KINGDOM OF BHUTAN
DEPARTMENT OF ENERGY
MINISTRY OF ECONOMIC AFFAIRS

# THE PREPARATORY SURVEY
# ON
# RURAL ELECTRIFICATION PROJECT (PHASE-2)
# IN
# KINGDOM OF BHUTAN

# IMPLEMENTATION PROGRAM

**November 2010**

**JAPAN INTERNATIONAL COOPERATION AGENCY**

**NIPPON KOEI CO., LTD.**
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# TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

# List of Terms

| Abbreviations | English |
|---|---|
| | **Bhutan Agencies** |
| BBSC | Bhutan Broadcasting Service Corporation |
| BEA | Bhutan Electricity Authority |
| BHU | Basic Health Unit |
| BPC | Bhutan Power Corporation |
| BTL | Bhutan Telecom Ltd. |
| CA | Competent Authority |
| CHPCL | Chukha Hydro Power Corporation Ltd.<br>(former: Chukha Hydro Power Corporation: CHPC) |
| DCS | Distribution Construction Section |
| DFO | District Forestry Office |
| DHR | Department of Human Resources, under Ministry of Labor and Human Resources |
| DOA | Department of Agriculture |
| DOE | Department of Energy<br>(former: Department of Power) |
| DOF | Department of Forest<br>(former: Department of Forestry Services) |
| DOP | former: Department of Power<br>(now: Department of Energy) |
| DoSLR | Department of Survey and Land Records |
| DOR | Department of Roads |
| DYT | Dzongkhag Yargay Tshogdu<br>/ Dzongkhag Development Committee |
| GYT | Gewog Yargay Tshogdu<br>/ Gewog Development Committee |
| HSD | Hydromet Services Division |
| MTI | Ministry of Trade and Industry |
| MHA | former: Ministry of Home Affairs<br>(now: Ministry of Home and Cultural Affairs) |
| MoWHS, MWHS | Ministry of Works and Human Settlement |
| MOA | Ministry of Agriculture |
| MOF | Ministry of Finance |
| NEC | National Environment Commission |
| NECS | National Environment Commission Secretariat |
| RCSC | Royal Civil Service Commission |
| RED（DOE), DOE/RED | Renewable Energy Division |
| RED（BPC), BPC/RED | Rural Electrification Department |
| RGoB | Royal Government of Bhutan |
| RNR-RC | Renewable Natural Resources Research Centre |
| | |
| | **Foreign organizations** |
| ACB | Austrian Coordinate Bureau |
| ADB | Asian Development Bank |
| ADF | Asian Development Fund |
| ANSI | American National Standards Institute |
| DANIDA | Danish Development Assistance (under the Royal Danish Ministry of Foreign Affairs) |
| e7 | An international NGO consisted of major 9 electric power companies from the seven G7 member countries |
| EOJ | Embassy of Japan |
| GEF | Global Environment Facility |
| Helvetas | NGO based in Switzerland |

## List of Terms

| Abbreviations | English |
|---|---|
| IDA | International Development Association |
| IEC | International Electrotechnical Commission |
| IMF | International Monetary Fund |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| JBIC | Japan Bank for International Cooperation |
| JICA | Japan International Cooperation Agency (Japan) |
| NORAD | Norwegian Agency for Development Cooperation |
| PTC | Power Trading Corporation of India Ltd. |
| SDA | Sustainable Development Agreement, Netherlands |
| SDS | Sustainable Development Secretariat, Netherlands |
| SNV | Stichting Nederlandse Vrijwilligers; NPO established in Netherlands |
| UNDP | United Nations Development Programme |
| UNEP | United Nations Environment Programme |
| UNIDO | United Nations Industrial Development Organization |
| WB | World Bank |
| WWF | World Wildlife Fund |
| | |
| | **Unit/Technical Terms** |
| AAAC | All-Aluminum Alloy Conductor |
| AAC | All-Aluminum Conductor |
| ABC | Aerial Bundle Cable |
| ACSR | Aluminum Conductor Steel Reinforced |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection radiometer |
| AVR | Automatic Voltage Regulator |
| BS | British Standards |
| B-C, B/C | B: Benefit, C: Cost |
| CFL | Compact Fluorescent Lamp |
| Ch | Chetrum |
| EIRR, FIRR | Economic/Financial Internal Rate of Return |
| EL.(    ) m | Meters above Sea level |
| FY | Fiscal Year |
| GIS | Geographic Information System |
| GDP | Gross Domestic Product |
| GHG | Green House Gas |
| GWh | Giga Watt Hour (one billion watt hour) |
| HV | High Voltage |
| IRR | Internal Rates of Return |
| kW | kilo Watt |
| LED | Light Emitting Diode |
| LV | Low Voltage |
| MIS | Management Information System |
| MV | Middle Voltage |
| MW | Mega Watt (one million watt) |
| Nu. | Ngultrum; Bhutanese currency; 1 Nu. ≈ ¥2.6<br>US$1=45 Nu., if not specified |
| OPGW | Optical-Fiber Composite Overhead Ground Wire |
| Paise | Paisa (singular); Indian currency; Rs 1 = 100 paisa |
| PLC | Power Line Carrier |
| PV | Photovoltaic |
| SHS | Solar Home System |

## List of Terms

| Abbreviations | English |
|---|---|
| SHLS | Solar Home Lighting System |
| SHWS | Solar Hot Water System |
| SWER | Single Wire Earth Return |
| TOE | tonne of oil equivalent |
| USc | US Cent; $1 = 100 c |
| US$ | US Dollar |
| | |
| | **Others** |
| ARE | Accelerated Rural Electrification |
| BC | Biological Corridor |
| BLSS | Bhutan Living. Standard Survey |
| CDM | Clean Development Mechanism |
| Chimi | Member of Congress |
| DFO | Dzongkhag Forest Office |
| C/P | Counterpart |
| Dungkhag | Sub-district |
| Dungkhag Administration | Sub-district administration |
| Dungpa | Sub-district administrator |
| Dzongkhag | District |
| Dzongda | Governor of the district |
| Dzongkhag Administration | District administration |
| Dzongrab | Vice Governor of the district |
| EC | Environmental Clearance |
| EIA | Environment Impact Assessment |
| EMP | Environmental Management Plan |
| FYP | Five Year Plan |
| F/S | Feasibility Study |
| Gewog | Block |
| GNH | Gross National Happiness |
| Gup or Mandal | Executive Officer of Gewog |
| HEPP | Hydroelectric Power Project |
| ICB | International Competitive Bidding |
| IEE | Initial Environmental Examination |
| JBIC SAPROF Study | JBIC Special Assistance for Project Formation Study |
| JPST | JICA Preparatory Survey Team |
| IEMMP | Integrated Energy Management Master Plan |
| Kamzhing | Dry land |
| LCB | Local Competitive Bidding |
| L/A | Loan Agreement |
| Mangmi | Elected Representative of Gewog |
| MOU | Memorandum of Understanding |
| M/M | Minutes of Meeting |
| M/P | Master Plan |
| NGOs | Non Governmental Organizations |
| NOC | No Objection Certificate |
| ODA | Official Development Assistance |
| O&M | Operation and Maintenance |
| PA | Protected Area |
| PSMP | Power System Master Plan |
| RE | Rural Electrification |
| REC | Rural Electrification Center |
| REMP | Rural Electrification Master Plan |
| RESCO | Rural Electrification Service company |

# List of Terms

| Abbreviations | English |
|---|---|
| ADB PPTA | Project Preparatory Technical Assistance by ADB |
| ADB/RE-1 | Rural Electrification Programme Phase I funded by ADB |
| ADB/RE-2 | Rural Electrification Programme Phase II funded by ADB |
| ADB/RE-3 | Rural Electrification Programme Phase III funded by ADB |
| ADB/RE-4 | Rural Electrification Programme Phase IV funded by ADB |
| ADB/RE-5 | Rural Electrification Programme Phase V funded by ADB |
| SEA | Strategic Environmental Assessment |
| S/W | Scope of Works |
| TOR | Terms of Reference |
| T/A | Technical Assistance |
| Tshogpa | Member of the village council |
| VEC | Village Electrification Committee |

# CHAPTER 1 INTRODUCTION

## 1.1 Background

Bhutan has a net surplus of electricity as the installed generation capacity is more than the total domestic demand. Presently, only about 65% of Bhutan’s population has access to electricity. About 70% of the total population lives in rural areas and only about 50% of the total rural households have access to electrical lighting. Accordingly, the Royal Government of Bhutan (RGoB) is highly committed to develop and promote rural electrification (RE) projects, which are expected to bring immense socio-economic benefits and improve the living conditions of the rural people.

During the 10th Five Year Plan (10FYP) starting from 2008 until 2013, poverty alleviation has been included as a core theme in the development process. Moreover, making electricity accessible to the rural population through RE programs has been identified as one of the conduits for reducing poverty. Accordingly, the RGoB has targeted providing ‘Electricity for all’ by 2013. Coverage is expected to reach 84% of the population by 2012 with the completion of two ongoing projects supported by JICA and ADB simultaneously. Furthermore, RGoB requested the Japan International Cooperation Agency (JICA) and Asian Development Bank (ADB) to cover the balance of fund requirements to achieve the targeted ‘Electricity for all’ by 2013.

# CHAPTER 2 THE PROJECT

## 2.1 Project Scope

In consultation with JICA, ADB and the Austrian Government, the Bhutanese Government has divided the remaining rural electrification tasks into three packages by dzongkhag (district). The region that JICA is responsible for covers 11 dzongkhags which are mostly located in the west while ADB's are located in the east as shown in Figure-2.1.1. These 11 dzongkhags are Chukha, Dagana, Haa, Paro, Pemagatshel, Punakha, Samtse, Sarpang, Trongsa, Tsirang, and Wangdue Phodrang.

The original request for electrification was submitted by Department of Energy (DOE) after surveying and determining the alignments for middle voltage (MV) and low voltage (LV) lines as well as the location of pole-mounted transformers to extend the power grid to the target villages, based on the villages designated as "on-grid" by the JICA REMP. The target feeders are summarized in Table-2.1.1.

After consultation with BPC and DOE, the JICA Preparatory Survey Team (JPST) has proposed the addition of two project components to increase the reliability of power supply in the Project areas. First of the components is overhead shield wire and counterpoise installation to reduce lightning damages, and the other is automatic reclosing circuit breakers.

