。発電設備の発電量から、電力消費量を差し引いて余剰電力量が発生した場合、余剰分を次の月に繰り越すか、もしくは定められた単価で電力会社が買取る。一方、消費量が発電量より多く、余剰電力が出ない場合は、その差分に対して需要家が電気料金を支払う。(図 3.5.2-3 参照)

NEM は、米国で多く実施され、全米 50 州のうち 43 州とワシントン DC が施行している。ただし制度の内容（メータリング方式や余剰分の精算方法など）は、州や電力会社ごとに異なっている。基本的に配電線に接続される分散型発電施設の自家消費を発電量でオフセット（相殺）するための制度であり、売電が主目的としない「自産自消型」である。

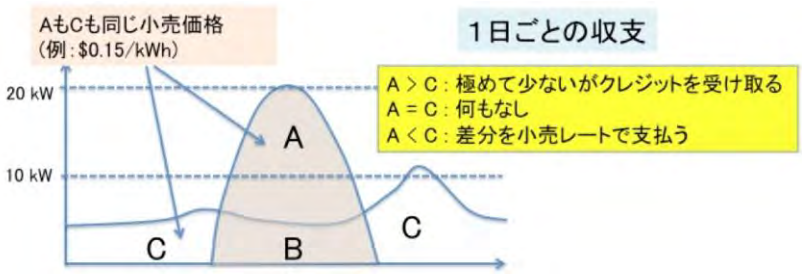


図 3.5.2-3 NEM の仕組み

(3) FIT と NEM の比較

FIT と NEM は、表 3.5.2-2 に示すように一長一短ある。

表 3.5.2-2 FIT と NEM の比較

	Net Metering (NEM)	FIT
長所	● 自家発電分で電気料金を相殺でき、自家発電電力量を超えた分だけ電気料金を払えばよい ● 法律等の取り決めがあれば、電気料金の相殺は保証され、より簡便でシンプル ● 電気料金高騰に対しリスクヘッジとなる	● 長期間に渡り一定価格で電気が売れることが契約で保証される。 ● 従って投資回収が見極められる ● 自家消費量以上を発電しても定められた価格で売電でき、その価格はインフレ率が加味されることもある ● RE普及スピードを制御でき、特に初期段階で加速させられる
短所	● 余剰電力分の取扱方法によりルールの内容が大きく変わる(一月毎の精算か？　余剰分はいくらで買取られるのか？) ● 自家消費量以上を発電しても、一般的にはあまりメリットはない ● 電気料金が下がるとペイバック期間が長くなる	● 契約締結の必要があり、より複雑 ● 電気料金がFIT価格よりも高いと、余剰電力買取の方が魅力的となる ● 電気料金高騰に対しリスクヘッジできない。

全量買取の FIT の方が設置者のリスクが少ないため、高コスト技術（例えば数年前の PV）の普及にはより適する面があった。実際に、先進国における助成効果としては FIT が初期段階の RE 導入促進において優れた結果を残している。しかしながら、制度設計によっては想定以上に RE 導入が進む可能性もある。ドイツやスペインでは制度の見直しがなされ、また日本でも、九州や沖縄では PV 設置が急速に進んだために系統における変動電源の許容量を越えてしまい、系統連系の申込を断らざるを得なくなっている（3.5.2.3 参照)。

FIT は急速かつ短期的な普及を後押ししても、長期的普及を持続させるには他の施策と比べて（特にデフレ下の先進国では）高コストかつ非効率的になりがちと言える。FIT は一般的に市場状況に迅速に対応することができず、対応できたとしても、ドイツ、フランス、スペインなどで起こったように、急速かつ劇的に価格が変動するため市場を混乱させ成長を妨げてしまう。

より良い施策とは、顧客の PV システム発電に対し適切な支援を行いながら、プログラム自体を低コストで持続可能な金銭的報酬にとどめるものであり、FIT よりも NEM が適切な場合もある。しかしながら、NEM にも課題が存在する。一般的な NEM では、発電量 1kWh は電力購入の小売価格と同等で取り扱われているが、米国カリフォルニア州では電力会社から「余剰電力買取価格を下げる」、または「PV システム所有者に送配電網利用費用などの特別料金を課す」との提案が出された。

いずれにせよ、PV システム設置者側のコスト削減を促すために、段階的に買取価格の妥当性を見直すことと、設置者が前もって事業計画を立てられるよう、急激な価格下落を起こさないようにすることが重要である。

3.5.2.3 他国 FIT 事例と動向

日本は 2012 年 7 月より FIT を始めた。最初の電力調達条件は、PV で 42 円（4.43 SCR, 0.34 USD) / kWh であり、容量の制限はなかった。調達価格が予想以上に高価であったために参入者が相次ぎ、メガソーラーシステムを建設して 50kW[18]毎の区分を分譲販売するような業者も現われ、バブル的な現象となった。そこで 2014 年 4 月以降は、38 円（4.01 SCR, 0.31 USD) / kWh に下げられ、」また分譲転売も禁止となったが、この改訂が有効になる直前の 2014 年 3 月には 27,000MW の PV 設置申請が出されている。いずれにせよ、改訂自体が遅すぎたため、2014 年 5 月には九州電力をはじめ四つの電力会社が新たな PV 系統連系を拒否する方針を打ち出した。また、系統に悪影響を与えるほど PV 出力が大きくなる場合は、補償なしで PV の出力抑制をする事態となっており、当初の制度設計面でのミスが大きな影響を残すこととなった。2016 年 1 月現在の調達条件を表 3.5.2-3 に示す[19]。

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[18] 出力 50kW 以上の太陽電池発電設備は、電気事業法上は発電用の電気工作物（発電所）である「自家用電気工作物」になり、技術基準への適合・維持、保安を確保、電気主任技術者専任などの義務が課せられる。

[19] 資源エネルギー庁，2013,

表 3.5.2-3 日本の FIT(2015)[20]

電源	調達区分	調達価格1kWh当たり 出力制御対応機器設置義務なし	調達価格1kWh当たり 出力制御対応機器設置義務あり※1	調達期間
太陽光	10kW未満(余剰買取)	33円	35円	10年間
	10kW未満(ダブル発電・余剰買取)	27円	29円	

※1 北海道電力、東北電力、北陸電力、中国電力、四国電力、九州電力、沖縄電力の需給制御に係る区域において、平成27年4月1日以降に接続契約申込が受領された発電設備は、出力制御対応機器の設置が義務付けられます。

電源	調達区分	調達価格1kWh当たり 平成27年4/1~6/30(利潤配慮期間)	調達価格1kWh当たり 平成27年7/1~	調達期間
太陽光	10kW以上	29円+税	27円+税	20年間

電源	調達区分	調達価格1kWh当たり	調達期間
風力	20kW以上	22円+税	20年間
	20kW未満	55円+税	
洋上風力※2	20kW以上	36円+税	
地熱	15,000kW以上	26円+税	15年間
	15,000kW未満	40円+税	
水力	1,000kW以上30,000kW未満	24円+税	20年間
	200kW以上1,000kW未満	29円+税	
	200kW未満	34円+税	
既設導水路活用中小水力※3	1,000kW以上30,000kW未満	14円+税	
	200kW以上1,000kW未満	21円+税	
	200kW未満	25円+税	

※2 建設及び運転保守のいずれの場合にも船舶によるアクセスを必要とするもの。 ※3 既に設置している導水路を活用して、電気設備と水圧鉄管を更新するもの。

電源	バイオマスの種類		バイオマスの例	調達価格1kWh当たり	調達期間
バイオマス	メタン発酵ガス(バイオマス由来)		下水汚泥・家畜糞尿・食品残さ由来のメタンガス	39円+税	20年間
	間伐材等由来の木質バイオマス	2,000kW未満	間伐材、主伐材※4	40円+税	
		2,000kW以上		32円+税	
	一般木質バイオマス・農産物残さ		製材端材、輸入材※4、パーム椰子殻、もみ殻、稲わら	24円+税	
	建設資材廃棄物		建設資材廃棄物(リサイクル木材)、その他木材	13円+税	
	一般廃棄物・その他の廃棄物		剪定枝・木くず、紙、食品残さ、廃食用油、汚泥、家畜糞尿、黒液	17円+税	

※4「発電利用に供する木質バイオマスの証明のためのガイドライン」に基づく証明のないものについては、建設資材廃棄物として取り扱う。

各国の FIT の概要を表 3.5.2-4 に、系統の小さな島嶼国については表 3.5.2-5 に示す[21]。

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http://www.enecho.meti.go.jp/saiene/data/kaitori/kaitori_jigyousha2013.pdf

20 http://www.enecho.meti.go.jp/category/saving_and_new/saiene/data/kaitori/2015_fit.pdf

21 Wind-works.org by Paul Gipe http://www.wind-works.org/cms/index.php?id=92

表 3.5.2-4 FIT 導入済みの国における制度概要

	Tariff level in 2014 [USD Cents/kWh] and duration of support for PV						
Country			Year	Rates	Rate for 3kW PV	Duration	NOTE
Australia	Australian Capitol Territory			45.94	45.94	?	
	South			40.03	40.03	5	*Primarily a form of net-metering. Not a true feed-in tariff. The tariff is paid only on excess generation. Cap: 10,000 systems, 10 kW single phase, 30 kW three-phase. Only generation in excess of consumption or "net".
Canada	Ontario Small FIT		2013	25.73 - 35.38	35.38	20	
China			2013	13.82 - 15.35	15.35	20	
France			2013	43.64 - 10.27	43.64 - 22.82	20	
Germany			2013	19.63 - 12.63	18.26	20	
Great Brtain			2013	24.65 - 10.94	24.65	25	
India	Kerara		2013	23.56 - 19.63	23.56		
Italy	Conto Energia V		2013	36.17 - 14.19	26.12	20	
Japan			2012	38.22 - 37.26	38.22	10, 20	
Malaysia			2011	36.16 - 24.99	36.16	21	
Phillipines			2012	23.41	23.41	20	
South Korea			2010	71.14 - 41.45	71.11	15	
Spain			2012	35.33 - 16.37	35.33	25	
Switzerland			2014	36.93 - 21.41	36.93	25	
Thailand			2013	31.41 - 14.50	22.42	25	
USA	California (PG&E)	Summer	2009	18.00 - 6.00	18.00 - 6.00	15	*This program is not a true feed-in tariff as it is alsmost impossible to project revenues from the "tariff". This kind of program is called by critics a FITINO, a feed-in tariff in name only.
		Winter		14.00 - 7.00	14.00 - 7.00	15	
	California (SCE)	Summer	2009	31.00 - 6.00	31.00 - 6.00	15	
		Winter		10.00 - 6.00	10.00 - 6.00	15	
	California (SDG&E)	Summer	2009	15.00 - 8.00	15.00 - 8.00	15	
		Winter		11.00 - 7.00	11.00 - 7.00	15	
	Florida (Gainesville)		2013	21.00 - 15.00	21.00	20	
	Oregon		2013	39.00 - 18.10	39.00	15	
	Texas (San Antonio)		2010	27.00	27.00	20	

Wind-works.org by Paul Gipe http://www.wind-works.org/cms/index.php?id=92

表 3.5.2-5 島嶼国の FIT

	Tariff level in 2014 [USD Cents/kWh] and duration of support for PV					
Cayman Islands			39.07	39.07	20	Pilot program beginning February, 2011 through 2012. Program cap: 1 MW; 70% reserved for commercial customers. Gross feed-in tariff: Payment of $0.37/kWh offsets consumption at $0.30/kWh.
Cook Islands			45.00	45.00	?	
Cyprus		2011	50.60 - 45.21	45.21	20	
Fiji			23.00	23.00	?	
Malta		2011	35.17 - 25.12	31.40	8	
Maldives		2011	21.05	21.05		
Mauritius		2012	82.92 - 49.75	66.34	15	Suspended in May 2011. Net Metering starts in 2015.
Rhode Island		2013	29.95 - 24.95	29.95	15	
Taiwan		2012	29.03 - 22.48	29.03		
USA	Hawaii	2011	27.40 - 18.90	27.40	20	

Wind-works.org by Paul Gipe http://www.wind-works.org/cms/index.php?id=92

フィジーやクック諸島では FIT 価格は提示されているが、それは電気料金よりも低額であり、また期間の明確な提示は見つけられなかった。

モーリシャスでは、SSDG を対象とした FIT 制度が 2010 年 12 月に始まったが、当初設定した 2MW の枠を満たしてしまったため、2011 年 5 月 6 日に新規申請を受理しないことが公告された。なお、新たな制度として Net Metering が 2015 年より開始されている。

また、パラオでは需用家設置の RE 発電機を対象としたネットメーターリング法(RPPL No. 8-39)が 2012 年 1 月 6 日に承認されている[22]。 家庭用、商用、政府、産業セクターにおける PV、小水力、風力が対象で、電気料金の 50%以上の価格で Palau Public Utility Corporation により買電される[23]。ただし、期間は 12 ヶ月間のみである。

一方、FIT が積極的に採用された欧州では、制度の見直しが始まっている。具体的には①入札方式、②導入量に応じて価格低減率を変化させる方式、③一定比率で毎年価格を低

[22] http://prdrse4all.spc.int/production/system/files/net_metering_act_-_rppl_8-39_dat.pdf
[23] http://energy.gov/savings/palau-net-metering

減させる方式などがある。ドイツのFIT価格決定方式の歴史を以下の表3.5.2-6にまとめる。また、欧州における太陽光発電に関するFIT制度等の変遷を図3.5.2-4に示す。

表3.5.2-6 ドイツにおけるFITの変遷[24]

<table>
<tr><td>2000-01年</td><td>価格維持方式</td><td>2000年4月、再生可能エネルギー法により50.62ユーロセント/kWhと規定（20年間適用。法改正を行わない限り、買取費用は変動せず）</td></tr>
<tr><td>2002-08年</td><td>一定比率で毎年価格を低減させる方式</td><td>長期的に一定年率の価格低減（建物固定は年▲5%、地上設置は2006年以降▲6.5%）を設定
100kWの太陽光発電（建物固定）
● 2004年:54ユーロセント/kWh
● 2005年:51.30ユーロセント/kWh
● 2006年:48.74ユーロセント/kWh
● 2008年:46.30ユーロセント/kWh
● 2009年:43.99ユーロセント/kWh</td></tr>
<tr><td>2009年～</td><td>導入量に応じて価格低減率を変化させる方式</td><td>直近1年間の太陽光発電導入総量に応じて、買取価格を低減する仕組みを導入。ドイツは年間2.5GWの導入を想定。
<table>
<tr><td>年間新規容量</td><td>適用月低減率</td></tr>
<tr><td>7.5.GW超</td><td>2.8%</td></tr>
<tr><td>6.5～7.5GW</td><td>2.5%</td></tr>
<tr><td>5.5～6.5GW</td><td>2.2%</td></tr>
<tr><td>4.5～5.5GW</td><td>1.8%</td></tr>
<tr><td>3.5～4.5GW</td><td>1.4%</td></tr>
</table>
<table>
<tr><td>年間新規容量</td><td>適用月低減率</td></tr>
<tr><td>2.6～3.5GW</td><td>1.0%</td></tr>
<tr><td>2.4～2.6GW</td><td>0.5%</td></tr>
<tr><td>1.5～2.4GW</td><td>0.25%</td></tr>
<tr><td>1.0～1.5GW</td><td>0%</td></tr>
<tr><td>～1.0GW</td><td>-0.5%</td></tr>
</table>
直近の導入量が想定より多い場合には、価格低減率が上昇するのに対し、想定よりも少ない場合には買取価格の上昇もあり得る。</td></tr>
<tr><td>2015年から試験導入</td><td>入札方式</td><td>事業者が支援を受ける価格水準について入札し、応札札が安い順に落札。ドイツでは2015年より太陽光発電地上設備向けの入札方式を実施。
<table>
<tr><td>年</td><td>入札期限・規模</td></tr>
<tr><td>2015年</td><td>● 2015年4月15日:150MW
● 2015年8月1日:150MW
● 2015年12月1日:200MW
合計：500MW
※ 2016年は400MW,
2017年は300MW</td></tr>
</table>
落札プロジェクトへの支援額はpay as bid方式。ただし2015年8月、12月の入札では試験的にuniform pricing方式を採用。</td></tr>
</table>

[24] 資源エネルギー庁「再生可能エネルギーの効率的な導入について」平成27年10月20日
http://www.meti.go.jp/committee/sougouenergy/kihonseisaku/saisei_kanou/pdf/003_01_00.pdf

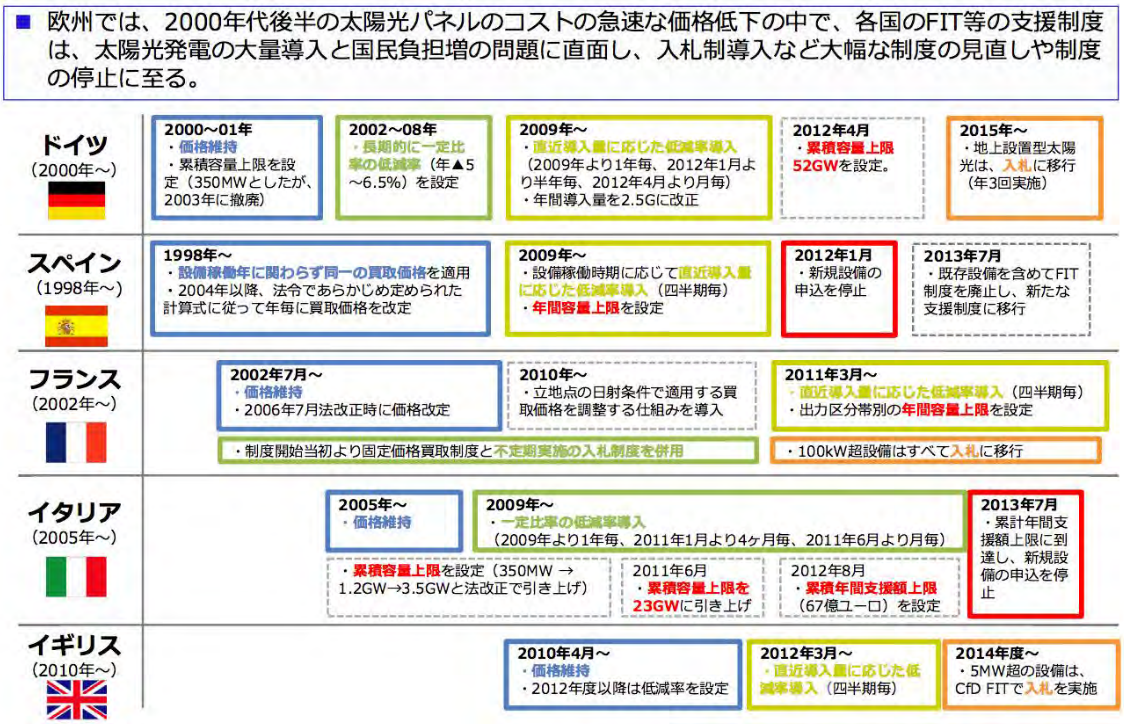

図 3.5.2-4 欧州各国における普及促進施策の変遷[25]

一方、アメリカでも NEM の見直しが始まっている[26]。PV システム所有者は、PV の発電により消費電力を相殺し、電気料金の支払い額を減らせる。この結果、電気料金に含まれる送配電網の運用・維持管理費などの支払いが減り、その分、PV システム非所有者に対するコスト負担が増え、所有者と非所有者間で不公平が生じることになる。

カリフォルニア州の電力会社は、買取価格を下げるほか、以下の新しい料金を、住宅用など分散型太陽光発電システムの所有者から徴収することを規制官庁に提案した。

(1) デマンド料金：過去の一定期間内の電力需要（デマンド値）の中で最も大きな値をもとに契約電力を決める

(2) グリッドアクセス料金：電力会社の電線網にアクセスする配電網使用料

(3) スタンバイ料金：曇りや夜間など PV パネルが発電しない時に備え、電力会社が供給量を確保し、待機するための料金

(4) 設置容量料金：PV システムの設置容量に合わせて月々決まった料金を納める

しかしながら、議論の末、カリフォルニア州では「小売レート」を維持することで 2015 年始めに決着している（NEM2.0）。これは、ネバダ州やハワイ州の結論とは反対の結果である。

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25 資源エネルギー庁「再生可能エネルギーの効率的な導入について」平成 27 年 10 月 20 日
http://www.meti.go.jp/committee/sougouenergy/kihonseisaku/saisei_kanou/pdf/003_01_00.pdf

26 日経テクノロジーonline 米加州の「ネットメータリング」制度が改正へ
http://techon.nikkeibp.co.jp/atcl/column/15/286991/010700011/

3.5.2.4 Energy Nautics による FIT 制度

(1) FIT 価格・期間

FIT 契約期間を 15 年と 20 年の 2 ケースについて、また、PV Rebate の有無ごとに、ROE10%のリターンが確保できる FIT 価格を、Excel 版 FIT モデルを用いて求めている。その結果を表 3.5.2-7 に示す。この FIT モデルは、FIT 価格を求めるためのツールとしては妥当なものであると考えるが、O&M コストをゼロとして FIT 価格を求めている点に留意する必要がある。

表 3.5.2-7 Energy Nautics により提案された FIT 価格（SCR/kWh）

Table 61: Proposed FIT Rates for Solar PV and Small Wind

Contract Length & Rebate Assumption	Solar PV 1-10kW	Solar PV 11-100kW	Wind 1-100kW
15-Year (With Rebate)	2.59	3.87	n/a
15-Year (Without Rebate)	3.30	4.05	5.49
20-Year (With Rebate)	2.33	3.52	n/a
20-Year (Without Rebate)	2.97	3.69	4.97

Energy Nautics は、FIT の期間は 20 年、現行の Net Metering は 5 年間併用（どちらにも申請可能）とし 5 年後に停止とすることを推奨している。

(2) PUC へのインパクト

PUC へのインパクトを表 3.5.2-8 のシナリオで比較している。

表 3.5.2-8 FIT による PUC へのインパクト検討シナリオ

シナリオ	住宅 PV (1-10kW)	商業 PV (11-100kW)	商業風力 (1-100kW)	総計
Scenario A: 住宅 PV	・設置数 1,000 ・各 5kW ・433 カ所が PV Rebate の対象 ・計 5MW	無し	無し	・設置数 1,000 ・計 5MW
Scenario B: 商業 PV	無し	・設置数 100 ・各 50kW ・全て PV Rebate の対象 ・計 50MW	無し	・設置数 100 ・計 5MW
Scenario C: 住宅・商業 PV	・設置数 150 ・各 5kW ・全て PV Rebate の対象 ・計 0.75MW (15%)	・設置数 75 ・各 50kW ・全て PV Rebate の対象 ・計 3.75MW (75%)	・設置数 10 ・各 50kW ・計 0.5MW (10%)	・設置数 235 ・計 5MW

表 3.5.2-9 が PUC へのインパクト分析結果である。ここで、No Policy は、逆潮・売電なしというスキームである。

表 3.5.2-9 FIT による PUC へのインパクト検討シナリオ（100 万 SCR）

Table 67: Summary of Policy Cost Scenarios to PUC (in Millions SR)

Deployment Scenarios:	Policy Scenarios: Scenario 1: Gross FIT	Scenario 2: Net Metering	Scenario 3: No Policy
Scenario A: Residential-Scale Solar	$(0.4)	$(7.6)	$(11.4)
Scenario B: Commercial-Scale Solar	$(6.2)	$(14.7)	$(14.7)
Scenario C: Residential & Commercial Solar & Wind	$(5.6)	$(12.6)	$(13.9)

このような分析を踏まえ、Energy Nautics は結論として以下を推奨している。

- Gross FIT（最も安い方策）
- 商業よりも住宅 PV を可能な限り多く
- 風力よりも PV を可能な限り多く

しかしながら、Energy Nautics の上記検討においては、以下の三つの課題が存在すると考える。

a) 削減された燃料コストを明示的にプラス分として加えている。支出されなかったコストはもちろんコストとして計上されないが、それは収入にもならないため、削減された燃料コストは損益計算書にはでてこなくなる[27]。経理面から見ると妥当な扱いとはいえないと考える。

b) 電気料金単価をひとつの値で計算しているが、これは使用量に応じて上がっていくものであり、現実を反映したものとなっていない。

c) APPENDIX F で、100kW PV を商業と住宅で設置した場合の、PUC と設置者におけるインパクト検討結果を出しているが、FIT の PUC におけるメリットを見せるためか、異常に安い FIT 価格で計算している。よって、設置者から見ると、FIT に加入するメリットは何もなく No Policy の方が良い結果となっている。

[27] ただし、バランスシートは多少改善される。

(3) PPA モデル契約書

100kW 以上の PV、風力と 10kW～5MW のバイオマス発電、流れ込み式水力を対象としており、5MW 以上の分散電源（IPP）と廃棄物発電は対象外としたモデル契約書である。罰則条項は設けていない。また、将来の電力セクター改革を想定して作るべきであるという付言を付けている。

契約書のひな形としての体裁は整ってはいるが、以下のような未決定事項が多くあり、完成品とは言い難いと考える。

- 供給義務どうするか？ 多くの途上国はベスト・エフォート型。
- 引き取り義務はどう規定するのか？
- 状況の変更（changed circumstances）、義理の変更（change-in-law）もしくは契約の再開（contract re-opener）条項を検討する必要があるだろう。
- 外資による設置を考えると、貸し手の権利（Lender Rights）条項も必要だろう。
- メータの精度は±1%でよいか？
- PPA 契約満了後の設備の供給側への売却について決めておく必要がある。

3.5.2.5 セーシェル国における支援制度

(1) セーシェル国における現状の支援制度

セーシェル国では既に環境エネルギー省のプレスレリース（2014 年 1 月 13 日）により、NEM が開始されている。この NEM は、余剰電力買取制度ではあるものの、日本や米国で実施されているものとは、メータリング方式や精算の仕方が異なっている。受電用と PV 発電用の二つのメータを系統に対して並列に設置し、一月毎に受電電力量と発電電力量を比較し、前者が大きい場合は差分を需用家に請求、後者が大きい場合は、燃料のマージナルコストの 88% (2016 年 6 月現在で 0.92SCR/kWh）で PUC が購入、という形で精算される。

なお、PV 設置容量には以下のような制限が設けられている。

- 一般家庭： ｛年間消費量/1400[28]｝kW まで
- 商　　業： 10kW 以下なら｛年間消費量/1400｝kW まで
10kW より大なら｛年間消費量/1400 の 50%｝kW まで

この容量制限があるため、NEM では、PUC が PV 設置者に支払うケースはほぼ発生しない。あったとしても小容量であるためごく僅かである。

(2) セーシェル国の支援制度：課題と対策

まず、現行 NEM についての課題をまとめる。以下では、NEM で用いる二つの電力

[28] 1kW の PV は、Capacity Factor を 16%として、1 年間に 1400kWh 発電可能と仮定している。

量計の読みを以下のような変数で表すこととする。

- X = 系統からの受電電力量計の読み（一月分）
- Y = PV 発電電力量計の読み（一月分）

a) NEM の運用コストを明確に把握していない。

- NEM の需要家に対して、現在 PUC は｛(X － Y）の電気料金｝を請求し、それを売上としている。しかしながらこれでは需要家の消費が単純に減った場合と同じである。
- 実際には、Y を購入する一方で、X を売るということを行なっている訳であり、PV 導入後も売上はやはり｛X の電気料金｝である。その際に Y を購入するコストが同時に発生していると考えるのが妥当である。
- 従って、NEM 運用コストは｛X の電気料金｝から｛(X － Y）の電気料金｝を引いたものとなる。電気料金は消費量に応じて、家庭用で５段階、商業で３段階毎に設定されているため、このような演算が必要となる[29]。
- NEM による PV 設置がなければ、化石燃料による発電コストは発生するものの、PUC は NEM 運用コストを支払う必要がなく、そこで一定の利益を得ていた。国の方針に従って NEM を実施することは、政府が PUC のビジネスチャンスを奪ったともいえる。

b) NEM のコスト負担が PUC のみに課せられている。

- PUC は Y を購入することが求められるが、その代わりに、Y に相当する電力を自ら発電する必要がなくなり、少なくとも燃料費は削減される。
- FIT であれ NEM であれ、その運用コストは、決して削減された燃料費で回収されるものではなく[31]、電力会社（PUC）のみに負担させることは合理的でない。

c) グリッドアクセス・コストやスタンバイ・コスト

- 既に述べたように、米国で議論されているコストであり、電力会社から見ると回避可能でないコストといえる。
- PV 設置者と非設置者間の公平性を保つ意味でも求められつつある。

このようなセーシェル国における課題と様々な制約を念頭において、NEM と FIT の比較検討を行なった結果を表 3.5.2-10 に示す。なお、表 3.5.2-10 における運用コストは、

29 より大きな消費量にはより高めの料金単価が設定されており、最初の２段階（300kWh/月以下）はナショナル・ミニマム（国が保障すべき最低生活水準）の考え方を導入した非常に低い料金となっている。

31 PUC の PL（損益計算書）では、確かに燃料コストは小さくなるものの、その減少分は PUC の収入や利益、儲け、浮いたお金にはならない。一般的には BS（バランスシート）において流動資産が増えたり、負債が減る可能性はある。しかしながら、燃料単価は常に改訂されており、その影響に付いてはより詳細な分析が必要である。

NME については前述の通り、FIT については総発電量の買取価格である。

表 3.5.2-10 セーシェル国における支援制度の比較検討

検討項目	Net Metering (NEM)	FIT (gross FIT)
設置者のインセンティブ	○ 電気料金の平均電力単価が大きくなる大需要家にとってはインセンティブ大。	× 大需要家は、電気料金の平均電力単価がFIT価格よりも高くなれば、インセンティブは小さくなる。
	× 小需要家はインセンティブが小さい。	○ 小需要家は、FIT価格が電気料金の平均電力単価よりも高くなれば、インセンティブは大きくなる
	× 需要家のみPV設置可能	○ 非需要家もPV設置可能
PUCへのインパクト（PV未設置の場合との収益比較）	○ 家庭用の300kWh以下は電気料金が安く設定（コスト割れ）されているため、そのような小規模需要家においては、PUCの損失を改善する。	× 左記小規模需要家において、PUCの損失は改善されない。
	○ 平均料金単価がFIT価格よりも安い小需要家のPVについては、FITよりも小さなコストとなる。	○ 左記以外の大需要家では、NEMより小さなコストとなる。
制度運用コストの資金源	× PUCのみが負担している。	△ 一般的にはサーチャージ
	× 持続性を確保するため、しっかりとした財源を確保する必要がある。 × PUCや政府等、関係者間でのコストシェアが必要。合意形成が難しい。 ● コスト算定に当たっては、回避可能コストのコンセンサスと、削減される燃料費がPUCのPLを改善するものではないことに留意する必要あり。	
グリッドアクセスやスタンバイのコスト	× 現状なし。PV設置者への費用請求を検討することが必要。	× FIT価格設定時に検討の余地あり。
制度運用事務コスト	○ 現行制度なので大きなコスト増にはならない	× 新制度の設計、制定、運用のためにさらなるコストが発生する。
逆潮流の最小化(設置容量の 制限)	○ 自家消費を促すものであり、制約に合致している。	× 一般的には、より大きな収益を求め設置容量は大きくなり、逆潮流は増える。 × 設置容量の制限があると設置者のインセンティブは小さくなる。
短周期面の制約である分散配置との適合性	○ 自家消費用の小規模PV設置となるため適合する。	× 一般的には、より大きな収益を求め、設置容量は大きくなり、NEMよりは適合度が下がる。
2020年にRE5%という目標（既設	○ 現行NEMを継続していけば達成可能。	× 今から設置を加速させる必要性は少なく、価格ベースで促進させるFITは不要。

1.2MW）		
支援制度（NEM）変更に係るリスク	○ なし。	× FITの適正な価格・低減率の設定は難かしい。 × 国民にFIT新規導入の理由をきちんと説明する必要がある。 × 説明に説得力がないと、NEMが失敗であったという印象を与えかねず、政府の信頼性に傷をつけることにもなりかねない。

原則論としては、このような検討・分析結果を踏まえ、セーシェル国の関係者がより良い案を自ら策定していくことが求められる。規制側、電力供給側、需要家、PV 設置者（投資家）間ではなかなか意見が一致しないことが普通であるが、議論を深めて妥協点を探っていく必要がある。

制度の対象期間が長めであるため、今後どのように状況や環境が変化していくか、その見極めが重要である。具体的には、電力需要の伸び率、インフレ率、割引率、PV システムの建設単価、燃料費などの変動などをどう想定するかにより、長期の見通しはかなり変ってくる。

なお、Energy Nautics は５年程度の間、NEM、FIT の２制度併用することを薦めているが、セーシェルのような小国で、同種の制度を並立させるのは正当化が困難であるし、それぞれの使い分け方を明確化する必要もあるため、現実的とはいえないと考える。

最後に、重要なポイントをまとめておく。

a) 配電設備の現状と短周期面での制約からは、小規模分散設置を支援し逆潮を抑えるように留意した制度設計が必要である。

b) 現状の料金制度の下では、平均電力単価が想定される FIT 価格よりも安くなるような小規模需要家の PV については、運用コスト面で FIT よりも NEM に優位性がある[32]。特に一般家庭で消費量が月間 450kWh 以下の需要家については、現在 PUC が被っている赤字を NEM により緩和することができるため、インセンティブの焦点をここに合わすことも考えられる[33]。

c) 運用コストのための原資をどこから得るかが最も大きな課題である。他国においては、電気料金への再生可能エネ促進のための付加金（サーチャージ）や化石燃料への炭素税、政府一般財源などを資金源としている。

d) 制度の持続可能性を確保するために、政府、電力会社、国民、設置者でどのよ

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32 このようなターゲットは電力消費量の小さい需要家、つまり低所得者層や小企業であろう。PV 設置のための初期投資が難しい層であるともいえるため、PV Rebate などの補助金はこのターゲットに限定する方が望ましいといえる。

33 例えば、このような小需要家のみを支援対象として限定してしまう案も考えられる。しかし、国全体の目標達成のためには、より多くの設置数が必要となる。

うにこのコストを分担するかを議論し、決定する必要がある。決して、PUC のみに負わせてはならない。これは経済的なロジックだけで割り切れるものではなく、社会的・政治的な判断が求められる非常にセンシティブな問題である。

e) 資金面の制約が大きいセーシェルにおいては、グリッドアクセス料金やスタンバイ料金の徴収を前向きに検討することが望ましい。

f) PUC 系統への再エネ導入上限量と導入状況の比較を定期的に行い、インセンティブの見直しを継続的に行なっていくことが重要である。

g) 必要な資金を可能な限り小さくするためには、PUC による PV 自社設置を積極的に推進していく必要がある。

3.6 離島マイクログリッド導入計画に係る財務分析

3.6.1 RE マーケットの動向について

SEC に登録している PV 業者は、表 3.6.1-1 に示す 12 社である。市場規模の割に業者数が多く、競争は激しい。このうち、住宅用から業務用までの各種 PV システムを手掛ける大手企業は、VetiverTech 社と Energy Solutions Seychelles の 2 社である。2015 年後半における Mahe 島の系統連系 PV システム価格は 1.8~2.0 ユーロ/W 程度が標準的な価格と推定される。Praslin 及び La Diegu 島の価格は、設置技術者の Praslin 島への配置状況によるが、Mahe 島と比べて 5~15%程度、その周辺の小規模な離島はさらに 10%程度設置費用が高くなる。また、IDC が管理する外島については、機材は IDC のフェリーで輸送し、テクニシャンは IDC のフライト及び宿舎を利用する必要がある。

表 3.6.1.1　セーシェルの PV 業者一覧

企業名	主要取扱製品		備考
	PV パネル	インバーター	
Vetiver Tech (www.vetivertech.com)	SolarWorld(独)	SMA（独）	電気工事業も兼業
Energy Solutions Seychelles (www.energysolutionsseychelles.sc)	LG（韓）, JA solar (中), Yingli（中）	SMA(独)	
Pace Global (www.paceafrique.com)	Sunpower (米)	SMA（独）、Fronius(独)	業務用に特化。省エネ ESCO 事業を展開。
Sun Tech Seychelles (www.sts.sc)	LG（韓）、BenQ (台湾系)、Panasonic(日)	SMA（独）	ドイツの Sea & Sun Technology 社とパートナーシップ。
ClimateCaring (www.climatecaring.org)	中国製	SMA(独)、Outback(米)	離島向けの独立型システムに特化。
Seysolar green energy Ltd. (www.seysolar.com)	イタリア製	Power one (ABB グループ)	本社はイタリア。
Trend Energy (www.trendenergy.com)			
Dolphin Technology and Trading International Ltd.	Yingli（中）製品の独占販売代理店		

Solar Energy Seychelles (www.solarenergy.sc)	Solon(独),シャープ（日）	SMA(独)	離島向けに焦点を絞り業務を展開
Sunny Systems Seychelles Ltd.			
DEC Service Inc.			
Island Roofing Pty Ltd. (www.island-roofing.com)			屋根の専門会社

3.6.2 PV 導入のための補助金制度及び低利融資制度の効果と課題

セーシェルにおいて PV 導入促進のために講じられている主要な施策は下記の通りである。税制面からは、PV 機器の輸入関税免除、企業向けには PV 投資に対する加速償却制度がある。

（１） ネットメーターリング制度

PUC は 2013 年 9 月から需要家の PV システムの系統連系を認め、需要家が PUC に対する売電電力計を設置して需要家の PUC からの購入電力量から PUC に対する売電電力量を差し引いて電気料金を請求するネットメーターリングを導入している。住宅用電力契約者については PV 設置容量の制限はないが、業務用等その他の契約区分の需要家については PUC からの購入電力量の 50%以下の容量に制限している。PUC に対する売電電力量が購入電力量を上回った場合には、差額電力量（売電電力量―購入電力量）について PUC が燃料費相当電気料金の 88%の価格で買い取る。ネットメーターリングの導入に伴い電気料金の高い需要家を中心に系統連系型 PV の導入が進んでいる。しかしながら PUC の系統連系に関する審査が厳しいこと、業務用については系統連系容量に関係なく PUC の経営上の理由（電気料金収入の大幅減少防止）により一律に需要電力量の 50%を PV 導入量の上限と設定していることが比較的大容量の PV システム導入の阻害要因となっている。また、このことが他の助成制度の効果を低減させる原因となっている。このため、PUC は PV システムの系統連系基準の明確化及び審査体制の強化（審査の迅速化）を図るとともに、系統連系容量と関係なく設定している業務用需要家に対する PV 導入容量の上限を撤廃すべきである。ネットメーターリング制度からフィードインタリフ制度に移行する場合にも PV の系統連系基準の明確化と審査体制強化は必要不可欠である。

（２）PV-rebate 制度

UNDP/GEF の支援で系統連系 PV 設置者に対する補助制度（PV-rebate scheme）が創設されている。住宅用 PV システムの補助制度は 2014 年春に補助率 35%、補助上限 3kW/戸、補助金単価 US$3.2/W で開始されたが、PV システム単価の大幅な下落を考慮して 2015 年 4 月に補助率が 25%、補助金単価が US$2.8/W に変更された。業務用 PV システムの補助制度は 2014 年 11 月に補助率 15%、補助上限 15kW、補助金単価 US$3.2/W で開始されている。

2015 年 12 月までの補助金利用者は、住宅用 PV システムはセーシェル内の住宅用 PV システム設置総件数 78 台（413.22kW、PUC 調べ）のうち 59 件で。補助金利用率は 76%である。住宅用 PV の規模は 3-5kW が多く、住宅用 PV に対する補助金総額は SCR2,200,000 である。

業務用 PV の補助金利用者は、業務用 PV システム総設置件数 33 件（927.8kW、PUC 調べ）のうち、14 件で、補助金利用率は 42%となっている。業務用 PV に対する補助金総額は SCR852,000 である。このように PV-rebate 制度は住宅用を中心に多くの PV システム設置者に利用されている。

PV-rebate scheme の予算執行状況は、総予算 SCR1400 万に対して執行額 SCR300 万であり、執行率は 25%となっている。現在、同制度について 2016 年 5 月終了を目標に UNDP が事業評価を実施中である。

（３）SEEREP 及び中小企業低利融資制度

世界銀行の支援で 2013 年に住宅部門を対象として、省エネルギー機器及び再生可能エネルギー機器の購入費用に対する低利融資制度”Seychelles Energy Efficiency and Renewable Energy Program”（SEEREP）が創設された。SEEREP は住宅用の省エネルギー及び再生可能エネルギー機器設置費用に対して上限額 SCR100,000 までを商業銀行を通じて低利融資する制度である。金利は 5%/年、返済期間は 1-5 年で、融資を受ける際には借入額の 2.5%を自己資金で賄うことが条件となっている。SEEREP は商業銀行に対して個別の貸付額の 50%までを保証し、貸し倒れリスクの低減を図っている。商業銀行の個人向け融資金利(12~14%/year)と比較すると非常に低利になっているが、これまでのところ利用実績は皆無である。現在、SEEREP の事業評価が行われているが、その結果では、制度の周知が不十分であること及び商業銀行の与信審査が厳しいことのその原因と指摘されている。このため、事業評価において制度の周知徹底のためのワークショップ、銀行の審査能力強化のためのワークショップ等が開催されている。

また、中小企業を対象とした低利融資制度があり、中小企業の PV システム導入にも利用可能である。融資期間は 5 年で 100 万 SR までは金利 5%、300 万 SR までは金利 7%である。

このようにセーシェルの PV 導入促進のための助成制度は良く整備されているが、油価格の急激な下落に伴い PUC の電気料金（Energy charge）が下表に示すように下落していることから PV システム価格の下落にも関わらずネットメーターリング、PV-rebate 等のインセンティブ効果は低下している。特に住宅用の電気料金 (Energy charge) の下落率が大きく、PV システムの投資回収年数が長期化している。このため、PV-rebate 制度の事業評価に当たっては、PV システムの補助金単価を現在の市場価格に合わせて見直す一方で、助成効果を高めるために補助率及び補助上限規模の見直しを行う必要がある。

表 3.6.2-1　PUC の電気料金（Energy charge）の下落率

料金区分		2014 年 第 4 四半期	2016 年 第 1 四半期	下落率（%）
Domestic (SR/kWh)	0-200kWh/M	1.40	0.37	73.6
	201-300	1.66	0.63	62.0
	301-400	3.48	2.45	29.6
	400-600	3.80	2.83	25.5
	Exceeding 600	4.50	3.51	22.0
Commercial (SR/kWh)	0-500	3.89	2.86	26.4
	501-1000	4.25	3.22	24.2
	Exceeding 1000	4.82	3.79	21.4

3.6.3 対象島（Curieuse 及び Desroches）における RE 導入の経済性分析

(1) Curieuse 島

Curieuse 島の公園管理事務所の電力供給は現在、ディーゼル発電機（5.5kW）及びガソリン発電機(5kVA)により行われている。2015 年 5 月の現地調査によれば、5kVA（4.5kW）のガソリン発電機のみが使われており、一日の平均的なガソリン消費量は 20L、需要が多い時で 40L とのことである。使用されているガソリン発電機の発電効率から一日の発電電力量は平均 30kWh、最大で 60kWh 程度と想定される。夜間の最大電力需要が約 5kW 程度である。主要な電力需要機器は管理棟（冷蔵庫、洗濯機、扇風機、TV、パソコン、照明及び揚水ポンプ）、マネージャー家族用住宅（冷蔵庫、照明等）、ゲスト研究者用宿舎（照明）、給水施設用ポンプである。公園管理事務所は、夜間のセキュリティ照明施設の整備等を希望している。現在の電力需要は供給面の制約から抑制されている状況にあることを考慮し、将来の電力需要を想定した。その結果によれば、最大電力需要は 9kW、需要電力量は 85kWh/日となる。図 3.6.3-1 に想定日負荷曲線を示す。

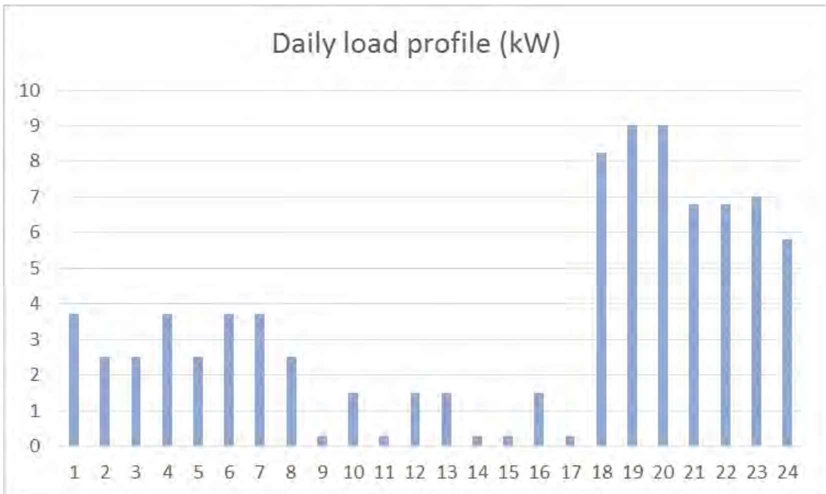


図 3.6.3-1　Curieuse 島の想定日負荷曲線

この電力需要に対応するための PV システム諸元を、HOMER を用いて算定（バッテリーの寿命５年以上を確保することを前提条件として試算）した。算定に用いた PV システムの主要コンポーネントの価格は下記の通りである。インフレ率は 3%/年、Discount rate は 10%/年と仮定した。

	初期投資額（US$/kW, US$/kWh）	交換費用（US$/kW, US$/kWh））	運転維持管理費（US$/kW/year）
PV モジュール(kW)	2,500	833	0.042
コンバーター(kW)	500	500	0
バッテリー(kWh)	500	500	0

その結果を以下に示す。最も経済性に優れたシステムは、PV 容量が 40kW、インバーター容量が 10kW（2.5kW のインバーター4 台）、バッテリー容量が 350kWh（2V, 600Ah のバッテリーで 292 台）となる。初期投資額は約 28 万米国ドルで、耐用期間均等化発電原価は US$1.16/kWh となる。年間の運転維持管理費は、インバーター及びバッテリー交換費用を均等化した費用として約 12.5 千 US ドル/年である。

PV (kW)	Battery (kWh)	Converter (kW)	COE (US$)	Operating cost (US$)	Initial capital (US$)	Renewable Frac (%)	PV/ Production (kWh/year)
40	350	10	1.16	12,500	280,000	100	63,000

ディーゼル発電機（Auto size generator、US$750/kW, 最低負荷 50%、燃料費 US$1.23/L (SEYPEC, January 2016)）を追加して HOMER で計算した結果を下記に示す。PV とディーゼル発電機のハイブリッドシステムは初期投資額が PV のみのシステムよりも少ないが、発電原価では PV のみのシステムの発電原価と同程度となる。さらに燃料輸送の有無等運転維持管理の容易さ、地球環境への影響等も考慮すると PV とバッテリーのみのシステムが好ましいと考えられる。

PV (kW)	Genset (kW)	Battery (kWh)	Converter (kW)	COE (US$)	Operating cost (US$)	Initial capital (US$)	Renewable Frac (%)
50	9.90	200	10	1.15	15,800	237,000	41
40	0	350	10	1.16	12,500	280,000	100

また、ロードリミッターを設置して夜間の最大負荷を 8KW に制限すると、システム構成は下表に示すように変化し、発電原価及び初期投資額を抑制することができる。冷蔵庫や給水ポンプの深夜負荷をロードリミッターで抑制することは初期投資削減に効果的である。

PV (kW)	Genset (kW)	Battery (kWh)	Converter (kW)	COE (US$)	Operating cost (US$)	Initial capital (US$)	Renewable Frac (%)
30	8.80	100	5	0.823	14,000	134,000	41
0	8.80	100	5	0.837	20,000	59,000	0

（2）Desroches 島

Desroches 島の主要施設は高級リゾートホテルであり、IDC がホテルを含めて島全体にディーゼル発電により電力供給を行っている。

電力需要は図 3.5-3-3 に示すようにリゾートホテルの稼働状況に応じて季節により大きく変動する。電力需要の多い月は、クリスマス・新年休暇がある 12 月及び 1 月、イースター休暇がある 4 月である。リゾートホテルのため、平日と週末の負荷の差異はない。電力需要が最も多い月は 4 月である。

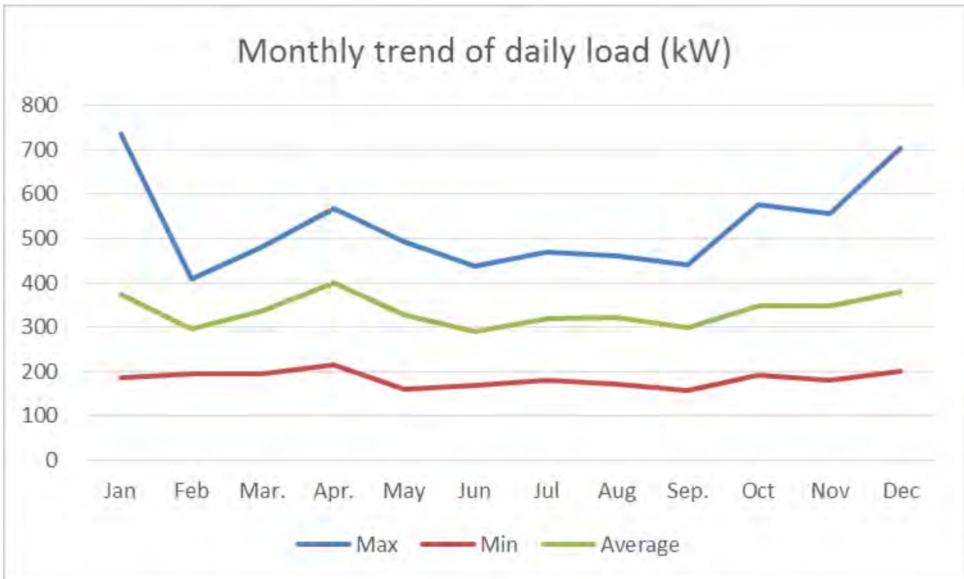


図 3.6.3-2　Desroches 島の電力需要の月別変動

一日の負荷変動は、図 3.6.3-3 に示すように朝 9 時ごろから夜 9 時ごろまで負荷が高い状態が続き、一般住宅と比較して昼間の負荷が高いため、太陽光発電の導入に有利である。

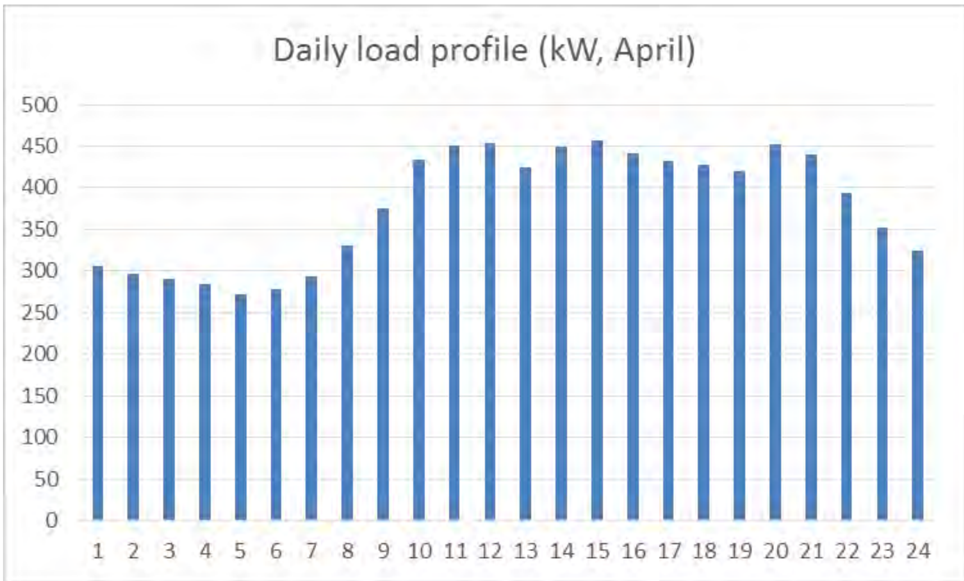


図 3.6.3-3　Desroches 島の日負荷曲線（4 月）

現在、リゾートホテルはホテルオペレーターの変更に伴い大規模なリノベーションを実施中である。リノベーションに伴い発電施設も更新を予定している。ホテルの大規模リノベーションに伴い電力需要も変化するものと思われるが、本調査では現状の電力需要（2014年の年間発電実績）を前提としてディーゼル発電と再生可能エネルギーのハイブリッドシステム導入の可能性を検討した。

NASA のデータベースから得た同島の再生可能エネルギーの賦存状況表 3.6.3-1 のとおりである。

表 3.6.3-1　Desroches 島の太陽光・風力資源賦存量

	Daily averaged insolation incident on a horizontal surface (kWh/m²/day)	Average wind speed at 50m height （m/second）
January	5.42	5.350
February	6.03	4.820
March	6.26	3.890
April	6.16	3.610
May	5.58	5.490
June	5.28	7.210
July	5.42	7.320
August	5.85	7.390
September	6.43	6.970

October	6.69	5.010
November	6.47	3.610
December	5.96	4.110
Average	5.96	5.40

日射量は良好であるが、風況はあまり良好とはいえない。このため、風力発電の導入を考慮せずに、ディーゼル発電と太陽光発電のハイブリッドシステムの導入可能性についてHOMERを用いて評価（バッテリーの寿命8年以上を確保することを前提条件として試算）を行った。評価に用いた各コンポ―トの価格は下表のとおりである。

	初期投資額（US$/kW, US$/kWh)）	交換費用（US$/kW, US$/kWh）	運転維持管理費（US$/kW/年）
PVモジュール(kW)	2,500	833	0.042
コンバーター(kW)	500	500	0
バッテリー(kWh)	500	500	0
ディーゼル発電機(US$/kW、最低負荷50%)	750	750	0.125

その結果を下表に示す。遠隔地の離島で燃料費が高いため、PV とディーゼル発電のハイブリッドシステムが最も経済的なシステムとなる。ディーゼル発電機の必要容量については、HOMERの算定では合計で約800kWになる。定期点検を考慮すると、300kW程度の単機容量の発電機4台と、1.4MWのPVとのハイブリッドシステムが想定される。この場合の再生可能エネルギー比率は約20%となる。

PV (kW)	Genset（kW）	Battery (kWh)	Converter (kW)	COE (US$)	Operating cost (US$)	Initial capital (US$)	Renewable Frac (%)
1400	820	900	700	0.614	1,397,000	4.92 million	22
0	820	50	100	0.751	2,157 million	0.69 million	0

3.6.4 大規模PVをIPPが開発する場合の収益性評価

セーシェルのRE導入目標を達成するためには、PUCの電力需要家が設置する系統連系ルーフトップPVシステムの導入とともに、IPPによる大型PVシステムの導入を進める必要がある。特にPUCの電力系統が脆弱な状況下でRE導入比率を高めるためには、PUCの系統が比較的強い地域にIPPによる大型PVシステムを立地させることは現実的な対策といえる。