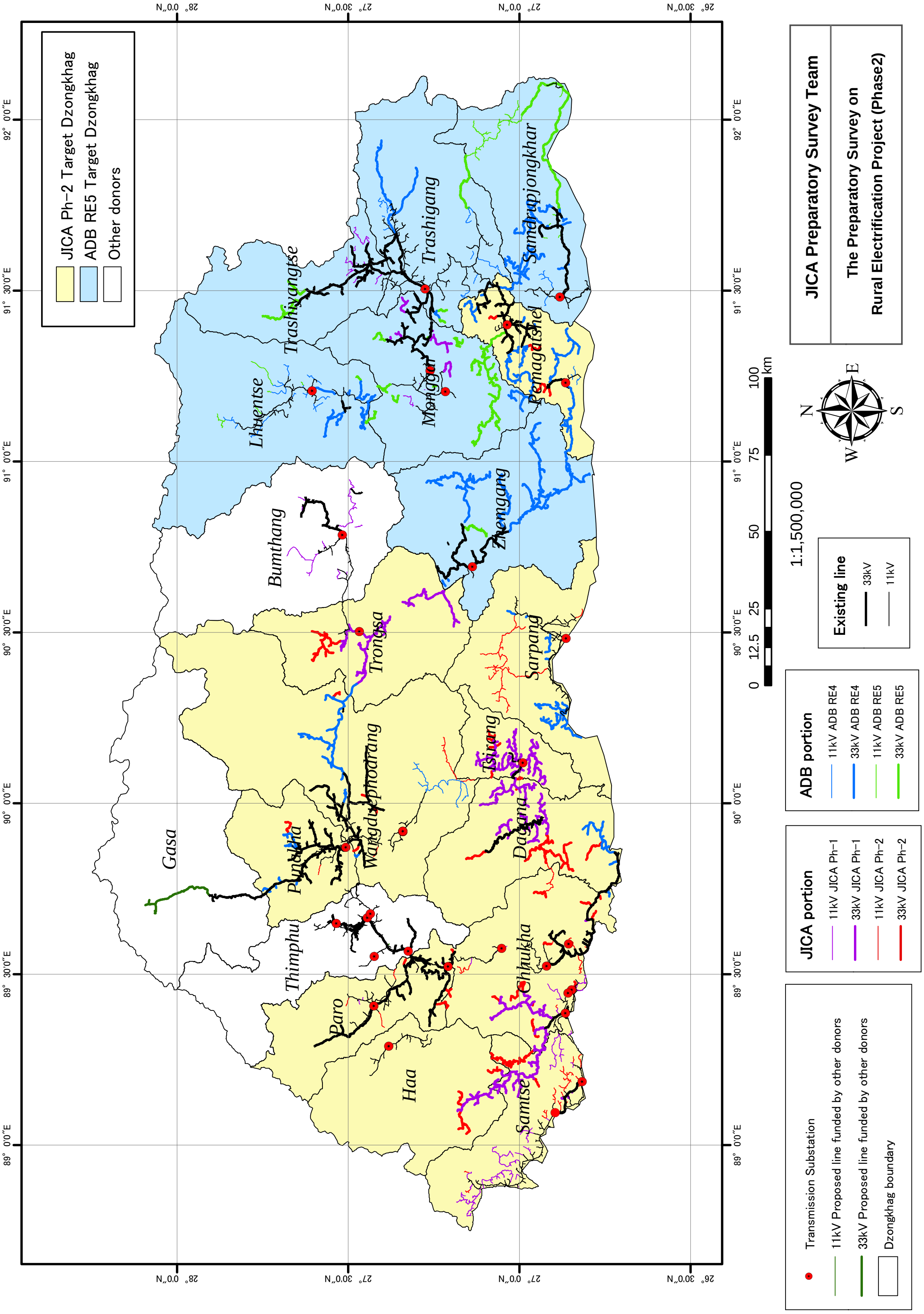



Figure-2.1.1 Target Dzongkhags of JICA RE-2 Project

## Table-2.1.1 Summary of the Target Feeders

| | No | Feeder | Total line Length | | Total Trans No. | Material cost (USD) | Erection cost (USD) | Headloading cost (USD) | Transportation cost (USD) | Total (USD) |
|---|---|---|---|---|---|---|---|---|---|---|
| Dzongkhag | | | MV(km) | LV (m) | | | | | | |
| Chhukha | 1 | ARE3B1 | 11.4 | 10,293 | 8 | 281,985 | 41,076 | 104,181 | 4,166 | 431,407 |
| | 2 | ARE3B2 | 1.3 | 4,042 | 1 | 59,662 | 7,922 | 20,901 | 905 | 89,390 |
| | 3 | ARE3B3 | 0.1 | 3,246 | 1 | 35,050 | 5,051 | 13,058 | 511 | 53,669 |
| | 4 | ARE3B4 | 6.0 | 3,299 | 3 | 121,627 | 17,193 | 43,989 | 2,007 | 184,817 |
| | 5 | ARE3B5 | 2.0 | 310 | 1 | 28,092 | 4,085 | 10,503 | 452 | 43,132 |
| | 6 | ARE3B6 | 19.9 | 10,606 | 9 | 375,730 | 55,192 | 145,018 | 5,499 | 581,439 |
| | 7 | ARE3B7 | 4.4 | 1,245 | 1 | 62,298 | 8,928 | 24,099 | 933 | 96,258 |
| | 8 | ARE3B8 | 7.4 | 3,039 | 3 | 138,380 | 18,720 | 48,865 | 2,306 | 208,271 |
| | 9 | ARE3B9 | 5.3 | 1,954 | 4 | 92,550 | 13,694 | 34,205 | 1,486 | 141,936 |
| | 10 | ARE3B10 | 1.9 | 2,226 | 1 | 43,109 | 6,058 | 16,121 | 664 | 65,951 |
| | 11 | ARE3B11 | 4.0 | 3,108 | 1 | 88,778 | 11,372 | 30,727 | 1,443 | 132,320 |
| | 12 | ARE3B12 | 2.4 | 454 | 1 | 33,927 | 4,885 | 12,782 | 538 | 52,132 |
| | 13 | ARE3B13 | 5.3 | 2,647 | 5 | 113,467 | 16,304 | 39,719 | 1,900 | 171,390 |
| | 14 | ARE3B14 | 1.2 | 482 | 1 | 21,165 | 3,108 | 7,721 | 347 | 32,342 |
| | 15 | ARE3B15 | 16.5 | 5,394 | 5 | 261,571 | 36,716 | 97,390 | 4,173 | 399,849 |
| | 16 | ARE1B16 | 11.1 | 3,059 | 5 | 169,516 | 25,565 | 66,248 | 3,098 | 264,427 |
| | 17 | ARE1B17 | 1.7 | 2,311 | 1 | 50,061 | 6,588 | 17,187 | 844 | 74,680 |
| | 18 | ARE3B18 | 4.1 | 951 | 1 | 55,499 | 7,948 | 21,369 | 848 | 85,664 |
| | 19 | ARE3B19 | 1.8 | 1,271 | 1 | 34,561 | 5,023 | 13,040 | 532 | 53,157 |
| | 20 | ARE3B20 | 5.4 | 4,063 | 2 | 121,405 | 15,887 | 41,927 | 1,969 | 181,188 |
| | 21 | ARE3B21 | 2.3 | 662 | 1 | 42,055 | 5,840 | 14,972 | 706 | 63,573 |
| | 22 | ARE3B22 | 3.6 | 1,200 | 1 | 52,834 | 7,568 | 20,288 | 806 | 81,496 |
| | 23 | ARE3B23 | 2.0 | 543 | 1 | 29,201 | 4,384 | 11,409 | 568 | 45,561 |
| | 24 | LV Extention | 0.0 | 2,007 | 1 | 21,934 | 3,234 | 7,944 | 338 | 33,450 |
| Dagana | 25 | ARE3C1 | 52.5 | 41,065 | 23 | 1,210,805 | 156,276 | 231,261 | 23,877 | 1,622,218 |
| | 26 | ARE3C2 | 0.8 | 4,289 | 2 | 69,571 | 8,088 | 11,985 | 1,324 | 90,969 |
| | 27 | ARE3C3 | 1.5 | 2,205 | 1 | 48,653 | 5,915 | 8,756 | 983 | 64,308 |
| | 28 | ARE3C4 | 9.0 | 4,024 | 3 | 142,348 | 19,394 | 28,691 | 2,793 | 193,226 |
| | 29 | ARE3C5 | 5.7 | 1,633 | 3 | 93,335 | 12,520 | 18,541 | 1,903 | 126,299 |
| | 30 | ARE3C6 | 2.5 | 1,676 | 1 | 44,595 | 5,996 | 8,870 | 888 | 60,349 |
| | 31 | ARE3C7 | 3.0 | 2,773 | 1 | 58,975 | 7,990 | 11,818 | 1,143 | 79,926 |
| | 32 | ARE3C8 | 2.3 | 2,763 | 1 | 51,482 | 6,949 | 10,279 | 999 | 69,709 |
| | 33 | LV Extention | 0.0 | 1,360 | 0 | 15,359 | 1,655 | 2,445 | 280 | 19,738 |
| Haa | 34 | ARE3E1 | 7.1 | 953 | 3 | 96,984 | 16,419 | 82,659 | 4,141 | 200,201 |
| | 35 | ARE3E2 | 7.5 | 1,833 | 3 | 113,256 | 18,955 | 95,891 | 4,652 | 232,754 |
| | 36 | ARE3E3 | 14.0 | 5,580 | 5 | 242,483 | 38,528 | 199,812 | 10,219 | 491,042 |
| Paro | 37 | ARE1H2 | 5.5 | 412 | 1 | 73,883 | 10,137 | 9,149 | 2,762 | 95,931 |
| | 38 | ARE3H3 | 1.6 | 269 | 1 | 25,266 | 3,268 | 3,107 | 970 | 32,611 |
| | 39 | LV Extention | 0.0 | 782 | 0 | 11,358 | 857 | 739 | 186 | 13,140 |
| Pemagatshel | 40 | ARE3I1 | 2.3 | 696 | 1 | 60,262 | 5,413 | 13,246 | 691 | 79,613 |
| | 41 | ARE3I2 | 7.6 | 7,088 | 5 | 181,023 | 25,883 | 62,573 | 3,551 | 273,030 |
| | 42 | ARE3I3 | 7.6 | 5,060 | 4 | 130,489 | 20,759 | 50,723 | 2,638 | 204,608 |
| | 43 | ARE3I4 | 3.4 | 4,326 | 1 | 75,497 | 10,768 | 27,457 | 1,431 | 115,153 |
| Punakha | 44 | ARE1J1 | 3.9 | 576 | 1 | 50,812 | 6,874 | 3,678 | 2,738 | 64,103 |
| | 45 | ARE3J2 | 6.6 | 5,572 | 4 | 137,130 | 17,535 | 9,998 | 5,979 | 170,641 |
| Samtse | 46 | ARE1L1 | 5.0 | 7,404 | 4 | 146,229 | 19,345 | 33,914 | 1,432 | 200,921 |
| | 47 | ARE1L2 | 7.5 | 5,064 | 3 | 139,707 | 19,227 | 33,965 | 1,439 | 194,338 |
| | 48 | ARE1L5 | 1.9 | 793 | 1 | 30,328 | 4,301 | 7,556 | 340 | 42,525 |
| | 49 | ARE1L6 | 25.8 | 31,346 | 25 | 696,281 | 92,888 | 162,023 | 7,172 | 958,363 |
| | 50 | ARE1L7 | 1.9 | 892 | 1 | 31,521 | 4,503 | 7,899 | 344 | 44,267 |
| | 51 | ARE1L9 | 6.6 | 2,769 | 5 | 113,289 | 15,989 | 27,829 | 1,284 | 158,391 |
| | 52 | ARE1L10 | 3.1 | 758 | 1 | 41,996 | 6,026 | 10,636 | 462 | 59,120 |
| | 53 | ARE1L11 | 3.3 | 6,506 | 3 | 122,590 | 15,813 | 27,658 | 1,192 | 167,254 |
| | 54 | ARE1L12 | 1.9 | 2,274 | 1 | 47,769 | 6,500 | 11,427 | 485 | 66,180 |
| | 55 | ARE3L1 | 38.9 | 62,080 | 37 | 1,351,776 | 172,450 | 300,538 | 12,086 | 1,836,849 |
| | 56 | ARE3L2 | 4.0 | 1,890 | 1 | 74,177 | 9,491 | 16,788 | 728 | 101,184 |
| Sarpang | 57 | ARE1M1 | 116.6 | 96,042 | 62 | 2,697,507 | 414,432 | 1,934,533 | 74,033 | 5,120,505 |
| | 58 | ARE1M2 | 2.4 | 3,258 | 3 | 85,820 | 15,587 | 59,980 | 2,092 | 163,480 |
| Trongsa | 59 | ARE3Q1 | 35.7 | 28,619 | 22 | 826,229 | 104,338 | 99,320 | 27,892 | 1,057,779 |
| Tsirang | 60 | ARE3R2 | 2.6 | 2,784 | 1 | 54,386 | 7,322 | 10,040 | 916 | 72,665 |
| | 61 | ARE3R3 | 5.5 | 5,816 | 3 | 119,628 | 16,019 | 22,021 | 2,049 | 159,718 |
| | 62 | ARE3R4 | 2.1 | 2,496 | 1 | 55,541 | 7,039 | 9,679 | 995 | 73,254 |
| | 63 | ARE3R5 | 2.3 | 3,848 | 1 | 71,085 | 8,796 | 12,069 | 1,246 | 93,196 |
| | 64 | ARE1R6 | 5.9 | 5,606 | 2 | 131,575 | 17,301 | 23,732 | 2,571 | 175,180 |
| | 65 | ARE3R7 | 2.2 | 2,311 | 1 | 54,515 | 6,859 | 9,434 | 981 | 71,789 |
| Wangdue | 66 | ARE3S3 | 2.5 | 146 | 1 | 31,053 | 4,098 | 5,725 | 1,584 | 42,459 |
| | 67 | ARE3S4 | 3.5 | 1,215 | 3 | 69,907 | 8,975 | 12,725 | 3,157 | 94,764 |
| | 68 | ARE3S5 | 0.1 | 391 | 1 | 13,012 | 1,561 | 2,259 | 552 | 17,384 |
| | 69 | ARE3S6 | 0.1 | 319 | 2 | 20,606 | 2,509 | 3,663 | 882 | 27,659 |
| | 70 | ARE3S7 | 1.8 | 28 | 1 | 24,309 | 3,233 | 4,570 | 1,141 | 33,254 |
| | 71 | ARE1S8 | 17.3 | 9,346 | 8 | 404,274 | 49,814 | 70,146 | 19,830 | 544,064 |
| Total | | | 566.0 | 447,351.2 | 317 | 12,723,137.0 | 1,766,929.8 | 4,675,469.3 | 278,073.8 | 19,443,610 |