このため、PUC の Victoria C 発電所の近傍に大型の PV システムを設置するケースを想定して収益性評価を行った。収益性評価の前提条件は下記の通りである。

- PV システム単価

セーシェルの PV システム（ルーフトップ型）単価は設置企業や場所により異なるが、図 3.5.3-4 に示すように、低価格のドイツ、オーストラリアと高価格の米国、日本の中間にある。大型の PV システムについては地上置き（ground-mounted）が一般的であることから、地上置きで価格が最も高い日本(US$2.50/W)と最も安いドイツ(US$1.33/W)の中間にある米国の価格（US$1.77/W）を採用する。

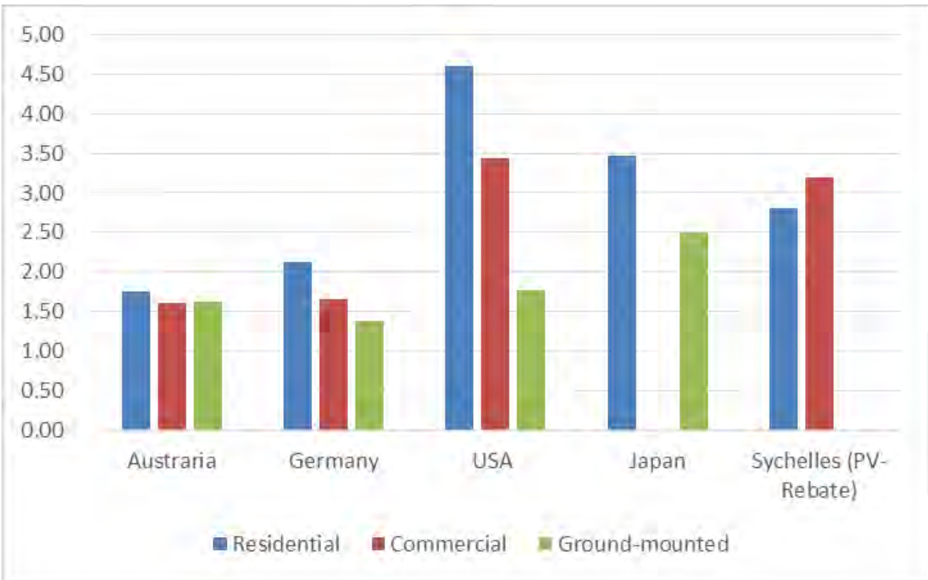


図 3.6.3-4　PV システム価格(2014 年)比較

（単位：US$/W、出典：IEA PVPS Trends 2015 in Photovoltaic Applications）

- 用地価格

政府が国有地を無償で提供するものと想定する。PV-IPP に必要な土地面積は PV アレイの配置等による差異はあるが、1MW 当たり 7,000~10,000 ㎡程度である。平地が少ないセーシェルにおいて広大な土地を民間企業が独自に確保することは困難である。

- 運転・維持管理費

長期間、安定的に PUC に電力を供給するためには、需要家が設置するルーフトップ PV と異なり、IPP は運転・維持管理体制を整備する必要がある。日本の事例によれば、出力 10kW 未満のルーフトップ PV の運転維持管理費はシステム費用の 1%/年と推定されているが、出力 1MW 以上の PV システムの平均的な運転維持管理費はシステム費用の 3%/年となっている。本試算では運転・維持管理費として建設費の 3%/年を採用する。

- 投資資金の調達

セーシェルの大規模再生可能エネルギープロジェクトが利用可能な低利融資制度とし

では、AFD（Agence Française de Développement）の SUNREF[1]（Sustainable Use of Natural Resources and Energy Finance）がある。この低利融資制度は、プロジェクト規模が700 万ユーロ以下、融資期間は 4 年以上でグレースピリオドは 3 年以内、金利は同制度の実施機関となる商業銀行と借り手の交渉で決定、プロジェクト開始後に融資金額の8%の補助する仕組みとなっている。現在、セーシェルの再生可能エネルギープロジェクトで同融資制度の適用を検討中のプロジェクトの融資条件は頭金（自己資金）15%、金利 5%/年となっている。このため、本プロジェクトの経済性評価においても同一の条件で SUNREF を利用することを想定し、自己資金 15%、借入金 85%、借入金利 5%/年の資金調達を想定する。同資金の適用プロジェクト規模の上限を考慮して、プロジェクト規模を 4MW とする。また、プロジェクト開始後（運転開始初年度）に借入金の 8%の補助金が支払われるものとする。

- 減価償却及び税

  減価償却については、PV システムはセーシェルの Business Tax Act 2009[2]の Approved environmental machinery の対象機器であることから加速償却(40%/年)が適用される。Business tax の税率は、利益 SCR100 万までは 25%、SCR100 万以上については 33%で、損金は最大 5 年間繰り越すことが出来る。

- プロジェクト期間

  PV パネルのメーカー出力保証は 20～25 年で出力 80%以上が一般的である。このことからプロジェクト期間としては 20 年以上を見込むことが出来るが、本プロジェクトは IPP プロジェクトとして民間資本で事業を行うことを考慮し、プロジェクト期間を物理的な寿命よりも短い 15 年とする。

- PV モジュールの経年劣化

  PV モジュールの出力低下率は EnergyNautics の試算と同様に 0.5%/年とする。

- 設備利用率(Capacity factor)

  EnergyNautics の試算と同様に 16%/年とする。

- 為替レート

  2015 年第 4 四半期の為替レートを参考に SCR13.1/US$と想定する。

試算の結果、IPP の PUC に対する売電価格が SCR2.35/kWh で ROE が 16%となり投資家にとって魅力ある水準となる。原油価格が 100 ドル/バレル台であった 2014 年夏の PUC の発電原価と比較すると PV-IPP からの電力購入は PUC のディーゼル発電よりも安価であったが、原油価格が 20~30 ドル/バレルに低下した現状では PV-IPP からの電力購入単価は PUC の発

[1] http://media.eib.org/attachments/gefior-project-leaflet.pdf
[2] http://www.src.gov.sc/pages/businesstax/businesstax.aspx

電原価の約 2 倍程度となる。しかしながら 4MW の PV-IPP の発電電力量は 2013 年の PUC 発電所の送電端発電電力量の 1.63％であるため、PV-IPP からの電力購入が PUC の発電単価に与える影響は 1.5%程度と小さい。原油価格の不安定性、地球温暖化対策等を考慮すると、将来の電力安定供給実現のために、燃料価格が低下して電気料金が低水準になっている時期に計画的に PV-IPP を導入することは適切な再生可能エネルギー導入政策といえる。

第 4 章　総括

4.1 セーシェルにおける現状課題

セーシェル政府はディーゼル発電以外の電源の確保及び将来の電力需要の増加に対応するため、太陽光発電や風力発電等の再生可能エネルギーの導入に積極的に取り組んでおり、国の方針としてその導入目標を 2020 年までに 5%、2030 年までに 15%と設定した。また、2012 年 12 月に策定されたエネルギー法に基づき、固定価格買取制度(Feed-in Tariff、以下「FIT」)やクリーン開発メカニズム(Clean Development Mechanism、以下「CDM」)等の関連する制度を整備した。これを受け SEC、PUC では目標達成に向け積極的に動いている。現に、SEC では国の方針に従い、アラブ諸国からの援助による風力発電設備 6MW(750kW×8 基)が既に Mahe 島のビクトリアに導入されており、また、2016 年には大規模太陽光発電設備 5MW の導入が計画されており、このような取組みは今後も続いていくことが予想される。

一方、再生可能エネルギーの大量導入は電力品質(周波数や電圧等)への影響が懸念され、系統を管理する PUC ではこのような技術的な問題・課題について懸念しているものの、SEC と PUC 間で対策について協議が進んでいない。上記の背景から PUC ではドイツのコンサルタント会社である Energy Nautics へ業務委託し再エネの導入可能量について検討を行い、2030 年までの導入可能量として 28%との結果である。

4.2 セーシェル国における再エネ導入マスタープラン

4.2.1 再エネ導入に関する技術的課題

(1)電力品質に及ぼす課題

太陽光発電や風力発電はその出力が気象の変化によって変動するため、電力系統に大量に連系された場合、周波数や電圧等、電力品質に影響を与えることが懸念される。

1) 周波数変動

太陽光発電等の出力は天候などの影響で大きく変動する恐れがある(図 4.2.1-1 参照)。短期的な需給バランスが崩れると周波数が適正値を超えて、電気の安定供給に問題が生ずる恐れがある。

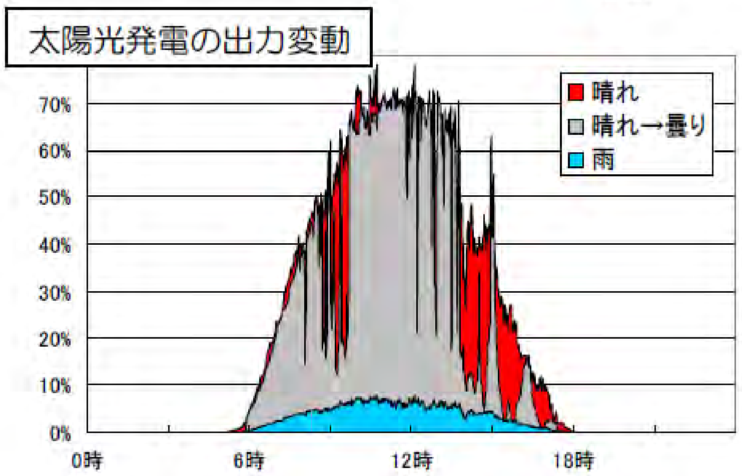


図 4.2.1-1 太陽光の出力変動

2）電圧上昇

太陽光発電の設置数が増加した場合、配電網の電圧を適正値に維持するため、太陽光発電の出力を抑制することを余儀なくされる恐れがある。

3）余剰電力の発生

太陽光発電が増加すると、休日など需要の少ない時期に、ディーゼル発電の出力と太陽光発電の出力の合計発電量が需要を上回り、余剰電力が発生する可能性がある。セーシェル国においては、ディーゼル発電機の最低出力は定格の 50%での運用となっていることから、出力下限値に抵触する恐れがある。

(2)PUC で行っている対策の現状

1）発電設備の改善

Mahe 島の VictriaC 発電所では 2015 年に 8MW のディーゼル発電機 2 基が新規で導入されたことにより、予備力が増加し、メンテナンス計画が立てやすくなった。一方では、発電機の運用を常時管理する記録計は設置されておらず、需要負荷を把握することができないことから、各発電機の出力を合計する総合系統負荷表示版の設置が必要であると考えられる。

2）送配電設備

Mahe 島の南部及び北部では多くのリゾートホテルが立地されているが、現在、送電能力の不足により PUC からの電力供給が十分に行われていない状況である。これに対し、PUC では今後、3 年間を掛け送電線の増強を行う計画であり、ホテルの需要増が見込まれる。一方では、現在、送電系統の潮流情報は把握されてないことから、今後、安定的な系統運用や PV 導入量を把握する観点から、潮流情報が把握できるようにする必要がある。そうすることによって、系統運用面（経済運用、潮流・電圧監視等）や系統計画の検討面に的確な対応が可能となる。

4.2.2 マスタープラン策定の基本的事項

再生可能エネルギーの導入においては、ベース電源であるディーゼル発電機や電力系統が健全であり、再エネを導入する際、支障が無いことが重要となる。そのため、図 4.2.2-1 に示すとおり、再エネ導入によって生じる課題に対し必要な改善策を検討する必要がある。

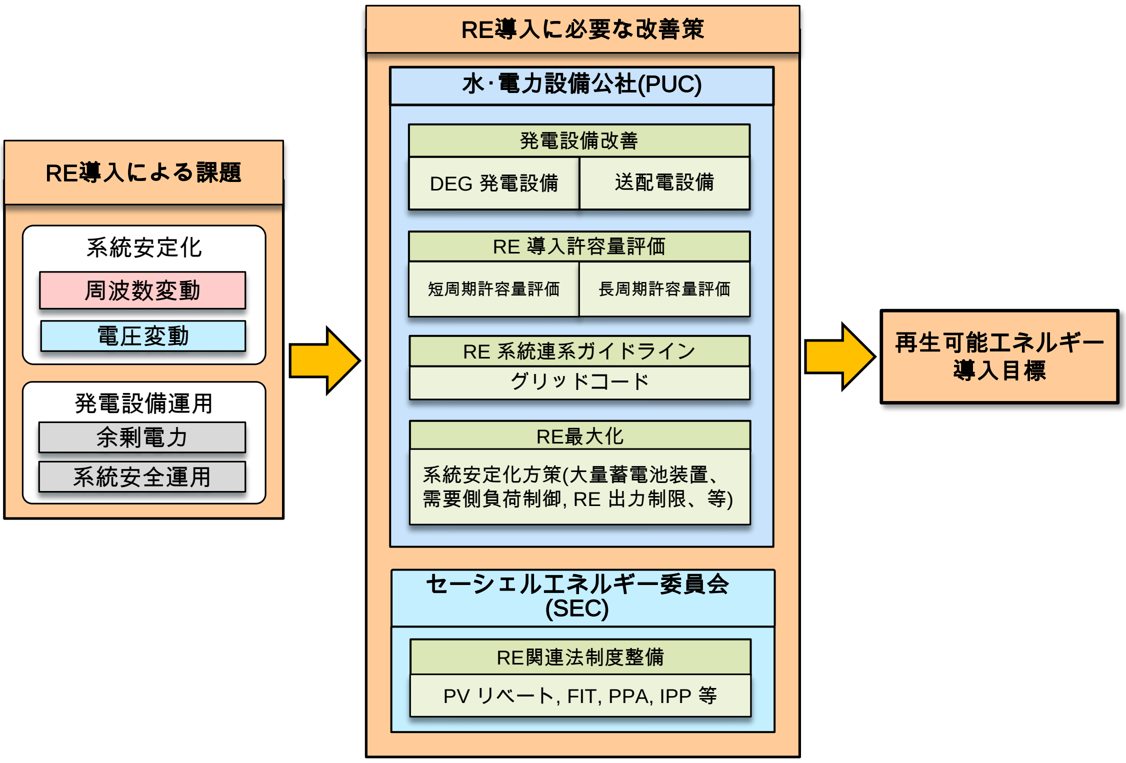


図 4.2.2-1 再エネ導入に必要な改善策

4.2.3 課題改善策の検討

再エネ導入を進めるには一般的に「発電設備の改善策検討」、「送配電設備の改善策検討」、「電力品質への影響検討」、「系統連系ガイドラインの検討」等が必要となる。

1) 発電設備の改善策検討

再エネを大量導入した場合、日射強度が高い時間帯(11:00～15:00 頃)にディーゼル発電機の低負荷運転が懸念される(長周期変動対策)。セーシェルのディーゼル発電機の低出力運転の下限値は現在、定格出力の 50%となっているが、再エネの導入拡大に伴い、50%出力での運転検討や DG 増設時にローロードディーゼル発電機の導入検討を行う必要がある。加えて、周波数変動対策として DG のガバナ応答性を調整することで、DG の能力向上に寄与できる可能性がある(短周期変動対策)。

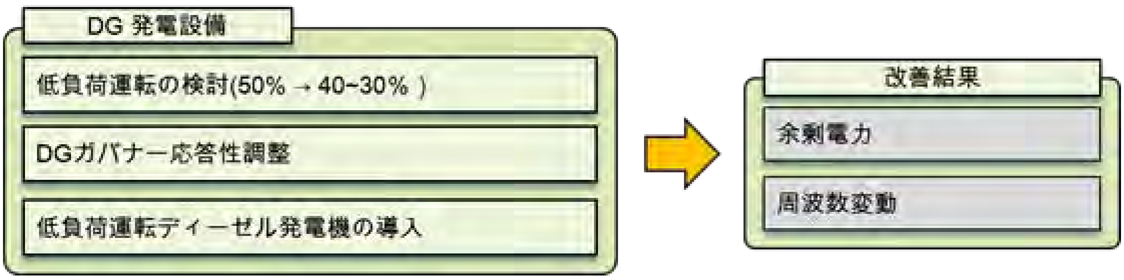


図 4.2.3-1 発電設備改善の検討及び効果

2）送配電設備の改善策検討

再エネを大量導入した場合、既存の送配電系統で再エネからの発生電力が送電できるのかどうかが問題となる。送配電系統の適正判断については、インピーダンスマップを作成し潮流計算を行うことで把握可能となる。加えて、保護リレーの設定値や時限についても併せて検討することが必要となる。

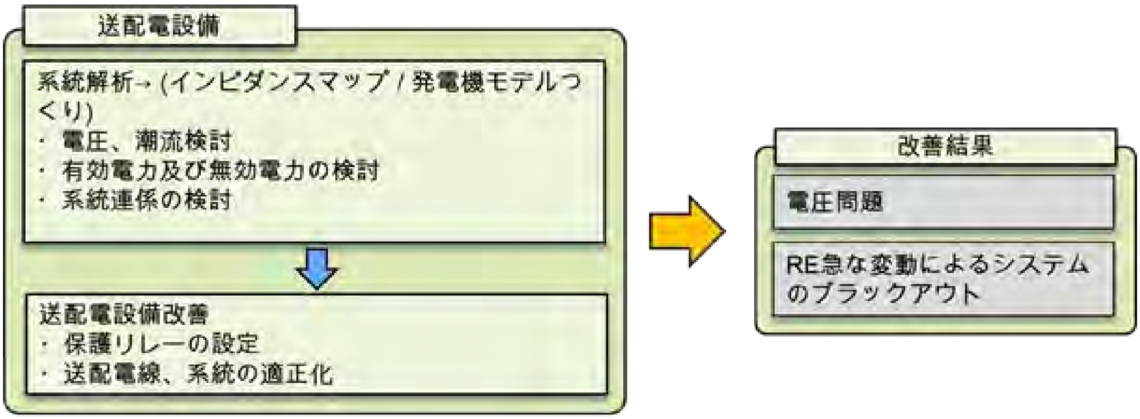


図 4.2.3-2　送配電設備改善の検討及び効果

送配電系統における計測装置導入から検証に関する一連の流れを図 4.2.3-3 に示す。

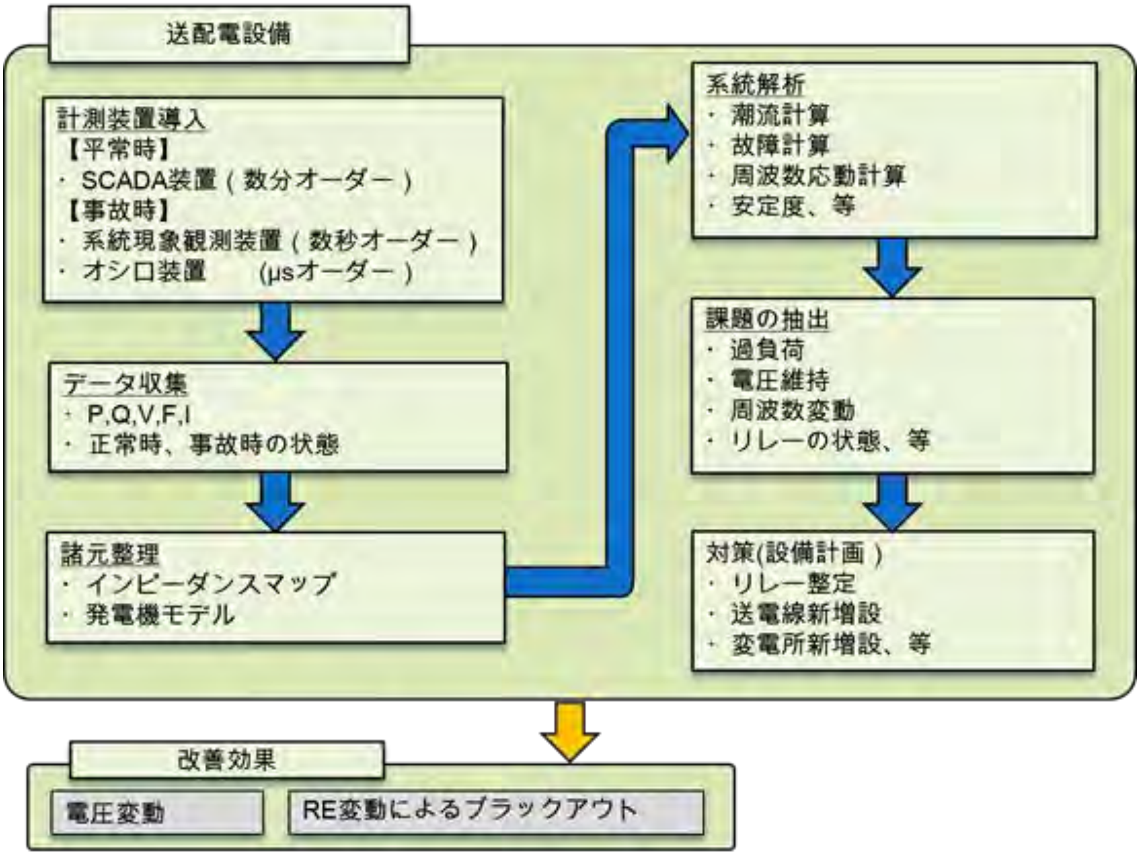


図 4.2.3-3　送配電系統における計測、解析フロー

3) 短周期変動、長周期変動の検討

電力系統を安定的に運用するには系統周波数の短周期的要素(数秒程度)と長周期的要素(数分程度)を安定化する必要がある。短周期の検討においてはシミュレーションソフトを用いて行う方法や代数的手法にて検討する方法がある。今回、セーシェル国での検討では、簡易的な手法である代数的手法にて検討を行った。一方、長周期の検討においては、シミュレーションソフトにて需給バランス計算を行い、必要に応じて蓄電池導入の有無についての検討を行った。

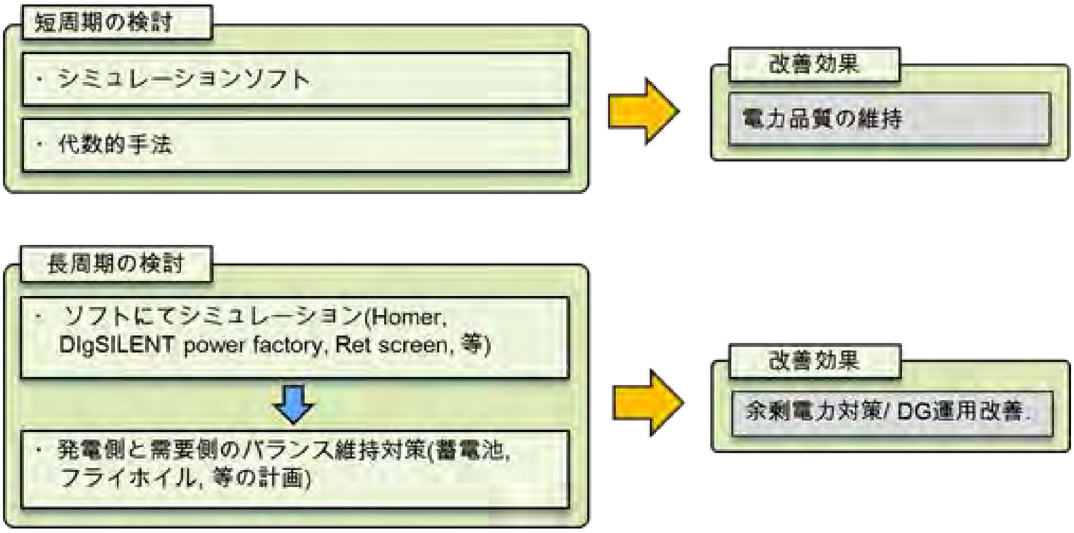


図 4.2.3-4　長周期変動、短周期変動の検討手法

4) グリッドコードの検討

再エネを大量導入する際、系統安定化が重要な要素となる。その為には、適正なグリッドコードを整備する必要がある。グリッドコードでは、周波数や電圧の管理範囲や電力品質の諸元に加え、系統保護装置の諸元等を整備する必要がある。

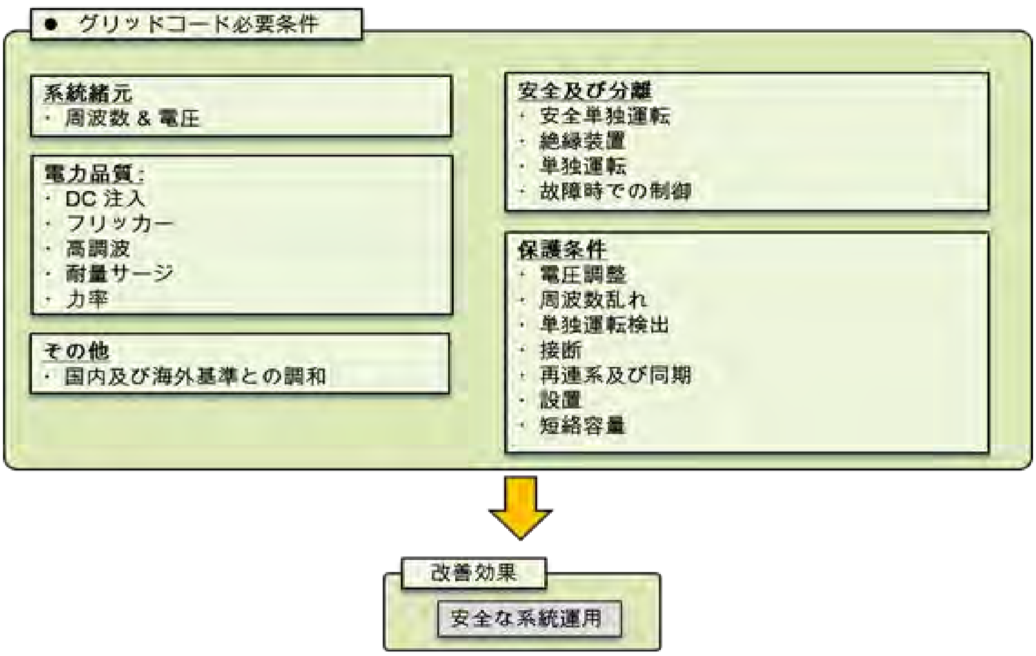


図 4.2.3-5　グリッドコードの検討

5) 再エネ最大化の検討

再エネの大量導入は、周波数や電圧の変動といった電力系統に与える影響が問題となる。この問題に対し、監視制御技術(EMS:Energy Manegement System)を用いて再エネや 蓄電池を監視制御し効率的な運用を行うことで安定的な系統運用に資することが期待できる。また、スマートインバータを導入することで、需要家側の PV 出力を抑制することも併せて検討する必要がある。但し、これらの技術については、実証試験による技術検証が進められている開発段階の技術であり、導入に当たっては ICT インフラの導入も並行して進める必要があるため、技術開発動向および適用可能性について都度精査が必要となる。

系統安定化

・ EMS (Energy Management System)
・ スマートインバーター。需要家側のPV出力制御。

図 4.2.3-6　系統安定化の検討

4.2.4 セーシェル国におけるマスタープラン

Mahe 島および Praslin 島における再エネ導入マスタープランを示す。マスタープランにおける再エネ導入目標は 2030 年で 15%とした。これはセーシェル政府により設定された目標であり、本目標達成に必要となる再エネ導入量および系統安定化装置（短周期/長周期変動対策）について検討を行った。また、需要の増加については、ドイツコンサル Energy Nautics の報告書に記載のある 2030 年のデマンド 875GWh を考慮して、年間 6%増加を見込んだ。それに加え、需要伸び率が低めに推移した場合を想定し、年間 3%増加ケースも追加検討した。

B. Load development up to 2030

The load in Seychelles has two peaks: one at around midday on workdays and another in the early evening. The load is inductive with a power factor around 0.86 thanks to the large number of air-conditioning units on the islands. The peak demand is expect to rise by 6% a year until 2030, with additional step jumps because of load that has been suppressed until the new 33 kV network is built (such as new hotel projects in the South of Mahé). The expected load development is shown in Table II.

The current yearly demand on Mahé is 323 GWh/a and will rise to 875 GWh/a by 2030; the minimum demand is around 52% of the peak.

図 4.2.4-1 Energy Nautics 報告書(抜粋)

(1)Mahe 島

Mahe 島において 2030 年までに再エネ 15%を達成するためのマスタープランを短周期変動での再エネ許容量の結果も考慮し、シミュレーションソフト HOMER を用いて検討した。

■ **需要想定 1：年間 6%増加**

Mahe 島において、需要が年間 6%増加することを想定した再エネ導入マスタープランを図 4.2.4-2 に示す。2030 年に再エネ 15%を達成するためには、太陽光発電設備 60.2MW、大規模電力貯蔵設備 120MWh の導入が必要となる。その際、2016 年に短周期変動対策、2021 年に長周期変動対策の検討が必要となる。また、需要の増加に伴い、ディーゼル発電機の予備率が低減することから、2019 年、2023 年、2026 年および 2029 年にディーゼル発電機の増設の検討が必要となる。

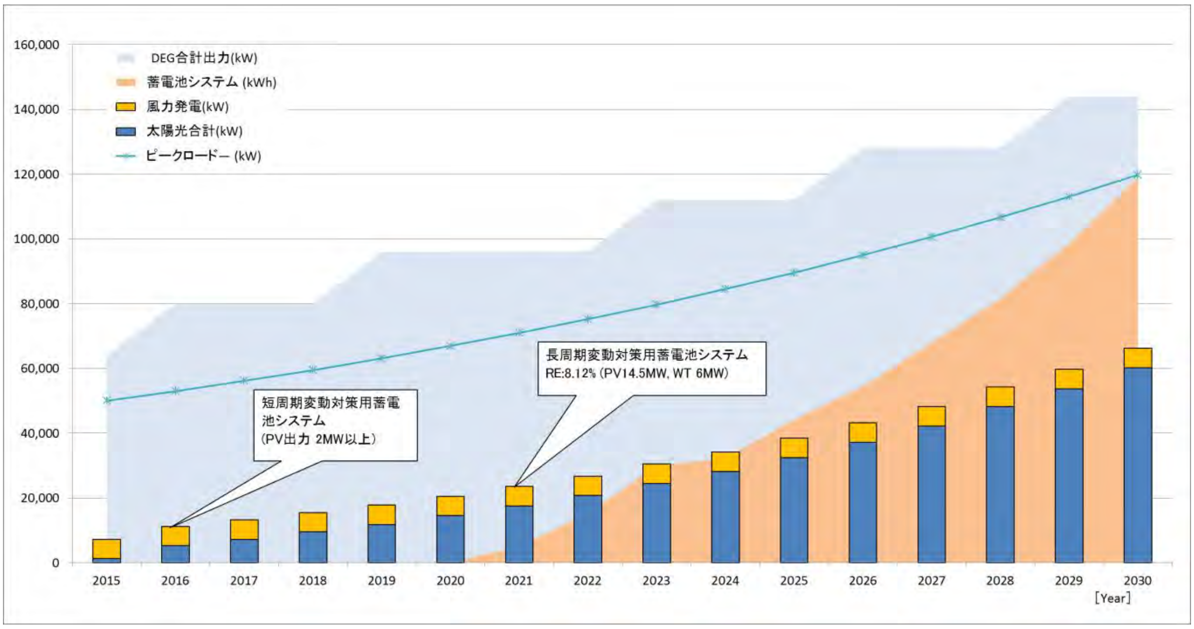


図 4.2.4-2 再エネ導入マスタープラン(Mahe 島)需要想定：年間 6%増

■ **需要想定 2：年間 3%増加**

Mahe 島において、需要が年間 3%増加することを想定した再エネ導入マスタープランを図 4.2.4-3 に示す。2030 年に再エネ 15%を達成するためには、太陽光発電設備 37.7MW、大規模電力貯蔵設備 74.8MWh の導入が必要となる。その際、2016 年に短周期変動対策、2021 年に長周期変動対策の検討が必要となる。また、需要の増加に伴い、ディーゼル発電機の予備率が低減することから、2024 年にディーゼル発電機の増設の検討が必要となる。

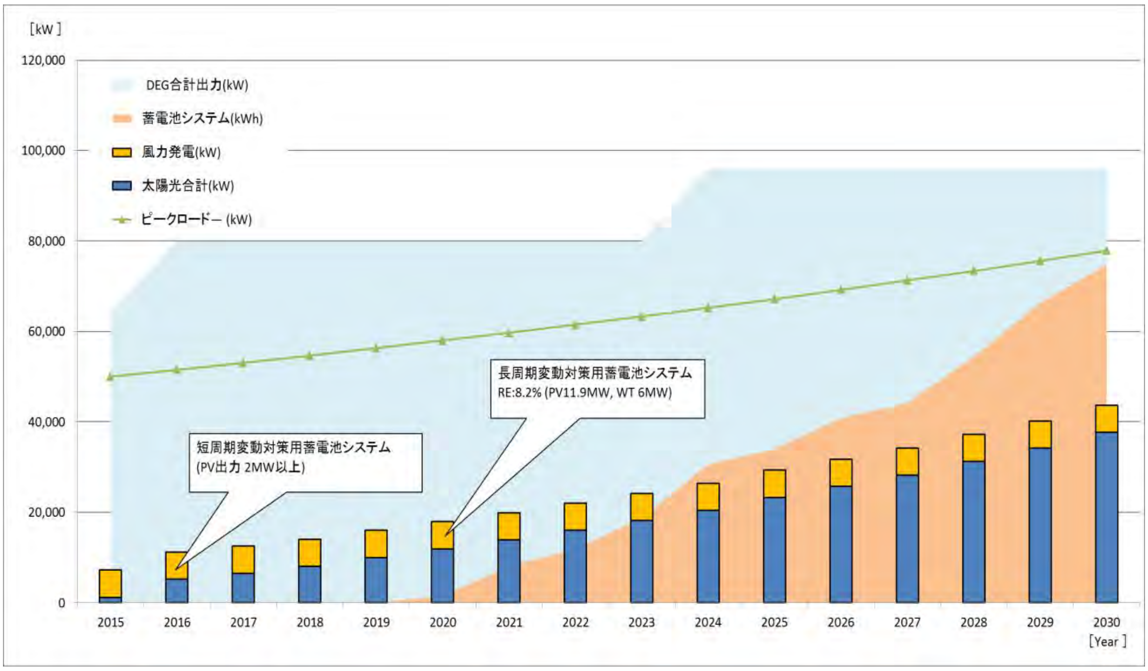


図 4.2.4-3 再エネ導入マスタープラン(Mahe 島)需要想定：年間 3%増

(2)Praslin 島

Mahe 島と同様に Praslin 島において 2030 年までに再エネ 15%を達成するためのマスタープランを短周期変動変動での再エネ許容量の結果も考慮しシミュレーションソフト HOMER を用いて検討した。但し、需要想定については、ヒアリング結果に基づく検討結果より 2020 年までに急速な需要増加が見込まれるため、下表の通り需要を想定した。

表 4.2.4-1 Praslin 島における需要想定

年	年間6%上昇率		年間3%上昇率	
	予想需要（MW）	年間上昇率（%/年）	予想需要（MW）	年間上昇率（%/年）
2015	8.1	11.86	8.1	5.93
2016	9.1		8.6	
2017	10.1		9.1	
2018	11.3		9.6	
2019	12.7		10.2	
2020	14.2		10.8	
2021	15.0	5.69	11.1	2.85
2022	15.8		11.4	
2023	16.7		11.8	
2024	17.7		12.1	
2025	18.7		12.4	
2026	19.8		12.8	
2027	20.9		13.1	
2028	22.1		13.5	
2029	23.3		13.9	
2030	24.7		14.3	

■　**需要想定 1：年間 6%増加**

Praslin 島における再エネ導入マスタープランを図 4.2.4-4 に示す。結果として 2030 年に再エネ 15%を達成するためには、太陽光発電設備 10.8MW、大規模電力貯蔵設備 4.1MWh の導入が必要となる。その際、2017 年に短周期変動対策、2027 年に長周期変動対策の検討が必要となる。また、需要の増加に伴い、ディーゼル発電機の予備率が低減することから、2019 年、2027 年にディーゼル発電機の増設の検討が必要となる。

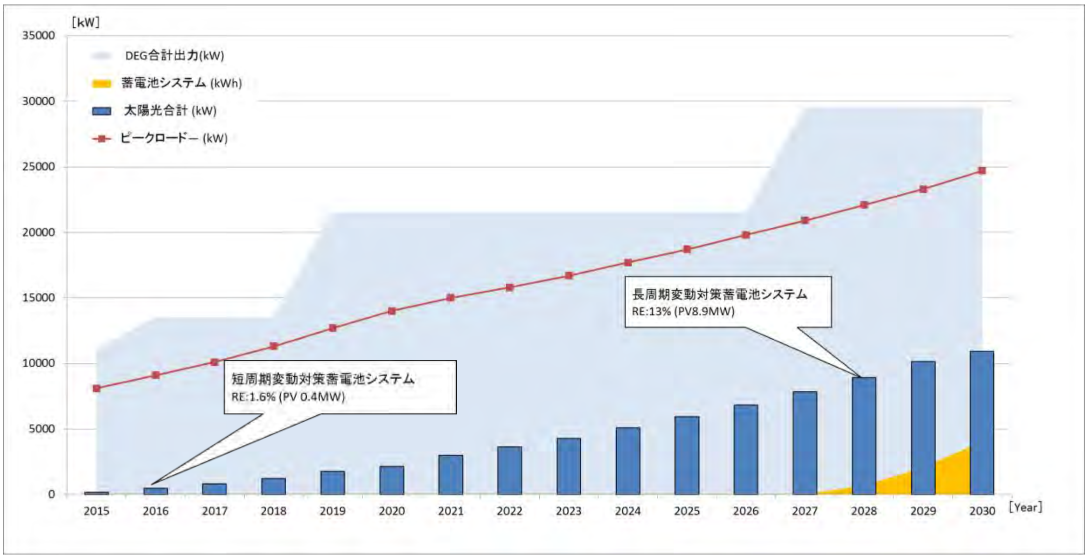


図 4.2.4-4 再エネ導入マスタープラン(Praslin 島)　：年間 6%増

■　**需要想定 2：年間 3%増加**

Praslin 島における再エネ導入マスタープランを図 4.2.4-4 に示す。結果として 2030 年に再エネ 15%を達成するためには、太陽光発電設備 6.6MW、大規模電力貯蔵設備 2.4MWh の導入が必要となる。その際、2017 年に短周期変動対策、2027 年に長周期変動対策の検討が必要となる。また、、需要の増加に伴い、ディーゼル発電機の予備率が低減することから、2025 年にディーゼル発電機の増設の検討が必要となる。

図 4.2.4-5 再エネ導入マスタープラン(Praslin 島)　：年間 3%増

4.2.5 マスタープランの各断面における検討例

本節においては、上記で示した再エネ導入マスタープランの内、Mahe 島について、各断面での具体的検討例を示す。図 4.2.4-6 に示す再エネ導入ロードマップ(Mahe 島)は、図 4.2.4-2 のマスタープランにおける検討が必要となる項目を示している。検討項目は以下の 3 つに分けられる。

検討項目 1：再エネの短周期変動対策

- 課題：大規模 PV(50kW 以上)の大量導入に伴う系統周波数の許容範囲逸脱の可能性
- 手法：代数的手法（本報告書 3.1.3.5 節）
- 内容：再エネ導入許容量の算定、および必要となる安定化装置の容量算定

検討項目 2：需要増加に伴う供給予備力の増強（ディーゼル発電機の増設）

- 課題：需要の増加に伴う供給予備力の不足の可能性
- 手法：HOMER によるエネルギー収支計算（本報告書　節）
- 内容：必要となる供給予備力の算定

検討項目 3：再エネの長周期変動対策

- 課題：再エネの大量導入に伴う余剰電力発生の可能性
- 手法：HOMER によるエネルギー収支計算（本報告書　節）
- 内容：余剰電力の算定、および必要となる電力貯蔵設備の容量算定

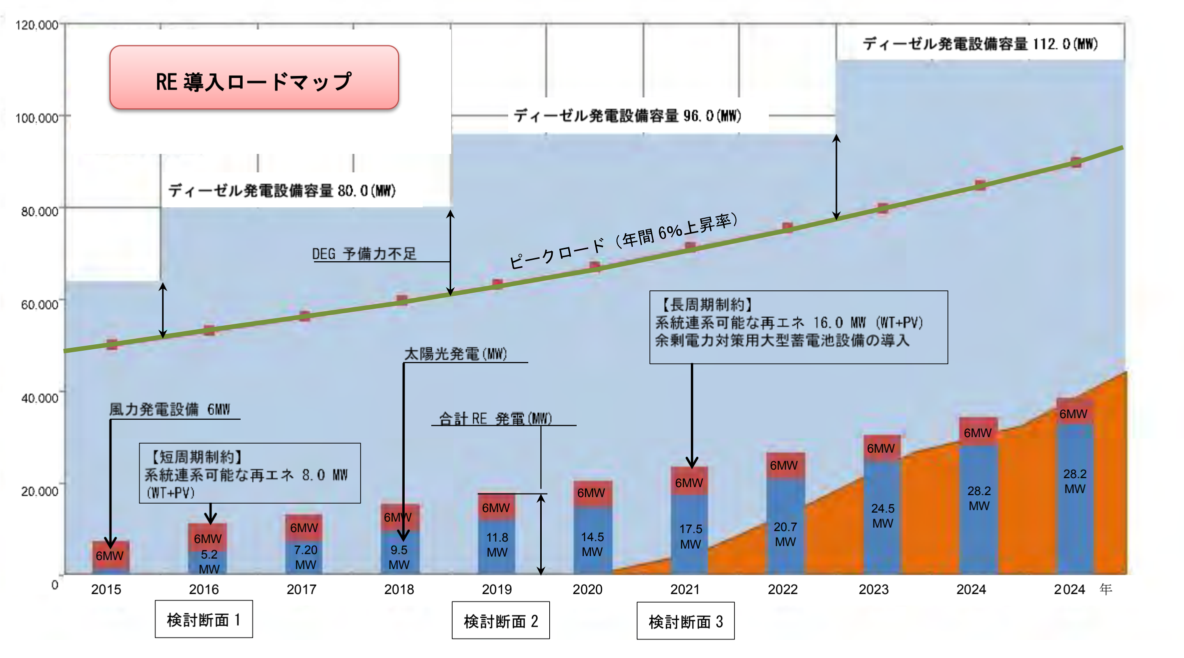


図 4.2.5-1 再エネ導入ロードマップ(Mahe 島) ：年間 6%増

検討項目 1：再エネの短周期変動対策

検討断面：2016 年に 4MW の太陽光発電設備を連系した場合

(1) 想定される系統状況

連系されている再エネ容量：11.2MW（PV5.2MW、WT6MW）

(2) 具体的検討項目

3.3.3 項にて同内容の検討を記載済みのため、以下に検討項目を列挙する。

① 系統定数算定：負荷遮断試験による発電機負荷追従性および周波数安定性確認
② 需要変動率算定：需要負荷の変動の確認
③ 需要分析：想定される最大需要の確認
④ 再エネ変動率算定：再エネの変動の確認

(3) 得られる結果

代数的手法にて短周期制約に伴う最大連系可能な PV 設備は 2.0MW となった。

表 4.2.5-1 短周期における RE 連系可能量算定結果（Mahe）（再掲）

	Demand (MW)	PV fluctutaion rate (%)	PV (MW)	WT (MW)	RE (MW)
Probability (95%)	32	80	0	6	6
	40		0		6
	50		2		8
16/03/2016	50	100	1.6	6	7.6

50kW 以下の 1.2MW を除いた PV 容量 4MW の内、短周期制約の 2.0MW 超える PV 容量 2.0MW に対しては、再エネ出力変動対策が必要となる。現在検討されている 4MW のメガソーラをに対する変動対策を勘案した場合、リチウムイオン電池の導入を想定すると、50MW の系統負荷に対して電力品質(周波数)が 95%の確率で管理許容値内に収める場合の電池容量は 1.6MW×0.5h＝800kWh となる。

表 4.2.5-2　4MW のメガソーラ導入のための系統対策(Mahe)（再掲）

	Demand (MW)	Allowable PV (MW)	PV required grid stabilizer (MW)	Battery(LiB) (MW) ×0.5h
Probability (95%)	32	0	4	3.2
	40	0	4	3.2
	50	2	2	1.6
16/03/2016	50	1.6	2.4	2.4

検討項目 2：需要増加に伴う供給予備力の増強（ディーゼル発電機の増設）

検討断面：2019 年に総需要が 63.1MW まで増加した場合

(1) 想定される系統状況

ディーゼル発電機合計容量：80MW

(2) 具体的検討項目

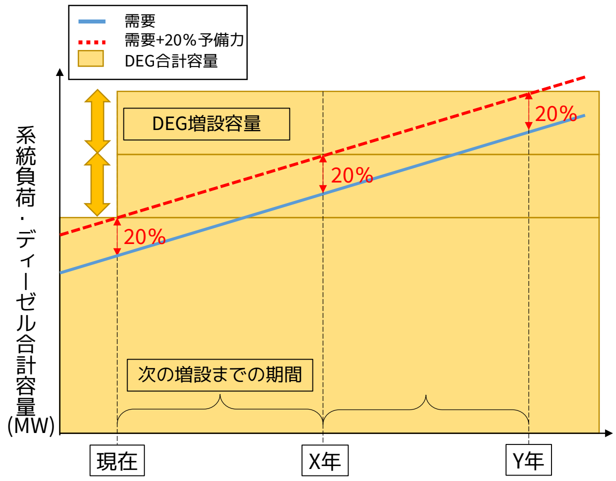
① HOMER による需給バランス収支計算：供給予備力の確認

HOMER による需給バランス収支計算結果より、供給予備力が 21.12%にて供給力不足となる可能性が生じるため、発電機の増設検討を行う必要がある。

② 発電機増設検討：増設容量の検討

HOMER による検討から供給予備力が不足することが想定される場合、増設計画を立案する

必要がある。図 4.2.5-2 に示す通り、検討には増設容量と次の増設までの期間を勘案して決定する。



検討カテゴリ	検討項目	検討内容
ディーゼル増設容量（技術面・運用面）	単機容量	• 供給力の確保 • 下げ代の確保
	ユニット数	• 故障やメンテナンスを加味したユニット数
次の増設までの期間（社会情勢・財政面）	需要想定の精度	• 大規模需要家の連系予定 • 誤差の勘案
	予算	• 確保できる予算の確認(導入費・O&M費)

図 4.2.5-2 ディーゼル発電機増設検討イメージ

(3) 得られる結果

2019 年断面では、8MW×2 機=16MW の増設が適当である。しかしながら、直近の PUC 導入実績より単機容量およびユニット数を決定しており、需要想定の精度についても未検証である。また、本検討は供給予備力の考え方や予算など、導入する PUC の検討断面における状況によって変化する可能性があるため、HOMER による供給力の確認、増設必要性の検討を定期的に実施する必要がある。

検討項目 3：再エネの長周期変動対策

検討断面：2021 年に 17.5MW の太陽光発電設備を連系した場合

(1) 想定される系統状況

想定需要：71.0MW

連系されている再エネ容量：23.5MW（PV17.5MW、WT6MW）

(2) 具体的検討項目

再エネの長周期変動対策については、長周期制約における再エネ導入許容量を算定して、再エネ導入量の推移と比較し、余剰電力の発生時期と発生量を確認する必要がある。3.3.4.2 節において、HOMER での需給バランス収支計算によって 2015 年断面における以下の項目を実施している。

① 長周期制約における再エネ導入許容量の算定
② 各断面における余剰電力発生量の推定
③ 余剰電力対策の検討

(3) 得られる結果

■ 2021 年より長周期制約における再エネ導入許容量を超える再エネが導入され、余剰電力が発生する可能性が生じる。

■ 例えば 2024 年においては、余剰電力量は 125MWh と推定され、これを蓄電池にて全量吸収する場合には 32MWh の容量が必要となる。

【参考】マスタープラン実施のための概算費用

2030 年までの概算費用は以下の通り。但し、単価については都度更新する必要があるため、この限りではない。また、PV および蓄電池導入費用については、PUC による実施を想定した。

表 4.2.5-3 マスタープラン実施のための概算費用（Mahe 島・需要想定 6%）

設備	費用(USD)	設備容量	単価および算出根拠
PV	119,000,000	60.2MW	2,000USD/kW セーシェル国の市場価格を参考に機器単価を想定した
DEG	64,000,000	64MW （追加分）	1,000USD/kW 国内メーカヒアリングによる相場価格
蓄電池 （長周期対策）	59,500,000	120MWh	鉛蓄電池：5 万円/kW[1] 経済産業省「蓄電池戦略」より
PCS (PV/蓄電池)	87,250,000	174.5MW	5 万円/kW 国内メーカヒアリングによる相場価格
合計	329,750,000	―	

4.2.6 マスタープラン実施のための検討プロセス

前節にて示したの各断面における検討例について、図 4.2.6-1 にその検討プロセスを示す。再エネ導入においては、電力系統の電源構成や負荷特性等により、系統安定性の指標となる系統周波数の維持能力が異なる。現在の Mahe 島における系統状態から得られた再エネ許容量は以下の通りである。

- 短周期制約：2.0MW
- 長周期制約：10.0MW

短周期制約については、基幹電源であるディーゼル発電機の負荷追従性が大きく影響するため、需要増加に伴う発電機増設の際には、本プロジェクトで実施した負荷遮断試験を行うことにより、再エネ出力の短周期変動に対する耐量を確認することが必要となる。これを超える量の再エネを導入する場合には、超過した再エネ容量と同出力を担保できる安定化装置を導入することで、系統周波数の安定化を図れる。

長周期制約については、ディーゼル発電機の出力下限に起因する余剰電力が発生する可能性があり、需要の変化やその時の電源構成および運用方針により、再エネの導入可能量は変化する。そのため、短周期制約の検討と同様に、電力系統の状態に変更があった際に、都度見直しを図る必要がある。本プロジェクトにおいては、シミュレーションソフト HOMER により需給バランス収支計算を実施することにより、需要負荷と自然条件（PV 出力・WT 出力）に対するディーゼル発電機の運用状況を確認できることを示した。本手法を定期的に実施することにより、長周期制約を超過する再エネ容量の把握、余剰電力の発生時期および発生量を確認し、必要な対策（出力抑制・蓄電池導入）を検討する必要がある。

また、HOMER によるシミュレーションにおいては、ディーゼル発電機による供給予備力も確認できることから、発電機増設のタイミングも確認することができる。

[1] http://www.enecho.meti.go.jp/committee/council/basic_problem_committee/028/pdf/28sankou2-2.pdf

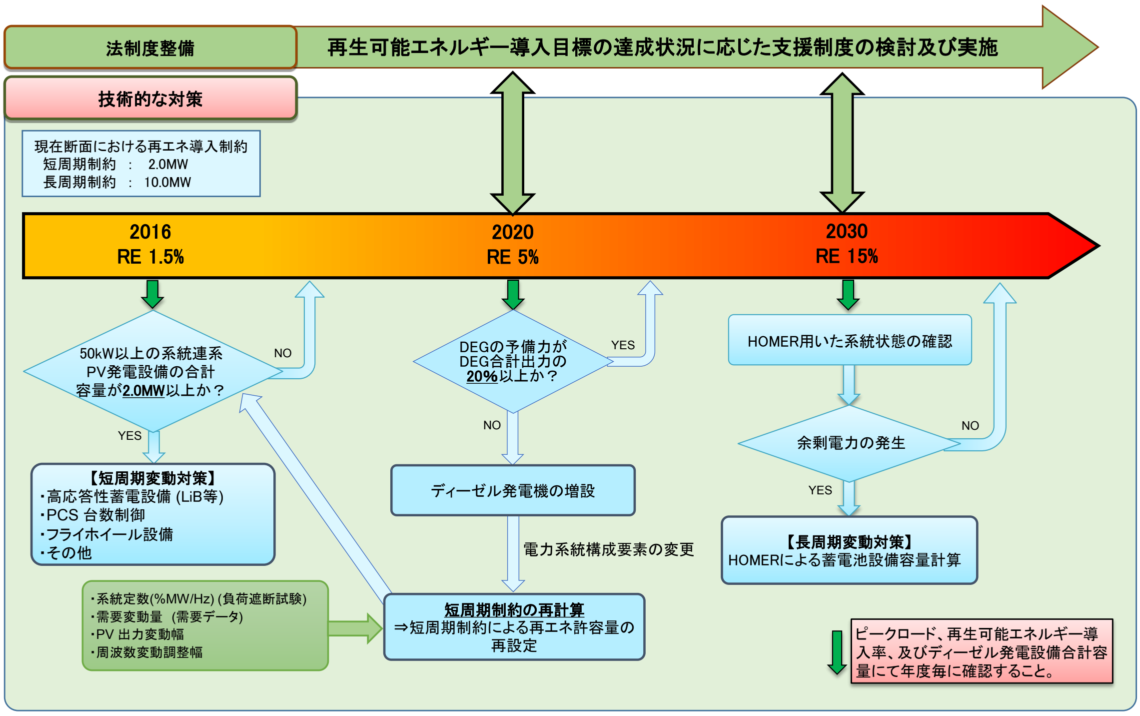


図 4.2.6-1 再エネ導入に係る検討プロセス

Okinawa Enetech Co., Inc.

Method for caculating the amount of RE deployable

(1) Algebraic method (simplified method)

■ This estimation method is simple and clear.
■ It has been proven in Japan and is highly reliable.
■ Model construction of generators is unnecessary, and when expanding the adjustability of generators and storage batteries, estimation is possible by applying it to the LFC value.

(2) Simulation method (detailed method)

■ This method reflects the grid's unique characteristics and is used in order to verify the validity of the algebraic method.

■ Real wind and solar power data is used, so it is highly reliable.
■ It requires dedicated tools for calculating and highly specialized knowledge.

About LFC (load frequency control) [Algebraic method]

◆ LFC (load frequency control) aims to control and eliminate the imbalance of supply and demand due to load fluctuations by automatically controlling the generator regarding components of a cycle of a few minutes to approx. 20 minutes with a calculator.