(Prepared by JPST)

## 2.2 Design for the Project

### 2.2.1 Design Considerations

The “Electricity for All” by June, 2013 is publicly announced by RGoB, to realize the national target of electrification. ADB RE-5 and JICA RE-2 are planned to be implemented at the same time.

Actually, RE-5 Project by ADB and RE-2 Project by JICA are considered to be two projects from donor side. However, both projects aimed at the realization of “electrification for all”. Therefore, these two projects are considered as one project from Bhutan side.

Accordingly, the basic consideration including design concept, specifications and packaging of the project components for both projects should be coordinated.

Regarding the specifications, JICA RE-2 will basically also apply the PPTA’s specifications.

### 2.2.2 Difference in Design

At first JPST adopted the design concept of PPTA for the pole allocation, which means the standard span length is to be 100 m, however, sag and tension calculation revealed that this span length is too long to the AAAC conductor from the viewpoint of mechanical strength. Hence, the standard span length of 80 m has been adopted to AAAC covered conductors.

### 2.2.3 Comparison of Steel Pole and Telescopic Poles

(1) Workability and Technical Issues

The steel tubular poles have been used as supports for medium voltage (MV) lines and low voltage (LV) distribution lines. However, it becomes more difficult to transport poles to remote areas by human transportation due to the lengths and unit weights of the poles. It was studied and discussed to reduce the burden to the workers and reduce the construction period by shortening the carrying time through human transportation. Finally, it was decided to use telescopic poles as supports instead of steel tubular poles.

The requirement of newly introduced telescopic poles should have equivalent or higher specifications compared with steel tubular poles, which have been used up to the present. Table-2.2.1 shows that newly introduced telescopic poles meet the requirements in place of steel tubular poles. Telescopic poles have an advantage that the surface of the pole is galvanized, hence application of anticorrosive paint at site is not required.

Table-2.2.1 Specifications of Tubular and Telescopic Pole

| Voltage | Steel Tubular pole | | Telescopic pole | | |
|---|---|---|---|---|---|
| | Length | Strength | Length | Strength | Remarks |
| LV | 7.0 (m) | 1.81 (kN) | 9.0 (m) | 3.29 (kN) | |
| 11kV | 9.0 (m) | 1.93 (kN) | 11.2 (m) | 3.29 (kN) | Without shielding wire |
| | | | 12.0 (m) | 3.29 (kN) | With shielding wire |
| 33kV | 10.0 (m) | 2.02 (kN) | 11 (m) | 3.29 (kN) | Without shielding wire |
| | | | 12.0 (m) | 3.29 (kN) | With shielding wire |

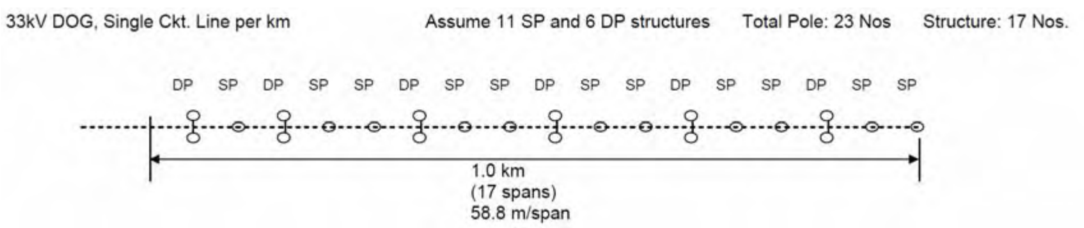
Source: BPC

(2) Cost Comparison

The comparison on the material cost per 1 km between tubular and telescopic poles with 33 kV, 3-phase dog conductor, fittings and civil materials is shown in Table-2.2.2 and 2.2.3. The assumption of the standard span for each pole is as shown in Figure-2.2.1 and 2.2.2.

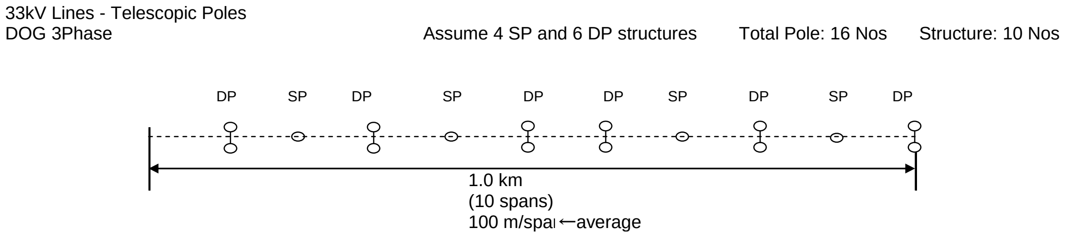
According to the basic design of ADB RE-5, the allocation schedule for telescopic poles per one kilometer consists of six sets of double pole arrangement, and four sets of single pole arrangement. Accordingly, the average span length is to be 100 m, and 16 poles are required for one kilometer line length.

The material cost of telescopic poles is Nu.660,331 per km, which is 8.3% more expensive than that of tubular poles because of the high unit cost of telescopic pole itself, though the shorter standard span of telescopic poles allows less number of necessary poles, fittings and civil material. In the case of other types of conductor, the difference in cost shows almost the same trend.




(Prepared by JPST)

Figure-2.2.1 Standard Span for Tubular Poles




(Prepared by JPST)

Figure-2.2.2 Standard Span for Telescopic Poles

Table-2.2.2 Bill of Materials for 33 kV line with Tubular Pole per 1 km

**Bill of Materials for 33 kV single circuit line (3 Φ) with DOG conductor**
**Length of line : 1.000 Km**

| Sl.# | Description of items | Unit | Total quantity | Unit cost (Nu.) | Total cost (Nu.) |
|---|---|---|---|---|---|
| **I** | **Foreign Materials** | | | | |
| 1 | Steel tubular poles 10 mtr. long with base plate, fixing bolts, etc. | No. | 23 | 9,512.80 | 218,794.40 |
| 2 | Single pole cross arm assembly complete with M&U clamps, nuts, bolts and other accessories. | Set | 11 | 967.50 | 10,642.45 |
| 3 | Top hamper assembly complete with M&U clamps, nuts, bolts and other accessories. | Set | 11 | 515.10 | 5,666.06 |
| 4 | Cross arm assembly for H-frame (O) complete with M clamps, nuts, bolts and other accessories. | Set | 6 | 3,965.11 | 23,790.65 |
| 5 | Cross brace arm assembly for H-frame with full clamps, nuts, bolts and other accessories. | Set | 6 | 2,837.63 | 17,025.75 |
| 6 | G.I. stay set assembly ( 1 no. turn buckle, 1 no. stay rod with base plate) | Set | 12 | 1,154.60 | 13,855.20 |
| 7 | 33 kV stay insulator | No. | 12 | 89.72 | 1,076.68 |
| 8 | G.I. stay wire 7/8 SWG | Kg | 120 | 79.99 | 9,599.28 |
| 9 | Stay clamp assembly | Set | 12 | 283.22 | 3,398.66 |
| 10 | Polymer Strain Insulator 33kV | Set | 36 | 1,323.68 | 47,652.64 |
| 11 | 33 kV pin insulator assembly with pin | Set | 33 | 787.51 | 25,987.78 |
| 12 | Preform dead end terminations - DOG | No. | 36 | 161.00 | 5,796.00 |
| 13 | Tension joints - DOG | No. | 9 | 250.79 | 2,257.13 |
| 14 | ACSR conductor - DOG | Km | 3.100 | 59,455.00 | 184,310.50 |
| 15 | P.G. clamp for DOG | No. | 18 | 55.13 | 992.36 |
| 16 | Spike earthing set 2500x20 mm complete with connecting plates, nuts & bolts with 4 metre G.I. wire 8 SWG . | Set | 23 | 450.24 | 10,355.44 |
| 17 | Barbed wire | Kg | 84 | 79.99 | 6,719.50 |
| 18 | Danger plate (enamelled) 33 kV | No. | 17 | 141.61 | 2,407.39 |
| 19 | Bituminous aluminium paint | Ltr. | 0 | 136.85 | 0.00 |
| 20 | Bituminous black paint | Ltr. | 8 | 73.95 | 591.56 |
| 21 | Miscellaneous items (1% on above) | | | 0.00 | 5,909.19 |
| | **Foreign material cost (Nu.)** | | | | **596,828.61** |
| **II** | **Local Materials** | | | | |
| 21 | Cement | MT | 1.3 | 3,440.00 | 4,472.00 |
| 22 | Sand | Cft | 42 | 23.00 | 966.00 |
| 23 | Stone chips 20 mm | Cft | 94 | 23.00 | 2,162.00 |
| 24 | Boulder for double pole bonding | Cft | 94 | 57.50 | 5,405.00 |
| | **Local material cost (Nu.)** | | | | **13,005.00** |
| | **Total material cost (Nu.)** | | | | **609,833.61** |