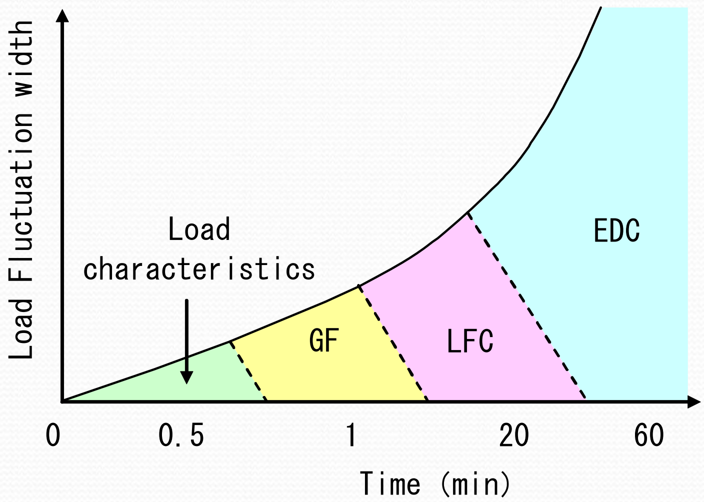
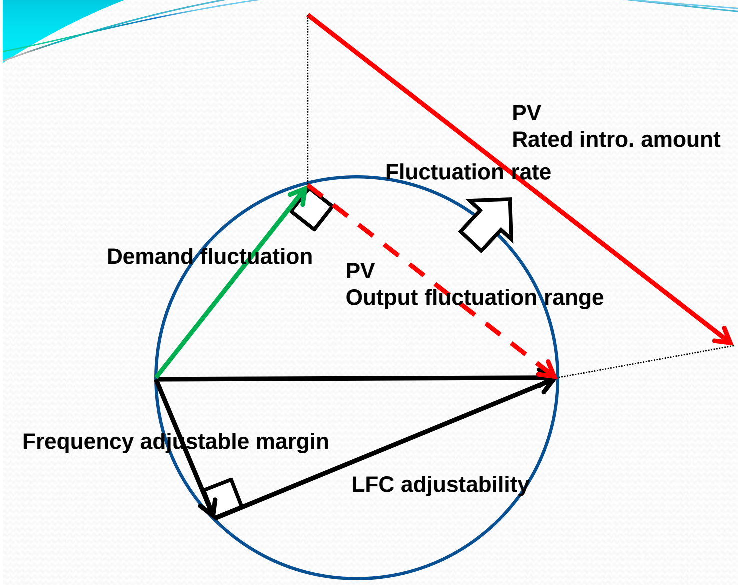


Fig conception of control share

Calculation of the amount of PV connectable to the grid [Algebraic method]



[Required Specifications]

① LFC adjustability
⇒ Operation method/specifications for generator

② Frequency adjustable margin
⇒ Total demand (kW)
⇒ System constant (% kW / Hz)
⇒ Allowable frequency fluctuation range (Hz)

③ Demand fluctuation
⇒ Demand data (resolution: a few seconds)

④ PV connectable to the grid (fluctuation rate)
⇒ Solar radiation intensity data (resolution: a few seconds)

PV Output fluctuation range

$$= \sqrt{(\text{Frequency adjustable margin})^2 + (\text{LFC})^2 - (\text{Demand fluctation})^2}$$

Connectable amount (short-period) = Allowable amount of PV fluctuation / PV output fluctuation rate

Control for load fluctuations using LFC [Algebraic method]

◆ The LFC control system has time elements such as change rate and control delays, but these time elements are shown as control delay curve β, and the figure below shows the relationship among load fluctuation amount, adjustability with LFC, and frequency adjustable margin.

OL: load fluctuation amount

LR: adjustability with LFC

OR: adjustable margin

β: control delay curve

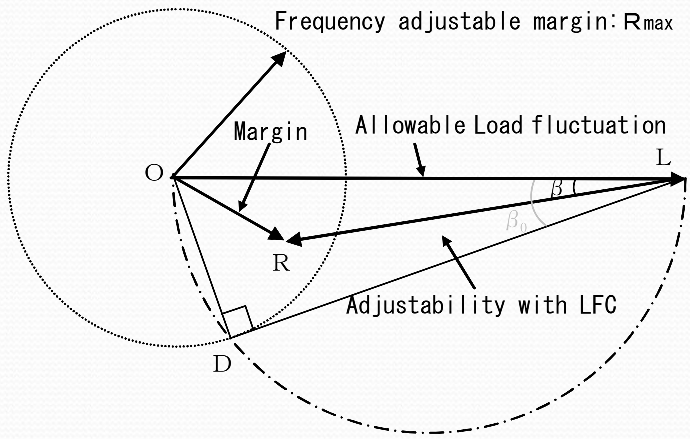


Fig Relation among Load fluctuation amount、

(See Institute of Electrical Engineers of Japan Technical Report No. 869 Figure 5.13)

Relationship between adjustability with LFC and allowable adjustable margin [Algebraic method]

◆ In the figure below,

・If the control delay curve is β_0 or higher, it becomes impossible to keep adjustable margin within the allowable value (Rmax) no matter how much LFC adjustablility (LR) is increased.

・Thus, for the allowable adjustable margin (Rmax) which is determined by an allowed frequency deviation, the allowable load fluctuation when the maximum LFC adjustability is utilized is when OR is perpendicular to LR.

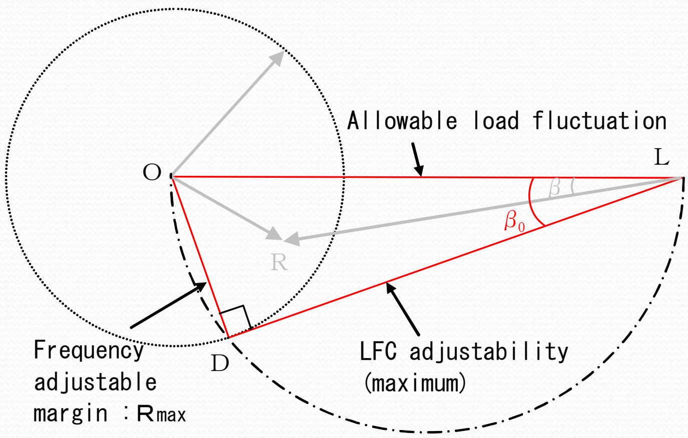
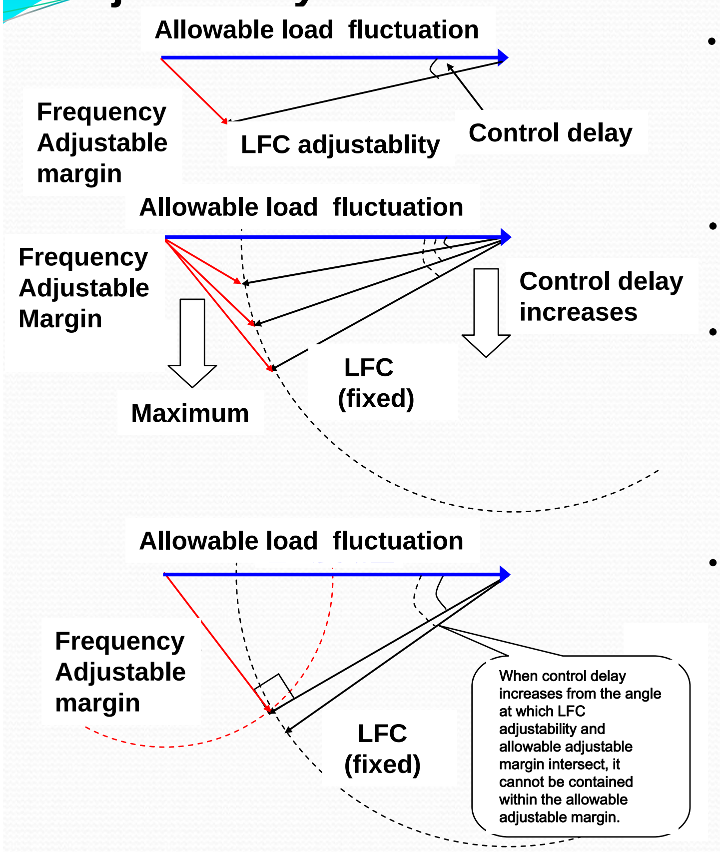


Fig allowable load fluctuation against frequency adjustable margin

(Additional) Relationship between adjustability with AFC and allowable adjustable margin

[Algebraic method]



- Since LFC performs generator control after detecting load fluctuation, the control is delayed by the responsiveness of the generator, and adjustable margin occurs.

- If LFC adjustability is constant, adjustable margin increases as control delay increases.
- In the lower portion of the algebraic method, even if control delay reaches maximum, a composite fluctuation amount which can keep adjustable margin within the allowable adjustable margin is calculated.

- The maximum control delay that can keep adjustable margin within the allowable adjustable margin is where LFC adjustability and adjustable margin intersect perpendicularly.

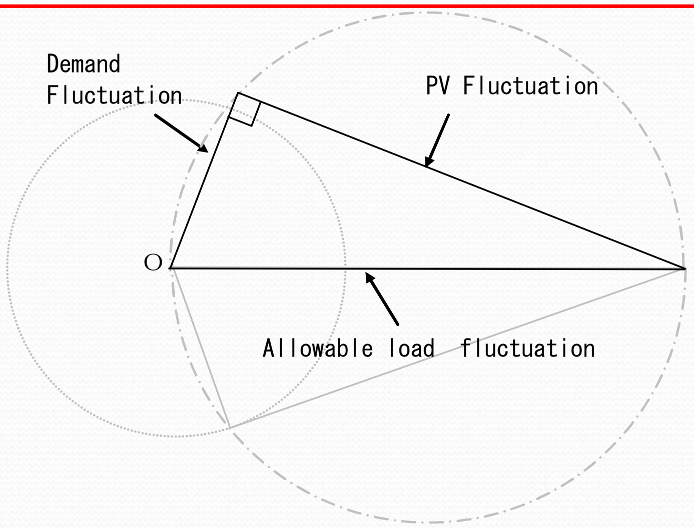
$$\text{Allowable load fluctuation} = \sqrt{\text{Adjustable margin}^2 + LFC^2}$$

Composite fluctuation of the load

[Algebraic method]

◆ On the other hand, the target fluctuation for AFC control, is the composite of load fluctuation and PV power variation, and because there is no correlation between the two, it is as follows.

$$\text{Allowable load fluctuation} = \sqrt{(\text{Demand Fluctuation})^2 + (\text{PV Fluctution})^2}$$



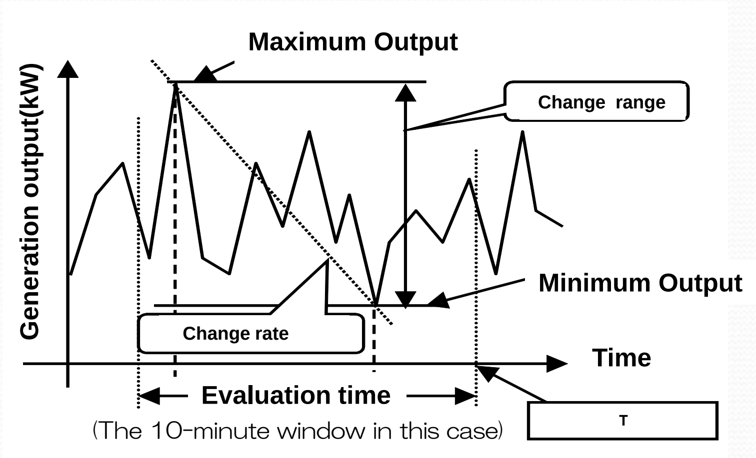
Composite fluctuation amount of Load and PV fluctuatior

Definition of PV output fluctuation range and change rate

■ The evaluation time window is set at 10 min, and the "output fluctuation range" is the difference between the maximum output and minimum output during this time.

＊Since Okinawa is a small island, the simulation is conducted with the time window set at 10 minutes as this is believed to be most suitable.

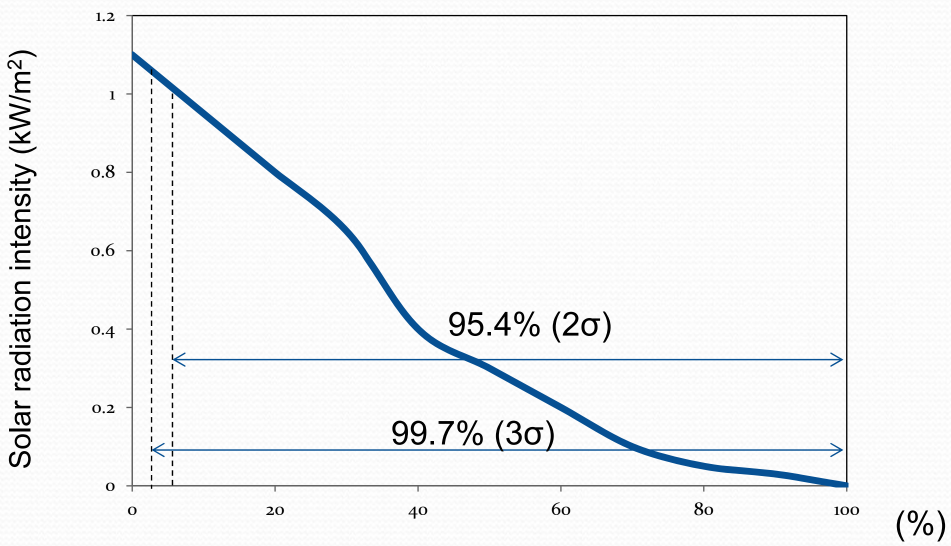
■ The "output change rate" is the result of the fluctuation range divided by the time required for the fluctuation range.



Definition of evaluation time window, output fluctuation range, and output change rate

About Probability (3σ)

Values that encompass 99.7% of all events are defined as 3σ values. Compared to using the maximum value (100% of all events), the amount of renewable energy introduced is expanded.



Remaining issues (Maximum amount of RE to the grid)

・Consider two points to determine RE amount

①Allowable Frequency change range

⇒0.3Hz,0.5Hz,1Hz or etc.

②How much risk do you take?

⇒3σ(99.7%),2σ (95.4%), σ(68.4%)

Example: allowable amount of PV kW in Majuro (Peak demand : 7MW)

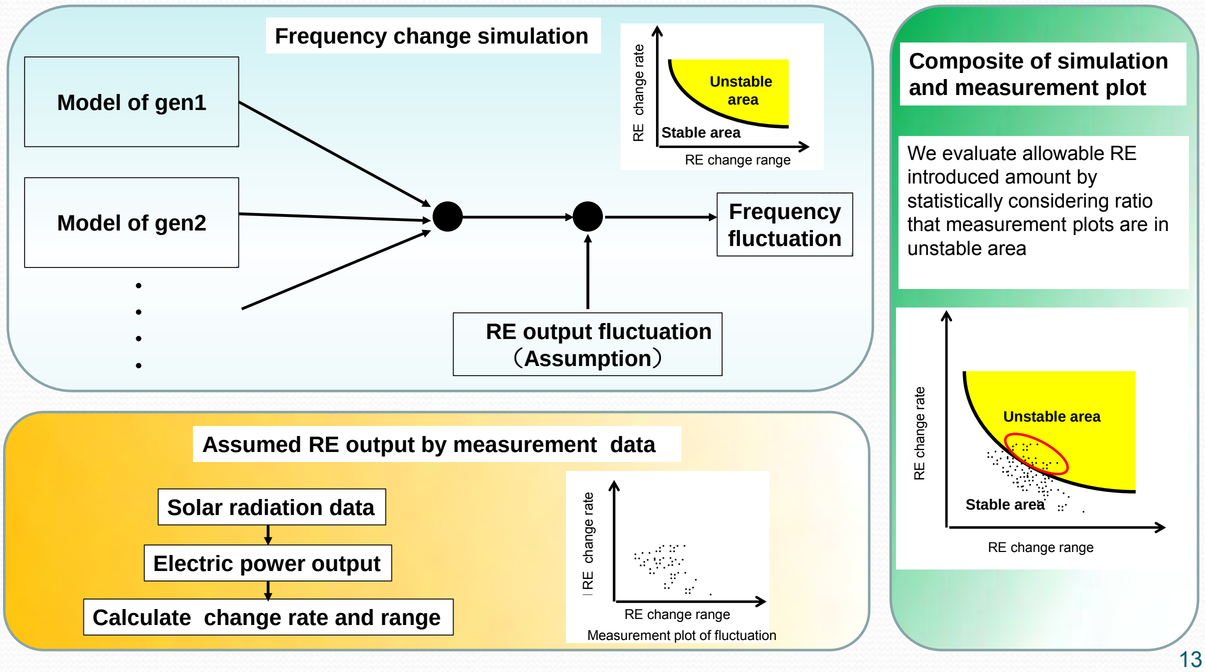
Allowable range	0.3Hz	0.5Hz	1Hz
3σ(99.7%)	170 kW	300 kW	610 kW
2σ(95.4%)	260 kW	440 kW	890 kW
σ(68.3%)	420 kW	700 kW	1410 kW

Thank you !!

Overview of the Simulation Method

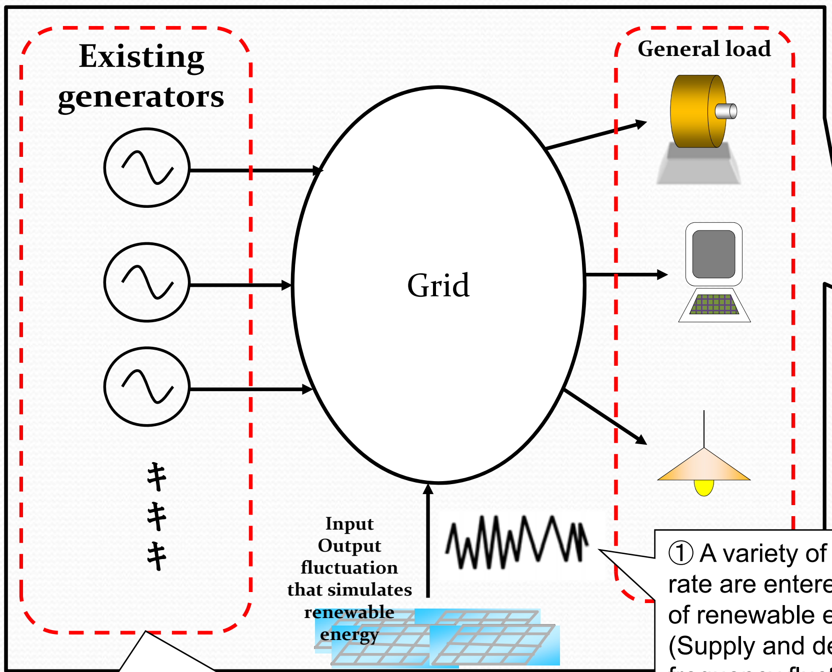
■ The simulation uses tools which are currently used for power system analysis to create a diagram showing the relationship between changes in the balance of supply and demand (fluctuation range and change rate) and frequency changes.

■ In this figure, the simulation is carried out by applying the result of power output estimated from the solar radiation data which considers the smoothing effect and verifying the number of frequency deviations (probabilistic method considered).



Schematic diagram of analysis

[Step 1] A model like the one below is constructed using a special tool, and the calculation is performed.



Due to the relationship between ① and ②, the fluctuation range and change rate that can be kept within ± 0.3Hz (for example) of the limit value is plotted to draw a curve.

A schematic diagram of the curve is shown on the next slide

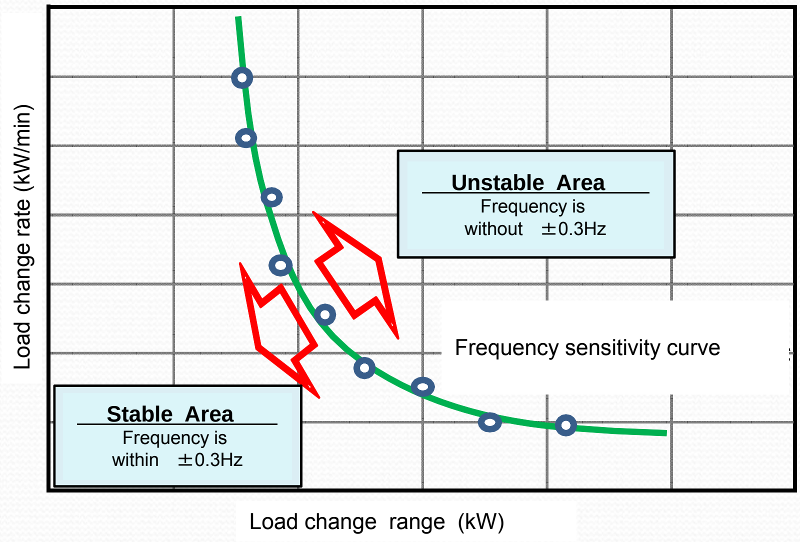
① A variety of data on fluctuation range and change rate are entered for simulation based on the amount of renewable energy to be connected.
(Supply and demand balance is lost, and the system frequency fluctuates.)

② Output is adjusted with the GF and AFC functions of the generators for the system frequency fluctuation.

Schematic diagram of analysis [Simulation method]

[Step 2] A variety of output fluctuations on the previous slide are entered and the points of the results ア0.3Hz (for example) are plotted to draw a curve.
(This curve is called frequency sensitivity curve)

Relationship between load change rate and range



[Step 3] The composite value of the expected PV output data based on measurement data is plotted in the above graph to verify the amount of frequency and whether it is within ア0.3Hz.

Schematic diagram of the analysis results [Simulation method]

A schematic diagram of the simulation results (for example) is shown in the table below. When the amount of PV connected was increased to 13MW, frequency deviation exceeded 0.3% (3σ or equivalent). Therefore, the connectable amount is 12MW.

Amount of PV connection [MW]	10	11	12	13	14
① Frequency ±0.3Hz deviation rate	0.17%	0.17%	0.17%	0.44%	0.44%
② [Reference] No. of days with ±0.3Hz deviation (Percentage of days)	1 day (3.2%)	1 day (3.2%)	1 day (3.2%)	5 days (16.1%)	5 days (16.1%)
Judgment (whether ① is within 0.3%)	Yes	Yes	Yes	No	No

By superimposing the frequency sensitivity curve calculated by the simulation model and the estimated values calculated on the basis of the PV measurement data [Data for 1 month: 7200 values], the number of frequency deviations are counted and the amount of PV connection that falls within 0.3% (22) is verified.
<Probabilistic method (3σ value) is considered>

EDC

Okinawa Enetech Co., Inc.
Energy Development Div.

Issues in remote islands power plants

・Geographical condition

Similar conditions to Southern pacific countries

・Energy

The diesel power generation cost in remote islands is relatively high compared to the mainland Okinawa. Reduction of the charge is one of the major business challenge for OEPC.

・Improvement effort of Diesel performance in Okinawa

Switching of fuel to FCC (Fluid Catalytic Cracking) class C heavy oil, Fuel transport through pipeline, Fuel recycle of waste oil, Integration of small grid systems with marine cables , Utilization of renewable power (hybrid system) , implementation of EDC assist system .

1. Introduction of remote islands in Okinawa

High dependency on diesel oil

- 11 isolated grids and all of those are highly dependent on fossil fuel, especially diesel oil.

	Locations	Generation system	Total rated output [kW]	Number of units	Fuel type (heavy oil)
1	Kume island	Internal combustion	18,500	8	CLASS A, FCC-C
2	Tokashiki island	Internal combustion	5,200	8	CLASS A
3	Tonaki island	Internal combustion	850	5	CLASS A
4	Aguni island	Internal combustion	1,600	6	CLASS A
5	Minami-Daito island	Internal combustion	3,640	6	CLASS A
6	Kita-Daito island	Internal combustion	1,540	6	CLASS A
7	Miyako island	Internal combustion	59,000	9	CLASS FCC-C
		Gas turbine	15,000	3	CLASS A
8	Tamara island	Internal combustion	1,860	4	CLASS A
9	Ishigaki island	Internal combustion	78,000	8	CLASS FCC-C
		Gas turbine	10,000	2	CLASS A
10	Hateruma island	Internal combustion	950	4	CLASS A
11	Yonaguni island	Internal combustion	2,410	4	CLASS A

What is EDC Assist System?

■EDC assist system

EDC (Economic load Dispatching Control) is one of the methods to support the control of multiple diesel power generators with the least fuel consumption of each unit based on their **fuel efficiencies**.

This system is practiced to conduct economic operation by lowering the consumption of expensive fuel in remote islands.

What is EDC System?

- Support system

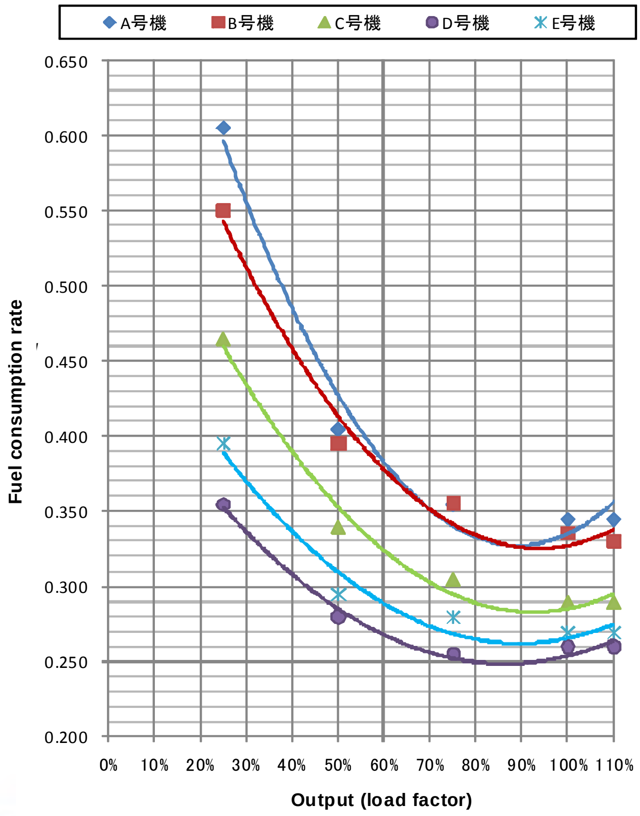
Implementation of EDC assist system in the power plant not control directly the effective output of each diesel generator calculated with the program, but it displays the results on TV monitor (or see in tables)so that the operator can manually controls the units. Since this system indirectly controls, it is called as "assisting system."

What is EDC System?

- fuel efficiencies

Generally, diesel engines perform the best around rated output level and the worst around the low load range. Next figure shows an example of comparison in fuel consumption rate of five generators (unit A: rate output 100kW to unit E: rated output 1000kW) used in Japan's remote islands. This indicates that both of diesel generators function most efficiently around the rated output range and worsen as the load factor decreases.

Fuel efficiency and load factor in diesel engines



Low load factor operation

- When operating with low load factor, a primary phenomena can be seen in diesel engine is the incomplete combustion, a poor burning of fuel-air mixture in the cylinder. A portion of fuel oil turning into soot is released as black smoke or white fume (liquid smoke), the fuel itself is discharged by the imperfect combustion. If the injected fuel doesn't converts fully into heat energy, necessary output can't be attained, thus more fuel needs to be supplied. This is the cause of increase in fuel consumption ratio.

Economical Load Dispatching Operation?

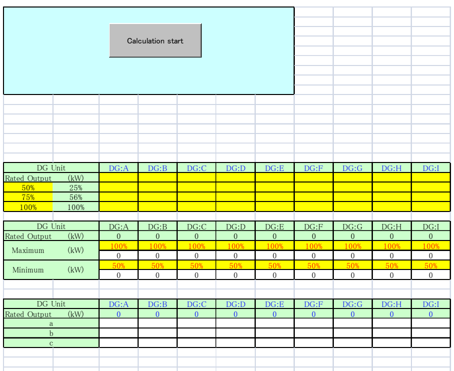
- Economical load dispatching operation controls outputs of each generator to gain the most economical load distribution among multiple DG units.

※ Operation with Economical Load Dispatching enables reduction of fossil fuel consumption in remote islands, and suppression of greenhouse gas release such as carbon dioxides.

EDC Software

- EDC software calculates load allocations with the least fuel consumption in operation of multiple diesel generators.

※ This EDC software is developed with VBA(Visual Basic for Applications) of Microsoft Excel, particularly useful for the formulation of EDC table.



DG Unit		DG:A	DG:B	DG:C	DG:D	DG:E	DG:F	DG:G	DG:H	DG:I
Rated Output	(kW)									
50%	25%									
75%	56%									
100%	100%									

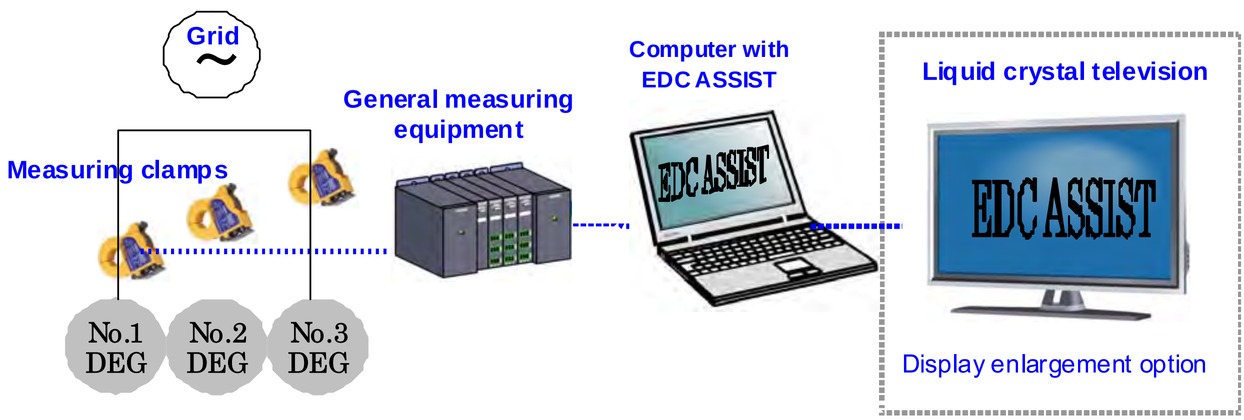
DG Unit		DG:A	DG:B	DG:C	DG:D	DG:E	DG:F	DG:G	DG:H	DG:I
Rated Output	(kW)	0	0	0	0	0	0	0	0	0
Maximum	(kW)	100%	100%	100%	100%	100%	100%	100%	100%	100%
		0	0	0	0	0	0	0	0	0
Minimum	(kW)	50%	50%	50%	50%	50%	50%	50%	50%	50%
		0	0	0	0	0	0	0	0	0

DG Unit		DG:A	DG:B	DG:C	DG:D	DG:E	DG:F	DG:G	DG:H	DG:I
Rated Output	(kW)	0	0	0	0	0	0	0	0	0
a										
b										
c										

EDC SYSTEM

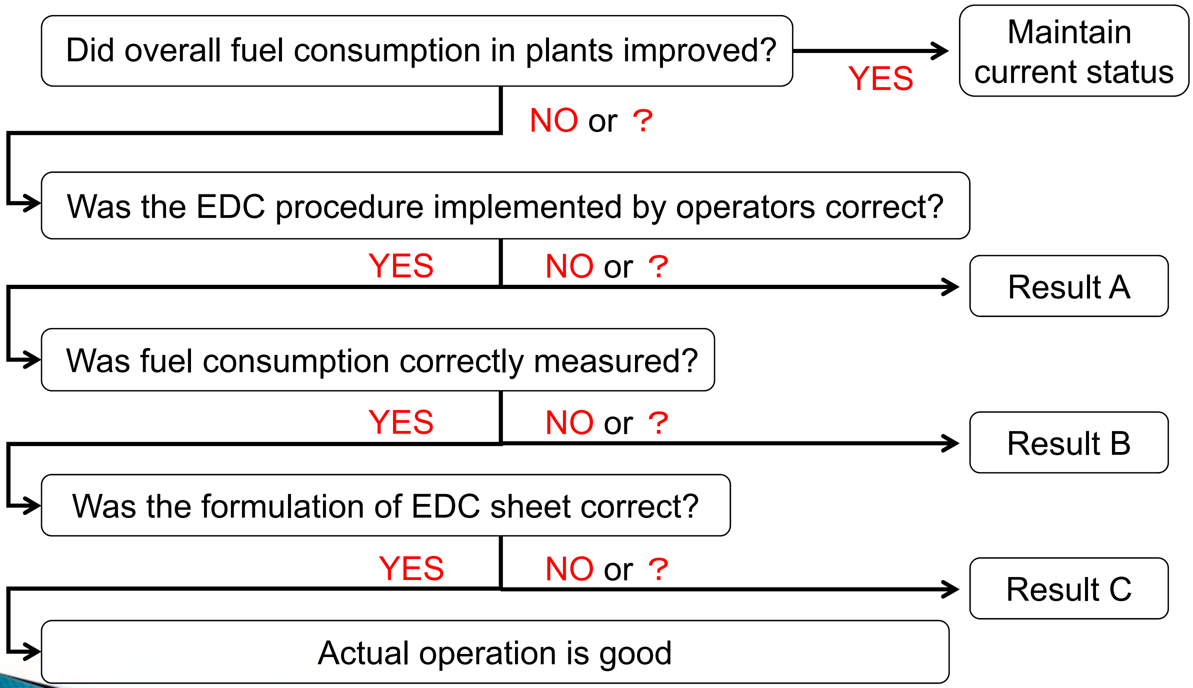
- EDC Assist System Hardware
  - ✓ Input the fuel consumption of each diesel generator into a **computer equipped with the EDC ASSIST software** and set up the efficiency characteristics of each unit
  - ✓ Power output of each unit is recorded with measuring device and the software calculates optimum load dispatching based on the power output data
  - ✓ Calculation results will be displayed on both **computer and display monitors**, and operators must adjust the unit power output as directed by the EDC program

EDC Measurement System Diagram



Because system cost is expensive, and the software is only in Japanese version yet, to implement the EDC system is necessary only a computer with the software to prepare the necessaries tables of running diesel combination.

Evaluation Flow diagram for EDC results



Result A | Was the EDC procedure implemented by operators correct?

- Insufficient realization of EDC benefit due to different operation methods applied by each operator.

Ex. Intervals of output conditioning differ with each operator.

- Is the work environment ready for operators to utilize the EDC?

Ex. Being in difficult situation to perform EDC operation as desired due to on-going maintenance, etc.

Improvement method:

. Training of operators

Result B | Was fuel consumption correctly measured?

- Accuracy in fuel flowmeter reading.

Ex. Flowmeter is not appropriately calibrated.

- Is measuring method unified?

Ex. Readings of display value are not unified.

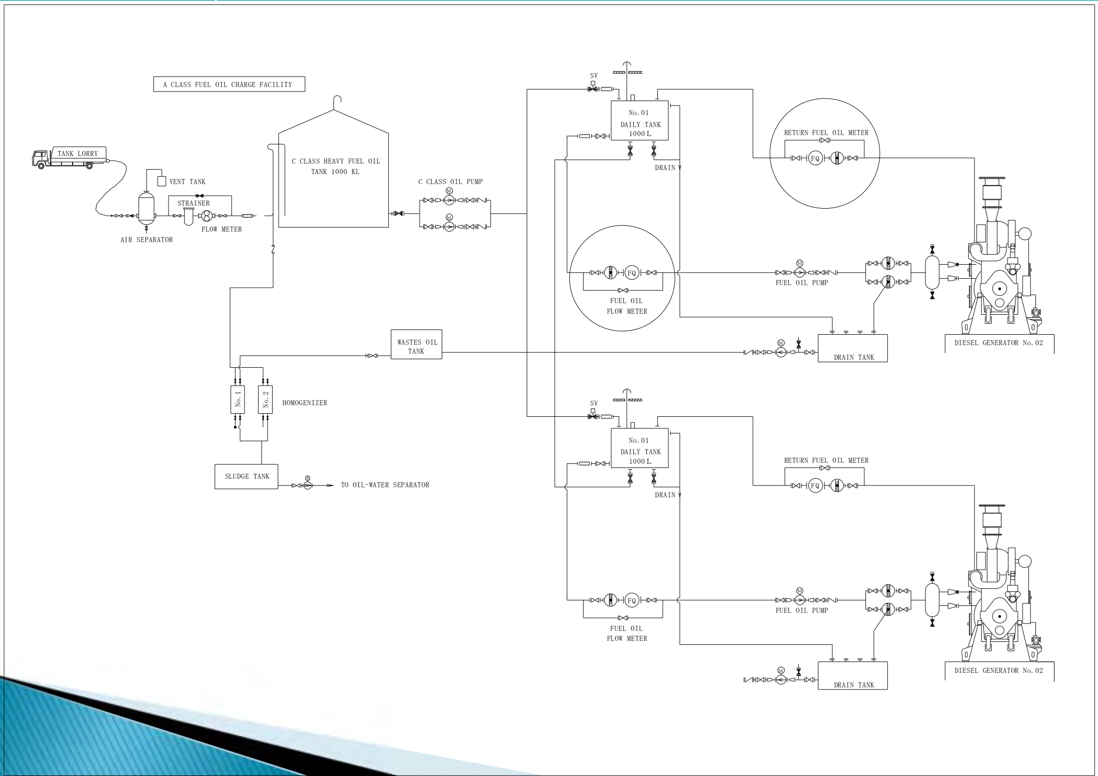
Calibration period：3 years

Result B | Was fuel consumption correctly measured?

- Returning fuel from the engine is considered into fuel flow amount?

Ex. When returning fuel increases, fuel consumption ratio improves though fuel flow amount at engine inlet is the same, and the returning fuel was not taken into account.

Result B | Was fuel consumption correctly measured?



Result C | Was the formulation of EDC sheet correct?

- Any errors on Economical load dispatching table?

Ex. Simple errors with data input or updating fuel consumption.

- Any problem during the use of the EDC soft?

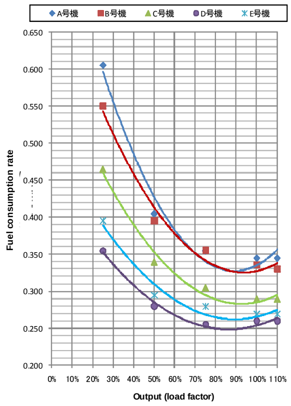
Ex. Not valid or appropriate values during load dispatching table are draw up.

Improvement method:

1.Review input process according explanation during the training course.

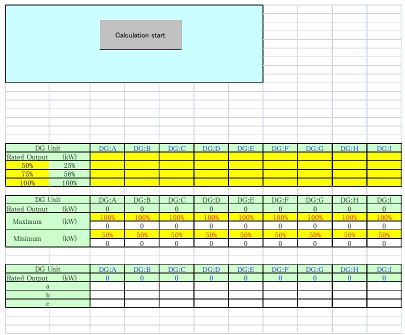
2.Ask for new data of EDC system soft .

Result C — Was the formulation of EDC sheet correct?

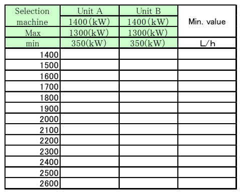


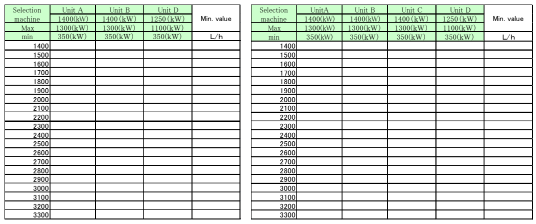
Fuel consumption data acquisition

Data input



Load dispatching table draw up





3. Economical dispatch control (EDC)

Difference of fuel consumption – same cap. DEG

Selection machine	Unit A	Unit B	Fuel consumption amount		Total	Min. value
	100kW	100kW	L/h			
Max.	100kW	100kW	Unit A	Unit B		
Min.	50kW	50kW			L/h	L/h
150	50	100	21.05	33.8	54.85	50.84
	60	90	22.5	29.79	52.29	
	70	80	24.15	26.72	50.87	
	80	70	26.48	24.36	50.84	
	90	60	29.97	22.38	52.35	
	100	50	35	20.45	55.45	
160	60	100	22.5	33.8	56.3	53.2
	70	90	24.15	29.79	53.94	
	80	80	26.48	26.72	53.2	
	90	70	29.97	24.36	54.33	
	100	60	35	22.38	57.38	
170	70	100	24.15	33.8	57.95	56.27
	80	90	26.48	29.79	56.27	
	90	80	29.97	26.72	56.69	
	100	70	35	24.36	59.36	
180	80	100	26.48	33.8	60.28	59.76
	90	90	29.97	29.79	59.76	
	100	80	35	26.72	61.72	
190	90	100	29.97	33.8	63.77	63.77
	100	90	35	29.79	64.79	
200	100	100	35	33.8	68.8	68.8

3. Economical dispatch control (EDC)

Difference of fuel consumption – same demand

Selection machine	Unit A	Unit C	Min. value	Selection machine	Unit B	Unit C	Min. value	Difference
	100kW	200kW			100kW	200kW		
Max.	100kW	200kW		Max.	100kW	200kW		
Min.	50kW	100kW	L/h	Min.	50kW	100kW	L/h	L/h
150	50	100	55.95	150	50	100	55.35	0.60
160	60	100	57.4	160	50	110	57.08	0.32
170	70	100	59.05	170	50	120	58.85	0.20
180	70	110	60.78	180	50	130	60.49	0.29
190	70	120	62.55	190	50	140	62.31	0.24
200	70	130	64.19	200	60	140	64.24	0.05
210	70	140	66.01	210	60	150	66.33	0.32
220	70	150	68.1	220	70	150	68.31	0.21
230	70	160	70.23	230	70	160	70.44	0.21
240	80	160	72.56	240	80	160	72.8	0.24
250	80	170	75.1	250	80	170	75.34	0.24
260	80	180	77.96	260	80	180	78.2	0.24
270	80	190	81.2	270	90	180	81.27	0.07
280	90	190	84.69	280	90	190	84.51	0.18
290	90	200	88.57	290	90	200	88.39	0.18
300	100	200	93.6	300	100	200	92.4	1.20

Result D Explore causes besides A~C

- Stability of fuel quality.

Ex. Uncertainty with stability of fuel quality due to the lack of periodic self-inspection.

- Consent level of willingness and understanding among operators towards the change.

Ex. Despite of being fully prepared and informed of the implementation of EDC, some operators are skeptical and unwilling towards new procedure.

ありがとうございました
THANK YOU

Facility Planning Method

(Large-scale PV system)

Text

April 4,2016

Okinawa Enetech Co,Inc

Contents

Chapter 1 Research

1. Initial Conditions

1.1 Purpose of Installation

In the beginning, the purpose and necessity of the PV system installation should be clarified. In some cases, issues to be studied and the contents of system design might be changed as a result.

Example purposes;

- To establish an electric utility business
- To reduce electricity bills and power consumption
- To utilize as a back-up power source for emergency
- To contribute to the prevention of global warming by CO2 emission reduction.
- To address environmental issues as a part of CSR activities
- To secure power sources in non-electrification area
- Effective use of unused lands and idle spaces

If the facility tour route for environmental education and enlightenment is set up in the planning stage, it will function optimally. In addition, it would be good to consider not only system installation but also system support requirements such as an effective measure to achieve targets, programs and so forth in the planning stage.

1.2 Installation Location

Installation location needs to select a suitable place for the purpose of installation, system size, cost, construction schedule and so forth. The contents of a design, electric power generation, cost and schedule may vary depending on site conditions. Hence, following items need to be taken into consideration comprehensively for the selection.

surrounding environment, snow coverage, area, salt damage, lightning damage, situation of electric facility, situation of power system, carry-in route, maintenance, related laws and regulations (necessity of several procedures), necessity of land grading, ground condition, drainage condition and so on.

1.3 Installation Scale

Installation scale is limited to some extent by installation area and its budget. Depending on the type of solar cell and tilt angle, but the PV array needs a location estimated at 10 - 15 ㎡ per kW as a standard. It is desired to consider installation space for ancillary facilities such as substation facility, PCS and so on.

1.4 Load

In grid-connected system that is generally employed, if generated energy is smaller than power consumption, the electricity will be supplied by the power system, and conversely if generated energy is larger than power consumption, reverse power flow (sell power) will be carried out to a commercial electric power system. Although the power consumption pattern of load does not influence an installation scale directly, especially in the case of a large-scale PV system, construction cost and schedule can be significantly affected by the response of the power system and protection facilities with the grid connected operation. Therefore, it is necessary to perform a prior consultation with the electric power company (grid operator) in the early stages of planning. In addition, a suitable substation facility commensurate with load system is usually installed. However, the power generation scale of PV systems (power generation facility) in Japan, an upper limit is set for each receiving voltage (receiving the power form) by "Grid-interconnection Code" that is publicly regulated. Hence, installation of substation facility (new installation, renovation, renewal, etc.) in accordance with installation scale is required.

If there is a facility that generates noise to the load, it needs to consider the impact on PV system and its measure, so it has to understand the type and characteristics of the load system.

1.5 Type of PV System

The type of PV systems has been changed its system design by connection with a power system and availability of reverse power flow.

Usually, “grid-connected PV system, without auto switching, with reverse power flow” is selected.

If the load is always larger than PV system output, or there is excess power temporarily but no reserve power flow case, “without reserve power flow” type can be selected.

In the case of a grid-connected PV system, in order to take cooperation with a PV system and a power system, it is necessary to perform an appropriate measure follow the “Grid-interconnection Code” in Japan. Technical requirements vary depending on the classification of interconnection (receiving power type) with the power system, so it needs to consider after decision of receiving power type. For disaster prevention, there is also the option of choosing “a grid-connected PV system and auto-switching type”.

A stand-alone PV system can be employed in places where commercial distribution lines are not installed, such as mountain areas and so forth.

As soon as a system type and necessary equipment are selected, it is better to contact manufacturers to ask if they can supply items within a time frame or not.

1.6 Timing for the installation

If a subsidy applies to an installation plan, it is necessary to make it consistent with the schedule of a subsidy for the reason of some restrictions on groundbreaking, completion time and so forth. In ground-based installation, it needs to harmonize the schedule of land formation with other schedule as well, thus prior information gathering and check are important. The construction period of a system installation depends on the type and size of the system. In the case of a system installation for 1MW type, estimated construction period is about six months as the shortest from groundbreaking to starting operation. If it’s a large-scale of PV system, the construction period is needed according to the scale of the PV system. If rough weather continues, the construction period is expected to be extended. Therefore, it is desirable to avoid rain and snow seasons.

Furthermore, it is necessary to count a schedule backward in anticipation of a period of time for required design, procurement of equipment, negotiation for interconnection, and procedures pertaining to relevant laws and regulations before construction work starting. Hence, it requires ample of studies in the planning stage.

1.7 Budget

The average unit cost of PV systems at 100kW and above is more than JPY730,000 / kW according to the “Field Test Project on New Photovoltaic Power Generation Technology” (FY2006) by NEDO in Japan. The cost varies depending on the installation location, the type and size of the system. For the installation of ground-based PV system, land formation cost is needed on top of the PV system cost, thus this cost has to be included in the budget. In addition, maintenance cost, insurance premiums and operation costs after the installation must be considered.

In Japan, there is a public assistance system such as “Tax Credits” that is advantage of national tax and local tax concessions, subsidies from the central government and local governments, also “Loan and Debt Guarantees” that can get loans at low interest rates for equipment funds. Additionally, it is necessary to take into consideration the trend of “Feed In Tariff” scheme for renewable energy.

2. Preliminary Survey

2.1 Environments of surrounding areas

① Possible shade on PV arrays

It is necessary to check neighboring buildings, trees, mountains, chimneys, utility poles, steel towers, and signboards for the influence of shade on the installation site. When a shadow is cast on PV arrays, the output power will reduce and also a heating phenomenon called a “hot spot” may occur due to the partial shade and it may cause of burnout. Therefore, PV arrays shall be installed in a place having no shadow in principle. At the same time, it is desirable to conduct a site survey through understanding of change in the surrounding environment such as tree growth, new building, extensions and renovations to existing ones in the future. Further, the depositions such as falling leaves, dust, volcanic ash, bird droppings, and oily smoke may cast shadows on the PV array, thus it should check its possibility.

② Snow condition

Knowing the amount of fallen snow is necessary for the study about frame height for the PV array and the snow sliding angle. Thus it is required to check the amount of fallen snow in advance by collecting data from the local meteorological agency. Also, it is better to check the location of the snow disposal yard, and the ground condition where the snow is expected. The information on the amount of fallen snow is a good reference for assumption of snow load (amount of snowfall per day, maximum depth of snow cover) on structural calculation of PV array frame.

③ Possible damage by salt, lightening and others

If the site is expected to receive salt damage or corrosion, for example, located near a coast, in a heavy industrial zone, or along a road having heavy traffic, it is necessary to check the neighboring area for the states of salt damage, rust and corrosion. This information is needed for design study for salinity tolerance and damage level of the bushing and insulator in a substation facility. Also, it is an effective data for decision on the grade of the rust prevention and corrosion-proof specification (e.g. Mass of the zinc deposit from hot dip galvanizing, countermeasure against bimetallic corrosion) of the metallic portion of the PV array frame and mainly the PV system.

Lightning is classified into indirect and direct lightning stroke. As a countermeasure for direct lightning strike, if a lightning rod is installed in nearby area, it might be able to protect your PV system, thus protection coverage has to be checked.

Regarding indirect lightning stroke, lightning arresters are installed in an array main circuit, junction box, and distribution board as a countermeasure against lightning surges. However, especially in a region that is frequently struck by lightning, a lightning protection transformer should be installed in A/C power source to take more prudent measures, or installation of the lightning rod is considered as one of the options, so it is better to check lightning strike data in the installation area.

Wind velocity used for intensity calculation of PV frame is based on the value stated in JIS (Japanese Industrial Standards). Blowing a stronger wind is considerable depending on the installation point, so it is better to check wind condition surrounding area and geological formation and so forth. In the case of ground-based installation, do not install in depressed places to avoid damage by flood, thus the conditions of drainage and foundation (bearing power of ground) are required to check. Also, in the case of slope, it has to check the possibility of a landslide. Therefore, potential installation site should be selected after a comprehensive identification of the surrounding environment with collected data.

④ Installation site

As an installation site for ground-based installation, flat or slope lands can be considered. As described previously, the points to be checked at the installation site are the surrounding environment, drainage condition, ground condition, the necessity of land grading and so forth. However, the check items that are difficult to identify at a glance such as a survey, bearing power of ground and buried objects, checking existing data is necessary. In the study of the installation scale and foundation practices, if necessary data is not available, a survey and a geotechnical survey are implemented as needed.

Concerning the slope, implementing some work such as placement of a drainage pipe, piling work, and modification of the slope gradient, if necessary. Since these constructions account for a large portion of the total cost, it is important to implement sufficient research on the planned installation site as well as review information data.

It is necessary to check the carry-in route of equipment and materials to the installation site. Following concerns are also considered; sufficient space for construction vehicles, width and bearing strength of roads to the installation site, and the presence and height of overhead distribution lines. In addition, storage space for materials, work space, and obstacles that may cause work difficulties should check too.

⑤ Electric Equipment

The PV array is connected to peripheral devices, a distribution board, and substation facility for use. When connecting with existing electric equipment, the present condition of electrical equipment and securing installation space for new equipment will be an associated design condition. Therefore, upon obtaining electrical connection diagrams of power system and equipment layout plan of electric room to check receiving power type and equipment situation, then consider system configuration, also simulate the necessity of the modification of the substation facility, and installation location of new equipment. All these are to verify the practicality at site survey.

Further, the wiring (piping) route and the carry-in route of equipment are necessary to check. In addition, by obtaining the information about monthly power consumption, reverse power flow of the PV system can be identified.

When a new substation facility is installed, in addition to the above-mentioned, the equipment situation of the commercial power network has to be checked in advance. Also the interconnection point, its method, and installation place of the substation facility have to be studied.

2.2 Research on design conditions

When the introducing a PV system, it is necessary to implement research on each design condition. It will design and construct based on each researched design condition. This subsection introduces the necessary research method of a PV system design in Okinawa.

① **Reference wind velocity**

Calculation of the wind pressure is stated in the 2nd clause of Building Standards Act Article 87 using the formula as follows;

$$q=0.6EV_o^2 \quad \text{(Formula 1.1.2-1)}$$

Where q, E and V_o are as follows;

q : Velocity pressure [N/m^2]

E : The numerical value calculated using a method stipulated by the Minister of Land, Infrastructure, Transport and Tourism, reflecting the roof height of the building and its surrounding environment, trees and others that give impact on the wind velocity.

V_o: Wind velocity [m/s] determined by the Minister of Land, Infrastructure, Transport and Tourism, is that the extent of wind damage based on the record of past typhoons in the district, and in the range between 30m per second and 46m per second depending on the wind behavior.

In relation to these figures, reference wind velocity (V_o) that should be used in each prefecture, is specified in No. 1454 Notice "The Calculation method of the figure E, and the stipulation of wind force coefficients" issued by the Japanese Ministry of Construction in 2000. The reference wind velocity in Okinawa is as follows;

Table1-1 Reference wind speed in Okinawa Prefecture

Construction sites		Reference wind speed V_o [m/s]
Okinawa Prefecture	Whole area	46

② **Terrain category**

Calculation of the figure E is stipulated in No. 1454 Notice “The calculation method of the figure E, and the stipulation of wind force coefficients” issued by the Japanese Ministry of Construction in 2000, as follows;

$$E = E_r^2 G_f \qquad \text{(Formula 1.1.2-2)}$$

In this formula, Er is the coefficient to show the distribution of height of the average wind velocity, and Gf shows the gust response factor. Both are determined by terrain category and the height of structures.

Table 1.1.2-2 shows a summary of terrain category. For example, if a PV planned site is applicable to ① a site is in the city planning area, ② a site is not in the city area, ③ the distance from the PV site to the coastline is 500m and more, the terrain category of this PV planned site is III. However, typhoons often approach and pass off Okinawa Prefecture, thus from the viewpoint of the measure against a strong wind, it is better to choose the level II of the terrain category for the design.

Table 1-2 Summary of terrain category

Terrain Category		Remarkss	
I	The area specified by the designated administrative agency, is very flat without obstacles, and out of the city planning area	Coastal areas	
II	The area is except terrain category I, and out of the city planning area. (Except building height is 13m and below) The area is except terrain category IV, the distance is within 500m to the coastline or shoreline, and within the city planning area. (Except building height is 13m and below)	Rural areas (Except building height is 13 meters and below.)	
III	The area except terrain category I, II, or IV.	General areas (Most of the buildings are under category III.)	
IV	The area specified by the designated administrative agency, is remarkable urbanization in the city planning area	Urban areas	

(Source: Sankyo Tateyama, Inc website)

③ **Landscape area**

In Okinawa Prefecture, "Okinawa landscape management policy"instituted in March 2004 stipulates landscape management policy, the summary of the landscape area system and so forth. In order to promote conservation of the city environment, the land to be maintained is designated as a landscape area. As for the contents of the regulation of the act in the area, each local government can stipulate ordinances, complying with the standards of the cabinet order according to the City Planning Act Article 58. In Okinawa Prefecture, following acts are regulated in order to sustain and create the landscape area.

(a) New construction, renovation, expansion and relocation of the buildings and other structures
(b) Residential land formation, land cultivation and alteration of the land shape
(c) Cutting of trees
(d) Collection of soils and stones
(e) Earth filling or reclamation of water area
(f) Change of structures' color
(g) Deposition of soils, stones, waste or recyclable resources in the outdoors

Table 1-3 shows situation of designated landscape area in Okinawa Prefecture.

Table 1-3 Situation of designated landscape area in Okinawa Prefecture.

(As of 31 March 2009)

Prefecture City of government ordinance	City and Nos of city	Area and Nos of area	Date of planning		Designated area	Classification	Zoning*	*Duplication with green space conservation districts, etc.
			Initial	Final	(ha)			
Okinawa Prefecture	Naha City	Lake Man	March-1956	August-1960	43.9	Urbanized area	D, A, C, B	
	Naha City	Sueyoshi	December-1961		67.6	Urbanized area	E, B, C	
	Nago City	Oomiya	July-1963		3.4	Non-classification	E, A	
	Nago City	Jingamori	July-1963		8.9	Non-classification	D	
	Nago City	Kunenmata	July-1963		29.8	Non-classification	E, C	
	Nago City	Agarie	July-1963		3.3	Non-classification		
	Uruma City	Maehara	December-1977	June-1986	2.1	Non-classification		
Total	3	7			159.0			

(Source: MLIT-City and Regional Development Bureau "Urban afforestation database")

Zoning*
A: Category 1 residential districts
B: Category 2 residential districts
C: Quasi-residential districts
D: Category 1 medium-to-high rise exclusive residential districts
E: Category 1 low-rise exclusive residential districts

2.3 Related laws and procedures

When introducing a PV power system, it is necessary to check related laws and take procedures. Related laws and procedures required at the time of PV power system installation are described as below.

2.3.1 Related acts on land use

Table 1.2.1-1 shows main related provisions of the land use relation statute relevant to PV system installation.

① City Planning Law

When considering the construction of buildings city planning laws are concerned with the maintenance of the city area and proper development. Permission must be obtained and following the established procedures will facilitate this.

② Civil Aeronautics Act

Any structures, plants or any other objects which protrude above the obstruction-limited surface, shall not be installed, planted or left. However, “temporary structures”, “lightning arrester equipment” or “objects that do not noticeably hinder the safety of aircraft in regard to topography or relation to other existing objects” pertaining to a horizontal surface, conical surface and outer horizontal surface which protrude above the obstruction-limited surface, are able to install when permitted by the director of Osaka Regional Civil Aviation Bureau. (Civil Aeronautics Act Article 49, and Article 56.3).

③ Act on Protection of Cultural Properties

Buried cultural properties are defined as 'cultural properties which are buried underground, and the areas that contain buried cultural property are called 'buried cultural property sites' (archaeological sites). In the Act on Protection of Cultural Properties, the procedures are stipulated for the implementation of construction and civil engineering work on a 'well-known place containing a buried cultural property', and the case of discovery of ruins after starting construction.

Table 1-4 Related provisions of the land use relation statute

Law	Provision	Title・Item
City Planning Law	Article 29	Permission for Development Activities
	Article 32	Consent of Public Facility Administrators, etc.
	Article 35	Notice of Granting or Not Granting of Permission
	Article 36	Inspection for Completion of Construction
Civil Aeronautics Act	Article 49	Restriction of Objects, etc.
	Article 51	Obstacle Lights
	Article 51.2	Obstacle Markings
Act on Protection of Cultural Properties	Article 93	Report and instruction pertaining to excavation by civil engineering works
	Article 96	Report and cease-and-desist order pertaining to discovery of ruins

(Source: NEDO “Manual for introduction of large-scale PV power system” preliminary version 2009)

④ The Act on Conservation of Endangered Species of Wild Fauna and Flora

The Act on Conservation of Endangered Species of Wild Fauna and Flora describes the obligations of landowners, countermeasure method when discovery and so forth.

Table1-5 Related provisions of environment relation statute

Law	Provision	Title・Item
The Act on Conservation of Endangered Species of Wild Fauna and Flora	Article 34	Obligations of landowners etc.
	Article 37	Management area
	Article 9	Prohibition against capture and transfer

(Source: NEDO "Manual for introduction of large-scale PV power system" preliminary version 2009)

2.3.2 Related acts on buildings

Table 1-6 shows main related provisions of the buildings relation statute relevant to PV system installation.

Table 1-6 Main related provisions of the buildings relation statute

	Classification	Contents
Building location	Fire prevention districts and quasi-fire prevention districts	It specifies fire prevention districts and quasi-fire prevention districts. Also, fire-proof buildings or quasi-fire-proof buildings are designated depending on the total floor space and number of stories of the buildings, or roofing material (non-combustible material) is specified in each district.
	Designated areas	In the districts designated by specific government agencies, it has specified that roof shall be made or shingled by non-combustible material.
Structures and purpose of buildings	Special buildings	Special buildings specify as a fire-proof building or a quasi-fire-proof building depending on the floor configuration and the floor area used for the purpose. Article 24 in the Building Standard Act stipulates that special buildings made from wood shall be fireproof for portions of external walls, and behind the eaves that will be in danger of spreading fire.
	Large-scale wooden buildings	A wooden building that total area is 1,000m^3 and above, shall be fireproof for portion of external walls and behind the eaves that will be in danger of spreading fire, thus roof shall be made or shingled by non-combustible material.
	Number of stories of the buildings and fire resistance performance of part of the building	It specifies fire resistance performance (fire resistance hour) by the portion of the number of floors, external walls, partition walls, pillars, floors, beams, and roof.
	Fire prevention measures for the portion of the risk of spread of fire	It stipulates a fire prevention measure for an outer wall and an opening as a part of the risk of spreading fire in the case of the distance of 3 meters or less on the 1st floor and 5 meters or less on the 2nd floor and above from a road center line, on a boundary line of adjacent land, or the center line of outer walls between more than 2 neighboring buildings on the same site.
	Structure of external walls etc. contacting with the fire retarding division	It stipulates installation of fireproof walls, eaves or fire door to the outer walls that contact with a floor or partition wall in the fire retarding division, in order to prevent fire spread.
Structural strength of buildings	Structural strength against wind pressure, snow load, seismic force, etc.	In order to secure the safety against external force that acts on a building, such as wind pressure, snow load, and seismic force, the standards concerning the structural calculation of the main parts such as an external wall, partition wall, pillar, beam, and roof, and the binding method of strip roofing are stipulated.

(Source: NEDO "Manual for introduction of large-scale PV power system" preliminary version 2009)

2.3.3 Electrical relation statute

Table 1-7 shows main related provisions of the electrical relation statute relevant to PV system installation.

① Electricity Business Act

The Article 50.2 in the Electricity Business Act stipulates that a person who installs Electric Facilities for Business Use to be installed or modified according to the construction plan for which notification was given pursuant to Article 48, paragraph 1, which are specified by an Ordinance of the Ministry of Economy, Trade and Industry, shall conduct a self-inspection of the Electric Facilities for Business Use before commencing the use thereof, record the inspection results, and preserve such records.

Table 1-7 Main related provisions of the electrical relation statute relevant to PV system installation

		Law	Provision	Title・Item
Procedures	Construction Plan	Electricity Business Act	Article 48	Construction Plan
		Regulations for Enforcement of the Electricity Business Act	Article 62	Approval of Construction Plan
			Article 65	Prior Notification of Construction Plan
	Revision of Construction Plan	Electricity Business Act	Article 48	Revision of Construction Plan
	Chief Engineer	Electricity Business Act	Article 43	Chief Engineer
		Regulations for Enforcement of the Electricity Business Act	Article 52	Appointment of Chief Engineer
	Notification of Commenceme nt of Use	Electricity Business Act	Article 53	Commencement of Use of Electric Facilities for Private Use
		Regulations for Enforcement of the Electricity Business Act	Article 87	Notification of Commencement of Use of Electric Facilities for Private Use
	Pre-use Safety Management Inspection	Electricity Business Act	Article 50.2	Pre-use Safety Management Inspection
		Regulations for Enforcement of the Electricity Business Act	Article 73.2-2	
	Pre-use Inspection	Electricity Business Act	Article 49	Pre-use Inspection
	Safety Regulations	Electricity Business Act	Article 42	Safety Regulations
		Regulations for Enforcement of the Electricity Business Act	Article 50	Safety Regulations
Installation	Definitions	Electricity Business Act	Article 2	Definitions
		Electricity Business Act	Article 38	Definition of Electric Facilities
		Regulations for Enforcement of the Electricity Business Act	Article 48	Definition of Electric Facilities for General Use (Except Mega Solar Power System)
		Enforcement Ordiance	Article 1	Facilities exclude from Electric

		of Electricity Business Act		Facilities
Operation	Order for Conformity to Technical Standards	Electricity Business Act	Article 40	Order for Conformity to Technical Standards
			Article 56	Order for Conformity to Technical Standards
	Obligation to Investigate	Electricity Business Act	Article 57	Obligation to Investigate
		Regulations for Enforcement of the Electricity Business Act	Article 96	Investigation of Electric Facilities for General Use (Except Mega Solar Power System)
	Maintenance of Electric Facilities	Electricity Business Act	Article 39	Maintenance of Electric Facilities for Business Use
	Penal Provisions	Electricity Business Act	Article 118	Penal Provisions
			Article 119	Penal Provisions
			Article 120	Penal Provisions

(Source: NEDO “Manual for introduction of large-scale PV power system” preliminary version 2009)

② Grid Interconnection Guideline

In Japan, when performing a grid interconnection, it is necessary to have a discussion about the conditions of grid interconnection between the grid operator and the owner of a generation system. As a necessary technical requirement for the grid interconnection, the following guideline was stipulated on the 1st of October, 2004. The contents of the guideline below were defined in “the Technical Guidelines for Grid Interconnection” before, but in order to be specific about the interconnection of distribution generator in the Interpretation of Technical Standards for Electrical Equipment, it has changed as below.

As a problem to be highlighted, “the Technical Guidelines for Grid Interconnection Concerning Securing the Electric Power Quality” has legal force to the owner of generation system and a grid operator.

■The Technical Guidelines for Grid Interconnection Concerning Securing the Electric Power Quality

It describes “Items to be mentioned in terms of securing power quality among the items concerning connection with distribution generator to the grid”.

The purposes are defined as follows;

- Adverse effects on other customers must be prevented (Electric power quality, power factor, voltage, frequency, etc. electric supply reliability: power failure, etc.)
- Obstacle to the maintenance of the facilities for the grid operator and other consumers must be prevented. (Maintenance staff, ensuring public safety, prevention of failure extension, etc.)

In addition, the definition of the harmonics that was described in the Technical Guidelines for Grid Interconnection, it is also stipulated in the “the Guideline of Harmonics Reduction for Consumers who have High or Ultra-High Voltage Power Receiving Facilities” and “Electromagnetic Compatibility (EMC) – Part 3-2: Limits for Harmonic Current Emissions (equipment input current is 20A or lower per phase)” in JIS C 61000-3-2:2005. Thus, it was removed from the technical guidelines for grid interconnection.

2.3.4 Other Acts

Table 1-8 shows main related provisions of the other statutes relevant to PV system installation.

① Fire Service Act

The Fire Service Act applies in a case of installation of facilities such as the NAS battery that falls under hazardous materials in the fire service act. Also, the act applies for fire prevention equipment such as a fire alarm for a building, and installation of the transforming facility such as transformer, storage battery and so forth.

Table 1-8 Main related provisions of the fire service act relevant to PV system installation

		Law	Provision	Documents required
Procedures	Application for completion inspection	Fire Service Act	Article 11, paragraph 5	Application form for completion inspection of storage facility (handling facility) of hazardous materials
		Cabinet Order Concerning the Control of Hazardous Materials	Article 8	
	Application for installation permission	Fire Service Act	Article 11, paragraph 1	Application form for installation permission of storage facility (handling facility) for hazardous materials
		Regulations for the Control of Hazardous Materials	Article 4	
	The provisions of prevention	Fire Service Act	Article 11	Authorization application for establishment or change of preventive regulations
		Regulations for the Control of Hazardous Materials	Article 62	
	Appointment of a Hazardous Materials Security Superintendent	Fire Service Act	Article 13	Notification for appointment of a hazardous materials security superintendent
		Regulations for the Control of Hazardous Materials	Article 48.3	
	Notification of commencement of work	Fire Service Act	Article 17.14 -15	Notification of Commencement of Work including the Facilities for Construction
		Enforcement Ordiance of Fire Service Act	Article 36.2, paragraph1	
	The application of the Special Exception	Cabinet Order Concerning the Control of Hazardous Materials	Article 19, paragraph 1	Request form for the Application of the Special Exception
		Notification Regarding Hazardous Materials	No. 53	
	Notification of Transforming Facility	Fire Prevention Ordinance	Article 44	Notification of Transforming Facility Installation, Commencement of Operation

(Source: NEDO “Manual for introduction of large-scale PV power system” preliminary version 2009)

②Bill on special measures concerning procurement of renewable energy sourced Electricity by electric utilities

(the feed-in tariff scheme for renewable energy)

The feed-in tariff scheme for renewable energy is that electric utilities are obligated to purchase the electricity generated from renewable energy sources such as PV, wind power, hydro power, geothermal and biomass at fixed price and duration stipulated by the government, it started on the 1st of July 2012 in Japan. The electricity, generated from renewable energy and purchased by an electric utility, supplied to customers through the grid, and the cost that the electric utility pays for purchasing the electricity generated from renewable energy, is collected from the customers as a part of the electricity bill in the form of a surcharge proportional to electricity consumption.

Regarding the purchasing price and duration, every fiscal year, the Minister of Economy, Trade and Industry respects the opinion of the special committee for determination of tariffs and durations and sets up a guideline stipulated by the category of renewable energy power generation system, installation form and scale, prior to the commencement of the relevant fiscal year. Approval of generation facilities, collection and adjustment of surcharge pertaining to the purchase cost for electricity generated from renewable energy, the reason for rejection of contract and grid-connection by the electric utilities are also stipulated in the feed-in tariff scheme. Promoting increment of energy independence, countermeasures against global warming, and industrial development by this scheme, and aiming that renewable energy will support energy in Japan by cost saving and technical development.

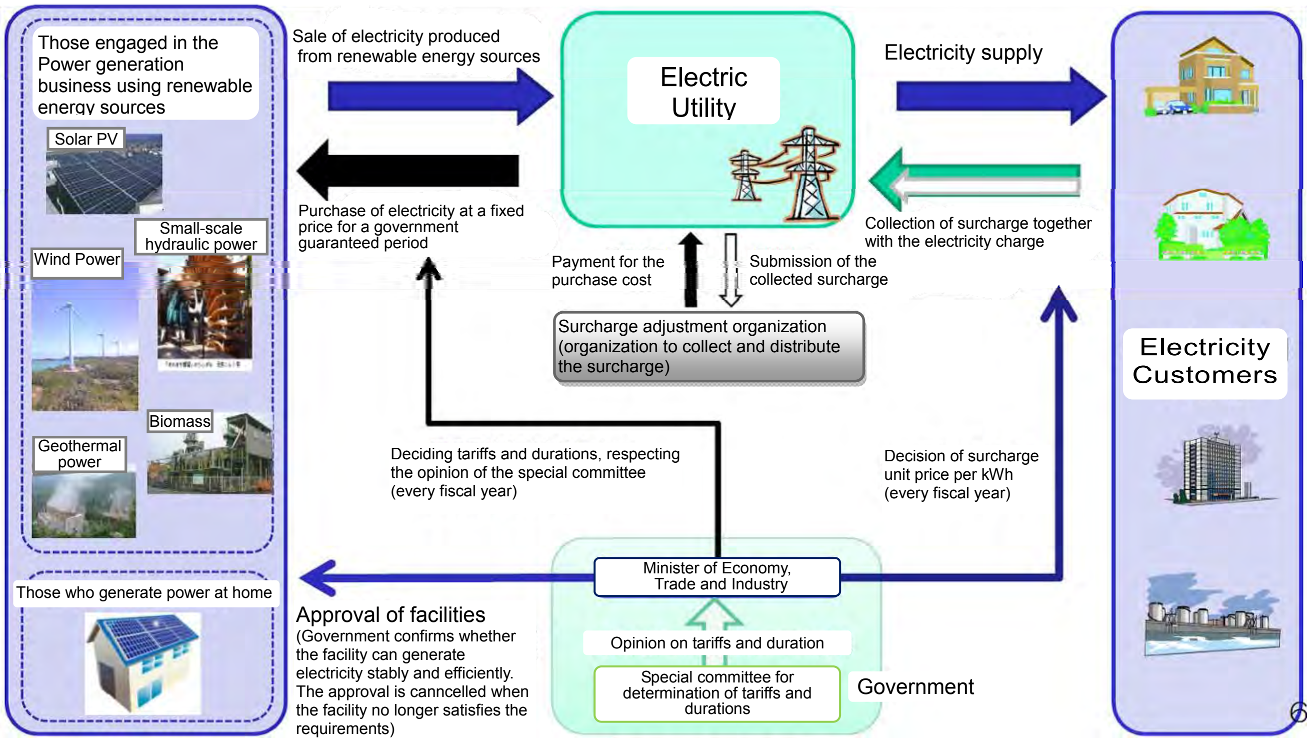


Figure 1-1 The Basic Mechanism of the Feed-in Tariff Scheme

(Source: METI "The Feed-in Tariff Scheme for Renewable Energy" as of July 2012)

Table 1-8 Purchase price and period of PV power generation (as of 2015)

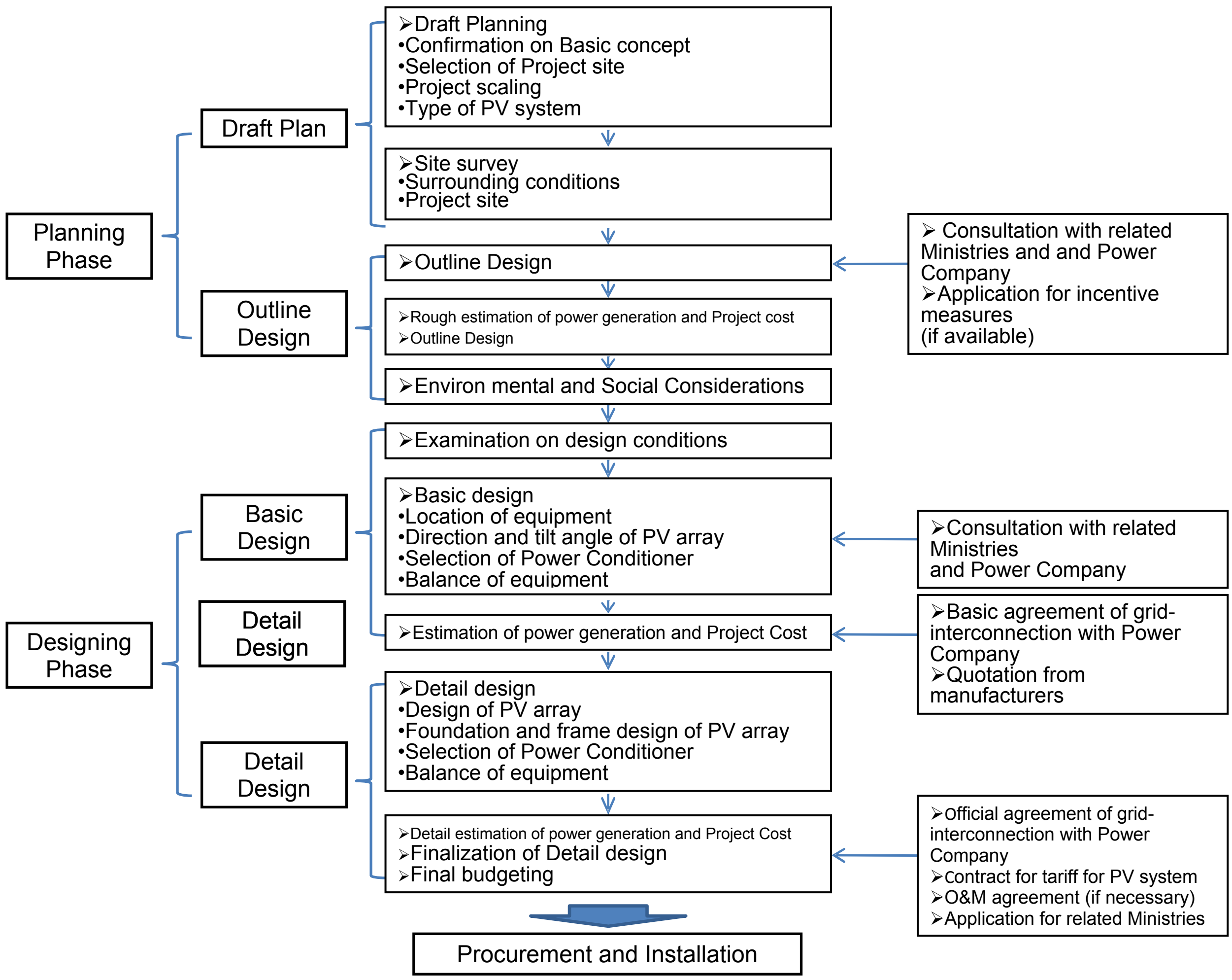
Solar PV	10kW or more	Less than 10kW	Less than 10kW (Combined generation)
Purchase Price	**JPY 29**	**JPY 33**	**JPY**
Purchase Period	**20 years**	**10 years**	**10 years**

*Less than 10kW is a purchase of excess electricity.

Chapter 2　Plan and Design

1. Outline procedures for plan and design

As shown in Figure 2.1-1, procedures for planning and designing a grid-connected PV system consist mainly of planning, outline design, basic design, and detailed design. In the first phase, we define the basic concepts and purposes of introducing the system, select a site, and set up the type and scale of the system.　In the next outline design phase, we have prior discussions with the concerned authorities and the power company and roughly plan PV system, electrical, and building facilities to be introduced.　In countries that employ a promotion scheme for PV system (e.g. Feed-in tariff), it is necessary to ask the authorities concerned to show requirements for applying the scheme.　In the basic design phase, we design the system (electrical and building facilities) according to a more concrete equipment layout plan and make basic design drawings.　In the detailed design phase, we design the facilities in more detail and make drawings that allow equipment and material suppliers to make a quotation and construction plan. In addition, we shall estimate generated energy by the PV system and rough project costs in each step of the outline, basic, and detailed design phases in consideration of the schedule to make a budget for the client and to make an application to the concerned authorities for applicable incentive schemes.



(Source: JICA Senior Advisor)

Figure 2-1: Plan and design phase to introduce PV system

2. Planning phase

2.1 Draft planning

① The basic concept of introducing grid-connected PV system

The introduction of a grid-connected PV system requires the clear recognition of the basic concepts and purposes, and the sharing them among the persons concerned, which makes it possible to implement the plan smoothly. Note that costs of introducing such a system are decreasing from year to year, but many countries face difficulty from an economical point of view because the system price is still higher than costs for buying power from power companies. Therefore, it is important to evaluate the effects of the introduction (environmental contributions, robustness, etc.) except the economic efficiency and share the purposes suitable for each project and the priority of them among the persons concerned.

The basic concepts mentioned above make it possible to select a suitable site and determine requirements for designing equipment and materials including a PV array. For example, if priority is given to the promotion of environmental friendliness or the improvement of a corporate image, the PV array will be installed on the front face of a building even if the system capacity is a little smaller because every public and visitor can see it. On the other hand, if it is required to maximize the power of the PV system, the PV system will be installed in a place where many people don't necessarily gather, such as a large undeveloped area or the rooftop of a building.

② Selection of project site

The selection of a project site has a significant effect on the operation and maintenance of the grid-connected PV system, so it is an important issue that makes the project successful or not. The experience of past projects in developing countries shows that necessary troubleshooting against accident or fault can be taken smoothly if a power company is involved in the operation and maintenance of the system. For example, if the power company has a power station or substation that includes large vacant land, it is a priority site for installing the PV system. In developing countries, we shall keep in mind measures against vandalism, such as stone throwing and theft of PV modules and others. When selecting a site, we shall examine a security level in the candidate area and post surveillance cameras and guards, if necessary. If the main purpose is to raise public awareness of PV, it is recommended to install the PV system in a facility, such as an airport or railroad station, because there are many passengers throughout the year.

Whether to install the PV array on the ground or on the rooftop of an existing or new building is important in the selection of a project site. In general, the former makes it easy to keep a wide area and to raise a promotion effect because everyone can see the array, but such a place may be subject to vandalism. The latter requires an investigation of the structure of the roof, but makes it possible to effectively use the vacant space in urban areas where the installation place is limited.

③ Consideration on PV system output (scale)

If a grid-connected PV system is introduced as a disaster-proof or emergency system, the necessary capacity of the PV system is derived from the total capacity of important loads to which power should be supplied during a power outage. If the main purpose is a peak shift, we can find the necessary capacity of the PV system by checking what percentage of the peak demand should be reduced considering the contract power with the power company. As mentioned above, we shall determine the capacity of PV system in accordance with the introduction concept, but there are other basic factors to determine it: (1) Budget or fund that can be prepared, and (2) Installation space (area) that can be kept.

2.2 Site survey

① Surrounding conditions

(a) **Possible shade on PV arrays**

When a shadow is cast on PV arrays, not only the output power reduces significantly but also a heating phenomenon called a hot spot may occur due to the partial shade. Therefore, PV cells shall be installed in a place having no shadow in principle and check it out during on-site survey. Table 2.2-1 shows possible factors causing such a shade on PV arrays.

Table 2-1: Possible factors to generate shade on PV arrays

Natural Conditions	Artificial Conditions
➢ Mountains and hills ➢ Slopes ➢ Trees (Future growth shall be considered) ➢ Falling leaves ➢ Dust and volcanic ash	➢ Infrastructures (towers, poles, railroads, etc.) ➢ Nearby buildings, Factories, Chimneys, Houses (Future potential renovation shall be checked) ➢ Building at the project site (Tower, facilities on the roof, etc.)

(Source: JICA Senior Advisor)

(b) **Wind velocity**

In Japan, to determine the mechanical strength of rack mount, wind pressure based on the past maximum wind velocity is calculated and adjusted according to the environmental factor and rack installation height. Therefore, it is recommended to know the wind conditions by checking the geographical features and structures around the instillation site.

(c) **Possible damage by salt and lightning**

If the site is expected to receive salt damage or corrosion, for example, located near to a coast, in a heavy industrial zone, or along a road having heavy traffic, it is necessary to check the neighboring area for the states of salt damage, rust, and corrosion. The investigation results are utilized in determining the rust- and corrosion-proof levels of the metal part of the system including the rack.

Lightning is classified into two types: direct and indirect lightning strike. In the PV system, no measures are normally taken against the direct lightning. To protect the equipment from damage caused by indirect lightning, we aren't only installing a surge protective device (SPD) but also need to consider the installation of additional protection devices, such as lightning protection transformers and rods, in a region that is frequently struck by lightning. Therefore, it is necessary to check the regional lightning data for the appropriate design of PV system.

(d) **Snow condition (if any)**

In a snowy region, the array shall be designed so that its slope is larger than the snow sliding angle. If the array has the possibility of being covered completely with snow, it is necessary to increase the rack height to avoid being covered. Therefore, it is required to check the amount of snowfall and the snow sliding angle in advance by collecting data from the meteorological agency and making a survey in the area.

(e) **Bird droppings**

Bird droppings on the array surface cause a shade on PV arrays because they are hard to dissolve in rainwater due to an oil content. It is recommended to check the neighboring building roofs and ground for existing droppings from birds, such as pigeons, claws, and other wild fowl, as well as for their amounts. In addition, the presence of trees or forests in the surrounding area is investigated to judge the necessity of metal fittings to repel birds nearby.

(f) **Transportation method and routes**

To identify the carry-in route of the equipment and materials, it is necessary to check the width and bearing strength of roads to the installation site as well as the presence and height of overhead power distribution conductors and communication cables.

(g) **Natural disaster**

If the planned installation site is lower in elevation than the surrounding area, a torrential downpour or typhoon might cause flooding the site due to bad drainage and immersing the PV array in water due to a flooded neighboring river. Accordingly, those risks and past disasters have to be considered in advance.

2.3 Consultation with related ministries and power company

① Related Ministries

The grid-connected PV system should be considered as one of major electrical facilities. If its size exceeds a certain limit, it is necessary to make a request for permission to the authorities concerned in the same manner as conventional power stations or substations in accordance with the regulations in each country. In Japan, the PV system is classified into two types according to its capacity: one is electrical facilities for private use (50kW and above) and the other is general electrical facilities (less than 50kW). According to this classification, it is required to follow legal procedures shown by each local bureau under the jurisdiction of the Ministry of Economy, Trade and Industry to submit a construction plan, to make a prior inspection, to select a chief electrical engineer, and to show safety rules.

There is the case where a notice shall be sent to other than the authorities in charge of the energy and power field. For example, most of developing countries require official application and permission for environmental and social considerations. The installation in or adjacent to an airport will need permission by the concerned aviation authority because sunlight reflected by the PV array may disturb safe takeoff and landing of airplanes within a certain distance from and the angle formed with the runway. In case of installation on an existing building, it is necessary to ask the authorities in charge of building work about standards for installing heavy structures. For example, it is required in Japan to submit of a building certificate or a request for constructing structure if the height of the PV array exceeds a certain limit or if indoor activities are planned under the PV array.

In countries with existing incentive schemes for PV systems, such as feed-in tariffs and subsidies, it is necessary to check procedures and schedules for using them before going to the planning and design phases. Particularly in countries that employ a feed-in tariff system, the latest information has to be confirmed because applicable tariffs and periods are often reviewed.

On the other hand, a PV system is defined as an electric facility for private use or for general use under the Electricity Business Act. If a grid-connected PV system with low voltage less than at 50kW, is specified as the electric facility for general use, thus it is not necessary to notify. However, the electric facility for private use requires to go through the procedures depending on the output capacity. That is to say, for the PV system with 50kW and over but less than 1,000kW output requires to get an approval for non-appointment of an electric chief engineer, and for the PV system with 1,000kW and above requires appointment of an electric chief engineer. In addition, notification of the Safety Regulations is required.

② **Power company**

Connecting the PV system to the grid owned by a power company requires the satisfaction of technical requirements specified in the grid-interconnection codes to prevent an adverse effect on the quality and reliability of power supply. However, many developing countries have no grid-interconnection codes, so it is necessary to develop codes suitable to the grid configuration of each country according to existing examples made by developed countries including Japan in cooperation with the authorities in charge of the power sector and the power company. Subsection 2.4 will describe the Japanese Grid-Interconnection Codes in detail.

2.4 Technical requirements for grid-interconnection

① **Outline**

The Japanese Grid-Interconnection Codes apply to all kinds of distributed generators, such as PV systems, internal combustion engines for power generation, wind turbines, and fuel cells. The codes specify the voltage levels of grids to which generators can be connected according to the generator capacity. Generators rated at less than 50kW, 50 to less than 2,000kW, or not less than 2,000kW can connect with a low-voltage (100/200V), medium-voltage (6.6kV), or extra-high-voltage (22/33kV and above) distribution network respectively. In addition, requirements for the power factor, protection coordination, and voltage regulation are defined with or without the presence of a reverse power flow from the distributed generator to the grid, which are shown in Table 2-2.

Table 2-2: Outline of Japan’s grid-interconnection code

<table>
<tr><th colspan="2" rowspan="2">Parameter</th><th colspan="4">Measures for equipment</th></tr>
<tr><th>Low-voltage distribution line</th><th>Medium-voltage distribution line</th><th>Spot network distribution line</th><th>Extra-high-voltage distribution line</th></tr>
<tr><td colspan="2">1. Power</td><td>Less than 50 kW in principle</td><td>Less than 2,000 kW in principle</td><td>Less than 10,000 kW in principle</td><td>—</td></tr>
<tr><td colspan="2">2. Electric system</td><td colspan="4">Same as that of grid connected in principle</td></tr>
<tr><td rowspan="3">3. Power factor</td><td>Common</td><td colspan="4">Not less than 85% at receiving point and no leading power factor when viewed from the grid.</td></tr>
<tr><td>With reverse flow</td><td colspan="2">Not less than 80% when it is necessary to prevent voltage rise. When small-output inverter is used or power factor at receiving point is proper, power factor is not less than 85% when generator’s reactive power is controlled, and not less than 95% if not controlled.</td><td>—</td><td>The value at which grid voltage can be kept correct.</td></tr>
<tr><td>Without reverse flow</td><td>Not less than 95% when the generator is connected to the grid via inverter.</td><td colspan="3">—</td></tr>
<tr><td rowspan="10">4. Protection coordi-nation</td><td rowspan="3">Common</td><td colspan="4">OVR and UVR (combination with the generator’s protection is possible)</td></tr>
<tr><td></td><td>OVGR (combination with the generator’s protection is possible or it can be omitted under certain conditions)</td><td rowspan="2">—</td><td rowspan="2">OVGR (combination with the generator’s protection is possible or it can be omitted under certain conditions)
DSR (for synchronous generator or it can be omitted under certain conditions) and current differential relay (neutral grounding system)</td></tr>
<tr><td>DSR (for synchronous generator or it can be omitted under certain conditions)</td><td>DSR (for synchronous generator)</td></tr>
<tr><td>With reverse flow</td><td>OFR, UFR, and islanding operation detector (one or more passive and active methods)</td><td>OFR (can be omitted in dedicated line), UFR, and transfer trip system or islanding operation detector (active method) (can be omitted under certain conditions)</td><td>—</td><td>OFR (not affected by voltage change) and UFR (not affected by voltage change) or transfer trip system</td></tr>
<tr><td>Without reverse flow</td><td>Inverter: RPR, UFR, and reverse charge detection function or islanding operation detector (one or more passive and active methods)
Synchronous/induction generator: UFR, islanding operation detector (passive method), UPR (can be omitted if generator output < on-site load), and RPR (can be omitted if islanding operation detector is fitted)</td><td>RPR (can be omitted if received power > inverter output and islanding operation detector can detect in high speed) and UFR (can be omitted if dedicated line and RPR enables high-speed detection and protection)</td><td>URR and RPR (can be replaced by network protector’s function) (generator is disconnected in a certain period if reverse power is detected in all circuits)</td><td>OFR, UFR, and RPR (if OFR and UFR cannot detect and protect)</td></tr>
<tr><td>Fault prevention when circuit is reclosed</td><td>—</td><td>Installation of line voltage detector at the feeder panel of distribution substation (can be omitted under certain conditions)</td><td>—</td><td>Installation of line voltage detector at the feeder panel of distribution substation (can be omitted under certain conditions)</td></tr>
<tr><td rowspan="2">Automatic load and power generation control</td><td rowspan="2">—</td><td colspan="3">Introduction of automatic load control if interconnected conductors or transformer may be overloaded when generator is disconnected.</td></tr>
<tr><td colspan="2"></td><td>Use of power generation control by overload detector in principle for connection with extra-high voltage line rated at not less than 100 kV.</td></tr>
<tr><td rowspan="2">Others</td><td>Power supply shall be prohibited during power interruption and for giving time after recovery.</td><td>Reverse flow shall be prevented at a transformer bank of the distribution substation (if reverse power flow exists).</td><td>—</td><td>—</td></tr>
<tr><td colspan="4">As a rule, the transformer shall be installed to prevent DC current flowing from inverter to grid (it can be omitted under certain conditions).</td></tr>
</table>

5.Voltage variation	The introduction of automatic voltage adjustment if low-voltage consumer's voltage may be out of regulation (101 ± 6 V and 202 ± 20 V) (it can be omitted under certain conditions). If it is difficult, distribution line shall be reinforced.	Use of automatic load control if the generator connects with general distribution line and when it is disconnected, low-voltage consumer's voltage may be out of regulation (101 ± 6 V and 202 ± 20 V) (it can be omitted under certain conditions). If it is difficult, distribution line shall be reinforced or generator shall be connected with dedicated line. Use of automatic voltage control if reverse flow may cause low-voltage consumer's voltage to be out of regulation (101 ± 6 V and 202 ± 20 V). If it is difficult, distribution line shall be reinforced or generator shall be connected with dedicated line.	Introduction of automatic load control if disconnection of generator may cause grid voltage to be out of regulation (within 1 to 2% of normal voltage).	Introduction of automatic voltage control if interconnection with generator may cause grid voltage to be out of regulation (within 1 to 2% of normal voltage).
	Synchronous generator: Use of amortisseur winding and automatic synchronizing function. Inductive generator: Use of current-limiting reactor if instantaneous voltage drop at parallel connection may cause the grid voltage to be out of regulation (within 10% of normal voltage in low voltage, high voltage, and spot network; within ±2% in extra-high voltage). If it is difficult, synchronous generator is employed.			
	Self-excited inverter: Use of automatic synchronizing function. Separately excited inverter: If instantaneous voltage drop at parallel connection may cause grid voltage to be out of regulation (within 10% of normal voltage in low voltage, high voltage, and spot network; within ±2% in extra-high voltage), self-excited type shall be used (in case of low-voltage distribution line, necessary reinforcement shall be considered).			
6. Short-circuit capacity	Installation of current-limiting reactor (for AC generator)	Installation of current-limiting reactor		
7. Liaison system	—	Installation of dedicated telephone line for safety and security communication between grid operator's office or power station and the owner of generation system	Installation of dedicated telephone line for safety and security communication between grid operator's office or power station and the owner of generation system	
8. Meeting	The owner of generation system and grid operator shall have sincere talks about interconnection.			

(Source: Grid-interconnection Code in Japan: JEAC 9701)

(Remarks) OVR: Over Voltage Relay, UVR: Under Voltage Relay, OVGR: Over Voltage Ground Relay, DSR: Directional Short circuit Relay, OFR: Over Frequency Relay, UFR: Under Frequency Relay, RPR: Reverse Power Relay

Adverse effects on other customers must be prevented by securing the **reliability** of power supply (preventing the expansion of the interrupted area in case of a fault by protection coordination) and by securing **power quality** (voltage, frequency, harmonics, etc.).

In case of Japan, already various distributed generators have been added to the grid of power companies, especially generators which utilize renewable energies (PV, wind power, etc.), reflecting the growing consciousness on global environmental issues. In this situation, it is gradually becoming difficult for power companies to keep "the quality of power supply" as shown on Table 2-3.

Table 2-3: Requirements for power supply quality in Japan

Parameter	Specification
Normal voltage variation (low voltage) Instantaneous voltage drop	101 ± 6 V and 202 ± 20 V (Ordinance for Enforcement of Electricity Business Act, Article 44) 10% (Technical Guidelines for Grid Interconnection)
Frequency variation	±0.1 to ±0.3 Hz (different code of practices by electric power companies)
Harmonics	• 6.6kV distribution line: Total voltage distortion factor of 5% • Extra-high-voltage line: Total voltage distortion factor of 3% (Harmonics Suppression Guidelines)
Flicker (low voltage)	$\Delta V10 \leq 0.45$ V (Recent Trends in Arc Furnaces for Steel Production and Power Supply, No. 72 Technical Report (Part 2), The Institute of Electrical Engineers of Japan)

(Source: Standards and Codes in Japan)

In addition, safety of general public and operators for power company must be secured. Adverse effects on power supply facilities and the facilities of other customers must be prevented (prevention of islanding operation and reversed charge).

② Electrical mode and power factor

(a) Electrical mode

The electrical mode of generating facilities must be the same as that of the grid connected. For example, if the grid connected is three-phase three-wire type, the generating facilities must be also three-phase three-wire type. This is because the voltage and current imbalance may be caused by possible phase imbalance.

(b) Power factor

When there is no reverse power flow, power factor at power receiving point should be 85% or higher, in principle, in order to alleviate voltage drop. Leading power factor against the grid is not allowed. Power factor is calculated as a formula of real power divided by apparent power. Power factor against the grid means real power coming to the load is positive, and power factor against the generating facilities means real power coming out to the grid is positive.

③ Voltage deviation

What happens if voltage is not properly kept within regulated range? Following malfunctions are expected;

- If the voltage higher than proper level continues, the lifetime and insulation of various equipment including home appliances are negatively damaged.
- On the other hand, if the lower voltage continues, performance of equipment might be lowered or discontinued.
- Instantaneous voltage drops may cause the loss of data in memories of PC, etc.

In case of Japan, quite a few numbers of small-scale residential PV systems are expected to be interconnected with low-voltage distribution lines in the near future. In order to avoid the voltage deviation, several measures will have to be taken. It is possible to adopt thicker conductors or bigger distribution transformers to up-grade distribution lines. However, those measures will be the last-resort as it will raise the total cost. Another method is to restrict power output during the period large amount of excess power is forecasted, such as Golden-Week (long public holiday in April and May) in Japan. But this means some part of real power output from PV system is not fully utilized. Also the customer with restricted PV output may claim that it is not fair to control his/her PV system because PV systems for other customers are still interconnected. In order to avoid such a situation, another solution is to control power factor or reactive power from the PV system. The followings are the detailed explanation of this method.

Figure 2-2 shows the example of the power system. The figure shows the voltage is kept within the proper regulation range both in case of light load and heavy load.
The distribution line voltage is regulated within the proper range by the tap of transformer in a distribution substation, for both light load and heavy load.

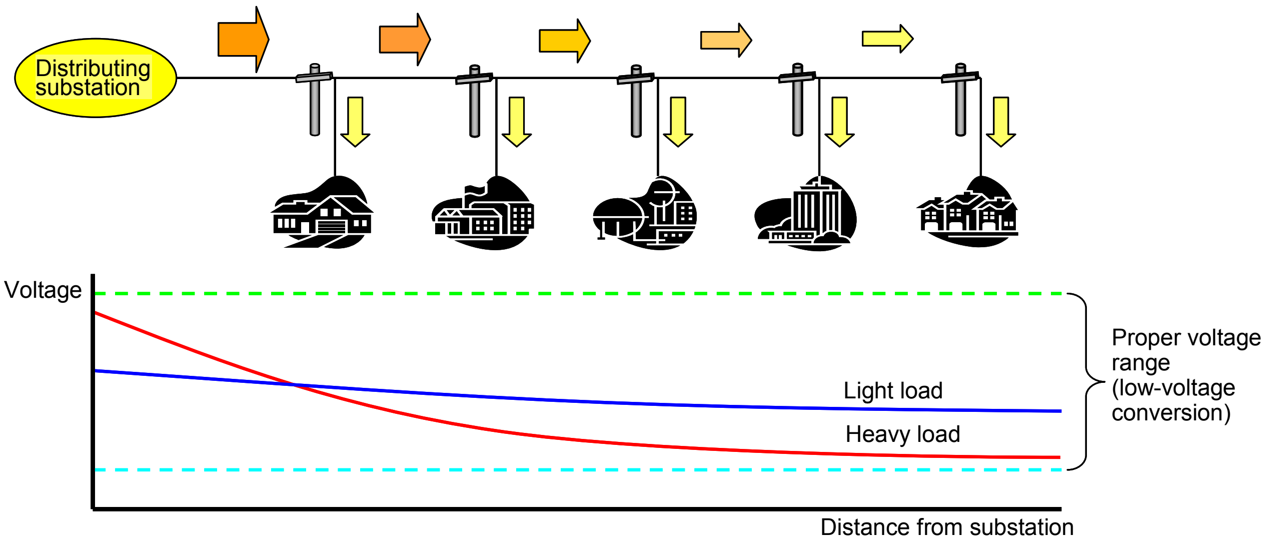


Figure 2-2: Before installing a grid-connected PV system

Figure 2-3 shows the voltage after installing a Grid-connected PV system. It shows if there is reverse power flow from the distributed generators to the grid, the grid voltage rises and may go beyond the proper voltage range at the light load condition.

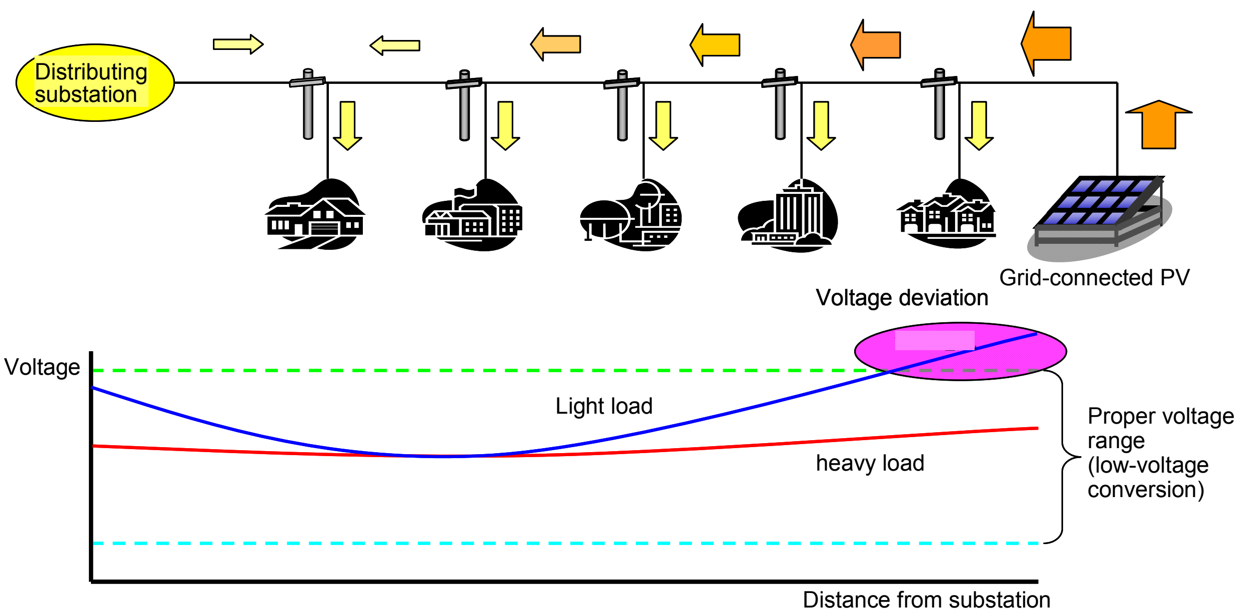


Figure 2-3: After installing a grid-connected PV system

Figure 2-4 shows the sample measure to suppress the voltage rise by a controlling power factor of distributed generators interconnected with the grid. If the power factor of a distributed generator is 1.0, deviation from proper voltage occurs. However, proper voltage can be kept by a controlling power factor of a distributed generator, as the power factor is shifted from 1.0 to 0.95 (leading power factor against the grid).

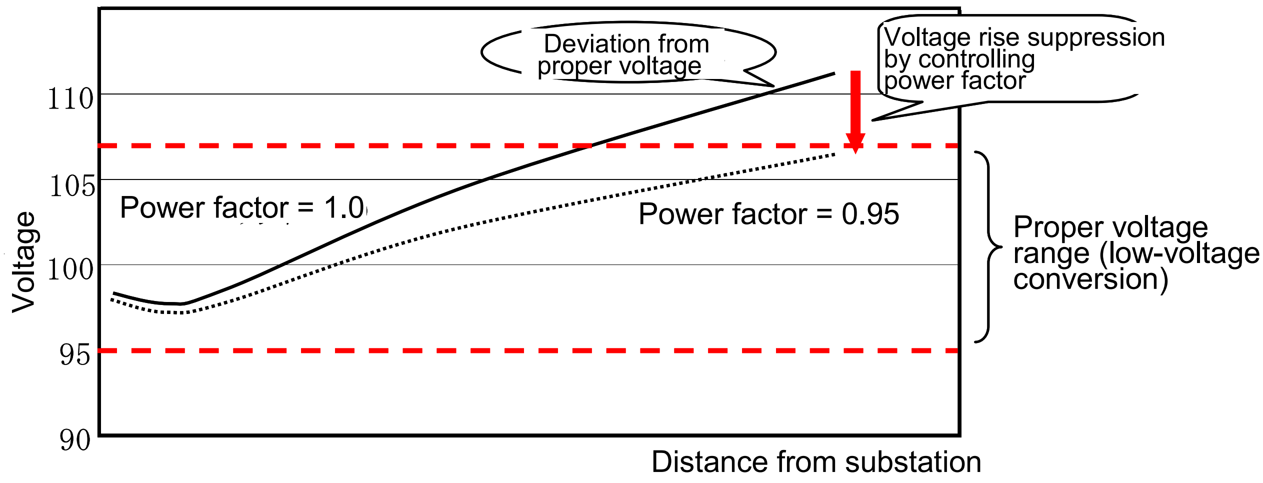


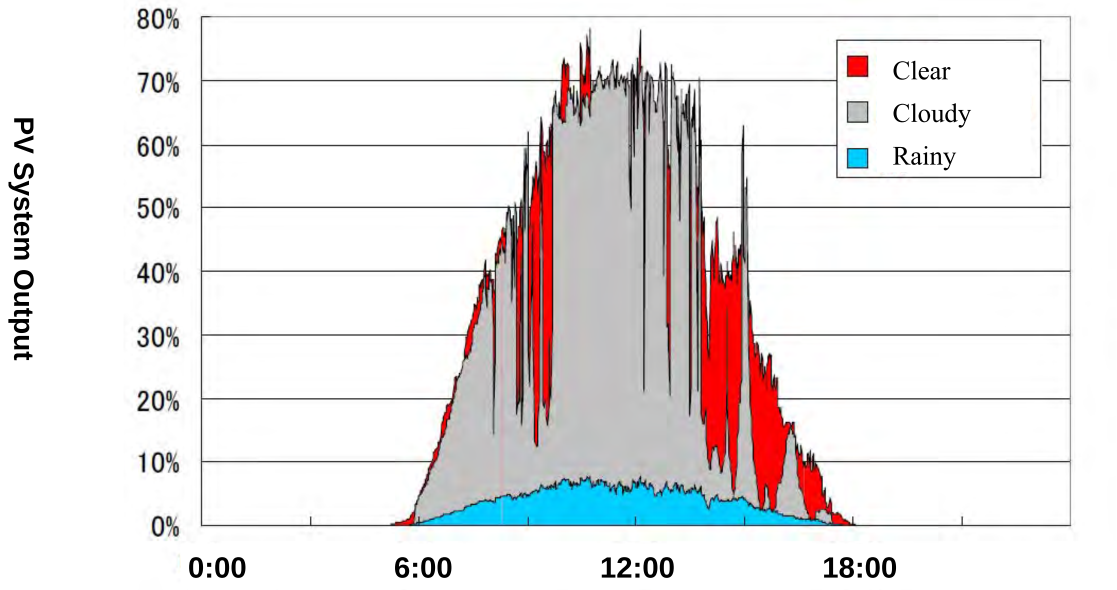
Figure 2-4: Suppression of voltage rise by controlling power factor

④ Frequency fluctuation

What happens if the frequency is not properly kept within regulated range? Following malfunctions are expected;

- Fluctuation of frequency results in the irregular motor rotation, which negatively affects manufactured products in assembly lines.
- Large fluctuation of frequency may generate resonance at rotating parts such as turbines of generators, which affects the lifetime of machinery.
- As the case may be, some generators cannot be synchronized as the stability of power system goes down. These generators will drop out from the synchronous operation of the power system. It brings about a further frequency drop, which causes the chain of drop out of generators and the whole grid may be stopped in the worst case scenario.

In general, the frequency of the power system is regulated by Governor Free operation of generators, Load Frequency Control (LFC), and Economic Load Dispatching control (EDC) in accordance with period of frequency fluctuation. However, the output of PV system changes rapidly depending on the weather conditions.



(Source: The Federation of Electric Power Company of Japan)

Figure 2-5: Fluctuation of PV system output

Therefore, in Japan and many European countries, appropriate technologies to control and regulate frequency is now under development and gradually deployed at sites. For example, the following measures are introduced.

- Introduction of variable-speed pumped-storage power station
  This system controls the rotation speed of the generator to change the pump turbine's velocity, resulting in changes in the pumping discharge. Therefore, it can precisely adjust the input power according to demand on the grid side even during pumping operation.
- Introduction of storage batteries
  As shown in Figure 2.2-5, the fluctuation of combined output to the grid side can be suppressed by introducing AC/DC converters and storage batteries.
- As a measure for increasing the amount of grid-interconnection of wind power, a request for interconnection based on the scheduled disconnection/output restriction method, in which disconnection or output restriction is done while the frequency regulation becomes difficult due to the light load condition.

In the future, we will need the method of estimating or grasping the output power of PV systems in accordance with weather forecasts, therefore, laboratories are now collecting PV output data.

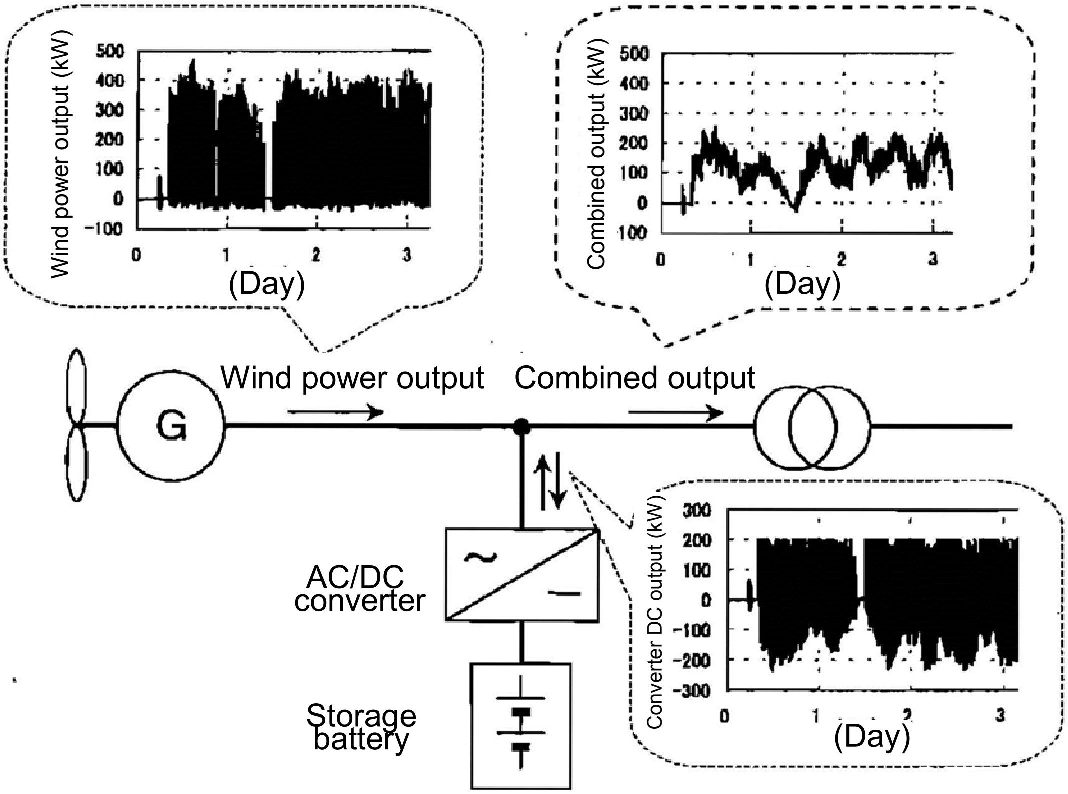


Figure 2-6: Suppression of output fluctuation by using storage battery

⑤ **Harmonics**

Harmonics are frequencies that have integral multiples of the fundamental frequency (50 Hz or 60 Hz). The inverter in the power conditioning system (PCS) has non-linear devices that generate harmonics. Therefore, we shall reduce their amplitude to levels regulated under concerned authorities and power company. Japan defines "Environmentally Targeted Levels of Harmonics," which show that the total voltage distortion factor shall be not more than 5% and 3% in 6.6kV distribution and extra-high-voltage transmission/distribution lines respectively. As a result, it is necessary to reduce the total current distortion factor of the PCS (harmonic generator) to less than 5% and the current distortion factor in each order to less than 3%. When selecting a PCS, we shall check whether it meets these requirements.