(Prepared by JPST)

Table-2.2.3 Bill of Materials for 33 kV line with Telescopic Pole per 1 km

**Bill of Materials for 33 kV single circuit line (3 Φ) with DOG conductor**
**Length of line : 1.000 km**

| Sl.# | Description of items | Unit | Total quantity | Unit cost (Nu.) | Total cost (Nu.) |
|---|---|---|---|---|---|
| I | **Foreign Materials** | | | | |
| 1 | Steel telescopic poles 11 mtr. long with base plate, fixing bolts, etc. | No. | 16 | 18,254.70 | 292,075.20 |
| 2 | 33 kV single pole cross arm assembly complete with M&U clamps, nuts, bolts and other accessories. | Set | 4 | 967.50 | 3,869.98 |
| 3 | 33 kV top hamper assembly complete with M&U clamps, nuts, bolts and other accessories. | Set | 4 | 515.10 | 2,060.39 |
| 4 | 33 kV cross arm assembly for H-frame (O) complete with M clamps, nuts, bolts and other accessories. | Set | 6 | 3,965.11 | 23,790.65 |
| 5 | 33 kV cross brace arm assembly for H-frame with full clamps, nuts, bolts and other accessories. | Set | 6 | 2,837.63 | 17,025.75 |
| 6 | G.I. stay set assembly ( 1 no. turn buckle, 1 no. stay rod with base plate) | Set | 10 | 1,154.60 | 11,546.00 |
| 7 | 33 kV stay insulator | No. | 10 | 89.72 | 897.23 |
| 8 | G.I. stay wire 7/8 GSW | kg | 120 | 79.99 | 9,599.28 |
| 9 | Stay clamp assembly, 33 kV | Set | 10 | 283.22 | 2,832.22 |
| 10 | Polymer Strain Insulator 33kV | Set | 36 | 1,323.68 | 47,652.64 |
| 11 | 33 kV pin insulator assembly with pin | Set | 12 | 787.51 | 9,450.10 |
| 12 | Preform dead end terminations - DOG | No. | 36 | 161.00 | 5,796.00 |
| 13 | Tension joints - DOG | No. | 9 | 250.79 | 2,257.13 |
| 14 | ACSR conductor - DOG | km | 3.100 | 59,455.00 | 184,310.50 |
| 15 | P.G. clamp for DOG | No. | 18 | 55.13 | 992.36 |
| 16 | Spike earthing set 2500x20 mm complete with connecting plates, nuts & bolts with 4 metre G.I. wire 8 GSW . | Set | 16 | 450.24 | 7,203.78 |
| 17 | Barbed wire | kg | 200 | 79.99 | 15,998.80 |
| 18 | Danger plate (enamelled) 33 kV | No. | 10 | 141.61 | 1,416.11 |
| 19 | Bituminous aluminium paint | Ltr. | 0 | 136.85 | 0.00 |
| 20 | Bituminous black paint | Ltr. | 20 | 73.95 | 1,478.90 |
| 21 | Miscellaneous items (1% on above) | | | 0.00 | 6,402.53 |
| | **Foreign material cost (Nu.)** | | | | **646,655.55** |
| II | **Local Materials** | | | | |
| 21 | Cement | MT | 1.3 | 3,956.00 | 5,142.80 |
| 22 | Sand | Cft | 42 | 23.00 | 966.00 |
| 23 | Stone chips 20 mm aggregate | Cft | 94 | 23.00 | 2,162.00 |
| 24 | Boulder for double pole bonding | Cft | 94 | 57.50 | 5,405.00 |
| | **Local material cost (Nu.)** | | | | **13,675.80** |
| | **Total material cost (Nu.)** | | | | **660,331.35** |

(Prepared by JPST)

### 2.2.4 Conductor Sag

(1) Conductor sag

The drawings which were prepared by PPTA in Figure-2.2.3 and 2.2.4 show that the clearance above ground to the cross arm is 7.22 m for single pole and 8.27 m for double pole, respectively. The clearance to be kept for 33 kV and 11 kV lines are specified as 6.1 m for road crossings and 5.8 m elsewhere.

As also shown in Fig. 2.2.2, single poles and double poles are allocated alternately, i.e., the sag and tension of the conductors are decided to keep the aforementioned ground clearance.

The conductor sag is considered as follows to keep the ground clearance of 5.8 m (Ground clearance of 6.1 m for "road crossings" is not considered, because poles usually be constructed near the road when the MV line crosses the road.):

Conductor sag = ((7.22 – 5.8) + (8.27 – 5.8)) / 2 = 1.94 m

Therefore, the conductor tension is decided with 1.94 m sag as a maximum value.

Conditions of sag calculation are as follows:

a. Safety factor of conductor: more than 2.5
b. Wind pressure on conductor: 44.86 kgf/sqm
c. Load condition (high): 15 ℃
d. Load condition (low): -10 ℃

a. ACSR

The conductors for 11 kV and 33 kV MV lines consist of aluminum conductor steel reinforced (ACSR) dog and rabbit conductors with their specifications shown in Table-2.2.4.

Table-2.2.4 Specifications of ACSR Dog and Rabbit Conductors

| Kind of conductor | Dog | Rabbit |
|---|---|---|
| Sectional area (sqmm) | 118.5 | 61.7 |
| Outer diameter (mm) | 14.15 | 10.05 |
| Weight (kg/m) | 0.394 | 0.214 |
| Elastic modulus (kg/sqmm) | 7,990 | 8,400 |
| Ultimate Tensile Strength (kg) | 3,340 | 1,870 |
| Coefficient of linear expansion (℃) | 0.0000195 | 0.0000189 |

Source: BS 215 Part2

To decide the sag and tension, the maximum working tension of rabbit conductor for a span length of 100 m is assumed and calculated as shown in Table-2.2.5. It is decided that the maximum tension of rabbit should be 600 kgf with 1.93 m sag at 75 degree Celsius.

Same study has been made for dog conductors, and it was decided that its maximum working tension should be 1,100 kgf with 1.89 m sag at 75 degree Celsius as shown in Table-2.2.6.

Table-2.2.5 Case Study for Rabbit Conductor

| Conductor Temperature (deg-C) | Max. working tension 400 (kg) | | Max. working tension 500 (kg) | | Max. working tension 600 (kg) | |
|---|---|---|---|---|---|---|
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | |
| -10 | 242.5 | 1.10 | 365.5 | 0.73 | 495.5 | 0.54 |
| 0 | 207.0 | 1.29 | 302.0 | 0.89 | 414.8 | 0.64 |
| 10 | 180.8 | 1.48 | 251.8 | 1.06 | 343.4 | 0.78 |
| 15 | 170.3 | 1.57 | 231.4 | 1.16 | 312.1 | 0.86 |
| 20 | 161.2 | 1.66 | 213.9 | 1.25 | 284.1 | 0.94 |
| 30 | 146.1 | 1.83 | 186.0 | 1.44 | 238.1 | 1.12 |
| 40 | 134.2 | 1.99 | 165.1 | 1.62 | 203.9 | 1.31 |
| 50 | 124.5 | 2.15 | 149.1 | 1.79 | 178.5 | 1.50 |
| 60 | 116.6 | 2.30 | 136.6 | 1.96 | 159.4 | 1.68 |
| 70 | 109.9 | 2.44 | 126.5 | 2.12 | 144.7 | 1.85 |
| 75 | 106.9 | 2.50 | 122.2 | 2.19 | 138.6 | 1.93 |
| 90 | 99.3 | 2.70 | 111.3 | 2.41 | 123.6 | 2.16 |
| 120 | 87.7 | 3.05 | 95.9 | 2.79 | 103.7 | 2.58 |

(Prepared by JPST)

Table-2.2.6 Case Study for Dog Conductor

| Conductor Temperature (deg-C) | Max. working tension 800 (kg) | | Max. working tension 900 (kg) | | Max. working tension 1,000 (kg) | | Max. working tension 1,100 (kg) | |
|---|---|---|---|---|---|---|---|---|
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | | | |
| -10 | 623.1 | 0.79 | 745.7 | 0.66 | 867.2 | 0.57 | 986.0 | 0.50 |
| 0 | 513.3 | 0.96 | 613.7 | 0.80 | 719.6 | 0.68 | 827.9 | 0.59 |
| 10 | 429.0 | 1.15 | 505.9 | 0.97 | 591.8 | 0.83 | 684.7 | 0.72 |
| 15 | 395.5 | 1.25 | 461.7 | 1.07 | 537.0 | 0.92 | 620.8 | 0.79 |
| 20 | 366.8 | 1.34 | 423.5 | 1.16 | 488.8 | 1.01 | 562.9 | 0.87 |
| 30 | 321.1 | 1.53 | 362.8 | 1.36 | 410.8 | 1.20 | 466.6 | 1.06 |
| 40 | 286.9 | 1.72 | 318.2 | 1.55 | 353.5 | 1.39 | 394.4 | 1.25 |
| 50 | 260.5 | 1.89 | 284.6 | 1.73 | 311.3 | 1.58 | 341.5 | 1.44 |
| 60 | 239.7 | 2.06 | 258.8 | 1.90 | 279.4 | 1.76 | 302.3 | 1.63 |
| 70 | 222.8 | 2.21 | 238.3 | 2.07 | 254.7 | 1.93 | 272.5 | 1.81 |
| 75 | 215.5 | 2.29 | 229.6 | 2.15 | 244.3 | 2.02 | 260.2 | 1.89 |
| 90 | 197.1 | 2.50 | 207.9 | 2.37 | 219.0 | 2.25 | 230.6 | 2.14 |
| 120 | 170.7 | 2.89 | 177.7 | 2.77 | 184.7 | 2.67 | 191.7 | 2.57 |

(Prepared by JPST)

b. AAAC covered conductor

Two kinds of AAAC (all aluminum alloy conductor) covered conductor, namely, hydrogen and fluorine, will be used in the protected area. Their specifications are shown in Table-2.2.7. The sag and tension of these conductors are studied in the same manner as the ACSR's.