⑥ **Protection coordination**

When operating the grid-connected PV system, we shall detect any problem in the transmission/distribution line or PV system within a given period of time and stop the PCS to keep the grid safe. Japan, therefore, develops technical standards for electric facilities to define the obligation to install necessary protection devices (e.g. Protection relays and islanding prevention function). These protection devices are typically built in the PCS.

The basic concept of protection coordination to eliminate fault and minimize the area of power interruption is explained as below.

- Disconnect generating facilities with malfunction or fault to localize the affected area.
- Disconnect generating facilities when short-circuit or ground fault occurs at the grid.

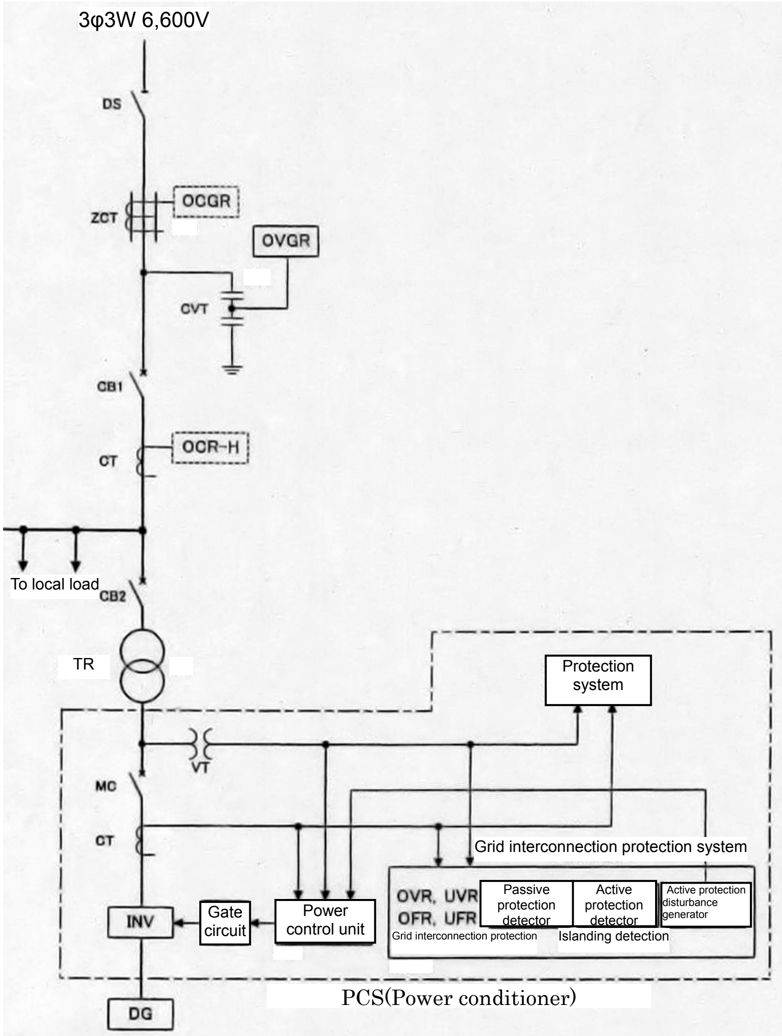
- Disconnect generating facilities for power interruption caused by transmission line faults, etc. to prevent any islanding operation.
- Generating facilities are in a disconnected state at the time of grid reclosing.
- Avoid disconnection for a fault other than the grid connected by generating facilities.
- Keep operation or recover automatically from a momentary voltage drop of the grid.

The Japanese Grid-Interconnection Codes not only require protection from the following events but also define more detailed protection requirements in accordance with the voltage levels of grids to be connected and with or without the presence of a reverse power flow. It is recommended to have talks with the power company before selection of the type of protection relays to be actually installed and settings according to the country-specific grid configuration and grounding method.

Table 2-4: Basic sets of protection relays and scope of protection

<table>
<tr><th colspan="2" rowspan="2">Symbol</th><th rowspan="2">Protection</th><th rowspan="2">Faults to be prevented</th><th colspan="2">Example of setting range</th></tr>
<tr><th>Detection level</th><th>Detection time</th></tr>
<tr><td colspan="2">OCR-H</td><td>Overcurrent</td><td>Short circuit on premises</td><td>70% of minimum fault current of power receiving bus bar</td><td>Instantaneously</td></tr>
<tr><td colspan="2">OCGR</td><td>Grounding overcurrent</td><td>Ground fault on premises</td><td>The level at which no malfunction occurs due to transformer's rush current or on-site equipment's charge current</td><td>Coordinated time setting of ground-fault relay at the installation site and distribution substation</td></tr>
<tr><td colspan="2">OVGR</td><td>Grounding overvoltage</td><td>Ground fault on grid side</td><td>Equal to or less than level set in ground detection relay (OVGR) in distribution substation</td><td>Allowable time based on Type B grounding resistance of the grid</td></tr>
<tr><td colspan="2">OVR</td><td>Over voltage</td><td>Generator malfunction</td><td>110 to 120%</td><td>0.5 to 2 seconds</td></tr>
<tr><td colspan="2">UVR</td><td>Under voltage</td><td>Generator malfunction, Grid power interruption</td><td>80 to 90%</td><td>0.5 to 2 seconds</td></tr>
<tr><td colspan="2">UFR</td><td>Under frequency</td><td>Grid under frequency, Islanding operation</td><td>48.5 to 49.5 Hz
/58.2 to 59.4 Hz</td><td>0.5 to 2 seconds</td></tr>
<tr><td colspan="2">OFR</td><td>Over frequency</td><td>Grid over frequency, Islanding operation</td><td>50.5 to 51.5 Hz
/60.6 to 61.8 Hz</td><td>0.5 to 2 seconds</td></tr>
<tr><td rowspan="6">Islanding operation prevention</td><td rowspan="2">Passive</td><td>Voltage phase jump detection</td><td rowspan="6">Islanding operation detection</td><td>Phase change: ±3 to ±10°</td><td>Within 0.5 seconds</td></tr>
<tr><td>Frequency change rate</td><td>Frequency change: ±0.1 to ±0.3%</td><td>Within 0.5 seconds</td></tr>
<tr><td rowspan="4">Active</td><td>Frequency shift</td><td>Frequency bias: Several % of rating</td><td>0.5 to 1 seconds</td></tr>
<tr><td>Active power change</td><td>Active power: Several % of operating power</td><td>0.5 to 1 seconds</td></tr>
<tr><td>Reactive power change</td><td>Reactive power: Several % of operating power</td><td>0.5 to 1 seconds</td></tr>
<tr><td>Load change</td><td>Inserted resistance: Several % of rated power
Insertion time: Within 1 cycle</td><td>0.5 to 1 seconds</td></tr>
</table>

(Source: Grid-interconnection Code in Japan: JEAC 9701)



(Source: Grid-interconnection Code in Japan: JEAC 9701)

(Remark: with the reverse power flow, two or more prevention measures for islanding operation, without line voltage detector)

Figure 2-7: Sample protection scheme for interconnection with medium-voltage grid

2.5 Rough estimation of power generation and project cost

① Rough estimation of required area

If the installation site of the PV array is limited or the PV array output is required to meet a certain level, it is significant to know the relationship between the output and installation area. Sunlight has the energy of $1kW/m^2$ after it reaches the ground through the space and atmosphere. The PV cell can provide an electrical power of 0.13kW = 1kW × 0.13 because the conversion efficiency of crystalline silicon cells is about 13%. This means that a power of 1kW requires an area of about $7.7m^2$. The thin-film type can supply a power of 0.08kW = 1kW × 0.08 because the conversion efficiency is about 8%. In this case, a power of 1kW requires an area of about $12.5m^2$. In the actual installation, a power of 1kW requires an area of $10\text{-}15m^2$ in consideration of the maintenance space between PV arrays. The following shows convenient rules of thumb for the calculation above.

Rule of thumb

- Multiplying the PV array output (kW) by 10 gives the necessary PV array area (m^2).
- Dividing the PV array area (m^2) by 10 gives the PV array output (kW).

Note that using the thin-film type whose conversion efficiency is lower than the crystal type requires the larger installation area.

② Rough estimation of power generation

In the grid-connected PV system, after concretely defining the parameters, such as the capacity and tilt angle of the PV array, and the solar irradiance and temperature of the installation site, we can find the output power with simulation software (see Section 2.3(10)). In the outline design phase, it is recommended to know how to roughly estimate it.

$$Ep = P_{AS} \cdot H_A \cdot K \cdot 365 \text{ days}$$

Where Ep = Expected annual energy (kWh/year)
H_A = Daily irradiation on yearly average ($kWh/m^2/day$) at the installation site
K = Total design factor (0.65 to 0.8 or about 0.7 in average)

If a 10kW system, for example, is installed in Tokyo with the array having an optimal tilt angle and pointing south, then the annual electric energy is given as follows:
10 (kW) × 3.92 ($kWh/m^2 \cdot day$) × 0.7 × 365 (days) = 10,016 (kWh/year)

The above shows that it is helpful to keep in mind "multiplying the rated power (kW) of a PV cell by about 1,000 gives the annual energy (kWh)." Note that this factor (1,000 times) varies depending on the weather and installation conditions, so we shall define it country by country and region by region.

③ Rough estimation of project cost

In the detailed design phase, the installation cost of the PV system will be calculated while taking account of the method of mounting the PV array (on the ground or rooftop), the grid voltage, and other BOS (Balance of System) such as storage batteries. In addition, it is helpful to roughly estimate the cost from past similar projects. In Japan, many grid-connected PV systems have already been installed. Table 2.2-5 shows the average installation costs in reference to the past projects.

Table 2-5: Average total cost of grid-connected PV system in Japan

System Size	System Cost per kW
10 kW	3,650 US$ / kW
10 ~ 50 kW	3,295 US$ / kW
50 ~ 500 kW	2,895US$ / kW
500～1,000 kW	2,625 US$ / kW

(Remark) 112JPY = 1 US$ (Feb. 2016)

(Source: Ministry of Economy Trade and Industry, METI)

Note that the costs above do not include expenses for installing other than the standard system, such as roof waterproofing work, foundation work, batteries, and data measurement units.
It is desired that every country that has a plan for installing a grid-connected PV system collects costs for past projects and keep them as a database, which will make it easy to estimate project costs based on the country-specific circumstances.

④ Scheduling and budgeting

When taking advantage of an incentive scheme for grid-connected PV systems, it is necessary to match the PV system installation schedule with the execution schedule of the applicable incentive scheme and collect information beforehand. If placing a separate order for the building construction and PV system installation work, we shall coordinate both schedules. This process may hinder the progress, for example, a delay in the construction work makes it difficult to install the PV system or the too early construction work requires temporary measures until the installation work starts. Accordingly, close coordination between both schedules is necessary. After determining the project schedule, we shall draw up a budget plan in consideration of profits (e.g. a reduction in the electricity bill and subsidies from the incentive scheme) derived from the estimated cost and PV output power.

⑤ Environmental and social considerations

The impact of grid-connected PV systems on the environment is classified roughly into two types: one is an impact during construction and the other is an impact during operation after installation. Both impacts need to be considered according to the project site and surrounding environment. Table 2.2-6 lists general impacts to be investigated. A large-scale mega-solar project requires a large installation area, which inevitably has various and profound impacts on the environment. Accordingly, it is necessary to investigate them and take countermeasures in advance.

Table 2-6 Expected Items for Environmental and Social Considerations

Stage	Origins of negative impact	Items to be considered
Installation	Operation of construction machinery	Dust, noise, vibration, toxic substances.
	Traffic of heavy vehicle (construction machinery and transportation vehicle)	Same as above. It is important to examine the route and volume of transportation in advance. Specific road conditions (jam, paved or unpaved) shall be checked.
	Preparation and development works for land	Construction waste such as excavated soil, concrete, sludge.
	Clearing bushes and trees	Especially when the land is within or near national park or conservation area.
	Temporary facilities (road, stockyard for equipment)	Location and area shall be checked.
	Flying up dust and sand by wind	Water sprinkling can be considered if necessary.
	Rainwater drainage	Catchment area, land excavation, and precipitation shall be checked.
Operation	Glare caused by reflection of PV array	Especially important where airport and residential areas are located nearby.
	Electrical equipment (PCS, transformers, etc.)	Unexpected noise, vibration, electro-magnetic wave, etc.
	Land usage and landscape	Especially when the land is within or near national park or conservation area.
	Lighting facilities	Too much lighting may disturb local residents.

(Source: JICA Senior Advisor)

3. System Design

3.1 Estimation of solar irradiation and power generation

①Estimation method of solar irradiation

In order to estimate the solar irradiation on an inclined surface, METPV-3 that is the standard meteorological data, and the software bundled with MONSOLAR05 (801) that is provided by NEDO were commonly used. However, the solar irradiance on inclined surface is found based on no objects in front of the PV array, but when a group of the PV array is installed next to each other like a large-scale power plant, it was clarified that is necessary to compute solar irradiation in consideration of the impact by a front PV array. A calculation method of solar irradiation in consideration of affection by a front PV array is shown as follows. However, it is important to consider PV array arrangement that is not to be affected by a front PV array basically.

(a) A calculation method of solar irradiation in consideration of the impact by a front PV array

Figure 2-8 shows PV array arrangement example in a large-scale PV power plant. Each solar radiation of a backward PV array (on the right side in the figure) decreases compared with a front PV array due to impact by a front array. In consideration of this point, when reflecting the impact of the front array in solar radiation calculation, the solar radiation in each string (PV string comprising an arbitrary number of series-connected modules is modeled./it's two or more wire connection of the PV module to the transverse direction) can be formulated as a formula 2-1,

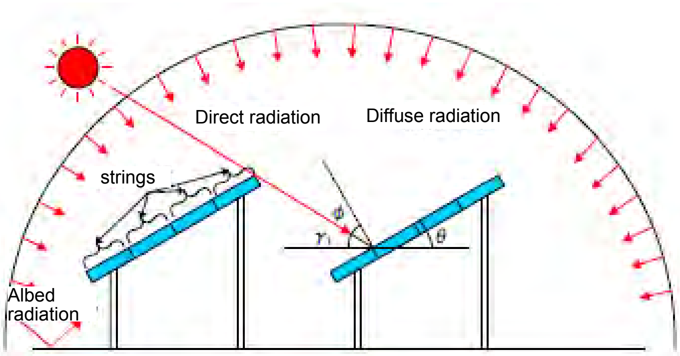


Figure 2-6 PV array arrangement texample

$$I_i = I_{ND}\cos\phi + I_S\left[\frac{1+\cos(\theta+\gamma_i)}{2}\right] I_{HT}\,p\,\tau\left[\frac{1-\cos\theta}{2}\right] \quad \cdots \text{Fomula 2-1}$$

I_i : Solar irradiance on inclined surface of the string of i row, I_{ND} : Direct irradiance, I_{HT} : Global irradiance,
I_S : Diffuse irradiance, ϕ : The angle formed by a line perpendicular to the inclined surface and solar altitude,
θ : PV array's tilt angle, γ_i : The topmost angle of elevation of a front array seen from the string of i row,
p : Reflectance of the ground, τ : Incidence rate of reflected light

The first term in formula 2-1 shows direct radiation. Since the brightness of diffuse radiation (quasi-direct radiation) around the Sun is strong compared with the diffuse radiation of other area in the sky, this diffuse radiation is considered as direct radiation and it is included in the first

term of the formula to calculate. The second term is diffuse radiation, and γi shows change of the sky area impact by the front array. The third term shows albedo radiation, and it is identified that has no effect if albedo radiation is considered as zero, according to the power generation record at Wakkanai site.
The calculation methods of each radiation show as follows.

i) Direct and quasi-direct radiation
Direct and quasi-direct radiation may have shade on a part of the surface on PV array depending on the solar altitude and its direction (figure 2-9). In order to reflect the shade impact on the incline, the length of the hypotenuse of PV array is set to 1, and the length of shade when direct or quasi-direct radiation comes in, is given by the formula 2-2.

$$L = \sin\theta \times \frac{\cosh}{\sinh} \times \cos A + \cos\theta \quad \cdot\cdot\cdot \text{Fomula 2-2}$$

The distance between each PV array (space between PV arrays) is set as Sp, the ratio that direct or quasi-direct radiation hits a backward PV array, can be given by Sp/L.
In the calculation, when a shadow falls on a part of a string, the string is considered not to generate, and when a module number of stages (module rows) is set as R, direct and quasi-direct radiation at incline that is calculated without considering the impact of a front array, are multiplied by coefficient which integer number of Sp/L x R is divided by R, to calculate solar irradiation in consideration of the front array.

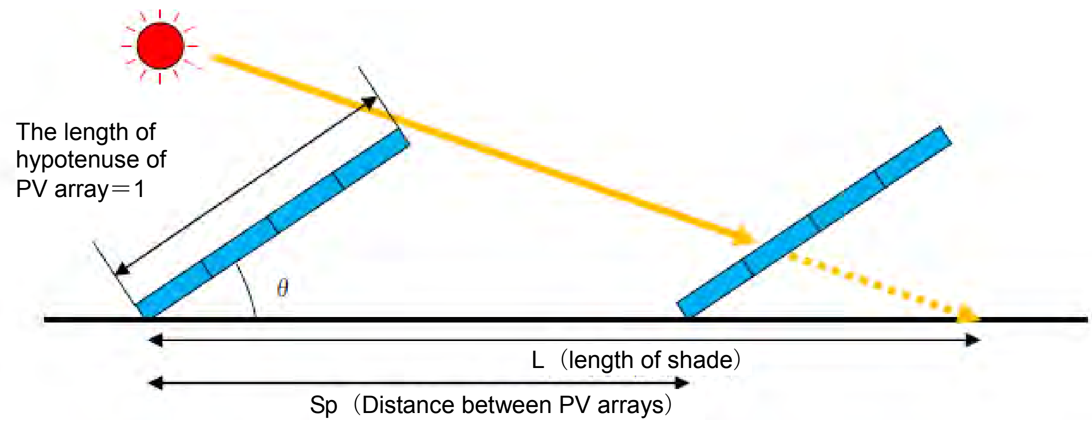


Figure 2-9 Shadowing effect by a front PV array in direct and quasi-direct radiation

(b) Diffuse radiation
Diffuse radiation is calculated at the second term in the formula 2-1. Formula 2-3 is when the ascending vertical angle which looked at the topmost part of the front array from the string of N row from the top of the array, is set to γN, and the module row is set to R, the distance between arrays is set to Sp, and the array ascending vertical angle is set to θ.

$$\gamma_N = \tan^{-1}\left(\frac{\frac{N}{R}\sin\theta}{Sp - \frac{N}{R}\cos\theta} \right) \quad \cdot\cdot\cdot \quad \text{Fomula 2-3}$$

Ascending vertical angle is given by this formula, and then calculate diffuse irradiance.

Calculation of solar irradiation in Japan, it is possible to figure out a total irradiance and optimal tilt angle in a large-scale PV power plant utilizing METPV-3 data compiled by Japan Weather Association in the NEDO project "Research and Development of common fundamental technology for photovoltaic power generation system – survey on improvement of geographical breakdown function of the standard data" (FY2003 – 2005), and also based on above-mentioned method.

②Expected power generation

When solar irradiation is calculated by the methods shown in the previous clauses, the annual energy production at DC terminal is denoted by the following formula. (Solar irradiance under the normal condition is at 1 [kW/m2])

Annual energy production at DC terminal [kWh]=

System rated output [kW] × Solar irradiation[kWh/m2/day] × 365days ×Total design factor (k)

※ Total design factor (k)：Approx. 0.65～0.8

The annual energy production at the AC terminal is computed by multiplying the annual energy production at a DC terminal by PCS conversion efficiency, but PCS conversion efficiency changes with outputs. In order to compute the annual energy production at AC terminal accurately, the solar irradiation per hour is calculated, and the energy production at DC terminal computed using this data is multiplied by PCS conversion efficiency. In addition, the loss rate of PCS conversion efficiency can be denoted the loss to an input by second polynomial, so it is easy to calculate the annual energy production at AC terminal.

Loss rate conversion formula (example)

y = -0.005087 x 2 + 0.062407 x + 0.012398

the mean squared error:0.983733 (x = input/ rated: y = loss/ rated)

Also, when solar irradiation is measured by location surveying, survey data is converted into direct irradiance, quasi-direct irradiance, and full diffuse radiation, and the accurate calculation can be figured out by calculating hourly basis solar irradiation on a PV panel by the above-mentioned formulas.

3.2 Selection of the tilt angle and the azimuth

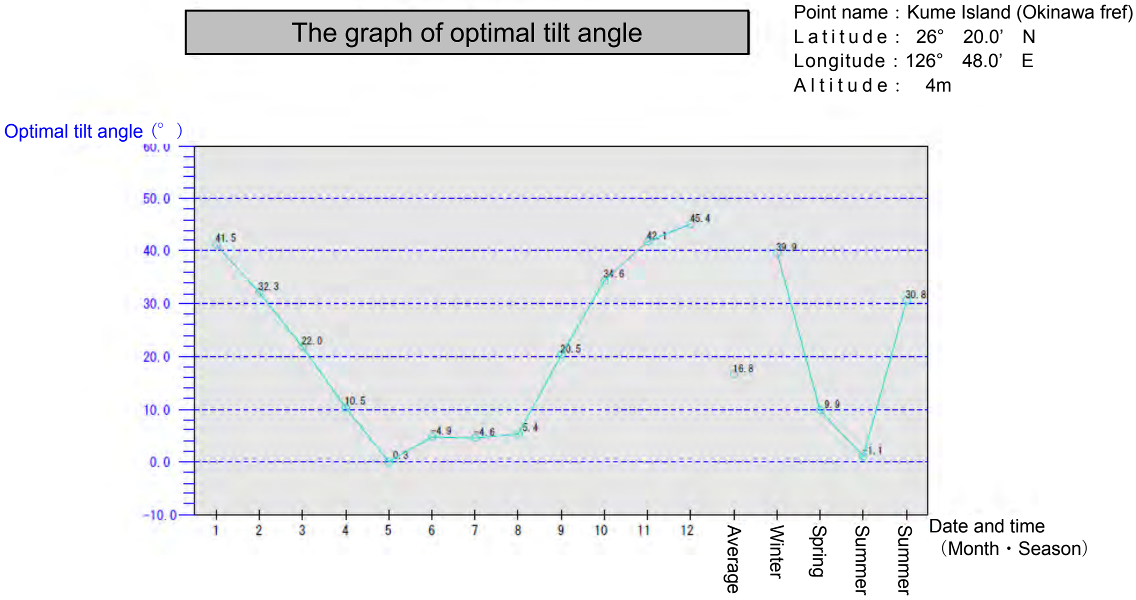
①Study on the optimal tilt angle that the annual maximum energy production can be obtained

The optimal angle of PV rack by a power generation simulation, in consideration of the influence by a front array, the optimal tilt angle will be different between the installation of a single PV array and the installation of plural PV arrays in a large-scale PV generation power plant.

The composite value of direct solar radiation, diffuse solar radiation and albedo radiation is the maximum angle as the optimal tilt angle in a single PV array installation. On the other hand, when plural PV arrays are installed like a large-scale PV power plant, the solar radiation on an inclined surface will decrease due to the influence by a front array, compared with a single array installation as the same angle. Therefore, if setting the optimal tilt angle in consideration of the influence, tilt angle will become small compared with the single array installation. In addition, the influence by the front array can be minimized by widening a distance between arrays. However, it is necessary to make a detailed study in consideration of available land area and land shape at the planned site when taking a layout into consideration. The case example of Kume Island studied on the selection of the optimal tilt angle is shown below.

■Optimal tilt angle

The result of the optimal tilt angle in Kume Island calculated from “Data map of national solar radiation average value (MONSOLAR05) by New Energy and Industrial Technology Development Organization (NEDO) is shown below. According to the graph, the optimal tilt angle is at 16.8°

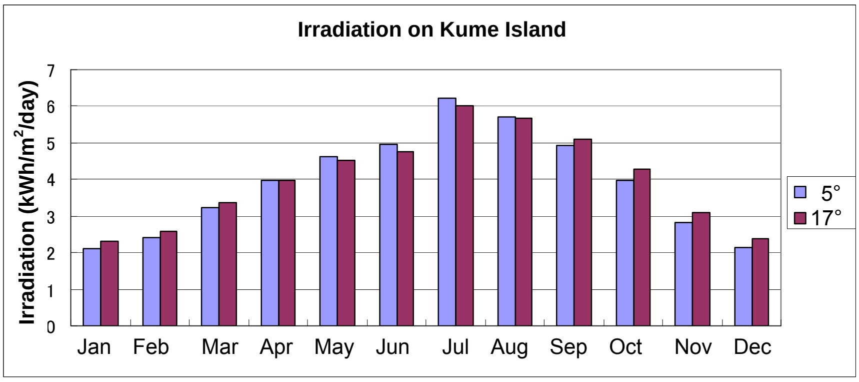


■Correlation between the tilt angle and solar irradiance

Using the "standard meteorological, solar radiation data (METPV-3)" by NEDO to calculate solar irradiation and the difference of solar irradiation in Kume Island between the tilt angle at 5°, and optimal tilt angle at 16.8°≒17° is compared. From the graph below, average solar irradiation on the tilt angle at 5° decreases about 2% compared with the optimal tilt angle at 17°.

Unit: $kWh/m^2/day$

Month	1	2	3	4	5	6	7	8	9	10	11	12	Average
5°	2.11	2.42	3.24	3.97	4.61	4.95	6.21	5.7	4.94	3.97	2.81	2.14	3.92
17°	2.3	2.57	3.36	3.98	4.51	4.76	6.02	5.68	5.11	4.29	3.1	2.39	4.01



②**Azimuth**

The azimuth of the PV array is an important factor for effective utilization of solar energy. In order to maximize of power production by the PV array, the azimuth of the PV array should be facing to the south in the Northern Hemisphere and facing to the north in the Southern Hemisphere in principal. However, as shown in the figure 2-9, even if the azimuth of the PV array is at 60° in a case of the tilt angle at 30° in Tokyo, the annual energy production drops about 8% only, hence it is possible to install.

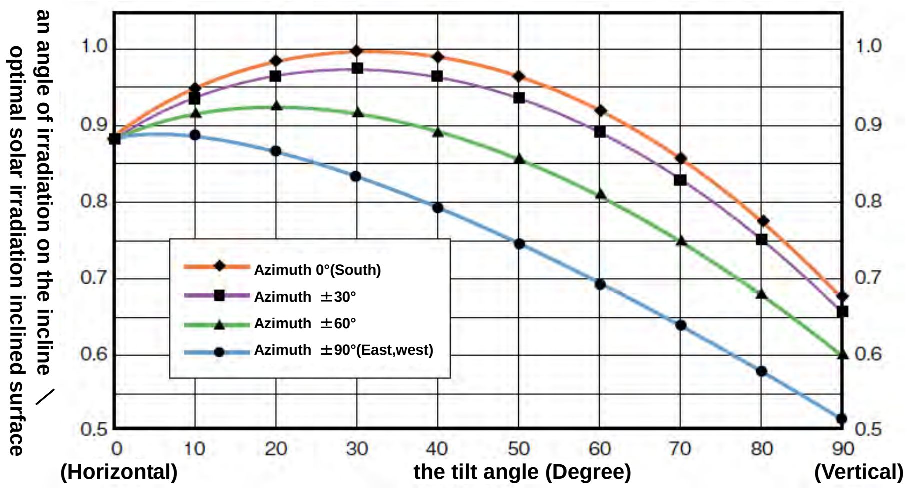


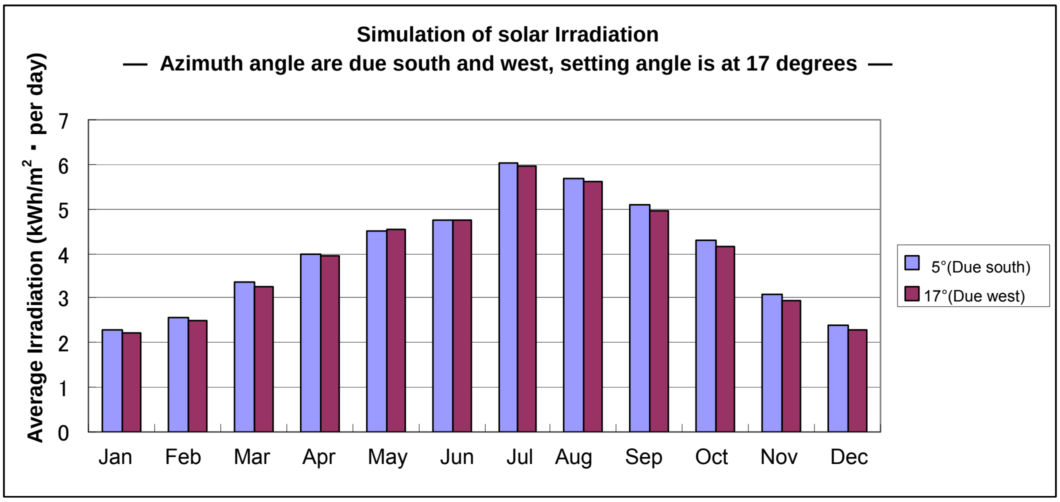
Figure2-10　Correlation between solar irradiance on inclined surface and the tilt angle in Tokyo

The case study in Kume Island for the azimuth selection is shown below.

■ Correlation between tilt angle, azimuth and solar irradiance

The difference of solar irradiation in Kume Island is compared between two cases: one is the tilt angle at 5° and the azimuth in the due south and the southwest, another case is the optimal tilt angle at 16.8°≒17° and the same azimuth condition as the tilt angle at 5° by using the "standard meteorological, solar radiation data (METPV-3)" provided by NEDO to calculate solar irradiation. From the graph below, average solar irradiation on the tilt angle at 5° and the azimuth in the southwest decreases about 2.5% compared with the optimal tilt angle at 17° and the azimuth in the due south.

	17°	5°
Due south (Azimuth: 90°)	4.01 (100%)	3.92 (98.0%)
Southwest (Azimuth: 135°)	3.93 (98.0%)	3.90 (97.5%)



■Result of the study

Above correlation between tilt angle, azimuth and solar irradiance, the tilt angle in Kume Island recommends at 5°. In a large-scale PV power system, it is possible to make narrow space between PV arrays when the tilt angle sets at 5°. Hence overall about 20% of required area can be cut down. Since the wind load is reduced, so the strength of a frame and the amount of concrete for the foundation can be reduced.

When the tilt angle sets at 5°, the annual energy production drops about 2% (It's the same situation as when the energy production is tremendously dropped for a week due to typhoon). However, as mentioned above, since the cost of civil engineering works is low, the tilt angle of the PV panel is set at 5° in the proven large-scale PV power systems (e.g. Mega solar system in Miyako Island, Abu mega solar system in Okinawa main island) in Okinawa.

3.3Installation plan for PV array

Installation plan for the ground type describes as follows.

① A PV array is installed on the specific place that is positioned in a layout plan of the entire facilities in the premises or a flow planning. Although there are some the restrictions, it should attempt to install the PV array faced in the south that maximum solar irradiation can be received and also set the optimal tilt angle to obtain annual maximum energy production.

② It is important to select the installation place that does not have impact by the shade. Hence, it needs to pay attention to the surrounding area such as buildings, structures, trees, etc. to select the installation site.

③ When two or more PV arrays are installed, it is necessary to consider the offset distance between PV arrays. The shadow length of the PV array varies depending on the latitude of the installation site, season and time. But it is desirable to make the installation plan that the PV array is not exposed to the longest shadow that appears between 9am to 3pm on the winter solstice. However, it is necessary to plan for the azimuth, offset distance and securing installed capacity of the PV array based on the restrictions by the relation between land shape and the azimuth and surrounding environment.

④ The installation site should select the place that may not have a risk of falling objects, and avoid oil contained dust and the affected area by special dirt. If it is difficult to avoid, it is necessary to take measures for these matters. Regarding adhesion and deposition of the usual dust, it can be cleared by rain and so on, so the output power is stable in the certain range clarified by the past experiences.

3.4 System capacity (size)

System capacity is limited to some extent by the installation area size and the budget. Although according to the type of PV cell, and tilt angle of PV panel, the space about 10-15 m^2/kW is required for PV array installation. Also, it is desirable to consider installation space for ancillary facilities such as substation facilities, PCS and so forth.

Consideration of system capacity, it is necessary to think about “design, cost and installation space”, and the key point is “how much the budget can be secured”. In addition, the necessary PV system size in order to meet the design is related to the system capacity setup as a result. For example, relation between the specification (design, function, performance) of necessary modules for the design and the installation space.

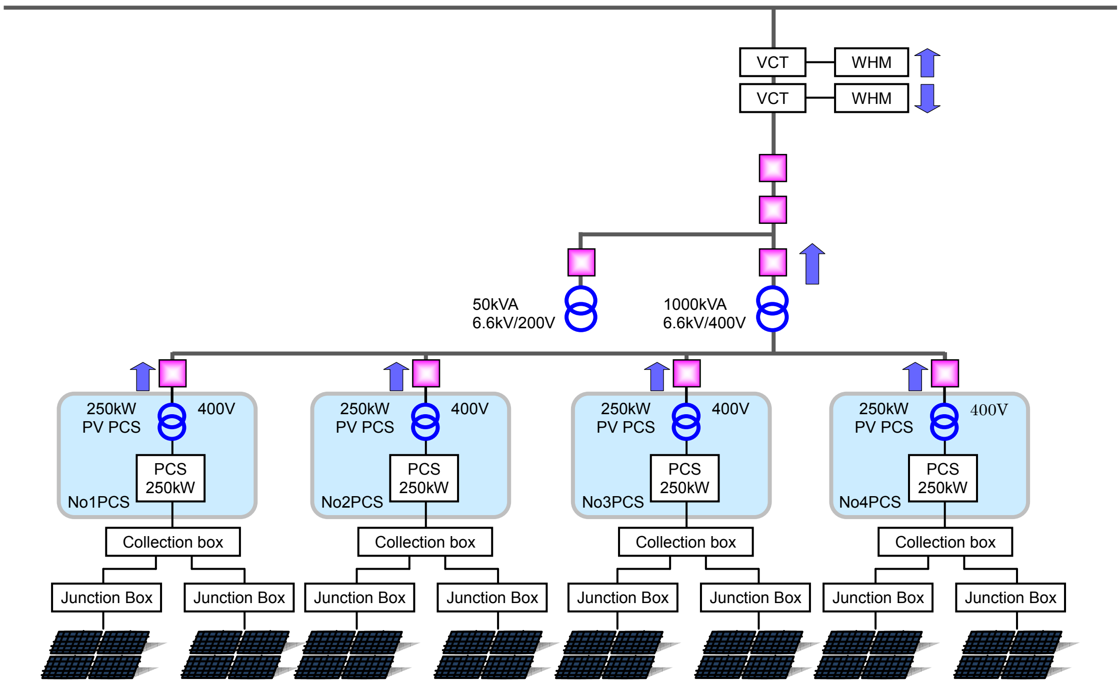
3.5 System Configuration

The basic PV system is that PV module receives solar radiation and generates power, combines generated power in a junction box / a collecting board, and converts into AC power by power conditioner, then connects to the grid via high voltage receiving board in general. When compiling generated power and solar irradiation as data or display for the purpose of promotion of environmental friendliness and energy management, a pyranometer, an outside air temperature gauge, a data measurement device, and a display device are additionally needed.

The components except PV array, a junction box is installed at outdoor (near the PV array), and a power conditioner is installed either outdoor or indoor due to the condition of its size and installation site.

When the capacity of the entire PV system is determined, generally the installation method of the

PV panel and power conditioner is also determined. Ideally, the distance between the PV array and power conditioner is better to be close. When distributed installation of the PV array is implemented, distributed installation of power conditioner is also implemented in nearby each PV array and it should have the sufficient capacity to respond to the capacity of the PV array. Figure 00 shows the sample of system configuration.



(Source: Kumamoto University, Eco-Ene Study Group “the 4th workshop” material)

Figure2-11 System configuration

4. Design of PV array

4.1 PV module selection

PV array consists of PV module that is connected in series and/or parallel to keep consistent voltage and capacity. That is to say, select PV module and determine the voltage and the output power per module in order to calculate the generation capacity of a PV power system. In the determination of installation area, it is necessary to know the dimension of the PV module. However, specification of PV module varies depending on manufacturers and there are no common standards. Hence, there is a wide variation according to the type of PV cell.

In the planning stage, if a manufacturer is undecided, or the public works that is difficult to decide PV module from the drawing for order, it is better to use average voltage and output power figures from manufacturers’ catalogs and make a detailed plan refer to the specific product according to the planning stage.

4.2 Number of series and parallel connections of PV module

PV array is made by PV modules that connect required number of modules in series, and further connect in parallel to form into a large-sized panel to generate required electric power. The number of modules to connect in series, are usually planned based on a figure calculated by 110% of power conditioner’s rated DC voltage divided by the maximum output working voltage. For example, PV array that is composed of modules (maximum output at 108.2W, maximum output working voltage at 36.2V) shown in the figure 00, connects to an inverter with rated DC voltage at 300V (input voltage operation range: 240V to 345V) to get AC output voltage, three-phase at 210V, the calculation is;

300 x 1.1 = 330   330V / 36.2V = 9.12 = 9 series

Therefore, when making a system with maximum output at 30kW,

30,000W / 108.2W = 277 pieces of modules

277 pieces of modules / 9 series = 31 parallels

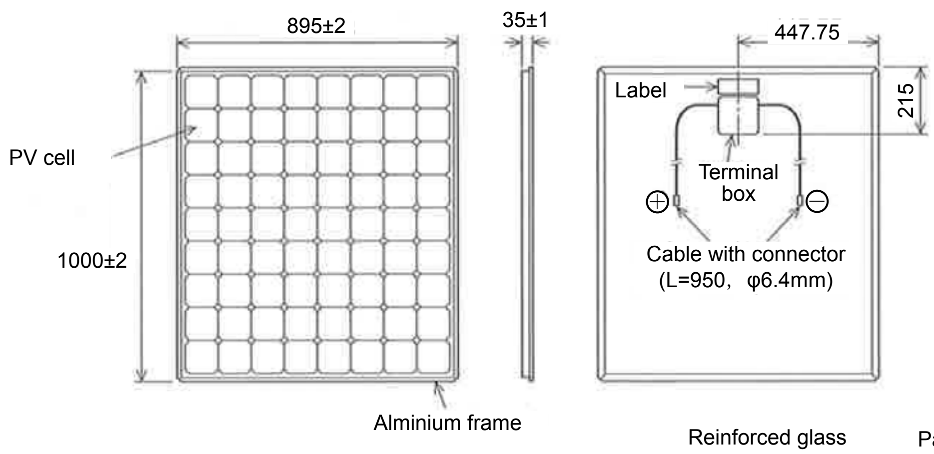
In a reference case, it sets as 32 in parallel due to the whole structure of the PV array. Hence, the number of modules and the maximum output of PV array is;

9 series x 32 parallels = 288 pieces of module

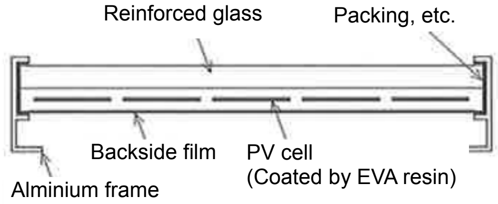
288 pieces of module x 108.2W = 31,160W = 31.16kW

In the actual design, it is necessary to determine the configuration of the PV array, form and division method in consideration of the conditions such as frame dimension, required space for installation and so forth. In addition, when determining the number of serial connections of a PV module in a detailed design, the fluctuation of module’s open circuit voltage and output working voltage caused by the module’s temperature characteristics shall be set within the power conditioner (inverter)’s the maximum allowable voltage, input voltage range, and MPPT working voltage range.

The DC voltage of an inverter is at 200V in a single-phase output, in the case of general 300V in three-phase output, PV modules with maximum output about 50 to 65W, the maximum output working voltage will be at 18 to 20V, so the number of serial connections required is 16 to 18 series. A large-scale PV module with the maximum output at 100 to 120W, the maximum output working voltage will be at 34 to 36V, the number of serial connections required is about 8 to 9 series. The circuit of a group of PV modules connected in serial is called a “string”.



Electrical characteristic	Standard value (at AM-1.5, 1kWm2, 25℃)
Max output (P_{max})	108.2W
Max power voltage (V_{pm})	36.2V
Max power current (I_{pm})	2.99A
Open circuit voltage (V_{OC})	4.35V
Short circuit current (I_{SC})	3.28A



(Source: NEDO “PV power system introduction guidebook”)

Figure 2-12 Configuration of PV module

4.3 Design for frame and foundation

① Frame design

(a) Outline of frame strength calculation

In Japan, the frame for ground installation type in a large-scale PV power plant is treated as an electric facility. Hence, it is necessary to design following the ministerial ordinance setting technical standards concerning electrical facilities.

Article 50-2 in the ministerial ordinance stipulates that the support structure for a PV module should have the strength specified in the "Design guide on structures for photovoltaic array" in the Japanese Industrial Standards – JIS C8955 (in 2004). It is necessary to design following JIS guidelines. The calculation of strength in JIS is set based on the Building Standard Law, and most of the concepts are the same as the Building Standard Law, but the "Deflection" stipulated in the Building Standard Law, is not stated in JIS.

The calculation of strength stated in JIS; calculate dead load, wind load, snow load, and seismic load, then select the material that can withstand each load. However, the selected material's weight is used for the calculation of dead load, seismic load and so forth. Hence, it is required to verify the calculation.

The next section describes about the calculation method of frame's strength.

(b) Expected loads

Expected loads put on the support structure are classified into 4 types such as dead load (G), wind load (W), snow load (S), and seismic load (K). The summary and notes of each load describe as follows.

i) Dead Load (G)

Sum of the module mass and the support mass

ii) Wind load (W)

Sum of wind pressure put on the module and the support structure. The calculation is shown in the formula 00.

W＝Cw × q × Aw・・・・Formula 2-4

(W: Wind load [N], Cw: Wind factor, q: Design velocity pressure [N・m-2], Aw: Receiving area [m2])

And, the design velocity pressure "q" is given by formula 2-5.

q ＝ 0.6×V2×E×I・・・・formula 2-5

(V: Reference wind velocity for design [m・s-1]、E: Environmental factor, I: Application factor)

[Reference wind velocity for design]

The figures indicated on the table of reference wind velocity for design in JIS are used.

[Environmental factor]

In the calculation of environmental factor E, it is necessary to check terrain category. The terrain category is specified by each local government, so check it from their websites and so forth.

[Application factor]

Application factor sets in consideration of the importance of the PV system to install. (Example: 1.3)

(iii) Snow load (S)

Vertical snow load put on the module surface. The calculation is shown in the formula 2-6.

S＝Cs×P×Zs×As・・・・Formula 2-6

(S: Snow load [N]、Cs: Slope factor, P: Average unit mass of snow [N/m^2·cm], Zs: Vertical snow depth on the ground [m], As: Snow area (Area of the PV array)[m^2])

[Average unit mass of snow]

The average unit mass of snow varies depending on general regions and snowy regions. Article 86, paragraph 2 in the Enforcement Ordinance of Construction Standard Law states that the unit of snow load shall be more than 20 Newton per one square meter in every one centimeter of snowfall. However, the designated administrative agencies can specify a heavy snow zone based on the standard stipulated by the Minister of Land, Infrastructure, Transport and Tourism, and the different stipulation can be applied to the heavy snow zone. (Notification relates to the Construction Standard Law No. 1455 – issued in 2000) It is possible to check which regulation shall be applied to the concerning region, from the each prefecture's website.

[Vertical snow depth on the ground]

In the calculation formula described in JIS, it is necessary to put "standard sea ratio in the area", and the various factors such as radius used for the calculation of sea ratio are specified by each area in JIS, but it is not easy to calculate. This calculation formula and each factor are the same as the one specified in the "Notification No. 1455 by the Construction Ministry in 2000", and this notification was issued by the Article 86, paragraph 2 in Enforcement Ordinance of Construction Standard Law. It says that the vertical snow depth specified in the Article 1 shall be the value that the designated administrative agencies define by a rule based on the standards provided by the Minister of Land, Infrastructure, Transport and Tourism. The vertical snow depth is posted on the website as "Enforcement Regulations of the Building Standards Law" in the each prefecture.

(iv) Seismic load (K)

Horizontal seismic force exerted on the support structure. Calculation shows in the formula 2-7.

K=k×G (general region)

K=k×(G+0.35S) (snowy region) ・・・・formula 2-7

(K: Seismic load [N], k: Horizontal seismic coefficient for design, G: Dead load [N], S: Snow load [N])

[Horizontal seismic coefficient for design]

Seismic zoning factor is required for the calculation of horizontal seismic coefficient for design. Seismic zoning factor is stated in the Ordinance of the Ministry of Land, Infrastructure Transport and Tourism, and also be available in the website.

Above four types of load are calculated utilizing the load conditions and combination in the table 2-7. When calculating wind load, it should calculate under the fair wind and adverse wind conditions, and the seismic load calculation, it should calculate under the vertical and horizontal directions.

Table 2-7 Load conditions and combinations

Load Condition		General Region	Snowy zone
Long-term	Always	G	G
	Snow		G+0.7S
Short-term	Snow	G+S	G+S
	Storm	G+W	G+W
			G+0.35S+W
	Earthquake	G+K	G+0.35S+K

(C) Notes for designing of a supporting structure

Notes for designing of a supporting structure are as follows.

(i) Installation direction of PV module

When installing the PV module horizontally, a purlin that supports PV module is installed vertically, and vice versa. Generally, C-shaped channel (lip channel) is often used for the purlin, to make it easy to fix the PV module by bolts, and a bending withstand load of these steel materials differs according to the X (horizontal) axis and Y (vertical) axis. In the wind load that the load is applied to the PV module constantly, there is no difference in the installation direction of the purlin. However, in the snow load that a load is applied vertical way to the ground, a big bending moment occurs toward a weak axis direction that the purlin is installed horizontally. Therefore, the PV module should be installed horizontally, and the purlin is installed vertically to obtain the strength.

(ii) Tilt angle of a supporting structure

The wind pressure load put on the PV modules will get stronger if a large tilt angle is taken. On the other hand, snow load becomes small. A tilt angle is desirable to select the angle that could be the annual maximum energy production. However, if the tilt angle sets small in a snowy region, snow load might exceed in PV module's allowable load, so it should be noted. In addition, PV module's allowable load may vary at the front side and the back side. If there is no specification, it is desirable to check with manufacturers when considering wind load, snow load and so forth.

(iii) Minimum height from the ground

In the snowy region, the snow piles up in front of a PV array, so it requires securing a space as a minimum height from the ground for the snow. In addition, when the minimum height from the ground sets low, it may cause of shadowing effect by weeds, and the PV panel may be broken by a stone hit when mowing, so the minimum height from the ground is needed to determine in consideration of these possibilities.

(iv) Selection for the structural pattern

Usually, the allowable stress of a component is in order that tension > compression > bend. Hence, the material having bending load, its size intends to become large. With the supporting structure of truss structure, the components receiving a bending load are purlin and beam materials. Especially, the purlin has many materials, and reduction of the bending load puts on the component of purlin contributes to the component weight reduction in the entire supporting structure.

Figure 2-13 shows a sample structure of a PV array rack. In the picture I and II, the bending moment at the point A and the span B are equal, hence bending moment of entire structure can be reduced. Meanwhile, comparing the picture I with the picture III, even if the number of PV module to the lengthwise direction is the same, the length of in-between supporting points of the picture III is 1.5 times longer than the picture I. In addition, the length of in-between supporting points in the picture IV is double than the picture II that has the same number of PV module to the lengthwise direction. In the case of a uniformly distributed load, the bending moment is proportional to the square of length. It means, 2.25 times of bending moment is added to the picture I compare with the picture III, and 4 times of bending moment is added to the picture IV compare with the picture II. Therefore, the size of the PV panel rack of the picture I and II can be smaller than the picture III and IV. Also, the size of the supporting back legs that the load is added most in the picture I and II can be shorter and this is the advantage of the aspect of buckling. However, if the width of the foundation is shorter, overturning moment to the foundation will increase. Hence, it needs to take note in the high wind area.

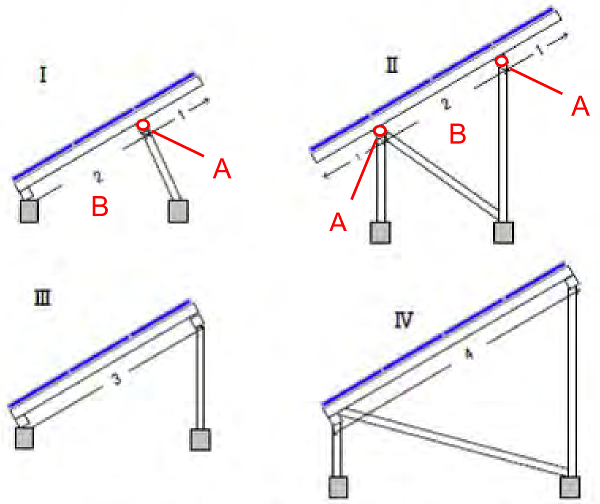


Figure 2-13 Basic structure pattern

(V) Allowable buckling load

There is no description about buckling in JIS, but when compression load adds on a component, it is necessary to consider about buckling.

Allowable value of tensile load depends on the cross sectional area of a component. Meanwhile the buckling occurs on the component by compression load, the buckling strength is given by the cross sectional area, and also the length of the component, radius of gyration of area. In order to increase the buckling strength, the calculation for the case of attaching auxiliary component towards weak axis is needed. Also, it is necessary to consider the bending buckling for H-shaped steel and channel steel (except lip) among the components that bending load puts on.

Calculation method is specified in “the Notification No. 1024 by the Ministry of Land, Infrastructure, Transport and Tourism – issued in 2001”, and it can use as a reference when designing.

② **Foundation design**

Generally, foundation type of a structure is classified as a figure 2-14. When a rack is mounted on a ground, independent footing or connected foundation is generally adopted among spread foundation. However, if a ground condition near the ground surface is bad and supporting layer is deep, a pile foundation may be adopted.

In a foundation design, a geological survey is performed in advance; also calculate required bearing power from leg stress computed in a mount design, and the foundation type that can bear the load, is chosen. The cost for foundation work needs sufficient consideration for its economic efficiency since the cost may fluctuate drastically with the foundation type to adopt.

Table 2-8 shows a foundation work example at a large-scale PV power plant.

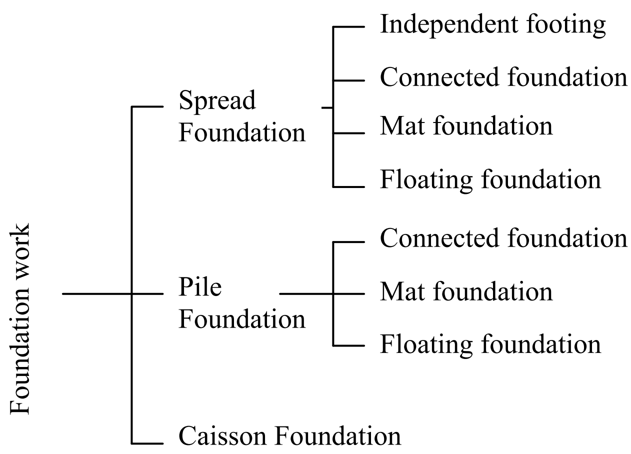
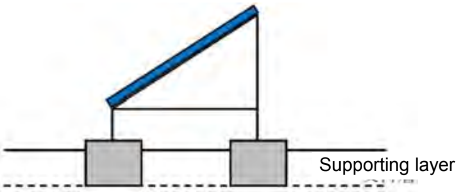
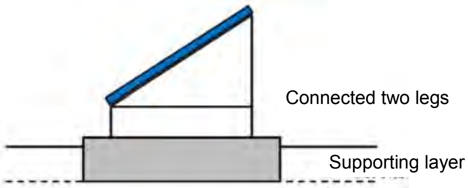
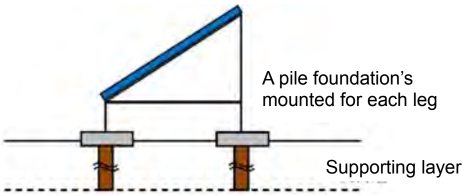


Figure 2-14 Foundation type

Table 2-8 Foundation work example of a large-scale PV power plant

Foundation type	Example of construction
Spread foundation (Independent footing)	 
Spread foundation (Connected foundation)	 
Pile foundation	 

5. Cable design

This subsection describes the cable design of the PV system, such as DC cable work from the PV module to the PCS and AC cable work from the PCS to the connection point with the grid.
Note that the numerical values that will appear below are referred to the “Technical Standards for Electrical Facilities”, and “Internal Wiring Codes” developed in Japan.

5.1 Cabling between the PV module and PCS

① To carry a short-circuit current, the common size of cables between the PV modules shall be $2mm^2$ and over. In general, two cables (with a connector) are derived from the terminal box on the back of each PV module and the polarities are shown. However, cares will be needed as different module manufactures present different identification.

② Necessary number of PV modules will be connected in series to constitute a string, which is terminated by a junction box. Parallel connections are made in the junction box (or a collection box).

③ It is recommended to install the junction box as near to the PV array as possible, but it may be difficult due to the structure of a building in which the array is installed. In this case, we determine the installation place in consideration of maintenance works such as inspection and changing parts.
In the wiring design from the junction box (or the collection box) to the PCS, the voltage drop should not exceed 1.0V at rated power. The Japanese standards specify that the voltage drop of a low-voltage cable shall not exceed 2% of the standard voltage in the main and branch circuits. Table 2-9 lists the maximum length of cables at a voltage drop of 1.0V in Japan.

④ For example, the voltage drop is not more than 6V in a PV system rated at a DC voltage of 300V.

Ex.: If DC voltage: 300V; Voltage drop (e): 6.0V; Current (I): 45A; Cable length (L): 50m, then the cable size is $14mm^2$, which is given by multiply the value selected from the Table 2-9 by six (6).

⑤ Table 2-10 shows how to find the cross-sectional area of a cable from a voltage drop. For example, in a PV system rated at a DC voltage of 300V, the voltage drop is not more than 6V as shown in the previous paragraph.

Ex.: If DC voltage: 300 V; Voltage drop (e): 6.0 V; Current (I): 45 A; Cable length (L): 50 m, then

$$A = (36.5 \times L \times I) / (1{,}000 \times e) = (36.5 \times 50 \times 45) / (1{,}000 \times 6.0) = 13.7\ (mm^2)$$

Accordingly, the cable size is $14mm^2$.

⑥ If the PV array is mounted on the ground, underground wiring is often used between the junction box (or the collection box) and the PCS. The underground wiring and piping work require an investigation of the depth based on the weight of the PV array and the weight of sand. In addition, it is recommended to take measures for protecting underground cables and to install hand holes or underground boxes if the cable length exceeds 30 meters.

Table 2-9: Maximum cable length (in the case of the DC or 1-phase 2-wire system)

Maximum cable length (m) at a copper-cable voltage drop of 1V																
Current	Solid cable (mm)				Stranded cable (mm^2)											
(A)	1.6	2.0	2.6	3.2	14	22	38	60	100	150	200	250	325	400	500
1	56	88	149	226	384	606	1,020	1,650	2,780	4,240	5,420	6,990	8,930	11,100	13,500
2	28	44	75	113	192	303	512	823	1,390	2,120	2,710	3,490	4,460	5,550	6,760
3	19	29	50	75	128	202	342	548	927	1,410	1,810	2,330	2,980	3,700	4,510
4	14	22	37	57	96	152	256	411	696	1,060	1,350	1,750	2,230	2,780	3,380
5	11	18	30	45	77	121	205	329	556	848	1,080	1,400	1,780	2,220	2,710
6	9.3	15	25	38	64	101	171	274	464	707	903	1,160	1,490	1,850	2,260
7	8.0	13	21	32	55	87	146	235	397	606	774	998	1,280	1,590	1,930
8	7.0	11	19	28	48	76	128	206	348	530	677	873	1,120	1,390	1,690
9	6.2	9.8	17	25	43	67	114	183	309	471	602	776	992	1,230	1,500
12	4.7	7.4	12	19	32	51	85	137	232	353	451	582	744	926	1,130
14	4.0	6.3	11	16	27	43	73	118	199	303	386	499	637	793	966
15	3.7	5.9	10	15	26	40	68	110	185	282	361	466	595	740	902
16	3.5	5.5	9.3	14	24	38	64	103	174	265	338	436	558	694	845
18	3.1	4.9	8.3	13	21	34	57	91	155	236	301	388	496	617	751
25	2.2	3.5	6.0	9.0	15	24	41	66	111	170	217	279	357	444	541
35	1.6	2.5	4.3	6.5	11	17	29	47	79	121	155	200	255	317	386
45	1.2	2.0	3.3	5.0	8.5	13	23	37	62	94	120	155	198	247	301

Source: Internal Wiring Rules (JEAC 8001-2005)

Notes:

1. If the voltage drop is 2V or 3V, the maximum cable length is given by multiplying the values shown in the table by two or three respectively (this applies to the other).
2. If the current is 20A or 200A, the maximum cable length is given by diving values shown in the 2-A row of the table by 10 or 100 respectively (this applies to the other).
3. In a stranded cable is $5.5mm^2$ or $8mm^2$ in size, the maximum cable length is the same as that of a solid cable 2.6mm or 3.2mm in diameter respectively.
4. The values shown in the table are found at a power factor of one (1).

Table 2-10: Equations for finding a voltage drop and cable's cross section area

Electric system	Voltage drop	Cable's sectional area
1-phase 2-wire DC 2-wire	$e = \frac{36.5*L*I}{1000*A}$	$A = \frac{36.5*L*I}{1000*e}$
3-phase 3-wire	$e = \frac{30.8*L*I}{1000*A}$	$A = \frac{30.8*L*I}{1000*e}$
1-phase 3-wire 3-phase 4-wire	$e' = \frac{17.8*L*I}{1000*A}$	$A = \frac{17.8*L*I}{1000*e'}$

Source: Internal Wiring Rules (JEAC 8001-2005)

Note:

e: Voltage drop across a cable (V)

e': Voltage drop between the outer or phase conductor and the neutral conductor (V)

A: Cross section area of the cable (mm^2)

L: Length of the cable (m)

I: Current (A)

Each equation shown in the table holds when the outer or phase conductors of the circuit are in equilibrium, and the cable conductance is 97%.

5.2 Cabling from the PCS to the grid connection board

① If the PCS capacity exceeds 10 kW, the typical electrical system on the output side is a 3-phase 3-wire type (or a 3-phase 4-wire type) and the voltage rating is 200V. In this case, the maximum cable length can be derived from the table below.

Table 2-11: Maximum cable length (in the case of the 3-phase 3-wire system)

Maximum cable length (m) at a copper-cable voltage drop of 2V															
Current	Solid cable (mm)				Stranded cable (mm^2)										
(A)	1.6	2.0	2.6	3.2	14	22	38	60	100	150	200	250	325	400	500
1	129	204	345	522	888	1,400	2,370	3,800	6,430	9,800	12,500	16,100	20,600	25,700	31,200
2	65	102	172	261	444	701	1,180	1,900	3,210	4,900	6,260	8,070	10,300	12,800	15,600
3	43	68	115	174	296	467	788	1,270	2,140	3,270	4,170	5,380	6,870	8,550	10,400
4	32	51	86	131	222	351	592	951	1,610	2,450	3,130	4,030	5,150	6,410	7,810
5	26	41	69	104	178	280	473	760	1,290	1,960	2,500	3,230	4,120	5,130	6,250
6	22	34	57	87	148	234	394	634	1,070	1,630	2,080	2,690	3,440	4,280	5,210
7	18	29	49	75	127	200	338	543	918	1,400	1,790	2,310	2,950	3,660	4,460
8	16	26	43	65	111	175	296	475	803	1,230	1,560	2,020	2,580	3,210	3,900
9	14	23	38	58	99	156	263	422	714	1,090	1,390	1,790	2,290	2,850	3,470
12	11	17	29	44	74	117	197	317	535	816	1,040	1,340	1,720	2,140	2,600
14	9.2	15	25	37	63	100	169	272	459	700	894	1,150	1,470	1,830	2,230
15	8.6	14	23	35	59	93	158	253	428	653	834	1,080	1,370	1,710	2,080
16	8.1	13	22	33	55	88	148	238	401	612	782	1,010	1,290	1,600	1,950
18	7.2	11	19	29	49	78	131	211	357	544	695	896	1,150	1,430	1,740
25	5.2	8.2	14	21	36	56	95	152	257	392	500	645	825	1,030	1,250
35	3.7	5.8	9.9	15	25	40	68	109	184	280	357	461	589	733	893
45	2.9	4.5	7.7	12	20	31	53	84	143	218	278	359	458	570	694

Source: Internal Wiring Rules (JEAC 8001-2005)

Notes:

1. If the voltage drop is 4V or 6V, the maximum cable length is given by multiplying values shown in the table by two or three respectively (this applies to the other).
2. If the current is 20A or 200A, the maximum cable length is given by diving values shown in the 2-A row of the table by 10 or 100 respectively (this applies to the other).
3. In a stranded cable is $5.5mm^2$ or $8mm^2$ in size, the maximum cable length is the same as that of a solid cable 2.6mm or 3.2mm in diameter respectively.
4. The values shown in the table are found at a power factor of one (1).

6. Lightning protection design

In many cases, a PV array is installed at an outdoor and large site without obstacles. In the installation in the area often struck by lightning, it is necessary to take measures depending on the importance of the PV system. This subsection mainly describes measures against indirect lightning that is assumed to have an impact on the PV array more frequently than direct lightning.

6.1 Kinds of lightning damage

Lightning is classified into direct and indirect strokes, which have different characteristics as shown below.

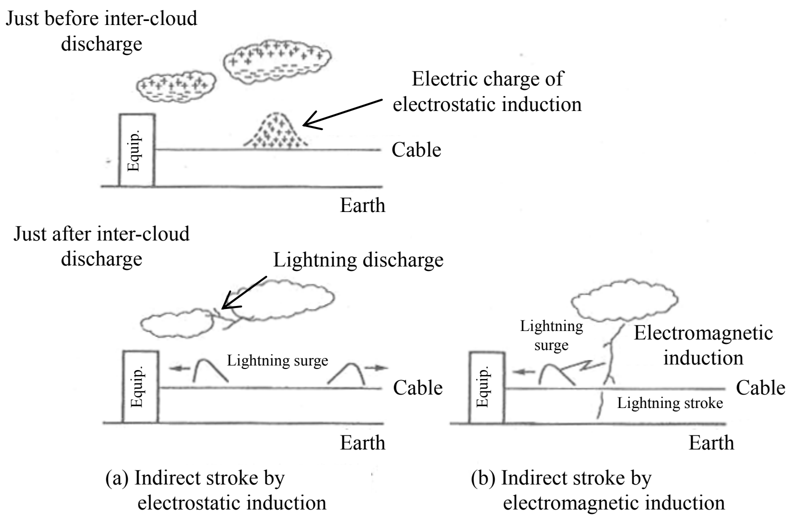
(a) Direct lightning stroke

Direct lightning strikes a PV array, low-voltage distribution line, and electrical devices directly or in the vicinity of them. The stroke having a current of 10 to 25kA commands 50% share but some have very high energy, for example a current of about 300kA. Therefore, it is very difficult to take measures against such a direct lightning stroke.

In Japan, there are not many cases that PV arrays have been struck by direct lightning. So, normally lightning rod is not installed. However, we the lightning rods can be installed in the vicinity of mountaintops and in the area often struck by lightning, or if the PV system is very important. The lightning rod may be installed so that the PV array and other electrical equipment are within a shield angle of 60° from the rod tip.

(b) Indirect lightning stroke

Indirect lightning is classified into electrostatic and electromagnetic induction. In case of electrostatic induction, positive charge induced in a cable causes a lightning surge because the stroke will let the positive charge move freely which has been kept neutralized by the negative charge on the ground surface. In the latter case, lightning that strikes the vicinity of a cable induces a lightning current in the cable, resulting in a lightning surge.



Source: Design and installation work of PV system, Japan Photovoltaic Energy Association (JPEA)

Figure 2-15: Principle of indirect lightning strokes

6.2 Measures against lightning surge

A lightning surge may invade the PV system through the PV array, the distribution and grounding lines, or both of them. The invasion via the grounding cable occurs when a lightning stroke given to the vicinity increases the earth potential, and the potential on the source side becomes relatively low, resulting in a current flowing from the ground to the power source. Possible measures against this problem are shown below.

① Installing a surge protective device (SPD) in the junction box and also scattering SPD over the main circuit of the array if necessary.

② Installing an SPD in the distribution board to prevent a lightning surge from the invasion via the low-voltage distribution line.

③ Installing a lightning shielding transformer in the AC power source as a safety measure in areas frequently struck by lightning.

6.3 Selection of surge protective device (SPD)

The PV module or array is not designed to withstand a direct lightning stroke. That is to say, the grid-connected PV system will be broken when it is struck directly by lightning and the resulting overvoltage or overcurrent exceeds the allowable value of any system component. If the PV system is installed in an important facility in a area frequency struck by lightning, measures against direct lightning is necessary. In this case, the installation of lightning rods is effective in reducing the risk of lightning strokes. Measures against indirect lightning include arresters and surge absorbers, which are surge protective devices to be installed in the main circuit of the array, junction box, and distribution board. In addition, lightning shielding transformers will have to be installed in areas frequently struck by lightning.

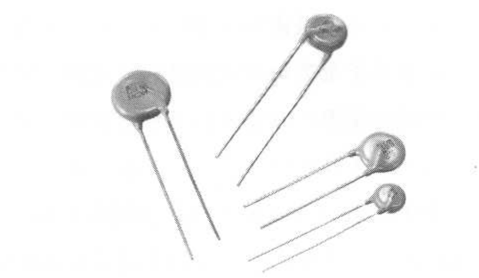
Note that arresters (whose discharge withstand current rating is large) shall be selected for the junction box and distribution board, and surge absorbers (whose discharge withstand current rating is small) for the main circuit of the array. Figure 2-16 shows the appearance of various SPDs.

① Arrester: Reduces lightning-caused sudden overvoltage applied to the terminal of an electric device and returns it to the normal voltage without a power interruption.

② Surge absorber: Damps the peak of abnormal voltage invading via a wire and reduces the amplitude.

③ Lightning shielding transformer: Consists of an insulation transformer, an arrester, and capacitors. When a lightning surge invades the transformer, the built-in arrester damps the abnormal voltage, the transformer attains the high insulation between the primary and secondary sides, and the shield cuts off the surge completely.

Lightning arrester



Surge absorber

Source: Design and installation work of PV system, Japan Photovoltaic Energy Association (JPEA)

Figure 2-16: Lightning arrester and surge absorber

6.4 Selection of lightning arrester

① When an arrester is built in the junction box, the maximum allowable or rated voltage shown in the manufacturer's specification shall be larger than the maximum voltage across the terminals to be protected. In case arresters are installed in the distribution board, the voltage requirements shall meet the rated voltage or one recommended by the manufacturer of distribution boards.

② Assuming that a surge current induced by indirect lightning is 1,000A (8/20μs), the arrester shall be rated at a discharge voltage of 2,000V or less. Discharge voltage is the remaining voltage across the arrester after the surge current flows with limited surge voltage. Note that some experiments show that PV arrays has an impulse withstand voltage of 4,500V (which means that no dielectric breakdown occurs when an impulse having this voltage and a standard waveform width of 1.2/50μs applies to the array three times negatively and positively), so we set the discharge voltage at 2,000V in consideration of an increase in the surge impedance proportional to the length of the arrester's grounding wire.

③ An induced current waveform may have energy exceeding 8/20μs. Therefore, the discharge withstand current rating (surge current withstand) of the arrester shall be at least 4kA, but we recommend 20kA if possible.

④ The arrester is required to have structure that makes it easy to remove itself from the circuit to allow maintenance staff to work during maintenance and inspection after damage caused by a lightning current.

⑤ Any arresters having a gap are not recommended because after they work due to a lightning surge, the working voltage of the gap reduces and a current from the PV array continues flowing through the gap, resulting in a break.

Table 2-12 shows examples of arresters chosen according to the above, and Figure 2-17 indicates how to install them in the junction box and distribution board.

Table 2-12: Selection of lightning arrester (sample)

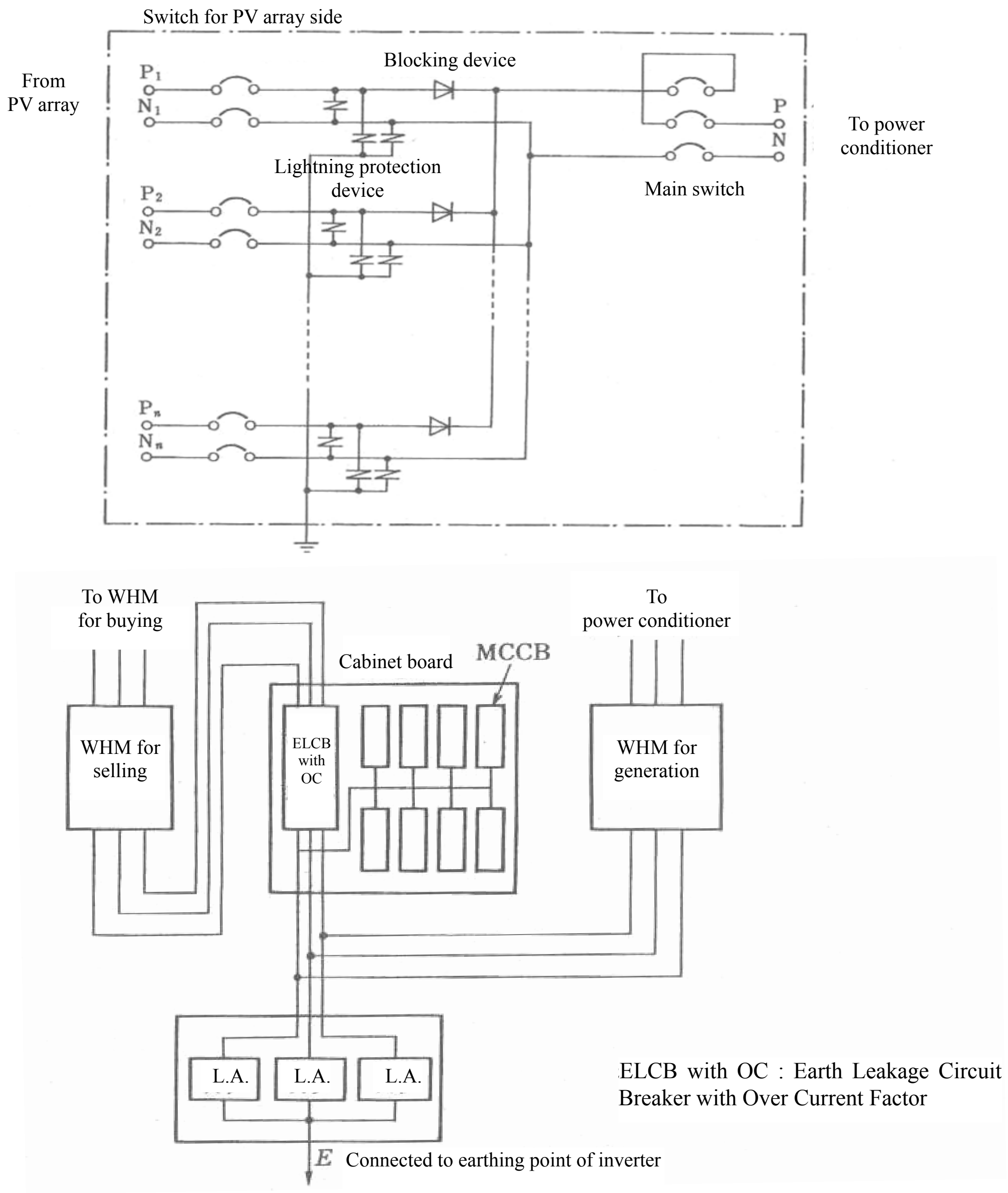
(A) Junction box

Properties / Model	Max. allowable voltage [V] (AC)	Rated voltage [V]	Nominal discharge current [A] (8/20 μs)	Working start voltage [V] ±12%	Discharge voltage [V]		Discharge withstand current rating	
					Discharge current 1,500 A (8/20 μs)	Discharge current 2,500 A (8/20 μs)	Lightning impulse current (8/20 μs)	Rectangle impulse current (2 ms)
GL-L4F	520	450	2,500	1,000	2,000 or less	2,200 or less	20kA Twice	100A 20 times

(B) Distribution board

Properties / Model	Max. allowable voltage [V] (AC)	Rated voltage [V]	Nominal discharge current [A] (8/20 μs)	Working start voltage [V] ±12%	Discharge voltage [V]		Discharge withstand current rating	
					Discharge current 1,500A (8/20 μs)	Discharge current 2,500A (8/20 μs)	Lightning impulse current (8/20 μs)	Rectangle impulse current (2 ms)
GL-L1F	130	110	2,500	250	560 or less	620 or less	20kA Twice	100 A 20 times
GL-L2F	260	220		500	1,000 or less	1,100 or less		

Source: Design and installation work of PV system, Japan Photovoltaic Energy Association (JPEA)



Source: Design and installation work of PV system, Japan Photovoltaic Energy Association (JPEA)

Figure 2-17: Sample installation of lightning arresters at junction box and distribution board

6.5 Selection of surge absorber

① When a surge absorber is built in the junction box, the maximum allowable or rated voltage shown in the manufacturer's specification shall exceed the maximum voltage across the terminals to be protected. In case surge absorbers are installed in the distribution board, the voltage requirements shall meet the rated voltage or one recommended by the manufacturer of distribution boards.

② Assuming that a surge current induced by indirect lightning is 1,000A (8/20 μs), the surge absorber shall be rated at a discharge voltage of 2,000V or less.

③ The discharge withstand current rating shall be at least 4 kA.

④ The surge absorber is required to have structure that makes it easy to remove itself from the main circuit of the PV system.

6.6 Selection of lightning shielding transformer

The arrangement of a lightning shielding transformer on the AC side of the PCS makes it possible to isolate the PV system from the commercial power line perfectly and to cut off a lightning surge almost completely. The lightning shielding transformer shall be installed when the arrester and surge absorber cannot attain perfect protection.

How to select a lightning shielding transformer is described below.

① Determining the primary and secondary voltage as well as the capacity, and selecting a transformer having good electrical characteristics, such as the efficiency and dielectric strength.

② Selecting a transformer that has a high lightning surge damping effect (equipped with more shielding sheets between the primary and secondary sides).

7. Grounding design

The "Japanese Technical Standards for Electrical Facilities" specify that exposed and uncharged part of a PV array, rack mount, junction box, frame for PCS, and metal duct shall be grounded to prevent an electrical shock or fire from occurring due to a ground fault. However, they define that a DC electrical circuit from PV array to PCS shall not be grounded because a ground fault may cause a short circuit.

The grounding methods and resistance values in this subsection are referred to "Technical Standards for Electrical Facilities" and "Internal Wiring Codes" in Japan. Therefore, in other countries, it is necessary to follow codes of practice developed by the authorities concerned or electric power companies.

7.1 Kinds of grounding

Grounding work in Japan is classified into four kinds. Table 2-13 shows grounding resistance values required on a grounding work type basis. Table 2-14 indicates grounding work necessary to steel racks, metal housings, and steel frames used for electrical and mechanical appliances, such as PV arrays and junction boxes.

Table 2-13: Grounding work types and resistance values in Japan

Grounding work type	Grounding resistance value
Class A	10 Ω or less
Class B	Not more than ohmage given by dividing 150* by the amperage of a single-line grounding current flowing through the power line on the high-voltage or extra-high-voltage side of a transformer (less than 5 Ω is not mandatory). *• This value is changed to 300 when the fault current can be disconnected between 1 and 2 seconds. • This value is changed to 600 when the fault current can be disconnected within 1 second.
Class C	10Ω or less (500Ω or less when a breaker is installed in the low-voltage line to disconnect the fault automatically within 0.5 seconds after the line is grounded)
Class D	100Ω or less (500Ω or less when a breaker is installed in the low-voltage line to disconnect the fault automatically within 0.5 seconds after the line is grounded)

Source: Technical Standards for Electrical Facilities, Article 18

Table 2-14: Application of grounding work to appliances in Japan

Classification of appliances	Grounding work
Low-voltage appliance rated at 300V or less	Class D
Low-voltage appliance rated at more than 300V	Class C
High-voltage or extra-high-voltage appliance	Class A

Source: Technical Standards for Electrical Facilities, Article 28

Note that the above does not apply to an appliance that uses a circuit rated at an operation voltage of not more than 300V DC or a voltage of not more than 150V AC to the ground and is installed in a dry place.

The following shows the Japanese classification of voltage shown in the table above.

Table 2-15: Japanese classification of voltage

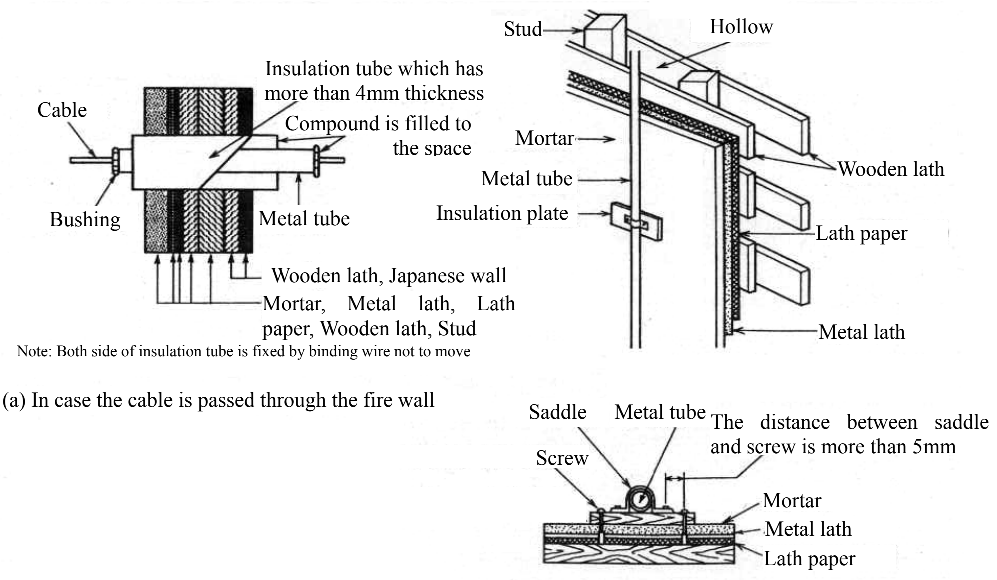
Classification	AC	DC
Low-voltage	Not more than 600V	Not more than 750V
High-voltage	More than 600V to 7,000V	More than 750V up to 7,000V
Extra-high-voltage	More than 7,000V	More than 7,000V

7.2 Design and methodology for grounding work

This subsection describes the Classes A, C, and D grounding work.

① **Grounding wire**

- An earth wire, except the part 60cm long from an appliance to be grounded and the underground part, shall pass through a plastic or metal pipe to prevent itself from being damaged. Class C or D grounding work will be required for the metal pipe when there is no risk of people touching the wire.
- If an earth wire is led in a building from the outside, water-proof works are required to prevent water from coming inside the building through conduits and so on.
- When installing an earth wire along a metal-lath, wire-lath, or metal-plate building material, “Internal Wiring Codes” 3102-8 (Insulation from Metal Lath) shall be referred (see Figure 2-18).
- Copper earth wires used for the Class A or C/D grounding work shall meet the size shown in Table 2-16 or 2-17 respectively.
- An aluminum wire can be used as an earth wire, except when it is laid underground, constitutes a part from a grounding electrode to a point 60 cm above the ground, comes into contact with wet concrete, stone, or brick, or is installed in a place where corrosive gas or solution is emitted. When applied, the size shall meet specifications shown in Tables 2-16 and 2-17.
- If earth wires, except ones installed indoors, are fixed to building materials or others, they shall have dielectric strength equal to or higher than that of Class IV wires. This is because using bare wires have electric shock and fire risks when a ground fault occurs.



(a) In case the cable is passed through the fire wall

(b) In case metal tube is fixed to the mortar wall

Source: Designing and Installing Photovoltaic Power Generation Systems (1st Edition, Figure 6.13), Japan Photovoltaic Energy Association

Figure 2-18: Insulation from metal-lath materials

Table 2-16: Sizes of earth wires for the Class A grounding work

Earth wire for Class A grounding work	Wire type	Wire size	
		Copper	Aluminum
When flexibility is unnecessary		2.6mm or over ($5.5mm^2$ or over)	3.2mm or over
When flexibility is necessary	Class III chloroprene cabtire cable or high-voltage cabtire metal wire for grounding	$8mm^2$ or over	

Source: Internal Wiring Rules JEAC 8001-2005

Table 2-17: Sizes of earth wires for the Class C or D grounding work

Minimum current rating of overcurrent breakers on power supply side of low-voltage line of metal housing of appliance to be grounded	Wire size			
	Normal work		When cabtire cable is used for part requiring flexibility	
	Copper	Aluminum	Single core	One of two cores to be grounded
20A or less	$2mm^2$ or over	2.6mm or over	$1.25mm^2$ or over	$0.75mm^2$ or over
30A or less	$2mm^2$ or over	2.6mm or over	$2mm^2$ or over	$1.25mm^2$ or over
50A or less	$3.5mm^2$ or over	2.6mm or over	$3.5mm^2$ or over	$2mm^2$ or over
100A or less	$5.5mm^2$ or over	3.2mm or over	$5.5mm^2$ or over	$3.5mm^2$ or over
150A or less	$8mm^2$ or over	14mm or over	$8mm^2$ or over	$5.5mm^2$ or over
200A or less	$14mm^2$ or over	22mm or over	$14mm^2$ or over	$5.5mm^2$ or over
400A or less	$22mm^2$ or over	38mm or over	$22mm^2$ or over	$14mm^2$ or over
600A or less	$38mm^2$ or over	60mm or over	$38mm^2$ or over	$22mm^2$ or over
800A or less	$60mm^2$ or over	80mm or over	$50mm^2$ or over	$30mm^2$ or over
1,000A or less	$60mm^2$ or over	100mm or over	$60mm^2$ or over	$30mm^2$ or over
1,200A or less	$100mm^2$ or over	125mm or over	$80mm^2$ or over	$38mm^2$ or over

Source: Internal Wiring Codes JEAC 8001-2005

② **Grounding electrode**

- Grounding electrodes shall be laid under the ground that has high humidity, uniform soil properties, no risk of corrosion by gas or acid, and no other buried metal materials.
- Grounding electrodes shall be securely connected with wire by means of brazing or pressure sleeve crimping.
- The depth of the grounding electrode shall be more than 75cm from the ground surface.
- The following shows types of grounding electrodes we can use.
    - (a) Copper plate: 0.7mm or over in thickness and $900cm^2$ or over in area.
    - (b) Copper or copper-clad steel bar: 8mm or over in diameter and 0.9m or over in length.
    - (c) Galvanized iron gas or steel conduit pipe: 25mm or over in outer diameter and 0.9m or over in length.
    - (d) Galvanized iron bar: 12mm or over in diameter and 0.9m or over in length.
    - (e) Copper-clad steel plate: 1.6mm or over in thickness, 0.9m or over in length, and $250cm^2$ in area.
    - (f) Carbon-clad steel bar: 8mm or over in diameter and 0.9m or over in length.

③ **Others**

- When the electrical resistance between the steel frame of a building and the ground meets the specification shown in Table 2.3.7-1, we can use the frame as an electrode for grounding work.
- When the electric resistance between a metal body subjected to the Class C or D grounding work and the earth does not exceed 10 or 100Ω respectively, and both are securely connected to each other electrically and mechanically, the grounding work is regarded as done.
- An earth wire for lightning rods shall not be attached to any support.
- Grounding electrodes and wire shall be laid at least two meters apart from those for lightning rods.

8. Metering device

Arrangements for metering device are deeply related to the incentive scheme for renewable energy and PV system.

The metering device records the electrical energy consumed by the loads within the property of a consumer. The meter records the number of units of energy consumed and a unit is typically one kWh. The consumer is then billed for this electricity based on the tariff set for each consumer category. In case of a residential consumer single-phase meter is installed, while three-phase meter is usually applied for larger consumers with bigger appliances.

There are many types of meters available. The simplest meter is a mechanical induction meter with a calibrated rotating disk that spins when a certain power is being consumed. A more sophisticated electronics meter can record the time of day that the power is consumed. This type of meter is used when electricity tariffs vary at different times of the day. The type of meter that will be installed with a grid-connected PV system will depend on the conditions of the purchasing agreement with the power company.

The simplest arrangement for metering power generated by PV system is so-called "**Net-metering**" arrangement. Net metering allows for the flow of electricity both to and from a customer's premises through a single, bi-directional meter as shown in Figure 2-19. At times when a customer's power generation exceeds the customer's power consumption, electricity supplied by the customer to the power company causes the meter to spin backwards, offsetting the electricity the customer must purchase from the power company at another time. The net-metering arrangement allows the consumer only to be billed for any insufficient power consumed from the grid. It effectively means that the power company is purchasing the power at the same unit tariff as they are selling to the consumer. Therefore, if the unit price of buying from the power company is different from the unit price selling to, this arrangement cannot work.

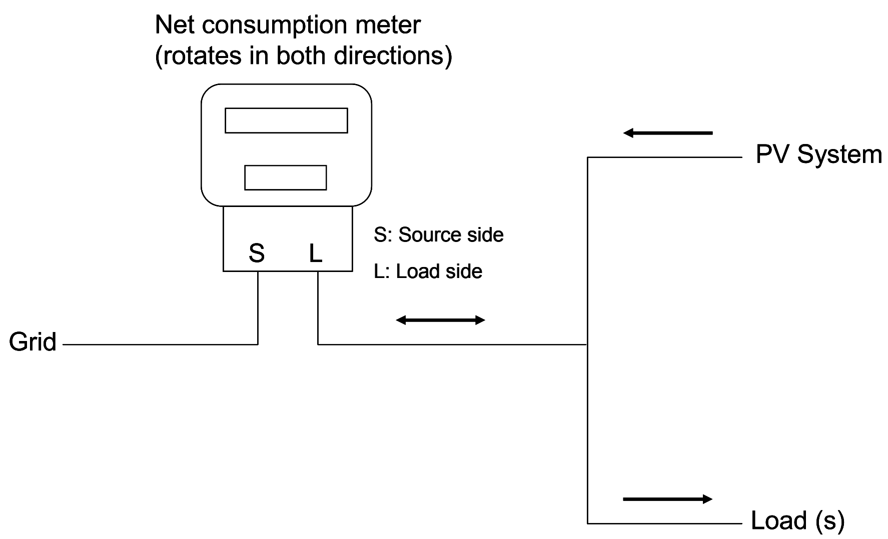


Figure 2-19: Schematic diagram of net metering

If the unit price of electricity for purchasing from and selling to the power company is different, two separate meters to measure both consumption and reverse power flow have to be installed as in Figure 2-20. Note the wiring connection of each meter is different. In this arrangement, each meter can rotate in one direction only. Usually mechanical meters can rotate in both directions, so

preventive function for backwards rotation will be installed for each meter. The export meter will record the amount of power generated by the PV system which is exported to the grid during the day, while the import meter will record the amount of power consumed from the grid.
This arrangement allows the power company to set a different tariff for the power consumed and sold by the consumer. The power company will deduct the amount of bill sold from the amount of bill consumed. This is so called "**Net-billing**".

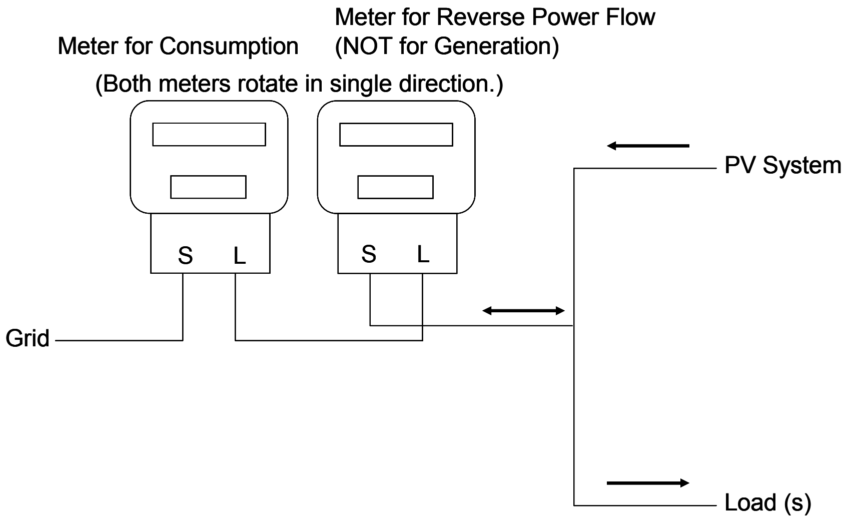


Figure 2-20: Schematic diagram of meters for consumption and reverse power flow

However, with the metering arrangements explained so far, the consumer cannot know the exact amount the PV system has generated and the gross consumption by the load. Those meters cannot measure the power flow which is supplied from the PV system to the loads within the building. If the power company requires one of the metering arrangements as shown above, it is recommended for consumers to install a separate meter (if not included in PCS) which records the exact amount of power generated by the PV system as shown in Figure 2-21. In this arrangement, the exact amount of power generated by the PV system can be measured by the generation meter while the gross consumption is measured by the consumption meter. This will allow analyzing the performance of the PV system and compared with the amount of power generation calculated through theoretical formula.

In this arrangement, it is possible to schedule tariff for net-metering (and net-billing) through deducting the amount of power generated from that consumed. In addition, separate tariffs can be applied for the power generated and consumed. Also this arrangement can be applied for countries where Feed-in tariffs are going to be introduced.

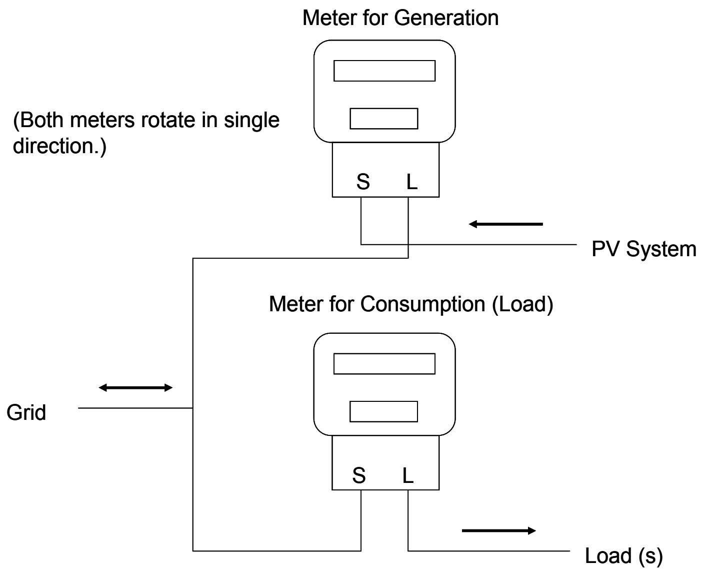


Figure 2-21: Metering arrangement for separate generation and consumption

As shown in Figure 2-20, the Japanese excess power purchase system obliges the consumer to install two watt-hour meters: one is used to measure power purchasing from the electric power company, and the other is used to measure power selling to the electric power company. Note that if installing a grid-connected PV system having a reverse power flow, the conventional watt-hour meter needs to be replaced with a meter which prevents reverse rotation. Moreover, if it is necessary to measure gross power generated by the PV system in accordance with the "Green Power Certificate" trading system independent of the excess power purchase system, the metering arrangement is required as shown in Figure 2-22.

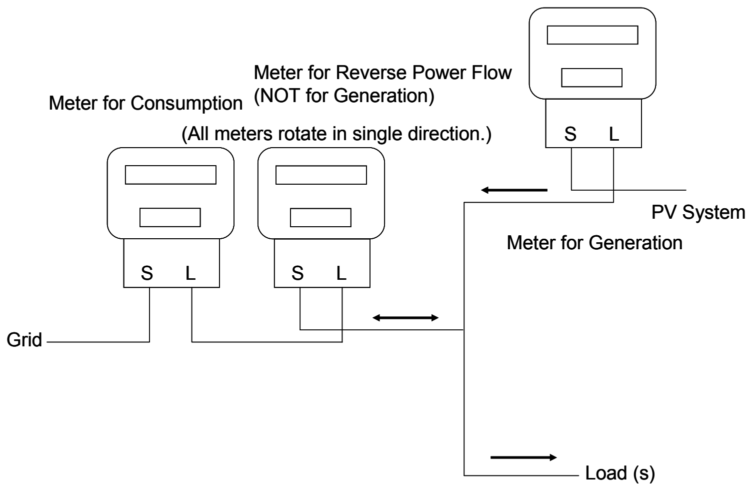
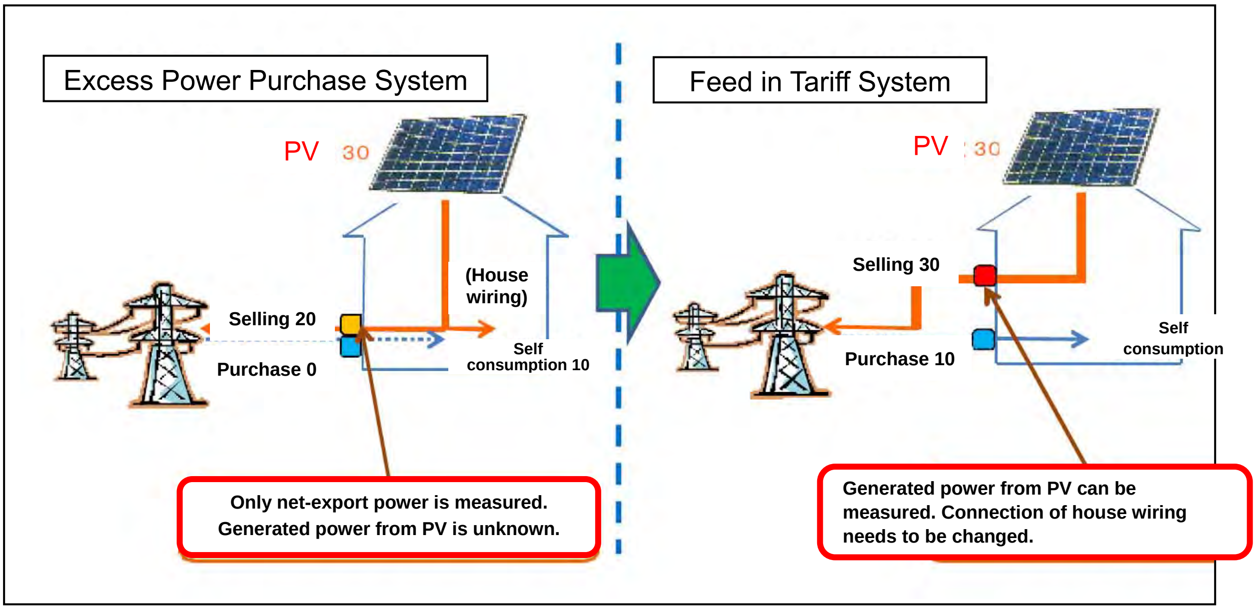


Figure 2-22: Metering arrangement for generation, consumption and reverse power flow

In general, the watt-hour meter for selling to power company shall be installed near to that for purchasing power regardless of the mechanical or electronic type. Note that it is necessary to have prior discussion with the power company to confirm who will pay the costs for installing the watt-hour meters for selling, including the costs for replacing existing meters if necessary.



Source: Whole power purchase system for Renewable Energy (METI)

Fig 2-23 Metering connection for excess power purchase system and Feed in Tariff system

In Japan, the Feed-in Tariff Scheme for Renewable Energy is introduced now, but it uses the different method of connecting the meter and indoor line from that for the excess power purchase system as shown in Figure 2-23. The existing customers will be required to pay vast costs for changing the wiring system, therefore, the excess power purchase system is applied for residential customers.

Figure 2-24: Mechanical watt-hour meter (left), and Electronics watt-hour meter (right)

9. Balance of system selection

9.1Power Conditioning System (inverter)

For the selection, it is necessary to check output capacity, PV array's output voltage and DC output voltage range. Also, it requires to make sure whether the voltage and the electrical mode are match with the grid power side (utility power side), and check a protection device, power quality (voltage, frequency, power factor), and supply stability (less noise occurrence, less high frequency wave occurrence, stability of start and stop operation) and so forth. (It requires to check with a manufacturer about installation requirements.)

① **Requirements for the installation place**

- The installation place shall ensure easy construction, maintenance, and inspection.
- It needs to keep a necessary space to avoid the increasing temperature generated by PCS and other equipments.
- It should avoid these places for installation under a dusty, dew condensation, corrosive gas environment.

② **Precautions to carry-in and installing work**

- The size and weight vary depending on the rated capacity, hence the consideration of lifting devices including a crane preparation is required for the large-scale PCS.
- Since the PCS for industrial use (100 to 700kg) is a self-standing type and a large-scale, delivery, unloading and installation methods (tied by foundation bolts, anchor bolts) should be considered.
- The self-standing PCS requires the consideration of leveling work (horizontal adjustment) and arrangements for neighboring equipment.
- In the case of indoor installation type, the acceptable noise level is between 35 to 40db. Hence the consideration of installation place is required if the noise is bothered.

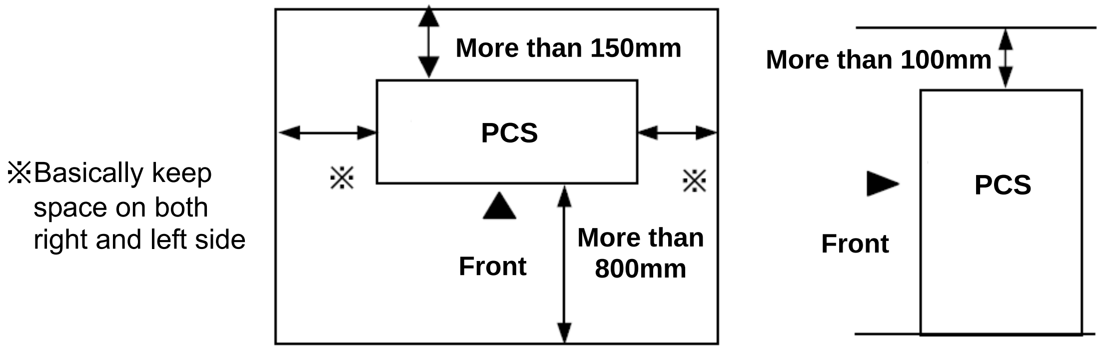


Figure 2-25　Sample of installation space of stand-alone type PCS
（Source：NEDO "Guidebook for an installation of a PV powergeneration"

＊This is just an example. Installation space varies depending on the model, so please follow the manufacturer's instruction.

③ Function

A power conditioning system performs to convert DC into AC, and further controls frequency, voltage, current, phase, real power and reactive power, synchronization, output quality (voltage fluctuation, harmonic), as following functions:

■Automatic start / stop:

the function performs start and stop operations automatically within the range of retrieving the output from PV module effectively as much as possible according to the solar irradiance condition from sunrise to sunset.

■Maximum Power Point Tracking:

the function responds and controls the output voltage and current fluctuation due to the change of the PV module's temperature and solar irradiance to get the maximum output power from PV modules by the operating point of a PV module always tracks the maximum output point.

■Islanding operation detection:

Since output voltage of inverter does not fluctuate if the output power of load power is the same as the output power of inverter at the time of the power failure by the grid side, it is difficult to detect power failure. Hence, electricity may still supplies from the system to the grid side. This is called islanding operation. In this case, electricity flow into the distribution line that supposed to be failure, and it is very dangerous for the security inspectors, islanding operation detective function is installed.

■Automatic adjustment of voltage:

When operating reverse power flow (flow to the grid) of excess power, the voltage at the receiving point goes up due to the reverse power flow, and it may exceed the operating range of the grid. Therefore, in order to keep proper voltage of the grid, it is operated to protect from voltage rise automatically.

■Parallel off / stop when abnormal event occurs:

When abnormal event occurs in the inverter or the grid side, parallel off or the stop operation of inverter is performed safely upon receiving the error detection.

For the inverter selection, it should determine in consideration of maximum output (system capacity), output voltage, with or without storage battery, necessary functions and so forth. Hence, capacity of inverter that matches with a system capacity is required. In addition, it is necessary to match the range of output voltage (DC) with a range of DC input voltage. If having a storage battery, it is necessary to match with voltage of PV module, voltage of a storage battery and DC input voltage of the inverter.

④ **Protection facilities with grid-connected operation**

In a PV power system that is operating under the grid-interconnection, when abnormal event occurs to the grid side or inverter side, the problem should be detected, the inverter should be stop operation promptly, and the safety of the grid side must be ensured. Therefore, installation of the grid-connected protective equipment (or with the equivalent circuit) is obligated in the Official Interpretation of Technical Requirement of Electric Facilities and the Grid-interconnection Technical Requirement Guidelines on Quality of Electricity in Japan. Generally, the grid-connected protective equipment is in the PCS

In the low-tension interconnection system with reverse power flow, over voltage relay (OVR), under voltage relay (UVR), over frequency relay (OFR), under frequency relay (UFR) are necessary to install. In the high-tension interconnection, over voltage ground relay (OVGR) is necessary to install. The installation place of the protection relay for the high-tension interconnection, practically the output point of the power conditioner is fine, except over voltage ground relay. Table ○○ shows the standard setting value and the settling time of the protection relay. The over voltage ground relay requires detecting the ground fault (mainly fault contact by high and low voltage) of the high power system, hence capacitor voltage transformer (CVT) requires installing to the high voltage side.

It requires having a prior consultation with a utility company about protection facilities with grid-connected operation, so it should have a sufficient discussion before selection.

Table 2-18 Setting value samples of protection relays

Type	Setting value	Setting time	Fail-safe action
1. UVR	80V(160V)	1	Shutdown of grid-connection, standby
2.OVR	115V(230V)	1	Shutdown of grid-connection, standby
3. UFR	48.5Hz/59.0Hz	1	Shutdown of grid-connection, standby
4. OFR	51.0Hz/61.0Hz	1	Shutdown of grid-connection, standby
5. Recovery timer	150sec/300sec		Keeping a standby status after recovery from the power failure

〔Remarks〕Setting values in the brackets are for 200V.

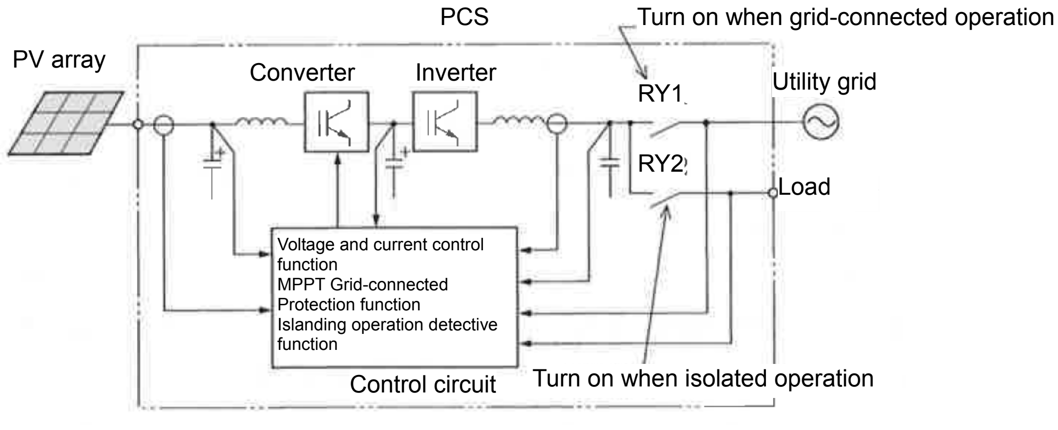


Figure 2-26 Configuration of PCS without transformer

(Source: Japan Photovoltaic Energy Association "A design and construction of a PV power generation system")

9.2 Junction Box

In order to collect the output of multiple PV modules into an electric circuit, separate the electric circuit from the grid to make inspection work easy during maintenance and inspection, and also minimize the stop operation area when the failure occurs on a PV array, it is important to install a junction box to the place where maintenance and inspection are easy.

① **Requirements for the junction box specification**

- Check number of switches on the PV array side
- Check if lightning arrester and blocking diode are set
- Check a wiring connection method (shape of terminals, type, etc.)
- Check the case size, for outdoor or indoor, material, waterproof, paint and so forth.

② **Precautions to installing work**

- Check the installation place that inspection and maintenance can be performed easily.
- For indoor installation, it should be aware that many cables are brought in an indoor.
- When the installing, a junction box should be fixed by screws and bolts referring to the product instruction manual.

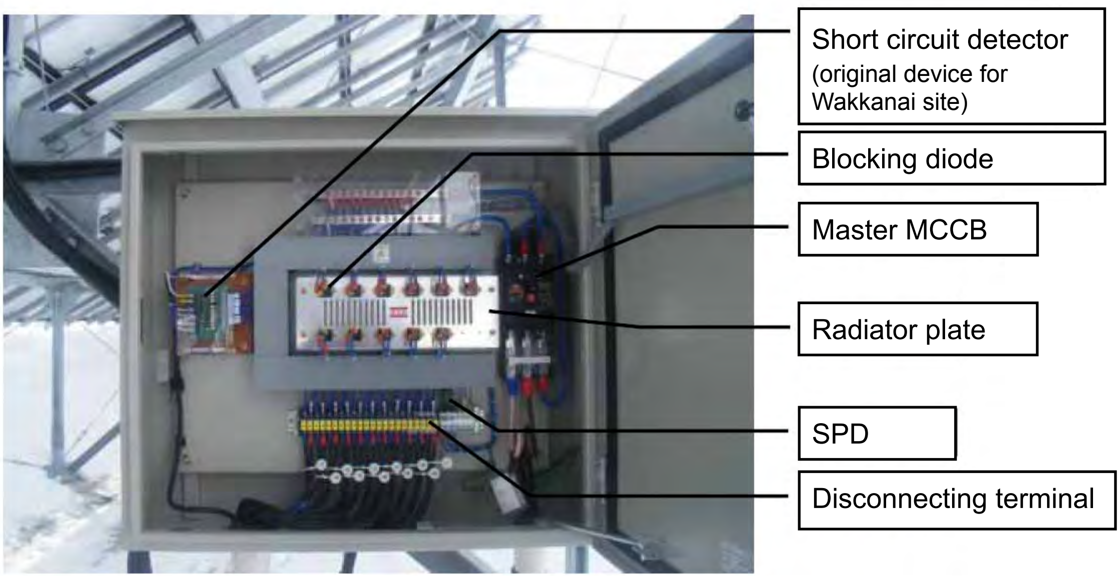


Figure 2-27 Junction box
(Source: NEDO “the manual for installation of a large-scale PV power generation system”)

9.3Supervisory control system

In a large-scale PV power plant, usually 24-hour supervising is not conducted that is different from thermal and nuclear power plants. Regarding the classification of supervisory control system, there is no clear description for the large-scale PV power generation. Therefore, it is commonly apply the definition of supervisory control system in a hydro power plant that is specified in “the power generation and transformation code” at present. (refer to Table 2-19). The explanation of the power plant facilities that 24-hour supervising is not conducted, is in the “Interpretation of technical standards for electrical equipment”

Table 2-19 Definition of supervisory control systems (in a hydro power plant)

Classification	Type	Definition
Continuous supervising at a power plant	Continuous supervisory control system by a technician on-site	Technicians are in the power plant or in the same premises for 24-hour to perform surveillance of the power plant and operation of equipment on-site.
Not supervising continuously in a power plant	Remote supervisory control system	Technicians are in the control station all the time to perform surveillance of the power plant and operation of equipment from the control station.
	Occasional supervisory control system	In the power plant equipped with an automatic load regulation equipment or automatic load limiting device, technicians are either in the power plant or in the engineer station outside of the power station all the time, and go to the power plant as needed to perform surveillance of the power plant and operation of equipment in the power plant, or go to the control station from the engineer station as needed to perform surveillance of the power plant and operation of equipment from the control station.
	Occasional patrol system	In the power plant equipped with an automatic load regulation equipment or automatic load limiting device, a technician goes to the power plant at some interval to perform surveillance of the power plant and operation of equipment in the power plant.

Since it needs to contact a utility company when the failure occurs in the grid side and a power plant side, it is necessary to discuss with a utility company about the communication structure and a means of contact.

10. Consideration of interconnection point

Negotiation on grid-connection is a plan and a discussion in order to convert the electricity from PV system into specified voltage and frequency to connect the utility power.