Table-2.2.8 and 2.2.9 show the sag and tension of two AAACs for the span lengths of 60 m, 80 m and 100 m.

Table-2.2.9 shows that the maximum applicable span length should be 80 m with maximum working tension of 460 kgf. This maximum working tension indicates that the safety factor of the conductor for ultimate tensile strength is 2.6. Accordingly, the standard span length for AAAC conductors should be 80 m instead of 100 m in the case of ACSR.

From this view point, the maximum working tension of hydrogen is also decided to be 850 kgf with 1.86 m sag at 75 degrees Celsius as shown in Table-2.2.9..

Table-2.2.7 Specifications of Hydrogen and Fluorine

| Kind of conductor | Hydrogen | Fluorine |
|---|---|---|
| Sectional area (sqmm) | 111.3 | 49.48 |
| Outer diameter (mm) | 20.3 | 15.3 |
| Weight (kg/m) | 0.485 | 0.26 |
| Elastic modulus (kgf/sqmm) | 6,500 | 6,500 |
| Ultimate Tensile Strength (kg) | 2,470 | 1,200 |
| Coefficient of linear expansion (℃) | 0.000023 | 0.000023 |

Source: BPC

Table-2.2.8 Case Study for AAAC (Fluorine)

| Max. working tension 400 (kg) | | | | | | |
|---|---|---|---|---|---|---|
| Conductor Temperature (deg-C) | Span length : 60 (m) | | Span length : 80 (m) | | Span length : 100 (m) | |
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | |
| -10 | 279.3 | 0.42 | 225.3 | 0.92 | 192. 7 | 1. 69 |
| 0 | 227.0 | 0.52 | 193.0 | 1.08 | 174. 0 | 1. 87 |
| 10 | 185.0 | 0.63 | 168.2 | 1.24 | 159. 0 | 2. 04 |
| 15 | 168.1 | 0.70 | 158.2 | 1.32 | 152. 6 | 2. 13 |
| 20 | 153.8 | 0.76 | 149.3 | 1.39 | 146. 9 | 2. 21 |
| 30 | 131.2 | 0.89 | 134.8 | 1.54 | 136. 8 | 2. 38 |
| 40 | 114.9 | 1.02 | 123.2 | 1.69 | 128. 4 | 2. 53 |
| 50 | 102.8 | 1.14 | 114.0 | 1.83 | 121. 3 | 2. 68 |
| 60 | 93.5 | 1.25 | 106.4 | 1.96 | 115. 1 | 2. 83 |
| 70 | 86.1 | 1.36 | 100.0 | 2.08 | 109. 7 | 2. 97 |
| 75 | 83.0 | 1.41 | 97.2 | 2.14 | 107. 3 | 3. 03 |
| 90 | 75.2 | 1.56 | 89.9 | 2.32 | 100. 8 | 3. 23 |
| 120 | 64.4 | 1.82 | 79.0 | 2.64 | 90. 6 | 3. 59 |

(Prepared by JPST)

Table-2.2.9 Case Study for AAAC (Fluorine)

| Max. working tension 460 (kg) | | | | | | |
|---|---|---|---|---|---|---|
| Conductor Temperature (deg-C) | Span length : 60 (m) | | Span length : 80 (m) | | Span length : 100 (m) | |
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | |
| -10 | 362.1 | 0.32 | 304.3 | 0.68 | 256. 5 | 1. 27 |
| 0 | 299.6 | 0.39 | 256.1 | 0.81 | 224. 5 | 1. 45 |
| 10 | 244.1 | 0.48 | 217.0 | 0.96 | 199. 2 | 1. 63 |
| 15 | 219.9 | 0.53 | 200.7 | 1.04 | 188. 6 | 1. 72 |
| 20 | 198.4 | 0.59 | 186.5 | 1.12 | 179. 2 | 1. 81 |
| 30 | 163.5 | 0.72 | 163.3 | 1.27 | 163. 2 | 1. 99 |
| 40 | 138.3 | 0.85 | 145.6 | 1.43 | 150. 3 | 2. 16 |
| 50 | 120.1 | 0.97 | 131.8 | 1.58 | 139. 7 | 2. 33 |
| 60 | 106.7 | 1.10 | 120.9 | 1.72 | 130. 8 | 2. 49 |
| 70 | 96.5 | 1.21 | 112.1 | 1.86 | 123. 3 | 2. 64 |
| 75 | 92.3 | 1.27 | 108.3 | 1.92 | 120. 0 | 2. 71 |
| 90 | 82.1 | 1.43 | 98.6 | 2.11 | 111. 3 | 2. 92 |
| 120 | 68.7 | 1.71 | 84.9 | 2.45 | 98. 2 | 3. 32 |

(Prepared by JPST)

Table-2.2.10 Case Study for AAAC (Hydrogen)

| Max. working tension 800 (kg) | | | | | | |
|---|---|---|---|---|---|---|
| Conductor Temperature (deg-C) | Span length : 60 (m) | | Span length : 80 (m) | | Span length : 100 (m) | |
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | |
| -10 | 675.4 | 0.32 | 603.6 | 0.64 | 540.9 | 1.12 |
| 0 | 540.6 | 0.40 | 496.7 | 0.78 | 463.0 | 1.31 |
| 10 | 427.0 | 0.51 | 412.8 | 0.94 | 402.9 | 1.51 |
| 15 | 380.3 | 0.57 | 379.1 | 1.02 | 378.3 | 1.60 |
| 20 | 340.7 | 0.64 | 350.2 | 1.11 | 356.8 | 1.70 |
| 30 | 280.0 | 0.78 | 304.3 | 1.28 | 321.1 | 1.89 |
| 40 | 238.2 | 0.92 | 270.1 | 1.44 | 293.0 | 2.07 |
| 50 | 208.6 | 1.05 | 244.0 | 1.59 | 270.4 | 2.24 |
| 60 | 186.9 | 1.17 | 223.5 | 1.74 | 251.9 | 2.41 |
| 70 | 170.3 | 1.28 | 207.1 | 1.87 | 236.5 | 2.57 |
| 75 | 163.4 | 1.34 | 200.1 | 1.94 | 229.7 | 2.64 |
| 90 | 146.5 | 1.49 | 182.3 | 2.13 | 212.1 | 2.86 |
| 120 | 123.8 | 1.76 | 157.1 | 2.47 | 186.1 | 3.26 |

(Prepared by JPST)

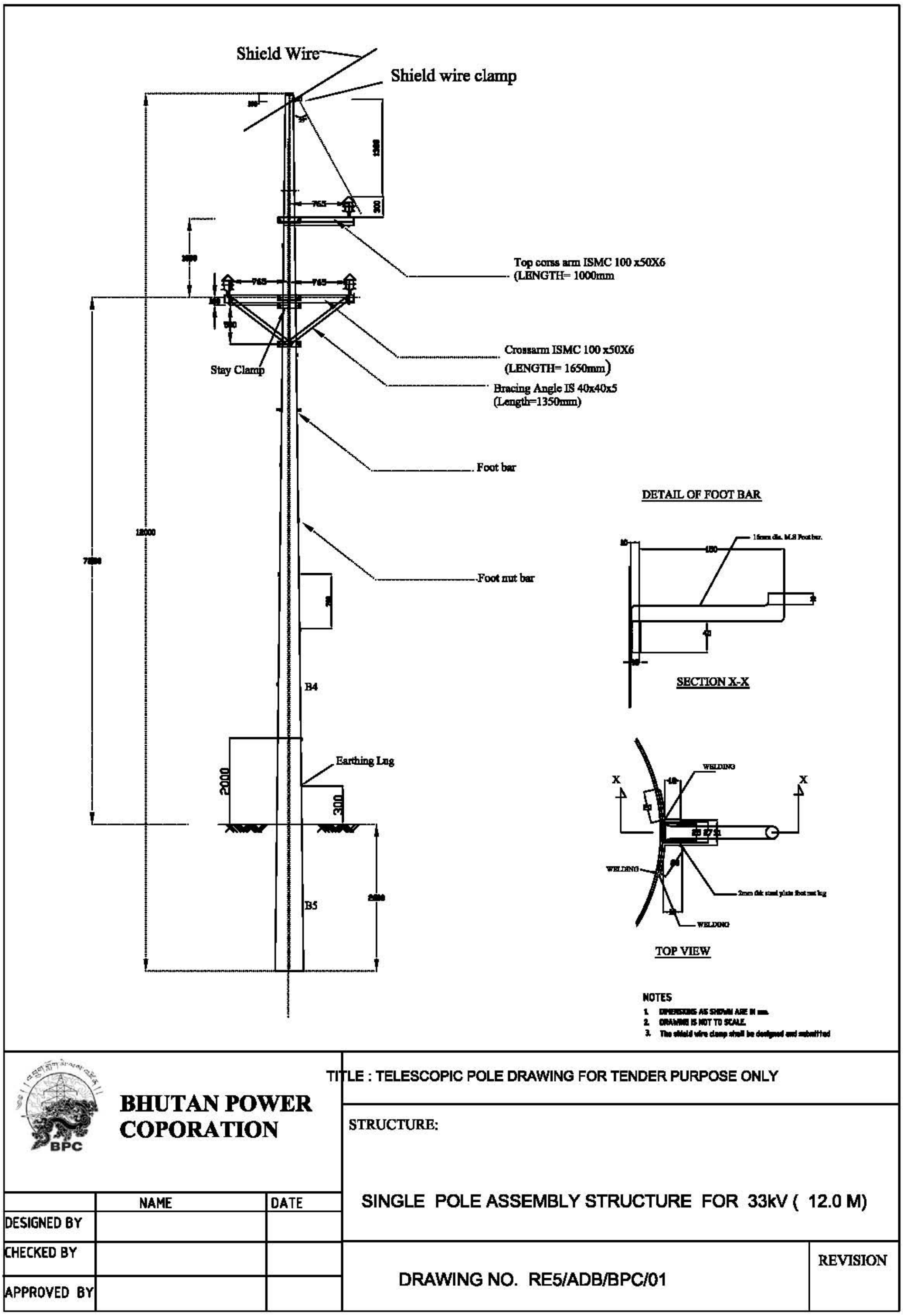
Table-2.2.11 Case Study for AAAC (Hydrogen)

| Max. working tension 850 (kg) | | | | | | |
|---|---|---|---|---|---|---|
| Conductor Temperature (deg-C) | Span length : 60 (m) | | Span length : 80 (m) | | Span length : 100 (m) | |
| | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) | Horizontal Tension (kgf) | Sag (m) |
| | | | | | | |
| -10 | 741.3 | 0.29 | 674.0 | 0.58 | 609.7 | 0.99 |
| 0 | 599.6 | 0.36 | 555.1 | 0.70 | 517.5 | 1.17 |
| 10 | 475.3 | 0.46 | 458.0 | 0.85 | 444.8 | 1.36 |
| 15 | 422.4 | 0.52 | 418.1 | 0.93 | 415.0 | 1.46 |
| 20 | 376.4 | 0.58 | 383.7 | 1.01 | 388.9 | 1.56 |
| 30 | 304.8 | 0.72 | 328.8 | 1.18 | 346.0 | 1.75 |
| 40 | 255.3 | 0.86 | 288.4 | 1.35 | 312.7 | 1.94 |
| 50 | 220.9 | 0.99 | 258.1 | 1.50 | 286.3 | 2.12 |
| 60 | 196.0 | 1.11 | 234.7 | 1.65 | 265.0 | 2.29 |
| 70 | 177.3 | 1.23 | 216.1 | 1.80 | 247.4 | 2.45 |
| 75 | 169.6 | 1.29 | 208.2 | 1.86 | 239.7 | 2.53 |
| 90 | 151.1 | 1.45 | 188.6 | 2.06 | 220.1 | 2.76 |
| 120 | 126.6 | 1.73 | 161.2 | 2.41 | 191.5 | 3.17 |