In a wiring plan on the basic design stage, it is necessary to study on the connection point and the protection relay. Discussion is not needed on this stage. Also, when connecting to the existing building, it is necessary to obtain a completion drawing, and estimate the classification of power supply connected, also check if the drawing suits the current condition by the site survey and the verification with the existing building.

When the connection point is at the commercial power, it is necessary to study on the grid-interconnection by a utility company. In this case, it needs to submit the application for PV power system installation as well as necessary documents for the consideration of grid-interconnection. The connection point should be near the utility company's existing transmission and distribution lines in principal, it will be finalized by the utility company after checking the request from a PV power producer. In principal, the system access facility from PV power system to the connection point is built by a PV power producer; the distance to the connection point should plan to be the shortest route.

11. Estimation of PV power generation

11.1 Calculation of power generation

In case of an off-grid PV system, the capacity of PV array can be calculated based on the power consumption by necessary loads. However, a grid-connected PV system has no correlation between its generation capacity and load. Therefore, the system capacity is determined according to the installation site (area) in many cases. Accordingly, we shall make a careful survey of the installation area of the PV array, then find the array capacity, and finally design the whole system.

Expected annual energy Ep can be represented by the following equation:

$$Ep = \Sigma\, H_A / Gs \cdot K \cdot P_{AS}$$

where Ep = Expected annual energy (kWh/year)

H_A = Average daily irradiation on monthly basis (kWh/m^2/day)

Gs = Irradiance under standard condition = 1 (kW/m^2)

K = Total design factor (= Kd × Kt × η_{INV})

*DC correction factor Kd:

Corrects change in solar irradiance due to stains on PV cell surface and characteristic difference in PV cell. Kd is about 0.9.

*Temperature correction factor Kt:

Corrects temperature rise of PV cell and change in conversion efficiency due to sunlight. Kt is about 0.85.

$$Kt = 1 + \alpha(Tm - 25) / 100$$

where

α: Temperature coefficient at max. output (= -0.5%/°C for crystal)

Tm: Module temperature (ºC) = Tav + ΔT

Tav: Monthly mean temperature (ºC)

ΔT: Module's temperature rise (ºC)

Rack-mount type	18.4
Roof-mount type	21.5
Roof integration type	28.0

* PCS efficiency η_{INV}:

AC/DC conversion efficiency of inverter. η_{INV} is about 0.92.

• P_{AS} = PV array output under standard condition (kW)

Standard condition:

AM = 1.5*; Irradiance = 1 kW/m^2; PC cell temperature = 25ºC

*AM (Air Mass):

Ratio of distance that sunlight passes through atmosphere at certain angle to distance that sunlight goes through standard air vertically (at a standard atmospheric pressure of 1,013 hPa).

Note that Σ means the total of expected energy found on a monthly basis.

The equation above shows that we can estimate the annual electric energy if knowing the irradiation H_A at the installation site, the output power P_{AS} of the standard PV array, and the total design factor K.

The conversion efficiency of a PV array under the standard test condition is represented by the following equation, where A is the area of the array.

$$\eta_S = P_{AS} /(G_S \times A) \times 100\ (\%)$$

The conversion efficiency of a PV cell or module is also given by the same equation. They are simply called the conversion efficiency in many cases, so it is necessary to distinguish them. In general, these conversion efficiencies have the following relationship:

(η of PV cell) > (η of PV module) > (η of PV array)

11.2 Sample calculation of power generation

In this subsection, we find the electric energy when installing a PV array on flat land. The specifications are shown below.

① Output power of standard PV array: 100 kW
② PV array's tilt angle: 30°
③ Installation azimuth: 0°
④ DC correction factor Kd: 0.9
⑤ Temperature coefficient at maximum output α: –0.5 (%/ºC)
⑥ Module's temperature rise ΔT: 18.4ºC
⑦ Inverter efficiency η_{INV}: 0.92
⑧ Monthly mean daily irradiation at tilt angle of 30º: See the following table
⑨ Monthly mean temperature: See the following table

Monthly irradiation and mean temperature

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Irradiation (H_A) [$kWh/m^2/day$]	3.04	3.26	3.42	3.58	3.73	3.23	3.61	3.79	3.02	2.60	2.80	2.79
Temperature (Tav) [°C]	5.2	5.6	8.5	14.1	18.6	21.7	25.2	27.1	23.2	17.6	12.6	7.9

For example, the electric energy in January is given as follows:

$$
\begin{aligned}
Ep &= \Sigma H_A / Gs \times K \times P_{AS} \\
&= \Sigma H_A / Gs \times Kd \times (1 + \alpha(Tav + \Delta T - 25) / 100) \times \eta_{INV} \times P_{AS} \\
&= 31 \times 3.04 / 1 \times 0.9 \times (1 - 0.5(5.2 + 18.4 - 25) / 100) \times 0.92 \times 100 \\
&= 7{,}858 \text{ kWh/month}
\end{aligned}
$$

Month-by-month calculations with the same equation give the following annual generated energy.

Annual generated energy

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Monthly generated energy [kWh]	7,858	7,596	8,695	8,559	9,000	7,418	8,404	8,731	6,879	6,307	6,747	7,115	93,308

11.3 Utilization of simulation software to calculate power generation

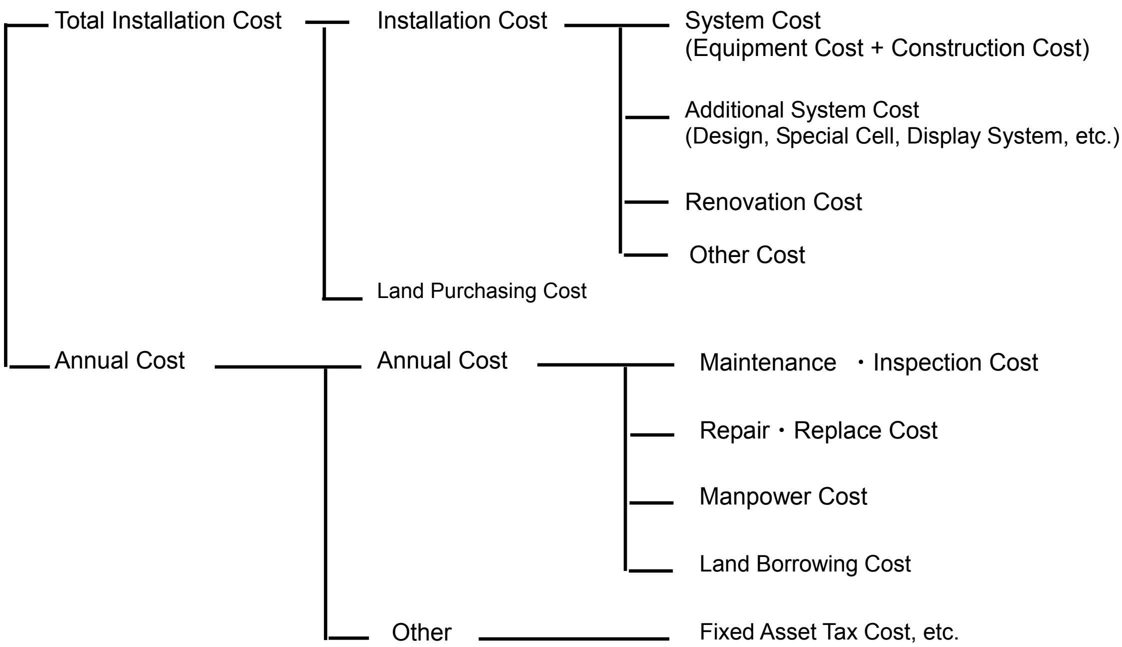
The electric energy generated can be given by the equation above. In addition, using simulation software, such as RETScreen (http://www.retscreen.net/) introduced in the chapter 7 – the method of system planning (PV system for residential use), makes it easy. It computes monthly electric energy, CO_2 emissions, and financial analysis when using this simulation software on a planning for mega solar system, so the feasibility study can be easily conducted. The software allows the user to select a variety of analysis types ranging from simple simulations to the in-depth analyses of costs, CO_2 emissions, financial data, and risk analysis to meet a wide range of requirements.

12. Cost estimation

Costs necessary for a grid-connected PV system are classified roughly into two kinds: "total installation expenses" and "annual expenses." The former is further classified into two types: "installation costs" and "land purchasing costs." The installation costs consist of "system expenses," "additional system expenses," and "renovation expenses." "Equipment costs" and "construction costs" are included in the system expenses.

The annual expenses include not only "maintenance and inspection costs" and "repair and replacement costs" but also "personnel costs" if additional employment is necessary to maintenance and inspection.

The following shows the diagram of these costs necessary to the PV system.



(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 2-28 Cost breakdown of grid-connected PV system

The PV system requires no fuel cost and doesn't include high-temperature or high-voltage equipment as well as high-speed rotating part. Therefore, the annual expenses tend to be lower than those for other power generation systems. However, if batteries are used as a backup unit or for a disaster-proof system, it is necessary to replace them once every seven to nine years. Accordingly, the replacement costs shall be estimated and included in the annual cost. Note also that necessary expenses for disposing and recycling of the batteries shall be investigated and included in the annual cost.

13. Financial evaluation

How to investigate the cost effectiveness of a grid-connected PV system varies depending on the following two cases: one is the case that an existing entity introduces the system, and the other is the case that a newly established company begins a power generation business by the PV system.

13.1 Introduction of PV system by an existing entity

When an existing company introduces a PV system, we apply incremental financial analysis to derive returns obtained as a result of it. Necessary expenses include costs for installing the system and annual costs associated with the system, but the cost for the existing equipment shall be excluded. Benefits given by the project include an income resulting from the introduction of the system except the existing equipment. Accordingly, finding the costs shown in the previous subsection makes it possible to evaluate the cost effectiveness. Note that if the time that it takes to introduce the system is long, we shall take account of the time value over the period.

Table 2-20 shows information necessary to the financial analysis of the project.

Table 2-20 Information necessary to judge the cost effectiveness of the Project

Item		Example	Remarks
Construction	Construction cost	US$XXX	
	Land price	US$XXX	
	Construction period	X years	
	Investment spending rate	XX%, XX%	Ex.: Civil engineering work (1st year) + Equipment installing work (2nd year)
Operation	Operation period	XX years	
	Unit price of energy to be sold	US$XXX/kWh	
	Annual energy to be sold	XXX kWh/year	Attention to the annual irradiation
	Annual expenditure	XXX US$/year	

(Source: Shikoku Electric Power Company)

Next, we create a cash flow based on the information above, find the project internal rate of return (PIRR) and pay-back period according to the cash flow, and evaluate the cost effectiveness from the viewpoint of Table 2-21. The PIRR is an index for evaluating the profitability of a project itself and a cut rate at which the net present value of the project is zero.

Table 2-21: Criteria for evaluating the cost effectiveness

Item	Example	Judgment criteria
PIRR	XX %	• Does the project satisfy action criteria? • Do returns correspond to risks?
Pay-back period	XX years	• Is the project below an expected level?

(Source: Shikoku Electric Power Company)

When various conditions change, in many cases, we conduct sensitivity analysis to check how the judgment criteria vary and to review the allowable variation range of introducing the system.

The following shows an example of the sensitivity analysis. In a certain project whose PIRR is 10.8%, the example indicates how the rate varies when the electric charge and power station construction cost have a 10% variation. Assuming that the threshold of the judgment criterion is 10%, the project feasible range is represented by yellow cells in Table 2-22.

Table 2-22: Relationship between the construction costs and electricity tariff in a feasible power station

Electricity tariff

Power station construction cost	10.8%	90%	92%	94%	96%	98%	100%	102%	104%	106%	108%	110%
	110%	7.9%	8.2%	8.5%	8.8%	9.1%	9.4%	9.8%	10.1%	10.4%	10.7%	11.1%
	108%	8.1%	8.4%	8.7%	9.0%	9.3%	9.7%	10.0%	10.3%	10.7%	11.0%	11.4%
	106%	8.3%	8.6%	8.9%	9.3%	9.6%	9.9%	10.3%	10.6%	11.0%	11.4%	11.7%
	104%	8.5%	8.8%	9.2%	9.5%	9.9%	10.2%	10.6%	11.0%	11.3%	11.7%	12.1%
	102%	8.7%	9.1%	9.4%	9.8%	10.2%	10.5%	10.9%	11.3%	11.7%	12.1%	12.4%
	100%	8.8%	9.2%	9.6%	10.0%	10.4%	10.8%	11.2%	11.6%	12.0%	12.4%	12.8%
	98%	8.9%	9.4%	9.8%	10.2%	10.6%	11.0%	11.4%	11.9%	12.3%	12.7%	13.1%
	96%	9.1%	9.5%	9.9%	10.4%	10.8%	11.2%	11.7%	12.1%	12.5%	12.9%	13.3%
	94%	9.1%	9.6%	10.1%	10.5%	11.0%	11.4%	11.9%	12.3%	12.7%	13.2%	13.6%
	92%	9.2%	9.7%	10.2%	10.6%	11.1%	11.6%	12.0%	12.5%	12.9%	13.4%	13.8%
	90%	9.3%	9.8%	10.3%	10.8%	11.2%	11.7%	12.2%	12.7%	13.1%	13.6%	14.0%

(Source: Shikoku Electric Power Company)

13.2 Introduction of PV system for commercial power generation by a new entity

If a company newly established offers a power generation business with the PV system, it is necessary to check the sound management and operation of the entity itself. Particularly, if the entity relies on project finance to collect money, work for evaluating the cost effectiveness increases.

To put it more concretely, following information as shown in Table 2-23 will be required.

Table 2-23: Data necessary to a survey of the cost effectiveness
(based on project finance)

Item		Example	Remarks
Construction	Construction cost	US$XXX	
	Land price	US$XXX	
	Construction period	X years	
	Investment spending rate	XX%, XX%	Ex.:Civil engineering work (1st year) + Equipment installing work (2nd year)
Operation	Operation period	X years	
	Unit price of energy to be sold	US$XXX/kWh	
	Annual energy to be sold	XXX kWh/year	Attention to the annual irradiation
	Annual expenditure	XXX US$/year	
Finance	Financing ratio	XX%	Necessity of talks with banks
	Interest rate	XX%	Necessity of talks with banks
	Financing Period	X years	Necessity of talks with banks
	Paying method	Interest or level	Necessity of talks with banks
Depreciation	Depreciating method	Fixed amount or percentage	
	Depreciating Period	X years	Required legally
	Residual value	XX%	Required legally

(Source: Shikoku Electric Power Company)

Next, financial documents shall be created such as balance sheet, profit and loss statement, and cash flow statement based on the information above. Then the equity IRR and pay-back period will be derived according to the cash flow, in order to evaluate the cost effectiveness from the viewpoint of Table 2-24. The equity IRR is the ratio of profits throughout the business period to equity capital, which corresponds to a cut rate at which the present value of money invested by the entity is equal to that of dividends. Note that we also need to check the financial statements to judge the sound management of the entity (e.g. whether debts are excess or whether deficit operation continues).

Table 2-24 Criteria for evaluating the cost effectiveness

Item	Example	Criteria
Equity IRR	XX%	• Does the project satisfy investment criteria? • Do returns correspond to risks?
Pay-back period	XX years	• Is the project below an expected level?

(Source: Shikoku Electric Power Company)

Finally, we conduct sensitivity analysis as shown in the previous subsection 1).

14. Preparation of a basic specification

14.1 Preparation of a basic specification (draft).

Prepare a draft basic specification based on a basic plan and a system design.

The items and the entry examples to specify in the draft basic specification are shown as follows:

① **PV cell**

（ i ） Output of PV cell (kW)

Output (scale) of PV cell should be specified. Which portion of output to define as the output of the PV cell is important.

e.g. It should be more than 00kW. However, the output capacity figure should be at the output terminal of PCS.

（ ii ） Installation area

It should be specified possible PV system installation area. The installation area should be in consideration of sufficient space for maintenance and the shadow impact by a front PV array.

e.g. It should be○○m^2 or small.

（iii） PV module performance

Each condition relevant to the performance of PV module should be specified.

Example: The PV module shall have the performances based on each following standard.

＜Crystalline PV cell＞

A crystalline PV cell is examined by the method stipulated in JIS C 8917 “Environmental and durability testing methods of crystalline PV cell” and satisfied with the performance stipulated in JIS C 8918 “Crystalline PV module”.

＜Amorphous PV cell＞

An amorphous PV cell is examined by the method stipulated in JIS C 8938 “Environmental and durability testing methods of amorphous PV cell” and satisfied with the performance stipulated in JIS C 8939 “Amorphous PV module”.

＜Other PV cells＞

The items that are not described in this specification, shall comply with the following standard, specification and so forth.

・JIS C 8918「Crystalline PV module」
・JIS C 8939「Amorphous PV module」
・JIS C 8917「Environmental and durability testing methods of crystalline PV cell」
・JIS C 8938「Environmental and durability testing methods of amorphous PV cell」
・IEC61215Ed.2「Compliance test standard of crystalline silicon PV module performance」
・IEC61646Ed.2「Compliance test standard of thin film PV module performance」
・IEC61730-1Ed.1「Conformity approval for safety PV cell: requirements for the structure」
・IEC61730-2Ed.1「Conformity approval for safety PV cell: requirements for the test」

Even if there is no statement in this specification, but requires to fulfill as a completed product, it should be included in this specification.

（iv） Annual energy production

The conditions such as estimation of annual PV energy production and so forth are described, and also it specifies submitting the estimation result of the annual PV energy production. It is necessary to check that the estimation result of the annual PV energy production is the same result of the one that was made at the time of system design.

e.g. The annual energy production by PV module is calculated based on following conditions, and submit it when submitting the quotation. ・Annual average figure on Kume Island Okinawa by METPV-3 is used as the solar radiation condition. ・Installation angle of PV module is at 5 degrees. ・The azimuth is designated separately. ・Loss by DC wiring should be 2% and below. ・The generated energy is given by the voltage at the DC terminal of PCS times the current at the DC terminal of PCS. ・The following loss factors stipulated in JIS C 8907 "Estimation method of generating electric energy by PV power system" is at 1.0: "Solar irradiation annual variation correction factor", "PV array circuit correction factor", "PV array load matching correction factor" ・Aged deterioration correction factor stipulated in JIS C 8907 "Estimation method of generating electric energy by PV power system" is at 0.95. However, if seasonal variation of output characteristics is identified, specifies the value to use.

（v） Power generating cost

Calculate power cost using the estimation result of energy production and the system estimation cost in the system design, then required power cost is specified.

e.g. The power cost in consideration of useful life-span of ○○ years, shall be at○○yen/kWh and below.

（vi） Conversion efficiency of PV module

The conditions pertaining to PV module conversion efficiency are specified. On the conditions of PV module conversion efficiency, when the conversion efficiency sets at low, many types of PV modules will be applicable.

e.g. Basically, it should be more than 10%. Conversion efficiency should not drop from the following values by aging. ・Characteristics of initial degradation: The maximum output shall not be lower than the output lower limit (90% of nominal value) stipulated in JIS C 8918 "Crystalline PV module". ・Characteristics of long-term degradation: The maximum output, either the nominal maximum output stipulated in JIC C 8918 "Crystalline PV module" or the output value at the time of shipment from the factory whichever is lower, shall be at -10%/ten years.

（vii） Azimuth and tilt angle

The conditions pertaining to the azimuth and the tilt angle of PV array are specified. Since the azimuth and the tilt angle of PV array significantly affect on the energy production depending on the conditions, these are the key points. Also, it is necessary to determine the tilt angle in consideration of sliding down of the snow in the snowy region.

e.g. The installation azimuth angle shall be at zero degree due south as much as possible. However, up to±45 degrees are allowable. The installation tilt angle is fixed at ○○degrees.

（viii） Insulation characteristic

The conditions relating to insulation characteristic are specified.

e.g. Insulation resistance: Measure the insulation resistance by an insulation-resistance meter (rated measured voltage at 500V) and it should be more than 50MΩ. However, the rated measured voltage of the insulation-resistance meter is at 1,000V, it should be more than 100MΩ.

② **Power conditioner(PV-PCS)**

（ i ） Number of unit installation

The conditions relating to number of PCS installation are specified. It is necessary to determine in consideration of risk diversification due to capacity factor drop when the PCS failure, and the maintenance cost after installation.

e.g. It will be necessary number of unit. Approximately it will be ○○ units if it's between ○○kW to ○○kW.

（ ii ） Rated capacity

The conditions of the rated capacity are specified. Actually, number of installation unit is determined by the rated capacity.

e.g. Rated capacity is between ○○kW to ○○kW, 440V. However, rated voltage can be changed by manufacturer's recommendation.

（iii） Conversion efficiency

The conditions relating to conversion efficiency are specified. Since conversion efficiency affects power production, but the installation cost will be high if conversion efficiency sets high, so it should be noted.

e.g. ○○% and above (30～100％at the time of output)

（iv） Protective function

Necessary protective functions are specified.

e.g. Grid side: overvoltage by the grid, undervoltage by the grid, high frequency by the grid, frequency drop by the grid DC side: overvoltage by DC, overvoltage by short circuit, overcurrent by DC

(v) Islanding operation detection

Detection of islanding operation is specified.

e.g. Implement detective function of islanding operation passively and actively.

③ **Layout**

(i) Shape of PV array

The conditions pertaining to PV array shape are specified. If it is not necessary to limit the conditions, a proposal from a manufacturer can be applied.

e.g. The shape of a PV array shall be the standard shape of a manufacturer, unless it is necessary to partially modify its shape to conform to the land shape.

(ii) PV array height

The condition of PV array height is specified. In the snowy region, the height sets in consideration of the amount of fallen snow. The condition sets also in consideration of maintenance of PV array.

e.g. The height of PV array should be ○○mm from the ground. (excluding the height of the foundation)

(iii) The distance between the east and the west of PV array

The distance between the east and the west of PV array is specified. The distance between the east and the west of PV array needs to take into consideration the maintenance space and the shadow impact by a front PV array.

e.g. It should be the minimum requirement. (○○m and above)

(iv) Reference wind speed

Reference wind speed required for the designing of PV array rack and foundation, is specified. (In Japan, the reference wind speed in each area is stipulated by the Building Standard Law.)

e.g. Reference wind speed is at 46m/s.

(v) Terrain category

The terrain category required to design the PV array rack and the foundation is specified.

e.g. Terrain category is class II.

(vi) Wind load, seismic load

The usage factors of both wind and seismic loads required for the designing of a PV array rack and a foundation, are specified.

e.g. The usage factor for wind load is at 1.32, and the usage factor for seismic load is at 1.5.

(vii) Strength calculation

The usage factors of both wind and seismic loads required for the designing of a PV array rack and a foundation, are specified.

e.g. It requires submitting a strength calculation sheet including PV array, rack and foundation.

（viii） Corrosion protection

Corrosion protection that is considered its necessity from a preliminary environmental survey at the installation site, is specified.

e.g. The bolts and nuts using for the installation should be made from the material with corrosion protection that is a stainless steel or more than equivalent. Also, these are finishing with hot dip galvanizing (equivalent to HDZ55), or equivalent to this.

（ix） Installation plan

Submission of a layout plan, a standard structural drawing and a strength calculation sheet for a PV array is specified.

e.g. Make an installation plan of a PV array, and attach it to an estimate specification together with the standard structural drawing and the strength calculation sheet of a PV array that are used for the installation plan.

④ Lightning protection

（ i ） Equi-potential bonding

The content of the equi-potential bonding pertaining to the lightning protection is specified.

e.g. Grounding that is newly installed in the testing facility (PV power generation system), all the grounding should be the potential equalization, and build a system to reduce a potential difference occurring in the conductor that connects to multiple grounding electrodes in the facility, due to rising earth potential at the time of lightning strike. For the conductor connection, direct conductor or SPD should be used.

（ ii ） Installation of SPD

For the protective measure from indirect lightning stroke, installation of SPD is specified.

e.g. The protection for the testing facility and equipment from indirect lightning stroke, zinc oxide type SPD (JIS C 5381-1)should be installed. The equipment for protection by SPD should include all the equipment that may suffer failure damage by indirect lightning stroke. JIS study data by domestic testing facility should present at delivery.

⑤ **Check list**

When a manufacturer requests for a quotation specification to present, it is necessary to check whether the contents of a quotation specification match with the contents of a purchase specification created by the orderer based on a check list. A sample of check list shows as below.

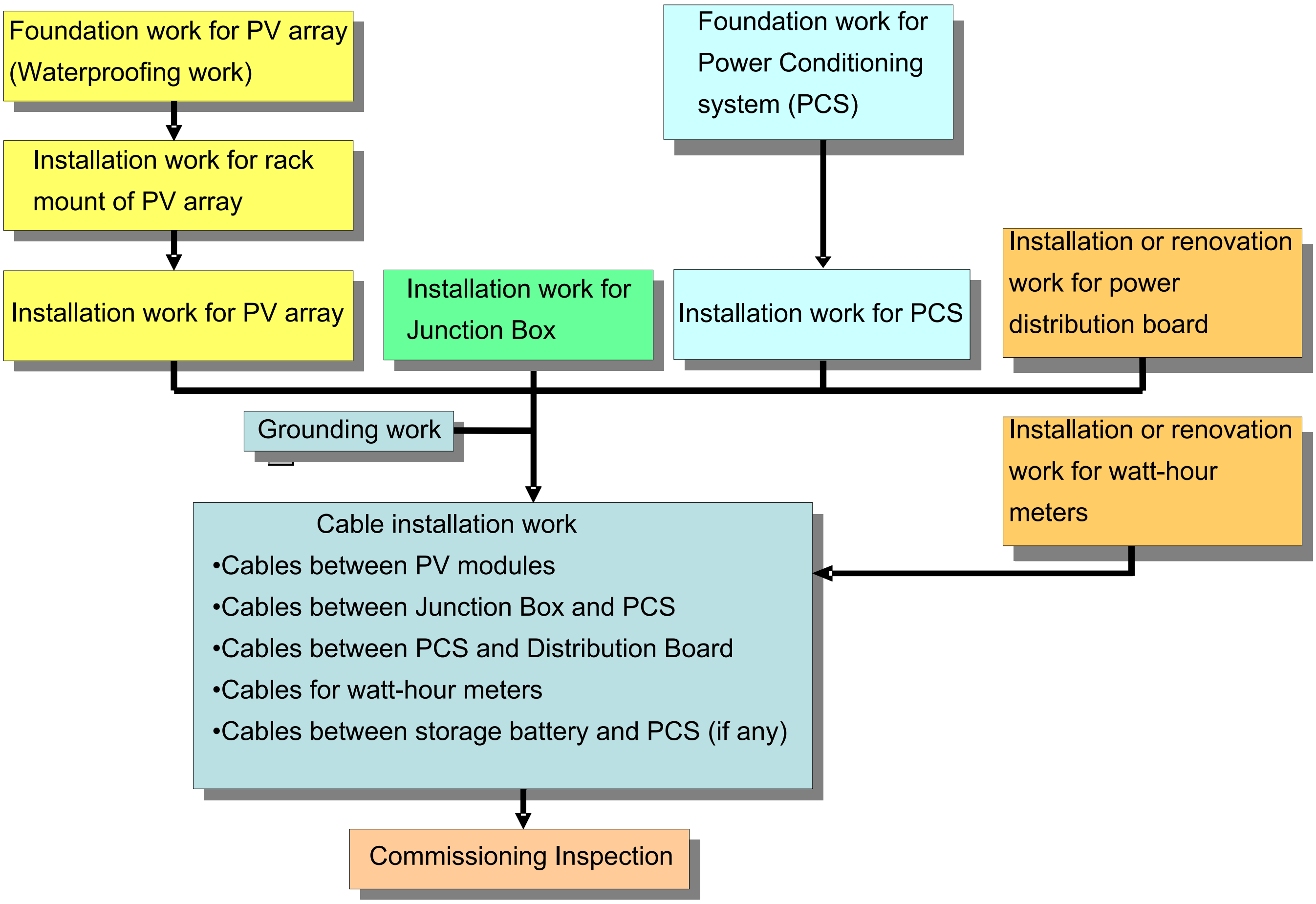
Table 2-25 Check list (sample)

Warranty	□Delivery date specified in the specification is assured?
	□Warranty detail is specified?
	□Warranty period is satisfied with the period and the detail designated in the specification?
Quotation	□Required number of copy of quotation and quotation specification are submitted?
	□Comprehensive construction schedule is attached?
	□Construction plan is attached?
	□Temporary installation plan is attached?
	□Transportation plan is attached?
	□Construction organization chart is attached?
	□Vendors list is attached?
	□Quotation classification is the classification designated by the specification?
General instructions	□Testing and inspection meet the items specified in the specification?
	□Construction contractor meet the requirement?
	□Quality management meet the items specified in the specification?
	□Training is considered?
Construction	□Construction management system and Safety measure are appropriate?
	□Site manager is selected as the person who is expert in the construction?
	□Safety manager is selected as the person who is expert in safety regulation?
	□Environmental conservation is considered?
	□Construction meets the Compliance pertaining to environmental conservation specified in the specification?
PV module	□Output level of PV module is the designated output level?
	□The type of PV module is the same kind?
	□PV module is selected in order to meet the designated specification?
	□Annual energy production is attached?
	□Power cost is attached?
	□Lightning protection is considered?
Foundation	□Foundation design is considered?
PV rack	□Design of PV array rack is considered?
	□Installation direction is a designated one?
	□Reference wind speed and terrain category are as per designation?
	□Salt damage countermeasure is considered?
	□Usage factors of wind load and seismic load are designated values?
	□Is there any description about the submission of strength calculation sheet including PV array, rack, foundation?
	□PV rack is a hot dip galvanizing or paint finish, or equivalent to these?
	□The bolts and nuts using for the installation are made from the material with designated corrosion protection?
PV array	□Installation plan of PV array is attached?
	□Standard structural drawing and strength calculation sheet for a PV array are attached?
Junction Box	□Junction box is the designated specification?
Grounding	□Grounding plan is considered?
PV-PCS	□Conversion efficiency meets the designated value?
	□Lightning protection is considered?
Electric equipment	□Necessary electrical facilities are considered?
	□Lightning protection is considered?
Data collection	□Data meet the measurement item designated in the specification?
	□Data meet the basic specification designated in the specification?

Chapter 3 System Installation and Commissioning

1. Outline procedures for system installation and commissioning

The installation work of a grid-connected PV system consists mainly of six tasks: the foundation and installation work of the PV array, the foundation and installation of the power conditioning system (PCS), the installation work of the junction box, the installation or renovation work of the distribution board and watt-hour meter, cable installation work, and commissioning inspection. In addition, it is necessary to ground the steel racks, metal housings, and metal pipes to avoid a ground fault due to earth leakage. In Japan, necessary safety measures shall be taken in accordance with the Industrial Safety and Health Act and related laws. Unlike a general power generator, the PV cell generates power whenever it is exposed to sunlight, so we shall take special care not to be involved in an electric shock.



(Source: For effective performance of solar photovoltaic system, NEDO (modified by JICA Senior Advisor))

Figure 3-1: Procedures for system installation and commissioning

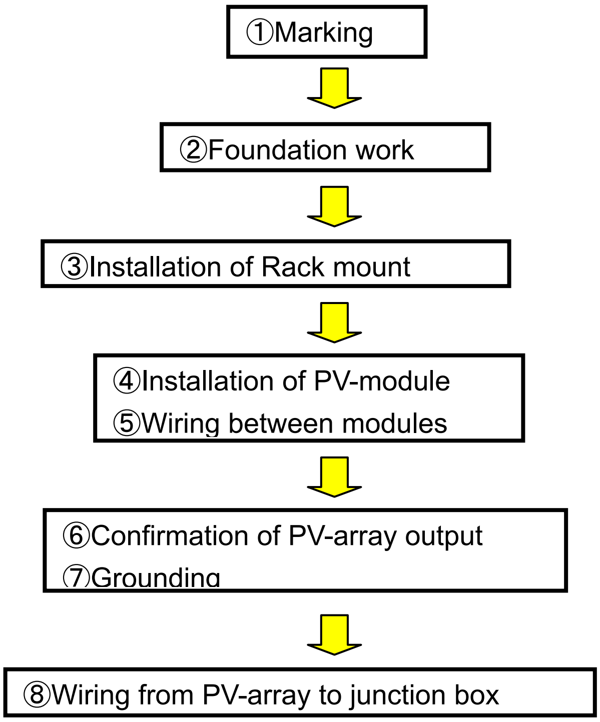
In Japan, the introduction of grid-connected PV systems is recently increasing rapidly. As a result, it is said that there are many low-quality installation works to be avoided. The responsible authority is now trying to introduce a qualification system for certifying that technicians who install PV systems in general houses have learned required skills for installation, maintenance, and inspection methods. In other developed and developing countries, the establishment of similar qualification systems is under way as a measure for increasing number of PV systems introduced.

2. Installation work for PV array

1) Standard procedure for installation work

Figure 3-1 shows detail procedures for installation work of PV array included in Figure 3-2. We assemble the rack on the foundation and then fix the PV modules to the rack with bolts and brackets to constitute the PV array. The carry-in and assembling work of steel frames for the rack requires a protection sheet to prevent them from coming into direct contact with a floor or the ground. In addition, to reduce the risk of theft and vandalism during installation, it is necessary to prepare an appropriate security system at a place where the PV modules are kept temporarily.

As an example, this subsection describes procedures for installing a ground-mounted PV array and precautions for each process.



(Source: Guidance for introduction of PV System, JPEA)

Figure 3-2: Procedures for installation work of PV array

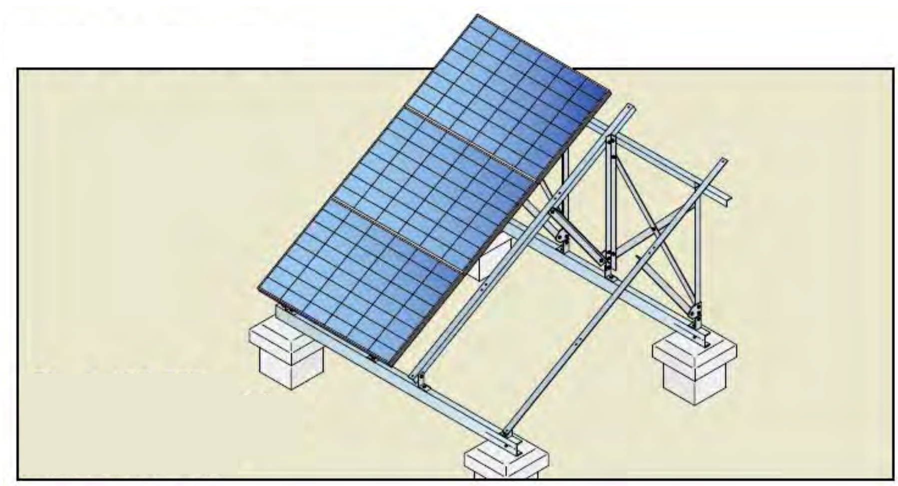


Figure 3-3 Installation of ground-mounted PV array

(i) Marking work

- Conduct marking work according to the design drawings including the layout of racks and modules and the manufacturer's construction manual.
- Note that it may be necessary to adjust the position of anchors at the site because it varies depending on the shapes of the roofing material and frame shape.

(ii) Foundation work

- Check the foundation pitch and shape

(iii) Rack installing work

- Temporarily put and fix racks on the ground according to the layout drawing.
- After the final fixation, check whether each joint is secured.

(iv) PV module installing work

- .Temporarily put and fix PV modules on the rack according to the layout drawing.
- .After the final fixation, check whether each module is fixed securely with bolts and nuts.
- Check the modules by appearance.

(v) Wiring between the PV modules

- .Connect cables while checking the polarities (+/–).
- Take care not to receive an electric shock during wiring.

(vi) Inspecting the PV array output

- .Use a tester to measure the open-circuit voltage of each string of the PV array.
- Check whether the measured voltage does not vary significantly between the strings.

(vii) Grounding work

- .Check where is grounded.
- Follow relevant laws to do grounding work.

(viii) Wiring from the PV array to the junction box

- .Check the wiring route from the PV array to the junction box in advance.

3. Installation works in extreme climate conditions

When installing a PV system in any of the following environments, the special method of assembling the PV modules and members shall be applied. In addition, regular maintenance may be necessary. The following shows precautions to this work.

(i) Heavy snow region

- Checking that the PV module and rack withstand the snow load.
- Mounting the PV module at an angle where snow slides down.
- Elevating the ground-mount or deck-mount type not to be covered with sliding snow.
- Reinforcing the module frame with the rack to prevent it from being broken by sliding snow.
- Checking the PV array for damage, deformation, and loose joints during maintenance work.

(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3.2-4: Installation of PV array in heavy snow area

(ii) Cold region

- Arranging a sufficient number of drip holes and giving an enough slope to the PV module to prevent water from staying around the array.
- Checking the PV array for no damage, deformation, and loose joints during maintenance.

(iii) High-wind region

- Checking that the PV module and rack withstand the wind load.
- Keeping the maintenance work safe (e.g. the installation of a fence).

(iv) Region exposed to salt

- Giving corrosion resistance to materials to be used.
- Taking measures to avoid electrical corrosion between different types of metals.
- Doing regular maintenance including cleaning.
- Checking the PV array for neither erosion nor electrical corrosion during maintenance works.
- Checking the PV module for no degradation in the electrical properties, such as the output power and insulation performance during maintenance works.

Caulking the contact surface between the rack and foundation

4. Installation work for balance of system (BOS)

①Power conditioning system (PCS)

The method of installing the PCS varies depending on the installation sites. The outdoor installation generally requires the concrete foundation of the PCS. Therefore, we need to keep routes for a required piping system for cables and check the installation procedures before the installation work. When using metal racks, it is necessary to prepare rustproof and corrosion-resistant measures, particularly in easy-to-rust bolts and brackets.

Self-standing Indoor Type (10kW)

Wall-hanging Outdoor Type (10kW)

Self-standing Outdoor Type (250kW x 4)

Foundation work for PCS

(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3-5: Installation of power conditioning system (PCS)

The following shows requirements for and precautions to the installation of the main body of the PCS.

○Requirements for the installation place

- The installation place shall ensure easy construction, maintenance, and inspection.
- In the indoor installation, ventilators shall be prepared to avoid increasing temperature in the room.
- No water shall condense and no dust shall be generated in the installation place.
- The PCS shall not be exposed to direct sunlight as a possible extent.
- There is no noise in the installation place.
- In the outdoor installation, it is necessary to take measures to prevent reptiles or insects from entering into the PCS.

○Precautions to carry-in and installing work

- The large-scale (heavy in weight) PCS requires the consideration of delivery and unloading methods because it is necessary to make a request for heavy machines including a crane.
- The self-standing PCS requires the consideration of leveling work (horizontal adjustment) and arrangements to neighboring equipment.
- Attention shall be paid to the surrounding environment, for example noise levels during work.

②Junction box and cable collection box

When installing the junction box, installation sites shall be selected in consideration of as short distance to the PV array as possible, wiring routes to the PCS, and conditions for maintenance. If the PV array is mounted on an inclined rack, it is standard to arrange the junction box on the rear side of the array. This installation has advantages: wiring work is easy because the PV array is near from the junction box, and sunlight little increases the temperature of the junction box because it is shaded by the array. In summary, the junction box shall be installed in such a place easy to access in consideration of operation and maintenance works in case of faults and regular inspections. When installing the PCS with a built-in junction box indoors, wiring routes shall be investigated in advance because the number of lead-in cables increase.

(under the shade of PV array)

(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3-6: Installation of junction box

If the number of circuits supplied from the junction box exceeds that of input ports for PCS, a collection box is necessary. For the collection box, we shall select a place that is located between the junction box and PCS, and that makes maintenance easy. Note that the outdoor installation of the junction and collection boxes, particularly in an area exposed to salty damage, requires the products to have protection levels (e.g. IP: International Protection) suitable to the surrounding environment.

③Circuit breaker

- It is necessary to check the specifications of the main circuit breaker in the existing distribution board (power receiving unit) to determine whether or not to change it.
- New load break switches or circuit breakers dedicated to the PV system shall be installed.

④Watt-hour meter

Selling excess power to the power company requires the installation of new watt-hour meters for sale. In this case, the entity who owns the PV system shall have talks with the power company about the following tasks:

- Replacement of the conventional watt-hour meter (for purchase) with new one which rotates in single direction.
- Who shall pay the replacement cost for the meter.
- Procurement and installation of the watt-hour meter for sale.
- Who shall pay the installation cost for the meter.

⑤Surge protection device

If installation of lightning protection device is required according to the existing regulations in the country, such as building codes and technical standards, the PV array shall be installed in consideration of the distance to the surge protection device and the shield angle. In an area that is often struck by lightning, lightning rods may be voluntarily installed even if there are no requirements by existing regulations.

⑥Storage battery (if any)

The installation of storage batteries requires the following considerations:

○Considerations to the installation place

- The battery shall not be exposed to direct sunlight.
- No water shall be condensed and no dust shall be generated.
- Ventilation connecting to the outside shall be kept.
- The floor of the electric room shall withstand the battery weight.
- The battery system shall have structure so that any battery does not move, fall down, or come off due to seismic vibration.

○Considerations to the operation methods

- A combination of new and old batteries shall be prohibited.
- A combination of batteries having different types or capacities shall be prohibited.
- The batteries shall not be left in an idling state for long hours.
- Care must be taken not to receive an electric shock because the batteries connected have high voltage.

5. Cable installation work

Most of cabling works on general premises are the parallel connection of AC loads. However, in case of a PV system, DC cables are installed between the PV module and the PCS, moreover series and parallel connections are mixed, so cares shall be taken not to connect wrong polarities. Since the PV system is an electrical facility, cable installation works shall be in accordance with regulations in the country. This subsection describes requirements for wiring the components.

① **Between the PV modules**

- We connect cables between the PV modules in parallel with the installation work of PV modules. In general, the cables are left exposed rather than pass through pipes or ducts. Dedicated metal ware shall be fixed to the rack and tie the cable to it. Cable ties shall be resistant to UV and water.
- The number of cables is equal to that of PV modules in series, so labeling a series number on each cable is helpful to maintenance works.
- Normally each cable is connected through the connector attached to PV module, which ensures level of quality works.

Storage of excess cable

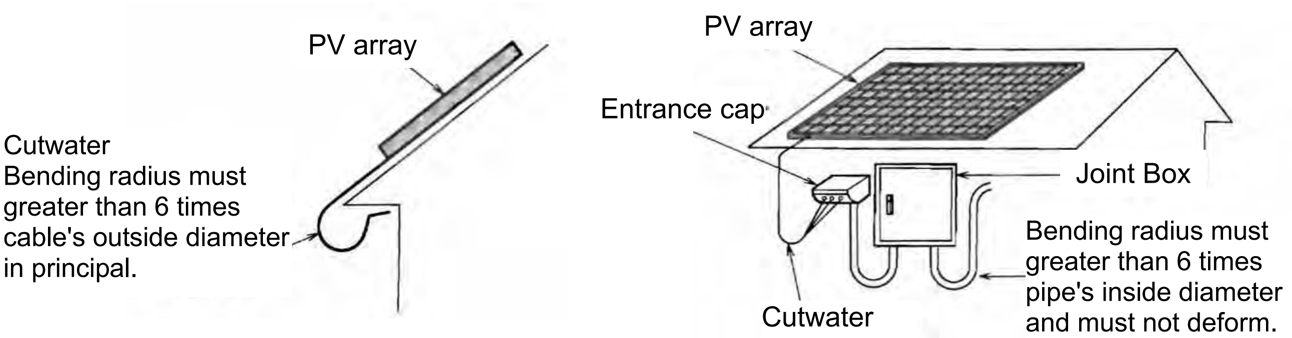
Installation with messenger wire

(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3-7: Cable installation between PV modules

② **Between the PV array and the junction box**

- It is necessary to check who will supply the PV output cable, and the specification of the cable. In general, the PV module manufacturer supplies the cables, which have a waterproof connector at one end and can be cut the other end if necessary. In addition, cables to be connected to the junction box can be cramped by pressure.
- The necessary length and size of the PV output cables shall be examined. The length is derived from the wiring route and the size is given by the length and current capacity. Moreover, we have to pay attention to a voltage drop (wiring loss).
- In the wiring work, we shall take care of the polarities (+/–), waterproof treatment at the inlet of the junction box, and the predefined tightening torque of the cramp-style terminal.
- If the junction box is positioned below the array, the cables shall have a cutwater part. As a rule, the radius of curvature of the cable shall be at least six times larger than the outer diameter of the cable. This holds true for pipes—we shall bend them at a radius of curvature at least six times larger than the inner diameter without deformation.



Source: Design and installation work of PV system, Japan Photovoltaic Energy Association (JPEA)

Figure 3-8 Cutwater and bending radius of cables

- When installing the cables through a duct or rack, cares shall be taken to prevent the duct from being immersed in water, or water from coming through the duct on a rainy day.

(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3-9: Cable installation between PV array and junction box

③ **From the junction box to the PCS**

- In general, two core single DC cables shall be installed in this section. Therefore, the cable shall be selected whose current capacity exceeds short-circuit current flowing through the PV array.
- In the indoor installation of the PCS, the cable used in this section goes through the wall. Accordingly, a waterproof sleeve or pull box shall be used to avoid water invasion.

④ **From the PCS to the connection point with the grid**

- In general, three core single AC cables shall be installed in this section. Therefore, the cable shall be selected whose current capacity corresponds to the output of the PCS.
- Each power company has different interconnection methods for PV system (connection with the primary or secondary side of the main circuit breaker) and electrical systems

(three-phase three-wire). Accordingly, those conditions shall be checked in advance.

- All cables shall be connected while paying attention to the polarities (R-S-T).
- When installing the underground cable, the cable depth, burying method, and the interval of hand-holes shall be confirmed in accordance with existing standards or regulations.

6. Safety management

The installation of a PV system requires safety measures similar to building construction and electrical works, and following precautions need to be observed:

6.1 Measures against falling accidents

When installing the PV modules on the high place (high-place work), necessary safety measures shall be taken as shown below.

- Wearing a helmet (safety hat).
- Wearing rubber-soled socks or safety shoes having a skid-proof effect.
- Wearing a safety belt (lifeline).
- Wearing a waist apron to prevent tools or materials from falling down.
- Installing scaffolds

In addition, we shall take safety measures to avoid following accidents during work.

- Falling down due to strong wind during carry-in and installation works of a PV module.
- Losing the footing on the glass surface of a PV module.
- Injury by pieces of the broken glass of a PV module when the foot is put on the surface.

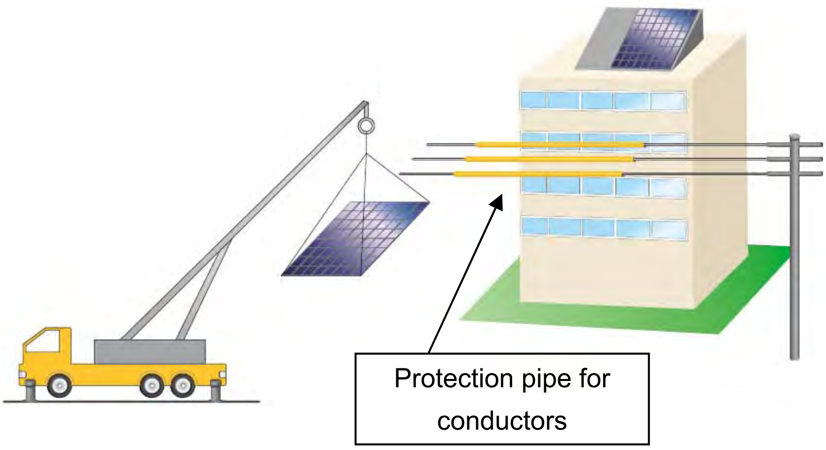
6.2 Measures against electric shocks

Connecting a necessary number of PV modules in series increases the open-circuit voltage to 250 V to 450 V, which is relatively high. Accordingly, following safety measures shall be observed:

- Covering the surface of the PV module with a shading sheet before the connection.
- Wearing low-voltage insulation gloves.
- Using appropriately insulated tools.
- Prohibiting work during rain.

6.3 Other safety measures

- When heavy machines including wrecker trucks are used to carry materials and appliances, temporary protection shall be posted to prevent the arm from approaching the distribution line, for example covering the line with a protection pipe. Consultation with the power company is recommended to take measures.
- When cutting materials, it is required to wear safety goggles and a dust respirator.



(Source: For effective performance of solar photovoltaic system, NEDO)

Figure 3-10: Protection measure for overhead conductors

7. Commissioning inspection

The purpose of commissioning (completion) inspection is to check that the PV system is installed as shown in the design documents and installation drawings and to transfer the equipment to the client. If a problem was found during the inspection, the problem shall be addressed and reported to the client. If necessary, we can ask the client to attend the inspection as a witness, so it is important to describe inspection procedures and how to inform the client of the schedule in the bidding document.

Checkpoints upon completion are shown below.

7.1 Visual inspection

○PV array

- Whether the surface is stained or damaged, the frame is broken or deformed, the rack is corroded or rusted.
- Whether the rack is grounded.
- Whether to caulk the contact surface between the rack and foundation and the joints between the members.

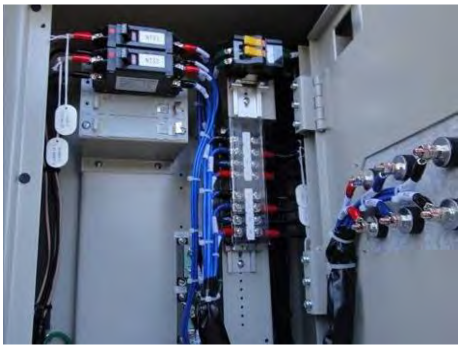
PV array

Earth wire connected to a rack

Bolt joints being caulked

○Junction box

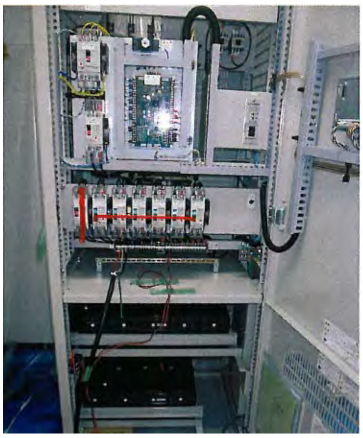
- Whether the housing is corroded or damaged, or the screws on the terminal block are loose.
- Whether the installing position for housing and waterproof measures are good.
- Whether the cables are connected with the correct polarities.



Junction box

○PCS

- Whether the housing is corroded or damaged, or the screws on the terminal block are loose.
- Whether the attachment state is good or the cables are connected to the correct polarities.
- Whether a connection with the earth terminal is good.



Terminal block in a PCS

○Others (e.g. watt-hour meter, main circuit breaker, and breaker for PV power generation)

- Whether the appliances are installed as designed.
- Whether the cable connecting state is good

7.2 Measurement and test

○PV array

- Grounding resistance: 100 Ω or less (Class D)

Measurement of grounding resistance

○Junction box

- Insulation resistance: 0.2 MΩ or over between the PV module and ground; 1 MΩ or over between the junction box's output terminal and ground
- Open-circuit voltage: Not less than the voltage specified in the module specification (moreover, the voltage variation of the string circuits shall be within a certain range)
- Polarities: Each string circuit shall be connected with the correct polarities (+/-).

○PCS

- Insulation resistance: 1 MΩ or over between the PCS and ground
- Grounding resistance: 100 Ω or less (Class D)
- Power receiving voltage: Within the specified value between the main circuit terminals (e.g. 200 V ± 10% when the rating is 200 V AC in Japan)

For reference, following description shows how to measure the grounding and insulation resistance, and the open-circuit voltage as well as circuit diagrams.

① **Grounding resistance test**

・Purpose: To measure the grounding resistance of electric appliances, such as PV arrays and PCS.

・Test method: Measurement with an earth-resistance tester.

・Criteria: The measured value shall be 100 Ω or less (Class D).

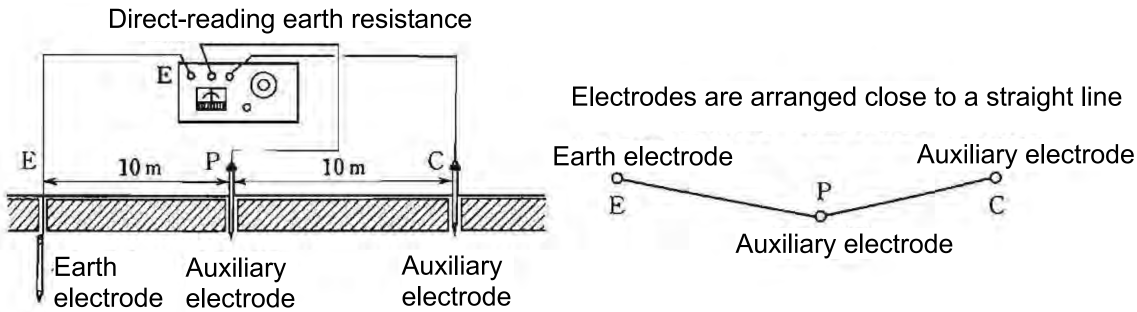


Figure 3-11: Measurement of grounding resistance

7.3 Insulation resistance test

- Purpose: To measure the insulation resistance of the cable between the PV array and junction box (DC input terminal) for each string circuit.
- Test method: Measurement of the insulation resistance of the PV cell circuit in the junction box with an insulation-resistance meter (megger rated at 1,000 V).
- Criteria: The measured value shall be 1 MΩ or over.

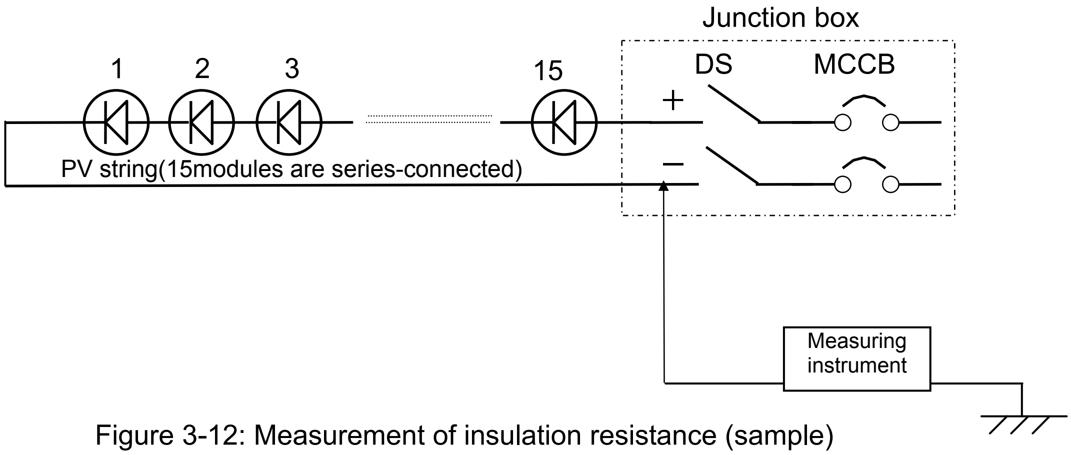


Figure 3-12: Measurement of insulation resistance (sample)

7.4 Open-circuit voltage measurement

- Purpose: To measure the open-circuit voltage of each string circuit.
- Test method: Measurement of the open-circuit voltage of the PV cell circuit with DS and MCCB turned OFF in the PCS by using a voltmeter.
- Criteria: Ex.: The difference between the circuits shall be within 15 V (the expected voltage is 350 V to 460 V).