(Prepared by JPST)

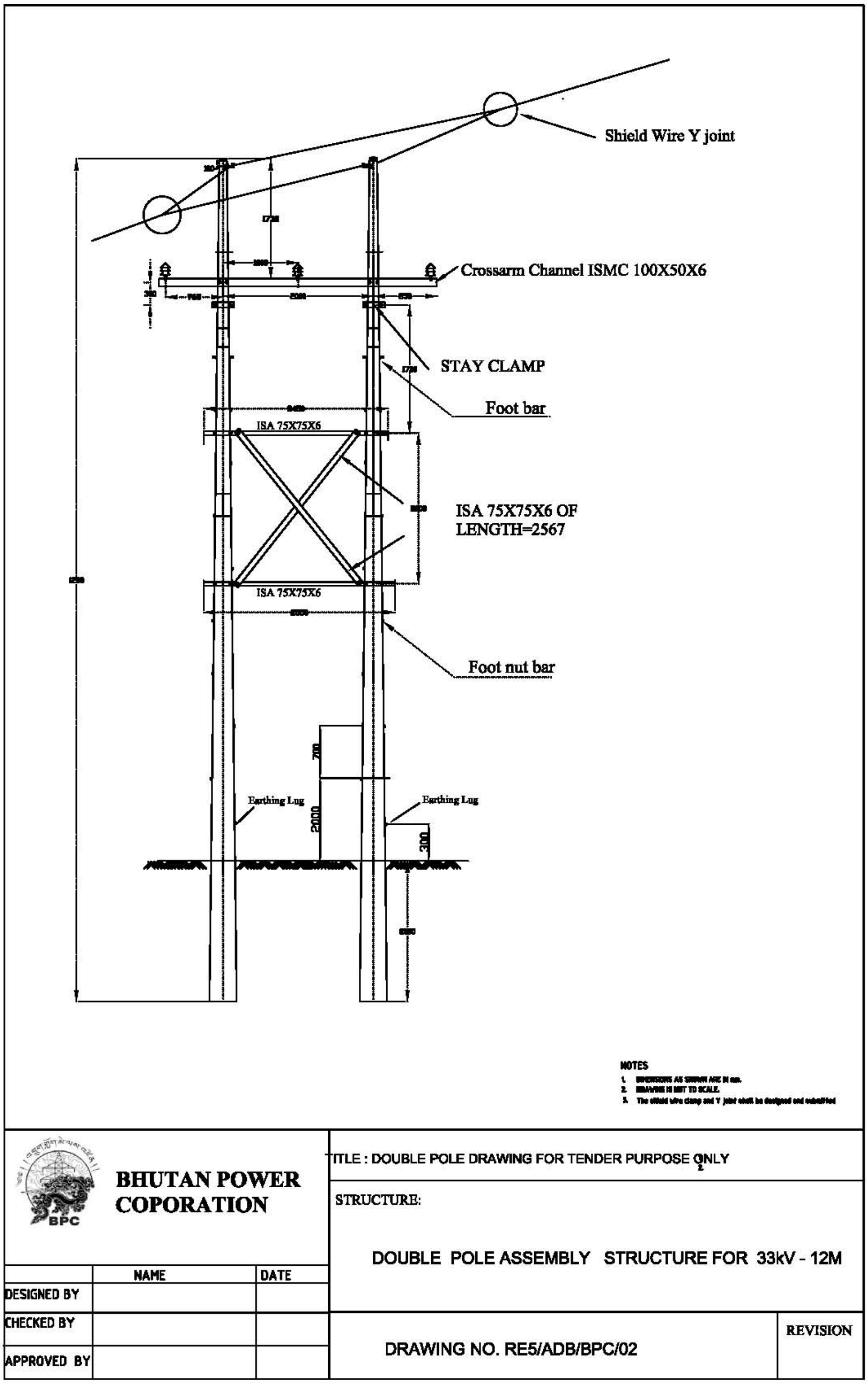
(2) Sag Calculation of Conductors

Table-2.2.5, 2.2.6, 2.2.8, 2.2.9, 2.2.10 and 2.2.11 show the summarized sag and tension of conductors. These summarized data are obtained from Appendix-I in the main report.




Source: BPC

Figure-2.2.3 Single Pole Assembly Structure for 33 kV Prepared by ADB PPTA




Source: BPC

Figure-2.2.4 Double Pole Assembly Structure for 33 kV Prepared by ADB PPTA

### 2.2.5 Lightning Prone Area

(1) Analysis of Power Interruption Records and Lightning Prone Area

As mentioned in the Minutes of the Meeting between ADB and BPC (see Annexture-1 attached), the power interruption and damages on the distribution facilities especially pole mounted transformers are seriously recognized by BPC. Hence, BPC intends to take countermeasures to reduce such power interruptions and damages on distribution facilities, by installing overhead ground wire to their MV lines.

Firstly, lightning prone area in Bhutan has to be identified, as it occupies an area covering 300 km from east to west and 150 km from south to north. Also, regarding climate conditions, its southern border with India is within a subtropical zone with high precipitation while the northern area is within high mountains with low temperature and less precipitation.

Accordingly, it was considered that lightning prone area is to be identified by analyzing the power interruption records of BPC distribution facilities.

The power interruption record was gathered and managed at the Distribution & Customer Service Department (DCSD). The JPST received the power interruption records from January, 2007 through April, 2010.

The monthly data are arranged in one excel file for each dzongkhag. For analysis purposes, these data (total of 40 excel files) are converted into one excel file as a data base information with 25, 810 records.

The lightning-related data have been searched using the keywords “lightning” and “thunder”. Total of 700 records are identified as power interruption incidents due to lightning. These power interruption records are tabulated in Table-2.2.12. Said table shows that these incidents are concentrated mainly in Chukha, Pemagatsel, Samtse Sarpang and Lhuentse. These dzongkhags are located in the southern Indian border, except Lhuentse. Please refer to Appendix-M in the main report for detailed information such as fault location, influenced feeders, etc.

To identify the lightning prone area by analyzing the power interruption records due to lightning, it is assumed that power interruption will be proportional to the length of MV lines of each dzongkhag. However, it should be noted that no power interruption record is registered in Samdrup Jongkhar. (Refer to Figure-2.2.5 for the existing MV lines in Bhutan.)

According to interviews with BPC Phuentsholing (ESD), lightning frequently occurred in the Indian border including Samdrup Jongkhar. Accordingly, there is a possibility that the keyword “lightning” or “thunder” have not been used at the time of recording the power interruption due to lightning.

Therefore, it is recommended that in inputting the keyword in the power interruption record, the pull-down menu of the excel file should be used instead of manually typing the words by the person in charge. Hence, only one keyword will be used for each cause such as lightning, relay operation, maintenance and so on.

Table-2.2.12 Frequency of Power Interruption due to Lightning

| Dzongkhag | Year | | | | Sub-total |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | |
| Bumthang | 3 | 1 | 0 | 0 | 4 |
| Chukha | 42 | 62 | 27 | 13 | 144 |
| Dagana | none | none | none | none | 0 |
| Mongar | none | none | none | none | 0 |
| Haa | 0 | 0 | 0 | 1 | 1 |
| Lhuentse | 5 | 0 | 25 | 1 | 31 |
| Mongar | none | none | none | none | 0 |
| Paro | none | none | none | none | 0 |
| Pemagatsel | 134 | 57 | 70 | 6 | 267 |
| Punakha | none | none | none | none | 0 |
| Samdrupjongkhar | none | none | none | none | 0 |
| Samtse | 61 | 55 | 44 | 11 | 171 |
| Sarpang | 2 | 17 | 23 | 3 | 45 |
| Thimphu | 0 | 1 | 0 | 0 | 1 |
| Trashigang | 6 | 1 | 0 | 0 | 7 |
| Trashiyangtse | 7 | 0 | 0 | 0 | 7 |
| Trongsa | 5 | 0 | 0 | 0 | 5 |
| Tsirang | none | none | none | none | 0 |
| Wandue | 2 | 0 | 4 | 0 | 6 |
| Zhemgang | 0 | 1 | 9 | 1 | 11 |
| Sub-total | 267 | 195 | 202 | 36 | 700 |

(Prepared by JPST based on the data provided by BPC)

(2) Lightning Prone Area

As mentioned in section (1), lightning prone area for the design of MV lines of BPC is identified to be within the Indian border, i.e., from west to east, Samtse, Chukha, Dagana, Tsirang, Sarpang and Pemagatsel dzongkhags. These are the coverage areas of JICA RE-2 Project.

These dzongkhags in the Brahmaptra valley along with other areas of North-East India have lightning activity close to the highest in the world and have been reported 120 days per year of lightning density.

(3) Month-wise Lightning

The yearly frequency of power interruption in Table-2.2.12 is classified on a monthly basis as shown in Table-2.2.13, 2.2.14 and 2.2.15. These tables show that no lightning occurs from November to January.

Table-2.2.13 Dzongkhag-wise and Monthly-wise Power Interruption due to Lightning (2007)

| | Nos./hrs | Bumthang | Chukha | Haa | Lhuentse | Pemagatsel | Samtse | Sarpang | Thimphu | Trashigang | Trashiyangtse | Trongsa | Wandue | Zhemgang | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Times | | 6 | | | | 4 | | | | | | | | 10 |
| | Tol duation | | 1.5 | | | | 0.1 | | | | | | | | 1.6 |
| Feb | Times | | 13 | | | 21 | 2 | 1 | | | | | | | 37 |
| | Tol duation | | 79.4 | | | 14.0 | 10.7 | 21.2 | | | | | | | 125.3 |
| Mar | Times | 1 | 4 | | | | 1 | | | | | 1 | | | 7 |
| | Tol duation | 1.0 | 11.6 | | | | 2.1 | | | | | 1.0 | | | 15.7 |
| Apr | Times | 1 | | | | 28 | 15 | | | 2 | | 2 | 2 | | 50 |
| | Tol duation | 0.2 | | | | 17.6 | 18.4 | | | 1.4 | | 0.4 | 17.8 | | 55.7 |
| May | Times | 1 | 12 | | | 27 | 9 | | | | 7 | 2 | | | 58 |
| | Tol duation | 3.5 | 48.6 | | | 2.1 | 1.0 | | | | 2.2 | 7.0 | | | 64.4 |
| Jun | Times | | 5 | | 1 | 12 | 6 | | | 2 | | | | | 26 |
| | Tol duation | | 1.9 | | 1.0 | 9.8 | 2.5 | | | 0.3 | | | | | 15.5 |
| Jul | Times | | | | 4 | 46 | 9 | | | 2 | | | | | 61 |
| | Tol duation | | | | 3.5 | 14.3 | 0.4 | | | 0.0 | | | | | 18.2 |
| Aug | Times | | | | | | 6 | | | | | | | | 6 |
| | Tol duation | | | | | | 5.4 | | | | | | | | 5.4 |
| Sep | Times | | 2 | | | | 7 | 1 | | | | | | | 10 |
| | Tol duation | | 1.0 | | | | 1.9 | 5.1 | | | | | | | 8 |
| Oct | Times | | | | | | 2 | | | | | | | | 2 |
| | Tol duation | | | | | | 0.1 | | | | | | | | 0.1 |
| Nov | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Dec | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Total | Times | 3 | 42 | 0 | 5 | 134 | 61 | 2 | 0 | 6 | 7 | 5 | 2 | 0 | 267 |
| | Tol duation | 4.68 | 144 | 0 | 4.5 | 57.75 | 42.6 | 26.3 | 0 | 1.7 | 2.2 | 8.4 | 17.8 | 0 | 309.9 |

(Prepared by JPST based on the data provided by BPC)

Table-2.2.14 Dzongkhag-wise and Monthly-wise Power Interruption due to Lightning (2008)

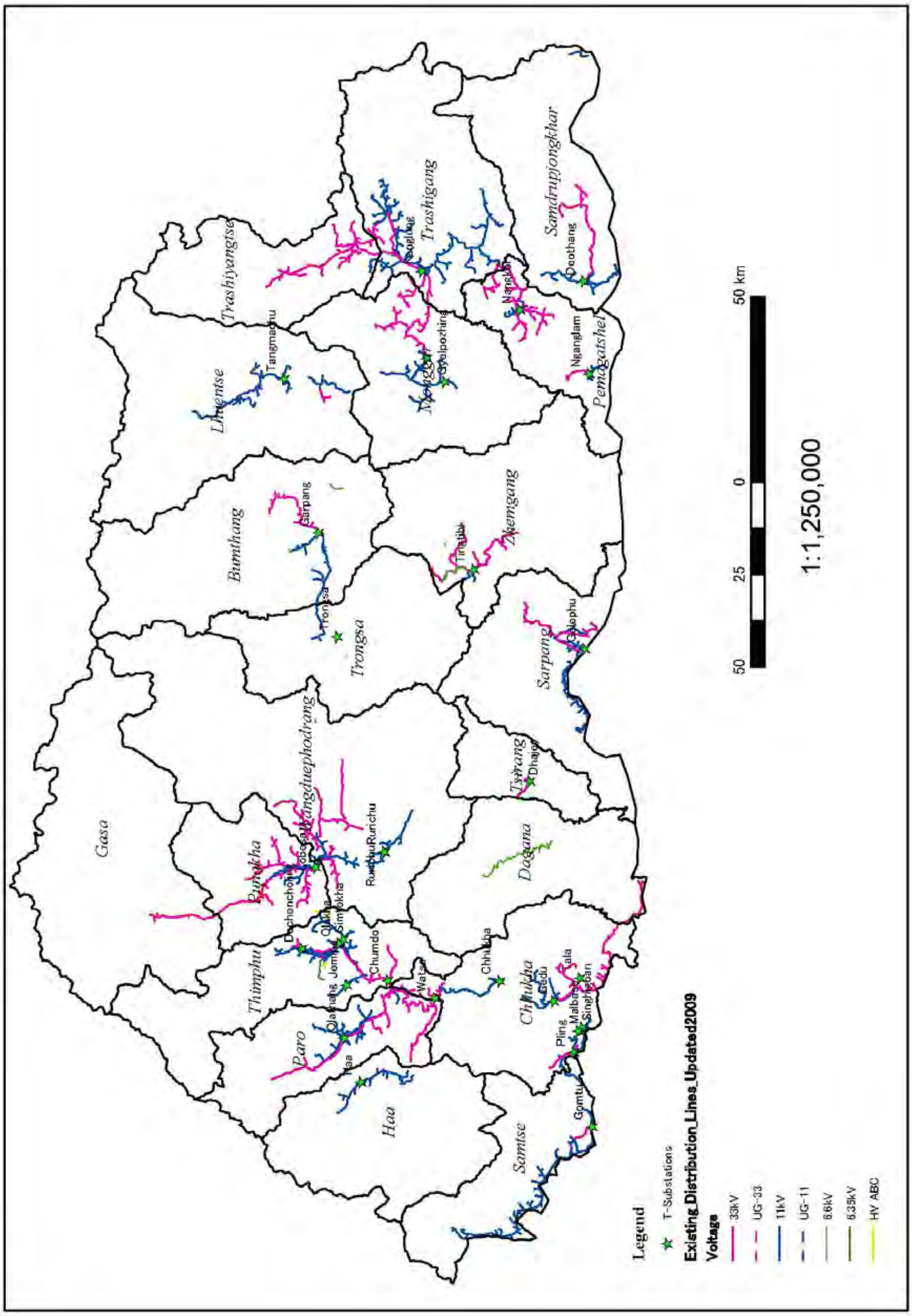
| | Nos./hrs | Bumthang | Chukha | Haa | Lhuentse | Pemagatsel | Samtse | Sarpang | Thimphu | Trashigang | Trashiyangtse | Trongsa | Wandue | Zhemgang | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Times | | | | | | | | | | | | | | 0 |
| | Tol duation | | | | | | | | | | | | | | 0 |
| Feb | Times | 1 | 1 | | | | | | | | | | | | 2 |
| | Tol duation | 0.5 | 4.7 | | | | | | | | | | | | 5.2 |
| Mar | Times | | 24 | | | 3 | 20 | | | 1 | | | | 1 | 49 |
| | Tol duation | | 9.3 | | | 12.4 | 13.3 | | | 2.4 | | | | 0.1 | 37.5 |
| Apr | Times | | 15 | | | 2 | 5 | 6 | | | | | | | 28 |
| | Tol duation | | 44.5 | | | 23.2 | 0.3 | 6.1 | | | | | | | 74.1 |
| May | Times | | 4 | | | 12 | 17 | 2 | | | | | | | 35 |
| | Tol duation | | 6.0 | | | 1.7 | 3.6 | 6.2 | | | | | | | 17.5 |
| Jun | Times | | 3 | | | 2 | 5 | | | | | | | | 10 |
| | Tol duation | | 0.2 | | | 2.2 | 1.2 | | | | | | | | 3.6 |
| Jul | Times | | | | | | 2 | 7 | | | | | | | 9 |
| | Tol duation | | | | | | 2.2 | 18.9 | | | | | | | 21.1 |
| Aug | Times | | 5 | | | 38 | | 2 | | | | | | | 45 |
| | Tol duation | | 1.7 | | | 3.2 | | 21.9 | | | | | | | 26.8 |
| Sep | Times | | 10 | | | | 6 | | | | | | | | 16 |
| | Tol duation | | 23.9 | | | | 0.2 | | | | | | | | 24.1 |
| Oct | Times | | | | | | | | 1 | | | | | | 1 |
| | Tol duation | | | | | | | | 0.2 | | | | | | 0.2 |
| Nov | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Dec | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Total | Times | 1 | 62 | 0 | 0 | 57 | 55 | 17 | 1 | 1 | 0 | 0 | 0 | 1 | 195 |
| | Tol duation | 0.5 | 90.3 | 0 | 0 | 42.7 | 20.8 | 53.1 | 0.2 | 2.4 | 0 | 0 | 0 | 0.1 | 210.1 |

(Prepared by JPST based on the data provided by BPC)

Table-2.2.15 Dzonkhag-wise and Monthly-wise Power Interruption due to Lightning (2009)

| | Nos./hrs | Bumthang | Chukha | Haa | Lhuentse | Pemagatsel | Samtse | Sarpang | Thimphu | Trashigang | Trashiyangtse | Trongsa | Wandue | Zhemgang | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Times | | | | | | | | | | | | | | 0 |
| | Tol duation | | | | | | | | | | | | | | 0 |
| Feb | Times | | | | | 21 | | | | | | | 2 | | 23 |
| | Tol duation | | | | | 1.9 | | | | | | | 12.6 | | 14.5 |
| Mar | Times | | 1 | | 2 | 11 | 1 | | | | | | 2 | 9 | 26 |
| | Tol duation | | 0.1 | | 0.9 | 6.4 | 1.1 | | | | | | 1.5 | 4.7 | 14.7 |
| Apr | Times | | | | | | 2 | 2 | | | | | | | 4 |
| | Tol duation | | | | | | 22.2 | 1.3 | | | | | | | 23.5 |
| May | Times | | 11 | | 1 | 18 | | 11 | | | | | | | 41 |
| | Tol duation | | 11.7 | | 0.2 | 4.1 | | 53.6 | | | | | | | 69.6 |
| Jun | Times | | 8 | | | 18 | 17 | 9 | | | | | | | 52 |
| | Tol duation | | 8.1 | | | 0.5 | 17.7 | 6.9 | | | | | | | 33.2 |
| Jul | Times | | | | | 2 | 6 | 1 | | | | | | | 9 |
| | Tol duation | | | | | 0.5 | 13.4 | 2.6 | | | | | | | 16.5 |
| Aug | Times | | 1 | | 22 | | 15 | | | | | | | | 38 |
| | Tol duation | | 0.1 | | 1.2 | | 2.4 | | | | | | | | 3.7 |
| Sep | Times | | 2 | | | | 3 | | | | | | | | 5 |
| | Tol duation | | 0.3 | | | | 1.6 | | | | | | | | 1.9 |
| Oct | Times | | 4 | | | | | | | | | | | | 4 |
| | Tol duation | | 0.9 | | | | | | | | | | | | 0.9 |
| Nov | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Dec | Times | | | | | | | | | | | | | | |
| | Tol duation | | | | | | | | | | | | | | |
| Total | Times | 0 | 27 | 0 | 25 | 70 | 44 | 23 | 0 | 0 | 0 | 0 | 4 | 9 | 202 |
| | Tol duation | 0 | 21.2 | 0 | 2.3 | 13.4 | 58.4 | 64.4 | 0 | 0 | 0 | 0 | 14.1 | 4.7 | 178.5 |

(Prepared by JPST based on the data provided by BPC)




Source: BPC

Figure-2.2.5 Existing MV Lines in Bhutan

(4) Countermeasure for Lightning

To reduce the damages or influences due to lightning (induced lightning not directly striking the MV lines), lightning arrester together with overhead ground wires are commonly used. Lightning arresters are specified to protect pole-mounted transformer in accordance with the Distribution Design and Construction Standards of BPC. Together with the installation of lightning arrester, installation of overhead ground wire is recommended to reduce the grounding resistance of the MV lines.