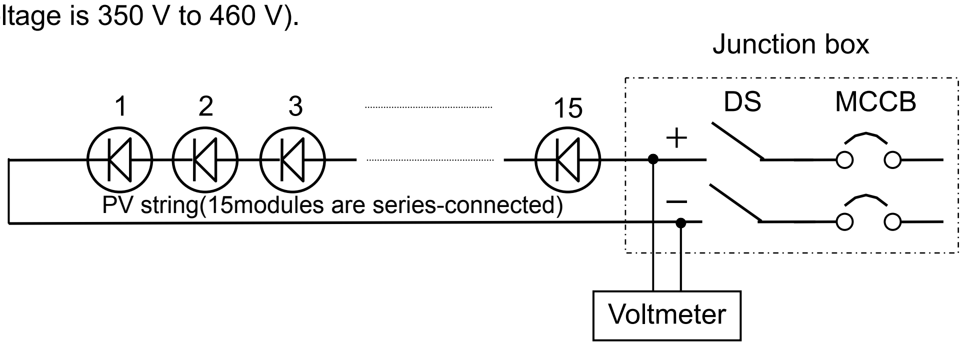


Figure 3-13: Measurement of open voltage (sample)

7.5 Grid connection check

- Protection relay: All settings shall be in accordance with the investigation by the power company.
- Run/stop: The system shall work according to the operation (ON) and stop (OFF) switches.
- Power interruption: When a power interruption occurs in the grid, the PCS shall stop instantaneously.
- Recovery: When the grid recovers from a power interruption, the PCS shall restart after a certain period of time (150 to 300 seconds).
- Indication: The indicator shall work correctly during operation.
- Noise: The system shall not generate noise, abnormal vibration, and bad odor during

operation.

The following shows sample important documents which shall be handed over to the client after the commissioning.

- Commissioning inspection results (report)
- PV system manufacturer's documents (e.g. product testing results, operation manual, and warranties)

8. Warranty after commissioning

It is important to acknowledge the kind of warranties effective after installation of Grid-connected PV system. Before we select the equipment manufacturers or companies responsible for the installation work, it is necessary to consider warranties provided on the equipment or the installation work at the time of quotation. Especially under the procurement process, particular product and period covered by the warranty shall be clearly specified in the Bidding Documents and the Contract.

In principle, there are four types of warranties applicable to the Grid-connected PV system.

① Defect warranties for each equipment by manufacturers
② Total system warranties covering whole Grid-connected PV system
③ Output warranties for PV Module
④ Generated energy warranties for the Grid-connected PV system over a period of time

(1) Defect warranties for each equipment by manufacturers

Not only PV module but all major equipment such as PCS, transformer, distribution board shall be covered by defect warranties. The range covered by the warranty will be different depending on the products and/or manufacturers. Some manufacturers provide warranty to cover natural disasters such as typhoon, flood. Typical coverage period is one year in case of Japanese manufacturers.

(2) Total system warranties covering whole Grid-connected PV system

It is possible to request the prime contractor, e.g. general trading firms and/or construction firms, to provide warranty for whole Grid-connected PV system. This warranty covers installation work of the equipment. The condition of the warranty will be described that after a specified period (e.g. 1 year) the system will provide a minimum output capacity in kW. Usually, the warranty period is determined considering the shortest coverage period of defect warranty for each product.

(3) Output warranties for PV Module

Most PV module manufacturers provide output warranties for the output performance of each PV module over a specified period. In case of Japanese manufacturers, typical guaranteed output is 90% of the minimum output (=90% of nominal maximum output) of PV module, and warranty period is 10 years. This means 0.9 x 0.9 = 0.81 times the nominal maximum output for the first 10 years. Also 20 years warranty for the 80% of the minimum output (0.9 x 0.8 = 0.72 times the nominal maximum output) can be provided by some manufacturers. This warranty is the most important, so the warranty condition should be checked in detail before making the Contract.

(4) Generated energy warranties for the Grid-connected PV system over a period of time

This warranty guarantees certain generated energy by Watt-hour over a specified period. In case Grid-connected PV system is operated as a power station, this warranty can ensure minimum generated energy and related energy sales for the operator of PV system. However, it may cause a lot of risks for the contractor because the generated energy will be dependent on the amount of solar irradiation available each year, and can be determined if the contractor is shared necessary information based on many years of irradiation data at the project site.

Therefore, this type of warranty is not so common for PV projects in Japan.

Chapter 4　Operation and Maintenance of Grid-Connected PV System

1. Operation and maintenance system

1.1 Selection of the organization in charge of operation and maintenance

If the grid-connected PV system exceeds a certain capacity, it shall be regarded as electrical facilities for utility, equivalent to power stations and substation owned by power companies. Therefore, it is highly recommended that the staff in charge of operation and maintenance have enough experience in operating and maintaining similar electrical facilities under both normal and emergency conditions. When the owner (e.g. hospital and school) that operates the project site has no engineer having similar experience, it shall make an operation and maintenance contract with an external organization like an electric power company having experience in operating and maintaining power stations. In addition, if the owner cannot handle all of the operation and maintenance works, it is necessary to consider outsourcing some of the works to the power company or private firms.

1.2 Checks on laws and regulations

When setting up a new organization that operates and maintains the PV system, regulations and laws enforced in the country shall be examined to check whether chief electrical engineers need to be appointed or safety code of practice are required, in accordance with existing regulations for the power generation. For example, we need to employ a chief electrical engineer if electrical facilities for private use are connected with a high-voltage distribution system in Japan. The chief electrical engineer is a qualified engineer who has a national license to supervise the safety during the construction, operation and maintenance of electrical facilities. Japanese safety codes require the entity to install electrical facilities for private use shall official submit following documents to the Ministry of Economy, Trade and Industry.

① duties and organizations of the personnel who manage the works relating to the construction, operation and maintenance of the facilities,
② safety education to be provided to the personnel who are involved in the construction, operation and maintenance of the facilities,
③ patrol, inspection, and examination for ensuring the safety of construction, operation and maintenance of the facilities,
④ operation or manipulation of facilities,
⑤ how to preserve the power station when the operation stops for a certain period,
⑥ measures against disasters or other emergency events,
⑦ records on the safety of the construction, operation and maintenance, and
⑧ a system for making legal voluntary inspections, and the preservation of records.

However, many developing countries have no regulations and/or standards concerning grid-connected PV systems as mentioned above. Accordingly, authorities concerned and power company shall be required to develop the realistic methods to apply and revise existing regulations and/or standards to the grid-connected PV system, according to the PV system capacity.

1.3 Organization necessary to the operation and maintenance

When the entity establishes the organization in charge of the operation and maintenance of power generation system, it is necessary to clearly define the purpose of the organization. Expected key purposes are shown below.

[Purposes of the system and organization of the operation and maintenance]

- To operate and maintain the power generation system in a sound and continuous manner.
- To keep the staff and neighbouring residents safe.

In order to fulfill the above purposes, the organization shall be required

- To employ technical staff in charge of the daily operation and maintenance.
- To set up required levels for operation and maintenance for each period in a day, and to build up a system suitable to them.
- To appoint groups which take action against a problem both during day time and night time.
- To establish liaison systems for normal and emergency cases.
- To examine the possibility of collaboration with other organizations in the company.
- To identify scope of works to be outsourced to utilities or private firms.
- To make education/training system and curriculum for the internal staff.

1.4 Operating and maintaining organization (example)

Table 4.1-1 shows an example of the organization that operates a PV system rated at about 1 MW or 10 MW. The PV system does not generate power during night, so the organization is set to be capable of supervising the system between the sunrise and sunset for every season. It is necessary to determine the number of maintenance technicians and operators as well as their technical levels in consideration of duties that the organization should address.

Table 4-1 Sample organization in charge of operating and maintaining a PV system

Post	Number of members		Duties	Working system	Necessary qualification, technical skills, and work volume
	～1MW	～10MW			
Manager	1	1	Final decision and order in operation and maintenance	Daytime work on weekdays. Call in emergency at night or on holiday.	Chief electrical engineer (when required in the country)
Operator	3	6	Operating and monitoring the system, daily patrol, and take measures against problems	2 shifts (e.g. 5:00 to 12:00 and 12:00 to 19:00 depending on season). 3 groups, each having 1 to 2 members (depending on scale). Note: Rotation including maintenance engineers is effective.	Engineers/Technicians who are familiar with basic principles of all facilities, and operating conditions and methods.
Maintenance staff	2	5	Planning and making regular inspection, and conducting technical maintenance and regular patrol	Daytime work on weekdays. Call in emergency at night or on holiday.	Engineers/Technicians who are familiar with basic principles of all facilities and maintaining work. Monthly patrol by group consisting of 2 members requires period between 1 and 2 MW/day.
Assistant worker	2	6	Assisting cleaning duties and work requiring no advanced expertise and assistance to regular patrol	Daytime work on weekdays. Call in emergency at night or on holiday.	Workload, number of members, and levels vary depending on system conditions, circumstances at site, and subcontracted work range. Sandy or dusty region requires the number of members that can clean all facilities in about a week.
Office worker	2	2	General affairs inside the station and communication with outside	Daytime work on weekdays. Call in emergency at night or on holiday.	
Total	10	20			

(Source: Shikoku Electric Power Company, Inc.)

1.5 Development of an operation and maintenance manual

Before preparing the organization such as above and staring operation and maintenance work, it is recommended to develop an operation and maintenance manual. The following shows the contents as an example.

① Facilities Name
② Operating Procedures
③ Basic Procedures for Proper Operation
④ Measures against Emergency
⑤ Organization
⑥ Inspection Tour and Maintenance
⑦ Safety
⑧ Training

The main purpose and important points of each chapter are shown below.

(1) Facilities Name

- To understand the operation and maintenance of PV system in terms of both the entire system and each component.
- Scope of the each term shall be explained clearly, with illustrations, photographs and so on.
- The application of each term is to be unified in the manual and the site
- The basic specification of the facility is to be described.

It is necessary to prepare several figures for general construction, components and facilities.

(2) Operating Procedures

- Procedure lists are to be prepared for each operating mode separately such as start-up and stop, and to be described entirely from the beginning to the end in one volume.
- Do not quote the procedure list of other modes partially.
- All procedures are to be described separately for each step.
- To be expressed in plain language so that even beginners can understand.
- Operations or items checking situation and numerical values are to be described separately in the order.
- It is desirable to use an illustration or a photograph for each step.
- The steps which tend to be misunderstood and operated in a wrong way are to be explained to draw special attention.

Some examples of mode from operation manual are as follows:

① Start-Up
② Stop operation (Normal shutdown)
(Operators are in the powerhouse)
③ Stop Operation (Emergency stop / Quick shutdown)
④ Basic operation procedures
In the case of voltage drop
⑤ Supervision work during operation

In the manual, the titles of modes are to be described clearly and operations or checking items are described individually.

(3) Basic Procedures for Proper Operation

It is important to show basic procedures for proper operation as follows:

- Normal operating conditions (targets)
- Skills to be acquired for operation

(4) Measures against Emergency

Measures against emergency which are supposed to happen frequently, are to be mentioned in advance. Those measures shall be explained in detail especially if there are some conditions such as climate to cause the fault. Concerning the equipment trouble, the troubleshooting method is to be described systematically.

Sample items are listed as follows:

① Operations in each season
② Measures against faults or blackouts
③ Measures against lightning stroke
④ Troubleshooting etc.

(5) Organization

Organizations for each condition including emergency case are to be decided in advance as follows:

- Operation organization
- Number of operators, shifts,
- In general and in case of an emergency
- Operation schedule
- Manager in charge
- Operation and maintenance works (incl. watering PV arrays, management of planned outages)
- Operating hours should be decided in consideration of the climate conditions.
- Procedures and flows for instructions
- Emergency action

(6) Inspection Tour and Maintenance

Operators should state system operation, patrol and maintenance method in the manual. Check items should be clearly stated.

The details of the patrol and maintenance should be stated after the “2. General concept of inspection tour and periodical inspection (maintenance)”.

(7) Safety

Operators should understand and be aware of the dangers during operation, inspection tour and maintenance of the system.

(8) Training

The organization shall build up its own education/training system and curriculum to prompt the operators and maintenance engineers to understand rules and technical principles for operating the power station, which engineers should know for each of their duties.

(9) Communication system

In case of an accident on the premises or grid side, the PV system owner shall build up a liaison system that allows for prompt exchange of information with the power company. The manual shall include contacts available around the clock, for example the contacts of the dispatch center operated by the power company, (including phone number for security communication, private and mobile phone numbers) as well as those of the manager and chief electrical engineer with whom operators or maintenance staff should contact first.

(10) Public awareness raising

In many cases, one of the purposes of a medium- to large-scale grid-connected PV system is to encourage and promote dissemination and awareness-raising of solar power generation among domestic and overseas leaders and general public. Therefore, it is recommended that the manual describes how to respond questions from visitors and to take a tour of the facility.

1.6 Budget for the operation and maintenance of the power station

Operating the power station continuously requires the profitable management from a long-term point of view. When estimating the project costs, we shall make an effective investment by precisely finding costs for the operation and maintenance.

(1) Budget for operating and maintaining the power station

The PV power station consumes no fuel, but the operation and maintenance as a whole requires costs for power generation, investments in communication and safety facilities, expenses for operating and maintaining them, and running costs for in-house power distribution, water consumption, and consumables for inspection and cleaning.

In addition, it is necessary to draw up a long-term financial plan for buying consumables, spares in case of failure, and maintenance tools that are necessary to the long-tem operation of the major facilities such as PCS.

The consumables include two types: one needs to be regularly exchanged and the other needs to be urgently procured to ensure the reliability of the operation when a fault occurs. Accordingly, a necessary number of the spares shall be kept in the consideration of the lead time. If there are consumables that will be difficult to procure after more than 20-years of operation, the spares shall be stocked in necessary quantities based on the mean time between failures (MTBF).

Table 4-2: Examples of spares

Spare	When	Reason and frequency	Quantity
PV modules	Failure occurs.	Module will be difficult to procure after more than 20 years of operation.	Quantity is derived from probability of damage due to thrown stone and failure in internal element and circuit, which vary depending on site conditions and module type. About 0.1% of the whole quantity for the moment. In consideration of damage conditions during 1 to 2 years after commissioning, it is necessary to consider early procurement based on failure rate.
DC Circuit Breakers for the termination of PV circuit	Abnormal event occurs.	If quick procurement is difficult upon failure, it has significant effect on operation.	1 unit for each kind
Fuse for PCS	Abnormal event occurs.	Failure rate may be high. Keeping spares is effective for the quick power restoration because on-site workers can take recovering action.	1 or more for each kind Note some PCS manufacturers don't allow the client to open the panel and change equipment inside the panel. Check your manufacturer first!
Condensers, Touch Panels, Batteries of touch panels, Fans for PCS	Replacement is necessary before life (5 to 10 years) or abnormal event occurs.	Failure rate may be high. In addition, regular inspection may show that component should be replaced. Periodical procurement is necessary according to life of each component.	
Circuit boards for PCS	Abnormal event occurs.	Circuit board has significant effect on operation and quick procurement is difficult.	
PCS (Whole equipment)	Abnormal event occurs.	If an engineer responsible for replacing parts judges that quick procurement is impossible for the site, a set of PCS shall be reserved to be replaced as a whole.	1 set Cool and secure storage space need to be prepared.

(Source: Shikoku Electric Power Company, Inc.)

Tables 4-3 and 4-4 show examples of testing devices necessary for regular inspection and taking measures against abnormal operation, and for maintenance works recommended to be prepared at site. The quantity of each device or tool can be derived from that of the facilities. The typical usage of the testing devices will be described later. They include expensive devices, therefore, we can lease them during inspection or ask the inspection vendor to procure them in consideration of the quantity of the facilities (to be checked), the financial state of the installer, and the necessary reliability of the system in question (the omission of checkpoints).

Table 4-3: Testing devices to be prepared

Items	quantity	necessity	main usage
Digital multi meter	1	◎	General measurement for circuit condition
Voltage detector	1	◎	
Clamp meter	1	◎	
Terminal boards & wire clips	1 set	◎	To make circuits for inspections
Insulation Resistance Tester (Megger)	1	◎	measurement for insulation condition of the circuit from PV to switching board
Grounding resistance tester	1	◎	measurement for circuit condition
I-V Curve tracer	1	○	Judgment of the condition of cells and the circuit
Infrared camera	1	△	Judgment of the condition of cells and wiring in modules
Current path detector	1	◎	Detection of disconnection wiring in modules

(Source: Shikoku Electric Power Company, Inc.)

Table 4-4: Maintenance tools to be prepared

Items	quantity (ex)		Specifications
Screwdriver (+ and -)	2	set	Screwdriver (+ and -)
Terminals board & wire clips	1	set	Terminals board & wire clips
Cutting nipper	2		Cutting nipper
Cutting Plier	2		Cutting Plier
Hammer	2		Hammer
Card tester	2		Card tester
Socket wrench	1	set	Socket wrench
Paint	2	cans	Paint
Anti-corrosive paint	2	cans	Anti-corrosive paint
Tool cabinet with door	1	unit	Tool cabinet with door

(Source: Shikoku Electric Power Company, Inc.)

1.7 Budget to manage the organization

In addition to costs for the facilities, we shall prepare a long-term financial plan for labor costs for the organization shown in Table 4-1, office construction/rental charges, and heat and lighting expenses.

2. General concept of inspection tour and periodical inspection (maintenance)

In general, “patrol” and “inspection” are required to maintain electrical facilities. In the patrol, we keep a record of the facilities in operation to determine whether conditions are good or not. In the inspection, we stop the system, replace components (if they can be exchanged only during a power interruption), make measurements, and inspect the inside to judge whether conditions are good or not. Both are very important.

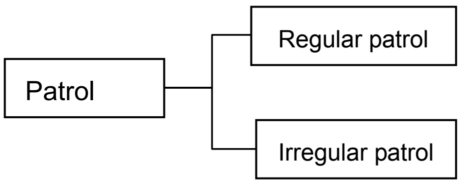
The checkpoints and frequencies should be determined on the viewpoints of the effective and efficient operation of the system, while they shall meet standards/regulations in the country and operator’s code of practice.

The maintenance work includes action against a possible failure, but it is necessary to take preventive measures to minimize the frequency of problems. The preventive measures are classified into two types: one is the method of controlling the implementation period according to the operating time and the number of elapsed years and the other is the way to check the conditions of the facilities through the items and values to be managed. If possible, maintaining the facilities according to their conditions generally tends to reduce the maintenance cost.

3. Daily inspection (inspection tour)

3.1 Inspection item

For the operation and maintenance of the PV system, it is required to conduct daily patrol taking preventive measures for faults, keep a record of the operation, detect any problem at an early stage, take a quick action against them, and monitor the performance of the system. Taking measurements and inspections while the facilities is under normal operation is called “patrol,” which is classified into two kinds: one is called “regular patrol” that should be conducted about once every month, and the other is called “irregular patrol” that should be conducted right after a heavy rain or earthquake that rarely occurs but has a significant effect on the facilities (Figure 4-1)



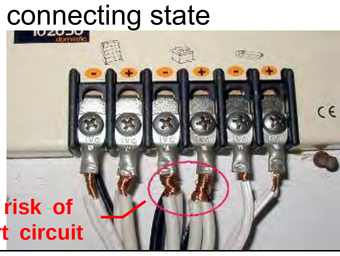
Type	Contents	Frequency
Regular Patrol	During Operation check the condition of all equipment to find failure.	Daily, monthly, etc.
Irregular Patrol	After heavy rainfall, earthquake or tsunami, operator should check the equipment condition.	Emergency case

(Source: “Basic concept of operation and maintenance”, NEDO textbook)

Figure 4-1: Type of patrol tour

Table 4-5 shows recommended checkpoints during the regular and irregular patrol.

Table 4-5: Recommended checkpoints during patrol

Equip	Component	Checkpoint	Aging ctrl.	Component	Checkpoint	Aging ctrl.
PV array	Module	Damage, stain on surface, noise, bad odor, and mounting state 		External wiring	Damage and connecting state 	
	External wiring along rack	Rust, corrosion, break, damage to assembly, and connecting state 		Earth wire	Damage and connecting state 	
	Foundation	Damage and tilt 		Ground	Tall plants	
Junction box	Housing	Rust, corrosion, break, and, mounting state 		Wiring	Damage, connecting state, bad odor, and burning mark 	
PCS	Housing	Rust, corrosion, break, and, mounting state 		Wiring	Corrosion, damage, and connecting state 	
	Conditions	Noise and bad odor		Protection relays	Check on operating state	

Equip	Component	Checkpoint	Aging ctrl.	Component	Checkpoint	Aging ctrl.
	Room temperature (present and peak values)	Check on specified range	Yes	Room humidity (present value)	Check on specified range	
	DC voltage (V)	Within total open-circuit voltage of modules 	Yes	Total generated energy (kWh)	Check on monitor	Yes
Distribution board (power receiving panel)	Conditions	Noise, bad odor, vibration, and break 		Output power (kW)	Below total capacity of PV modules. Irradiation data is used to evaluate power generation if available. 	Yes
Output board	AC voltage (V)	About design value	Yes	AC voltage (A)		Yes
Output board	Total energy supplied to grid (kWh)	Check on watt-hour meter for selling to the power company 	Yes	In-house energy consumption (kWh)		Yes
Transformer and switch board for grid	Conditions	Noise, bad odor, vibration, break, and oil leak 		Oil temperature (present value)	Check on specified range	Yes
Transformer and switch board for grid	Oil level (present value)	Check on specified range		Conditions	Noise, bad odor, vibration, and break	
Transformer and switch board for grid	Open/close counter	Check on specified range	Yes			

Equip	Component	Checkpoint	Aging ctrl.	Component	Checkpoint	Aging ctrl.
Yard of PV arrays	Irradiation (kW/m^2)	Check on cleaning condition 	Yes	Tempera-ture (present, peak, and bottom values)	Check on cleaning condition 	Yes
	Humidity (present value)		Yes			
Security equipment	Outer fence	Installation condition, breakage or damage				
Circumstance	Possible shadow by structure	Growth of trees and newly constructed buildings		Dust generation	Ground and construction work around site	

(Source: Shikoku Electric Power Company, Inc.)

For monthly patrol, we shall develop a checklist as shown in Table 4-6 in order to prevent missing any checkpoint and to keep records.

Table 4-6: Checklist for regular monthly patrol (sample)

From :　　/　　/　　.
To :　　/　　/　　.

Records of Monthly Patrol

✓ : Good　△ : Caution　B : Bad　C : Cleaning　A : Adjustment　X : Exchange　L : Lubrication

	Date	／	／	／	／	／	／
	Name						
Items	Check Point						
General conditions at the yard							
Time							
Temperature (present)	(ºC)						
Temperature (maximum)	(ºC)						
Temperature (minimum)	(ºC)						
Relative humidity (present)	(%)						
PV array 1							
Modules	Damage, Dust, Abnormal noise, Abnormal smell, Installation condition						
Wires	Damage, Looseness						
Frames	Rust, Corrosion, Damages, Installation condition						
Grounding wires	Damage, Looseness						
Foundations	Damage, Slant						
Ground, surroundings	High plants and constructions, contamination						
PV array 2							
Installed room							
Temperature (present)	(ºC)						
Temperature (maximum)	(ºC)						
Relative humidity (present)	(%)						
General conditions	Dust, Security condition						
Incoming panels							
Generated Power (present)	(kW)						
Generated Power (maximum)	(kW)						
Total energy sold to power company	(kWh)						
Irradiation (present)	(kW/m2)						
Irradiation (maximum)	(kW/m2)						
General conditions	Abnormal noise, Abnormal smell, Installation condition						
Housing, Panels	Rust, Corrosion, Damages,						
Wires	Damage, Looseness						
Protection relay	Indications						
Power conditioner 1							
Input direct voltage	(V)						
Watt-Hour (accumulated)	(kWh)						
General conditions	Abnormal noise, Abnormal smell, Installation condition						
Housing, Panels	Rust, Corrosion, Damages,						
Wires	Damage, Looseness						
Protection relay	Indications						
Remarks							

(Source: Shikoku Electric Power Company, Inc.)

3.2 Evaluation of actual generated energy

This subsection describes how to evaluate the solar irradiation, output power, and energy that should be recorded regularly for aging control. Particularly, the irradiation should be measured at a frequency (shorter than one hour) that makes it possible to find the daily energy.

If there is data on the irradiation, we can compare it with the output power (kW) in the same period or with the energy (kWh) over a certain period. That is to say, we can continuously check if the calculated power derived from the recorded irradiation is consistent with the actual data measured monthly or annually (Table 4-8). The example below uses presumed parameters to make the calculation easy, while the measured values do not give absolute evaluation because they include errors that are difficult to quantify correctly. However, collecting the data for a long time right after commissioning allows us to grasp a relative degrading tendency and to detect a fault.

Table 4-7: Evaluation of recorded energy

How to find the energy matching degree E = Pr/Pc

Parameter	Unit	Variable	Value/calculation
Energy matching degree	1	E	**=Pr/Pc**
Energy (measured) per day	kWh/d	Pr	Measured value (kWh (daily record) or kW × hr)
Energy (calculated) per day	kWh/d	Pc	**= Ir × p × n × K' × Kpt** (variables are described below)
Inclined irradiation (measured) per day	$kWh/m^2/d$	Ir	Measured value (Horizontal irradiation should be converted to inclined one)
Rated capacity	kW	P	Rating (at 25ºC and 1 kW/m^2)
Number of modules	piece	n	Recorded value
Basic design factor (crystal)	1	K'	0.756 (informative value, which should be replaced with measured one if available)
Basic design factor (amorphous)			0.693 (informative value, which should be replaced with measured one if available)
Temperature correction factor	1	Kpt	**=1+α(Tcr-25)/100**
Efficiency's temperature change factor (crystal)	1	α	–0.5% (informative value, which should be replaced with measured one if available)
Efficiency's temperature change factor (amorphous)			–0.2% (informative value, which should be replaced with measured one if available)
Module's weighted mean temperature	ºC	Tcr	**=T+ΔT**
Mean temperature at daytime	ºC	T	Announced value (which should be replaced with measured one if available)
Module's average temperature rise	K	ΔT	18.4 (informative value for rack-mount type, which should be replaced with measured one if available)

Where, the basic design factor is given by K' = Khd × Kpd × Kpm × Kpa × ηpc.

Irradiation's annual change correction factor (informative value)	Khd	0.97
Chronological change correction factor (informative value for crystal type)	Kpd	0.95
Chronological change correction factor (informative value for amorphous type)	Kpd	0.87
Array's total load correction factor (informative value)	Kpm	0.94
Array's circuit correction factor (informative value)	Kpa	0.97
PCS effective efficiency (informative value)	ηpc	0.90

Hence, the basic design factor (crystal) is 0.756 and
the basic design factor (amorphous) is 0.693.

(Source: Shikoku Electric Power Company, Inc.)

3.3 Example of log sheet for generated energy

Table 4-8 shows a proposed form for recording and evaluating the monthly energy data including the energy matching degree as mentioned above. Aging control with this form is helpful to evaluate the operating conditions of the facilities. Moreover, it makes further detailed evaluation possible by recording the energy generated, various operating quantities, and grid information hourly and daily.

Table 4-8: Collection of energy records

Record of Output energy
Year = 20XX
Record Capacity:Pi = XXX,XXX kW

Month	Number of days	Monthly Accumulated Watt-Hour energy (measured)	Maximum power (measured)	Station Service Power (measured)	Monthly Accumulated Irradiation energy (measured)	Monthly Accumulated Watt-Hour energy (calculated)	Coincidence of generated energy	Load Factor	Capacity Factor
	N	Pr (kWh)	Pmax(kW)	Ps (kWh)	Ir (kWh/m2)	Pc (kWh)	E = Pr/Pc	Fl=Pr/(N*24)/Pmax	Fc = Pr/(N*24)/Pi
Jan	31								
Feb	28								
Mar	31								
Apr	30								
May	31								
Jun	30								
Jul	31								
Aug	31								
Sep	30								
Oct	31								
Nov	30								
Dec	31								
Annual	365								

(Source: Shikoku Electric Power Company, Inc.)

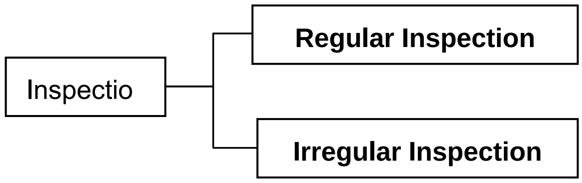
4. Periodical inspection (maintenance)

Compared with the patrol, the inspection is made as long-term preventive measures to grasp the state of the PV system more precisely by stopping the operation regularly. The checkpoints and frequency of the inspection shall be defined in accordance with country-by-country and capacity-by-capacity standards for operating electrical facilities. The inspection is also classified into two types: one is called "regular inspection" that should be made in a legally specified cycle or in a necessary cycle from the viewpoints of the performance and durability of the facilities, and the other is called "irregular inspection" that should be made when a problem is found during patrol or an accident occurs suddenly due to disaster (Figure 4-2). In Japan, the frequency of regular inspections is defined as follows:

(1) Generation capacity with 100kW over, interconnected with high-voltage or or special-high voltage grid
→Once every two months or more

(2) Generation capacity with less than 100kW, interconnected with high-voltage grid
→ Twice a year or more

(3) Generation capacity with less than 20kW, interconnected with low-voltage
→ Inspected by their own (no required interval by law)



Type	Contents	Frequency
Regular Inspection	Check equiment condition regulraly	Periodically
Irregular Inspection	If there is a fault or abnormal condition, inspection of each equiment is necessary.	When necessary

（Source：(Source: “Basic concept of operation and maintenance”, NEDO textbook)

Figure 4-2 Type of Maintenance Works

Figure 4-9 Examples of checkpoints during regular inspection

Equipment	Component	Checkpoint	Measurement/test
PV array	Module	Damage, stain on surface, noise, bad odor, and mounting state	Measurement of insulation resistance and open-circuit voltage
	External wiring	Damage and connecting state	
	Rack	Rust, corrosion, break, and assembling state	
	Earth wire	Damage and connecting state	
	Foundation	Damage and tilt	
	Ground	Tall plants	
Junction box	Housing	Rust, corrosion, break, and, mounting state	Measurement of insulation resistance
	Wiring	Damage, connecting state, bad odor, and burning mark	
Distribution board (common)	Housing	Rust, corrosion, break, and mounting state	Check on display function, measurement of insulation resistance, and test of protector
	Wiring	Damage and connecting state	
	Earth wire	Damage and connecting state	
	Conditions	Noise, bad odor, vibration, and break	
	Filter at ventilating port	Check on clogging and replacement	
	Installation environment	Water, dust, and temperature	
Transformer for grid	Conditions	Noise, bad odor, vibration, break, and oil leak	Measurement of insulation resistance
	Oil temperature (present value)	Check on specified range	
	Oil level (present value)	Check on specified range	
	Conditions	Noise, bad odor, vibration, and break	
	Open/close counter	Check on specified range	

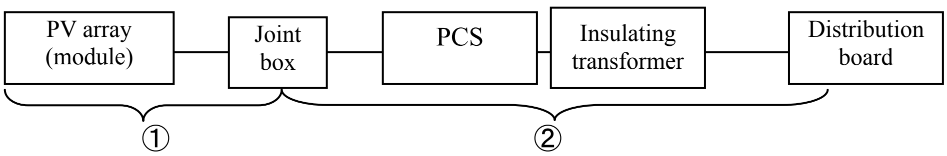
(Source: Shikoku Electric Power Company, Inc.)

Of the inspection methods and checkpoints shown in Table 4-9, the appearance (visual) check and the measurement of the open-circuit voltage are described in the section “7 Commissioning inspection.”

4.1 How to measure the insulation resistance of the PV system

It is necessary to measure the insulation resistance during regular inspection or when measures against a failure are taken. This subsection describes how to do it and precautions to take the measurement as it is normally made during daytime when power is generated by PV module.

We measure the resistance in two sections: one includes only the PV array (modules) as shown by (1) in Figure 4-3, while the other ranges from the junction box to the distribution board as indicated by (2) in Figure 4-3.



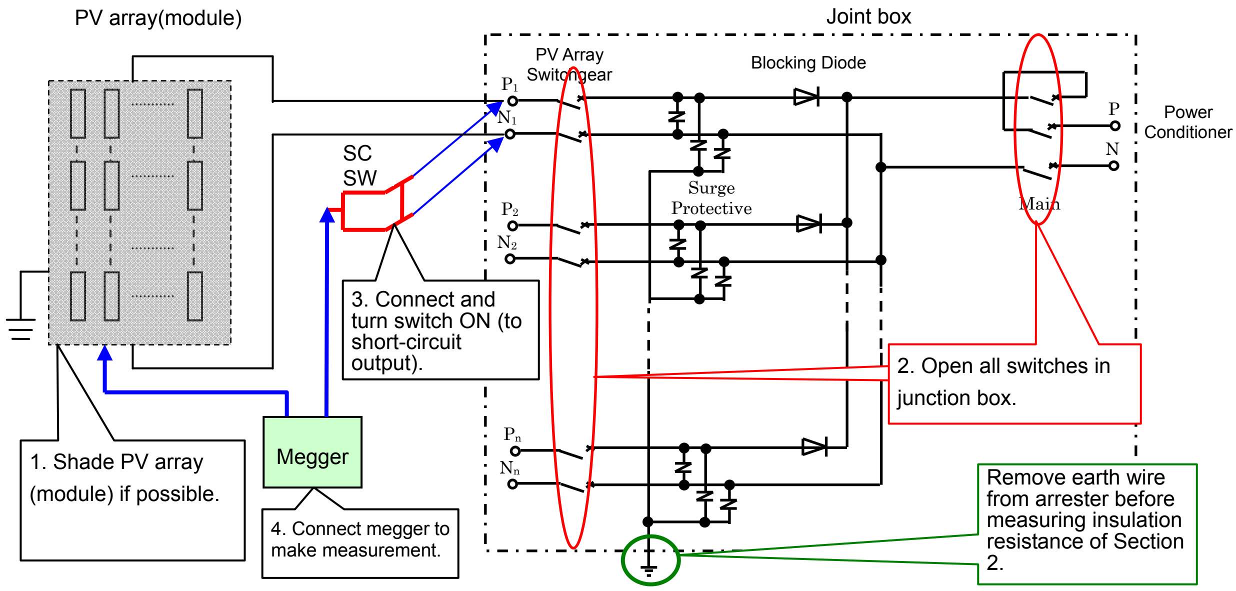
(Source: Shikoku Electric Power Company, Inc.)

Figure 4-3: PV system configuration diagram

Note that measuring the insulation resistance requires simultaneously keeping a record of the atmospheric temperature and humidity because they have a significant impact on the resistance. Therefore, the measurement should be avoided, if possible, on a rainy or humid day (or the measured value should be kept just for reference data).

As the PCS having many semiconductors, the manufacturer’s manual must be read thoroughly before the measurement to check the measurement range of the insulation-resistance meter (megger) and surge protective devices to be removed, such as arresters and surge absorbers. Table 4-10 shows the classification of voltage to be used by the megger.

① Measuring the insulation resistance of the PV array (modules)



(Source: Shikoku Electric Power Company, Inc.)

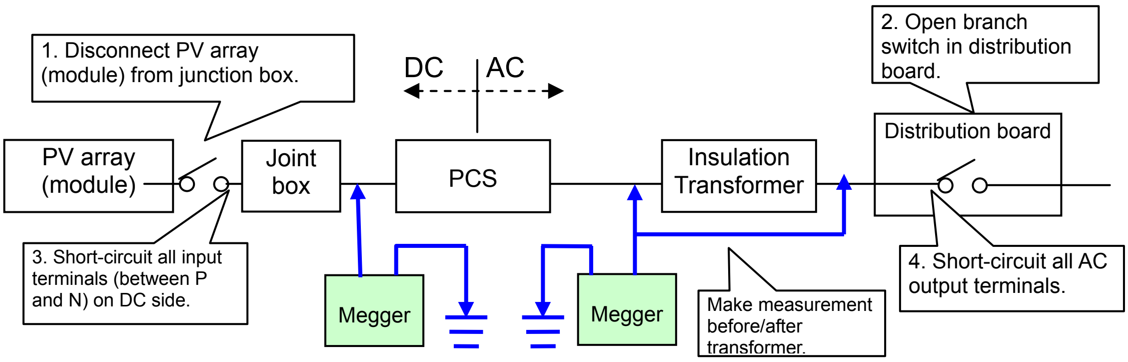
Figure 4-10: Wiring diagram for measuring the insulation resistance of the PV array (modules)

○Measuring procedures

1. Prepare a megger and a "short-circuiting switch" (SC SW) that withstands the short-circuit current Isc of the PV array (modules).
2. To keep the measurement safe, shade the array (modules) if possible to reduce the output power.
3. Open all the switches in the junction box.
4. Open the "short-circuiting switch" and connect it between P and N on the terminal block for the PV array (PV array switchgear in Figure 4-4).
5. Close the short-circuiting switch (to short-circuit the array output).
6. Under the condition, connect the megger between the live part of the short-circuiting switch and the ground to measure the insulation resistance to the ground (criteria are shown in Table 4-11).
7. After the measurement, disconnect the megger and then open the short-circuiting switch.
8. Repeat Steps 2 to 7 for the next array (modules).
9. After all the arrays (modules) have been measured and if Section 2 will not be measured, remove the instruments, etc., close the switches in the junction box, and return the system to the normal operation.

Note that before making connections as shown above, the inspector shall make sure if voltage applies to the connection point and wear insulation gloves to avoid an electric shock. In addition, it is recommended to put lead wires used for the short-circuiting switch and connection on an insulation sheet.

② Measuring the insulation resistance of the section from the junction box to the distribution board



(Source: Shikoku Electric Power Company, Inc.)

Figure 4-5: Wiring diagram for measuring the insulation resistance of the section from the junction box to the distribution board

○Procedures for measuring the input circuit (DC)

1. Disconnect the PV array (modules) circuit from the junction box.
2. Open the branch switch in the distribution board to disconnect the AC output of the PCS (insulation transformer).
3. Short-circuit the input terminals (P and N) on the DC side of the junction box.
4. Short-circuit the AC output.
5. Connect the megger between the DC terminal and ground to measure the insulation resistance to the ground. Note that criteria are shown in Table 4-11.

○Procedures for measuring the output circuit (AC)

6. Short-circuit all the input terminals of the PCS.
7. Connect the megger between the AC terminal and ground to measure the insulation resistance to the ground. The measurement should be made once before and after the insulation transformer. Note that criteria are shown in Table 4-11.
8. After the measurement, disconnect the megger, remove the short-circuiting switch, return the switches to the state before the work, and restart the array with the normal operation.

9. Repeat Steps 2 to 8 for the next array (modules).
10. After all the arrays (modules) have been measured and no section after the junction box will be measured, remove the instruments, etc., close the switches in the junction box, and return the system to the normal operation.

○Others

If there is no insulation transformer on the AC output side of the PCS (transfomerless type), the insulation resistance shall be measured according to the method recommended by the manufacturer.

Table 4-10: Classification of voltage to be used by an insulation-resistance meter (megger)

Voltage	Equipment to be measured
125V	Low-voltage line or equipment rated at less than 100 V
250V	Low-voltage line or equipment rated at not more than 200 V
500V	Low-voltage line or equipment rated at less than 600 V
1,000V	High-voltage or extra-high-voltage circuit, or equipment rated at more than 600 V

(Source: Shikoku Electric Power Company, Inc.)

Table 4-11: Criteria for the insulation resistance of low-voltage circuits
(Japanese Technical Standard for Electrical Facilities, Article 58)

<table>
<tr><th colspan="2">Voltage</th><th>Insulation resistance</th></tr>
<tr><td rowspan="2">300 V or less</td><td>Voltage to ground = Not more than 150 V (voltage between wire and ground in grounded electric circuit or between wires in isolated electric circuit)</td><td>0.1 MΩ or over</td></tr>
<tr><td>Other</td><td>0.2 MΩ or over</td></tr>
<tr><td colspan="2">More than 300 V</td><td>0.4 MΩ or over</td></tr>
</table>

(Source: Shikoku Electric Power Company, Inc.)

4.2 Trouble Shooting

Table 4-12 summarizes measures against abnormal conditions that possibly occur during normal operation or that are assumed from regular patrol results or aging control based on continuous measurements. If any problems are found, the operating conditions shall be evaluated while cross-checking points for patrol (Table 4-5) and inspection (Table 4-9) that are related to the abnormal conditions.

Table 4-12: Measures against key abnormal conditions

Abnormal condition	Component	What is checked	Evaluation/action
Output power is lower than value estimated from measured irradiation.	PV cells	Check tilt angle and azimuth of each array.	Evaluate it by remeasurement and recalculation.
		Check whether structures increased or trees grown around the site. Note that shadow may be cast only for a certain period.	Investigate on how to reduce shadows if cast.
		Check whether module surface is stained.	Survey degree of stain's effect and clean surface.
		Check cell for appearance (crack, browning, and damage on surface or back). ⇒ See Figures 4-6 and -7.	Check whether part of cells is out of order. → Make detail inspection (measuring panel surface temperature with IR (Infrared) camera and investigating broken or continuity-failed part with circuit probe).
		Check module for appearance (break, browning, damage, and air bubble on electrode). ⇒ See Figures 4-8, -9, and -10.	
		Check bypass diode in appearance (browning and heating on front or back of terminal) ⇒ See Figures 4-10, -11, and -12.	Check whether a failure in string causes bypass diode to be heated or out of order. → Make precise inspection (measuring panel surface temperature with IR camera and investigating broken or failed part with circuit probe).
	Cables	Check cables in appearance (sagging, broken, and corroded wire between modules or PCSs)	Repair or replace failed cables. → Make precise inspection if output power is not recovered.
Monthly (annual) energy generation is lower than before.	General	Check trends in energy matching degree (comparison between value derived from measured irradiation) under aging control.	Check any failure and degradation in performance. → Make precise inspection.
• No power is generated. • Output power reduces significantly.	PCS, junction box, and cables	Check each switch for state (opened/tripped switch and blowing fuse)	Find cause of open/tripped state and then close switch or connect fuse.
		Check for various settings (whether input voltage tap from string and output voltage tap to grid are chosen correctly).	Correct wrong setting. → If output power does not return, check each string for continuity, voltage, and current.
		Check blocking diode of string for appearance (broken, short-circuited, or opened state).	Repair failed diode. → Make precise inspection if output power is not recovered.
		Check lighting rod of string for appearance (broken or short-circuited state).	Repair failed part. → Measure insulation resistance to identify failed element.
		Check cables for appearance (whether any wire sags, has break, or corrodes)	Repair or replace failed cable. → Make precise inspection if output power is not recovered.

(Source: Shikoku Electric Power Company, Inc.)

If the survey results show any abnormal condition, we shall make detail inspections as shown in Table 4-13 to identify failed part and find out the cause. This work may require long hours depending on the layout of expensive instruments and the scale of the facilities, but the persistent problem causes the loss of power in proportional to the scale. Accordingly, we shall determine whether or not to take the necessary measures.

Table 4-13: Detail inspection to identify an abnormal portion

What is checked	Instrument	What happens	Expected state
Measuring I-V curve (String-by-string measurement Measurement on sunny day when no shadow is cast on array)	I-V curve tracer	Output current does not reach design value though open-circuit voltage is near to design value.	• Presence of cells that have conductivity but failed to generate power (number of failed clusters is given by dividing difference between voltage at maximum power and present value by cluster voltage). • Reduction in cell efficiency.
		Open-circuit voltage does not reach design value.	• Cell circuit has break or bypass diode works (number of failed clusters is given by dividing insufficient voltage by cluster voltage).
Inspecting IR image (Identifying part of module having abnormal temperature Measurement on sunny day when no shadow is cast on array)	IR camera	Cell (single) temperature is too high (presence of hot spot).	• Failure in soldered connector between cells (cell out of order is heated because solar energy changes to heat).
		Cell (whole cluster) temperature is too high.	• Bypass diode may work due to a failed cell or cluster having break.
		Cell (whole string) temperature is too high.	• Module may have break or failed connection. • Wrong control by PCS.
		Bypass diode temperature is too high.	• Bypass diode may work cell due to failed cell or cluster having break. • Bypass current may be caused because the cell is shaded.
Checking break (Note 1)	Circuit probe	Circuit has break. ⇒ See Figure 4.5-8.	• If results of checking module for appearance or IR image show that part of circuit has break, it is necessary to make inspection to identify it.

Note 1:

(The circuit probe used for wiring inspection is a tester that generally checks whether wiring is conducted correctly and there is a failure like a break in a AC (DC) power circuit. In this document, we use it to inspect the PV modules for conductivity to detect failed part. The probe has advantages and disadvantages: the advantage includes low price and inspection results independent of the weather, while the disadvantage includes the necessity of stopping the PV system and bringing the tester close to the module. Therefore, the instrument shall be used in combination with other inspection methods.)

(Source: Shikoku Electric Power Company, Inc.)

If an abnormal condition occurs in the inverter itself, or the grid side, it appears on the PCS panel and the protection panel for grid-interconnection. In this case, the operator shall follow the operation manual of the PCS and work in cooperation with the power company to determine whether to continue or stop the operation according to the range and degree of the problem.

Therefore, the operator shall have prior discussion with the power company to develop procedures for running, stopping, and restarting the system when an abnormal condition occurs as well as to build up a liaison system between the parties concerned, and both parties shall place their signatures on the Memorandum of Understanding (MOU).

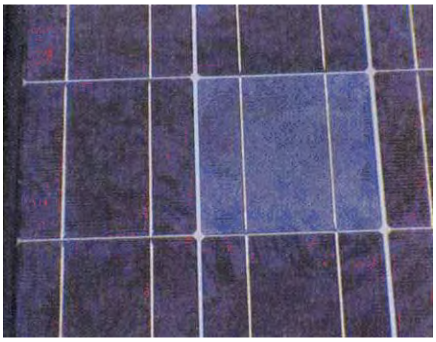


Figure 4-6: Discolored cells

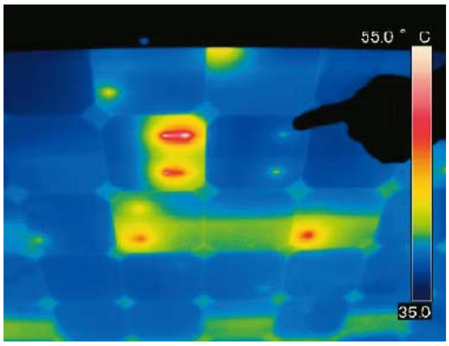


Figure 4-7: Heat due to failed soldering in the interconnection between cells

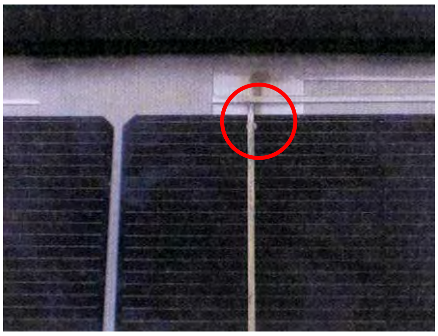


Figure 4-8: Browned soldered part of the bus bar of a module

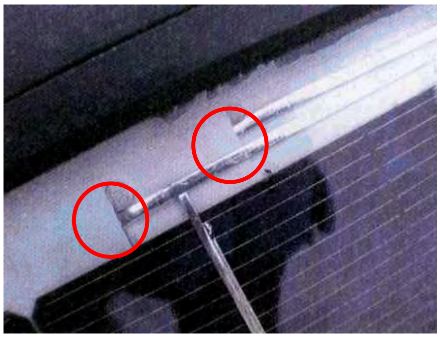


Figure 4-9: Air bubbles in a module

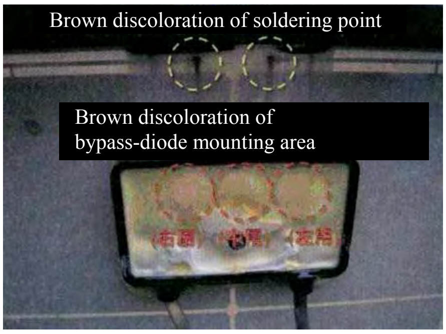


Figure 4-10: Solder browned due to heated bypass diodes

○If a shadow is cast on the PV module or a problem occurs in the internal circuit, a current flows through the corresponding bypass diode built in the terminal box on the back of the module, which causes the diode to be heated as shown in Figure 4-11

○In this case, the bypass current stops the power generation of the corresponding cluster. As a result, the cluster is heated as shown in Figure 4-12 because the whole solar energy on it is converted to heat rather than electric power.

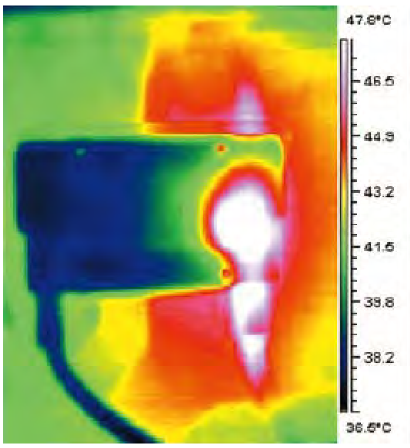


Figure 4-1: Heated bypass diode in a terminal box

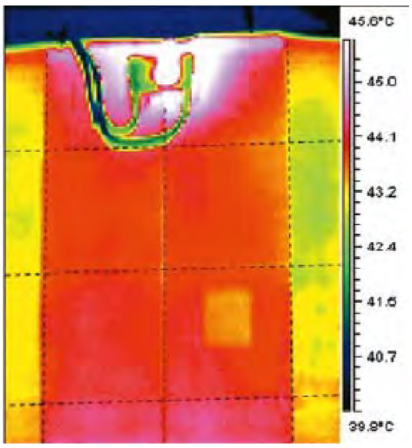
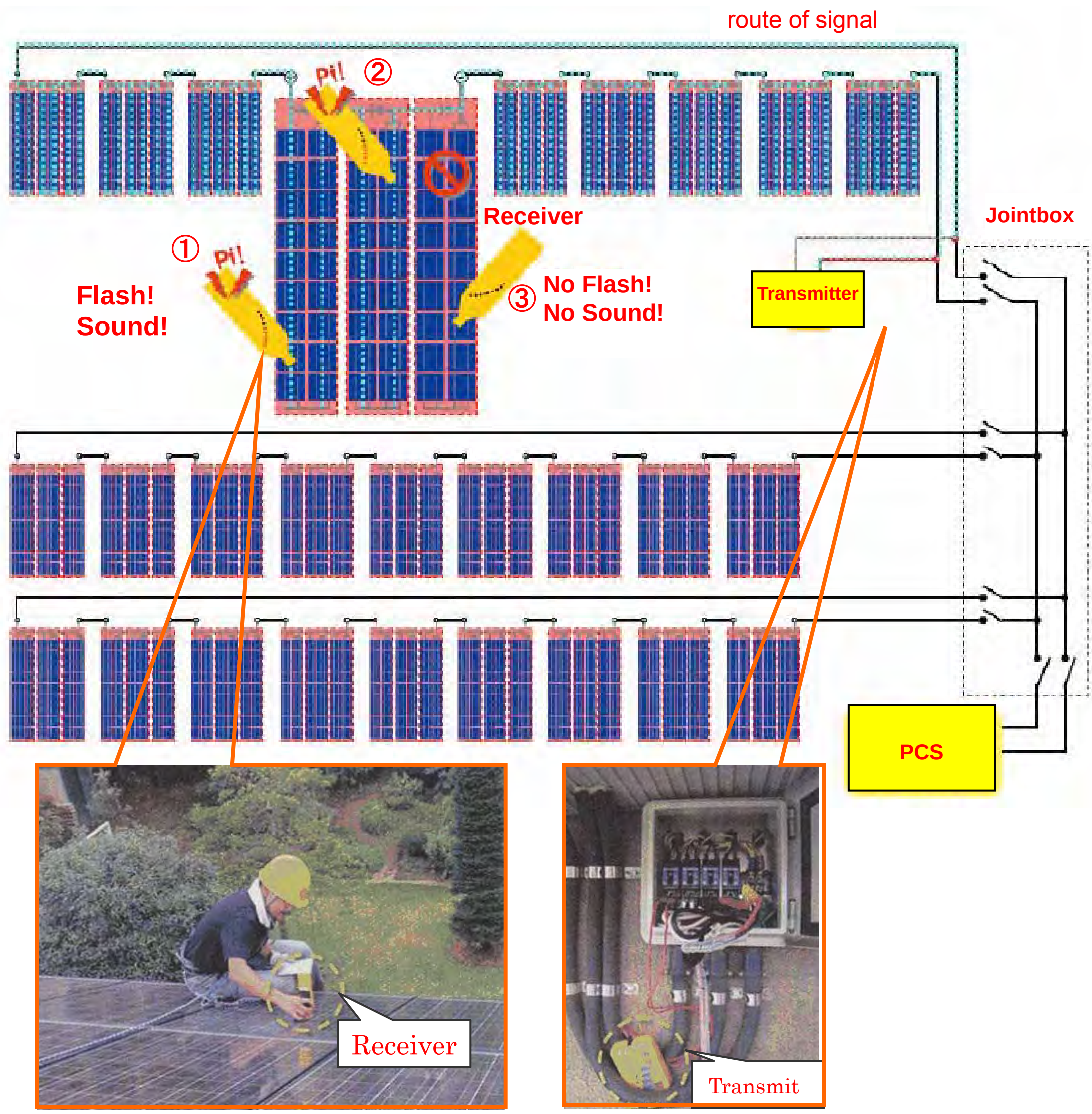


Figure 4-12: Heated cluster because a current flows through a bypass diode



(Source: Shikoku Electric Power Company, Inc.)

Figure 4-13: Conceptual diagram of detecting conductivity failures with a circuit probe

○ Detection principle: The transmitter connected to a circuit to be inspected sends s a minute current signal and the receiver detects the strength of a magnetic field induced by the circuit to check for contductivity.

○ Inspection procedures

1. Connect the transmitter to the lead wires of a module to be inspected in the junction box, and send a signal.
2. Bring the receiver close to the front or back of the module to check for reaction.
3. In a good portion, the LED blinks and the receiver sounds, while in a failed part, neither occurs. Accordingly, we can identify the continuity-failed portion.

The above figure shows that the receiver reacts at Points ① and ②because the connection is good, while it does not react at Point ③ because it has a break.