The grounding resistance of substations (pole-mounted transformers) should be kept within or lower than the specified value (5 ohms[1] and 10 ohms[2] as per the Distribution Design and Construction Standards of BPC) to ensure the protective performance of the lightning arresters.

However, it is not easy to keep the ground resistance within the specified value due to the high soil resistivity in Bhutan, which is as high as 1,200 ohm-meter. Salt is commonly used to lower the grounding resistance together with charcoal to reduce the grounding resistance of substations. However, use of salt does not seem to maintain the performance over a long period because it is easily washed away by rain water.

The use of overhead ground wire is recommended to reduce the grounding resistance over a long period by connecting the poles which are grounded in parallel.

(5) Countermeasure for Existing facilities

No overhead ground wire is installed in the existing 33 kV and 11 kV MV lines. Furthermore, additional installation of overhead ground wire to the existing MV lines is not easy for the pole assembly.

However, it is necessary to take countermeasures to reduce the damage or influence by lightning. The only protective device for pole-mounted transformer is a lightning arrester. To secure the performance of lightning arresters, the grounding resistance is the key factor, i.e., it should be within or under the specified value, or as low as possible.

As countermeasure for reducing the grounding resistance of existing transformer poles, installation of counterpoise is recommended. The number and length of counterpoise is estimated to be 2 and 30 m, respectively.

1 The resistance of pipe earthing systems at distribution substations
2 The resistance of stake earths

## 2.3 Expansion of Scope: Quality Improvement

### 2.3.1 Improvement of Reliability in Power Supply

After the completion of the proposed grid extension, Bhutan will complete the RE work except for some minor additional work. The distribution network will extend to 3,000 km of MV lines at its completion covering over 95% of the rural population. After completion of the Project, the longest MV line will extend over 100 km. The larger the network becomes, the higher the chance for supply disruption. Thus, reducing blackout time is critical in order to maintain consumer benefits that are gained from grid extension. The measures to improve reliability of electricity service are twofold; first is the reduction of lightning damages, and second is the automatic re-closure system to reduce blackout duration from temporary short circuits and grounding fault.

### 2.3.2 Shield Wire and Counterpoise

After the examination of comprehensive failure records (2007-2010) that was compiled by each ESD of BPC, the JPST found out some noticeable occurrences of damages caused by lightning.

According to a “Tour Report” dated April 27, 2010, it is reported that coils of a 63kVA transformer at Upper Gangkha were burned due to heavy lightning on April 03, 2010 and same kind of failure was occurred at Shema Gangkha on April 04, 2010 due to the same cause.

And “Failure Reporting for Transformer” reported that transformer failures were occurred at Lower Gangkha, Gangkha School and Upper Shemakha due to heavy lightning on March 26, 2010.

The Study Team recommends the introduction of shield wires for the lightning-prone dzongkhags of Samtse, Sarpang, Chukha and Dagaga. The total shield wire length requirement is estimated to be 290km of the new MV lines.

Another effective measure to lower the grounding resistance of transformer poles is to install counterpoises with 30 m of bare conductors that are buried horizontally in two opposite directions. It is estimated that a total of 700 transformers are to be protected with this measure with 298 to be newly installed and 402 of the existing ones.

### 2.3.3 Automatic Reclosing Circuit Breaker (ARCB)

Another improvement envisaged by the Project is to install ARCB, which is an equipment to reconnect the distribution line at the time of electrical faults. At present, BPC has installed 26 nos. of ARCB at different locations in the country. Given the rapid expansion of the rural distribution network, human intervention based responses are limited in shortening and area-wise limitation of blackouts.

The purpose of ARCB installation is to improve the power supply reliability, and BPC installs ARCB under the following conditions.

- ✓ Based on the terrain through which line passes. If the line passes through thickly forested area, BPC installs such equipment to clear the transient faults.
- ✓ If the line is very long, ARCBs are installed to clear the downstream faults.
- ✓ Based on the type of feeder. If the feeder is getting T-off from urban line, then ARCBs are installed to segregate rural and urban faults for better reliability.
- ✓ In some places, ARCBs are also installed to avoid 33kV and 11kV substations/switching stations which helps to reduce the cost.

The Project requires 20 sets of 33 kV ARCB and 13 sets of 11 kV ARCB, these quantities are the request basis by ESD (Electricity Services Division).

The locations where ARCB will be installed may be indicated on the single line diagram by the respective ESD. The single line diagram is attached in Annex-N.

### 2.3.4 Step Voltage Regulator (SVR)

In the radial MV distribution system, it is often necessary to regulate the feeder voltage by means of step voltage regulator.

Step-voltage regulators can be either (1) station-type, which can be single- or three-phase, and which can be used in substations for bus voltage regulation or individual feeder voltage regulation, or (2) distribution-type, which can be only single-phase and used pole-mounted out on overhead MV feeders.

The step-voltage regulator basically is an autotransformer which has numerous taps in the series winding. Taps are charged automatically under load by switching mechanism which responds to a voltage-sensing control in order to maintain voltage as close as practicable to a predetermined level. The voltage-sensing control receives its inputs from potential and current transformers and provides control of system voltage level and band width. In addition, it provides features such as operation counter, time-delay selection, test terminal, and control switch.

In case of MV lines of BPC, the feeder length sometimes reaches to eighty (80) km, it is difficult to maintain the feeder voltage to an allowable level, installation of distribution-type may be the option to improve the consumer end voltage.

## 2.4 Grid Extension Cost

There are two aspects to cost estimation. Since the Project is comprised of a number of geographically discrete feeders and subfeeders, the cost of each subfeeder needs to be calculated. The costs of feeders can be combined in order to derive cost summaries per dzongkhag. Another combination is by contract packages. Since the BPC procures the materials directly, the contract packages need to be grouped according to vendor types such as electric poles, transformers, conductors, metal fittings manufacturers, civil work contractors and transporters

The quantity and cost of material procured in the project is summarized by dzonkhags in Table-2.4.1 and Table-2.4.2. Within these dzongkhags, there were 71 feeder lines which extend 566 km of MV lines and 447 km of LV lines as shown in Table-5.1.1. The feeders are expected to supply electricity to 3,701 customers in total. The total Project cost is estimated to be JPY 2,713 million (USD 30.9 million) out of which JPY 1,867 million (USD 21.3 million) is required for the procurement of materials and construction as the base-cost for JICA financing shown in Table-2.4.3). The detail of the project cost is shown in Appendix-R in the main report. The remainder is required for transportation by vehicles and human workers, as well as erection. The average cost per customer is estimated at JPY 460,688 (USD 5,253). The high cost requirement arises from two major factors. Since the remaining electrification targets are located in less densely-populated and far areas, the line length are much longer and each substation (transformer) supplies less number of customers. In the case of the JICA RE-2 Project, the average MV line length is 152 m per customer while that for the JICA RE-1 Project is 60 m per customer. The adoption of new poles has also led to an increase in unit material cost per length.

Table-2.4.1 Project Quantity Summary by dzonkhags

| Dzongkhag | Nos. of Total consumer (household and institute) | MV length (km) | LV length (km) | Nos. of substation | Nos. of ARCB | Lightning damage prevention | | Average headloading distance to village (km) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Shield wire (km) | Nos. of Couter-poise | |
| Chukha | 629 | 121.1 | 68.4 | 59 | 33 | 290 | 700 | 13.2 |
| Dagana | 416 | 77.2 | 61.8 | 35 | | | | 6.8 |
| Haa | 99 | 28.6 | 8.4 | 11 | | | | 30.3 |
| Paro | 43 | 7.1 | 1.5 | 2 | | | | 4.0 |
| Pemagatshel | 168 | 21.0 | 17.2 | 11 | | | | 12.2 |
| Punakha | 49 | 10.5 | 6.1 | 5 | | | | 2.2 |
| Samtse | 988 | 100.0 | 121.8 | 82 | | | | 8.3 |
| Sarpang | 730 | 119.0 | 99.3 | 65 | | | | 26.6 |
| Trongsa | 321 | 35.7 | 28.6 | 22 | | | | 4.1 |
| Tsirang | 93 | 20.6 | 22.9 | 9 | | | | 6.3 |
| Wangdue | 165 | 25.3 | 11.4 | 16 | | | | 6.5 |
| **Total** | **3,701** | **566.0** | **447.4** | **317** | **33** | **290** | **700** | |

(Prepared by JPST)

Table-2.4.2 Project Cost Summary by dzonkhags

| | | Material cost (Million JPY) | Erection cost (Million JPY) | Headloading cost (Million JPY) | Transportation cost (Million JPY) | Total cost (Million JPY) | Total cost (Million USD) |
|---|---|---|---|---|---|---|---|
| Distribution lines | Chukha | 204.7 | 29.1 | 75.7 | 3.2 | 312.9 | 3.6 |
| | Dagana | 152.2 | 19.7 | 29.2 | 3.0 | 204.1 | 2.3 |
| | Haa | 39.7 | 6.5 | 33.2 | 1.7 | 81.0 | 0.9 |
| | Paro | 9.7 | 1.3 | 1.1 | 0.3 | 12.4 | 0.1 |
| | Pemagatshel | 39.2 | 5.5 | 13.5 | 0.7 | 59.0 | 0.7 |
| | Punakha | 16.5 | 2.1 | 1.2 | 0.8 | 20.6 | 0.2 |
| | Samtse | 245.2 | 32.1 | 56.1 | 2.4 | 335.8 | 3.8 |
| | Sarpang | 244.1 | 37.7 | 174.9 | 6.7 | 463.4 | 5.3 |
| | Trongsa | 72.5 | 9.2 | 8.7 | 2.4 | 92.8 | 1.1 |
| | Tsirang | 42.7 | 5.6 | 7.6 | 0.8 | 56.6 | 0.6 |
| | Wangdue | 49.4 | 6.2 | 8.7 | 2.4 | 66.6 | 0.8 |
| Other items | ARCB | 89.2 | | 29.4 | 3.6 | 122.2 | 1.4 |
| | Shield wire | 23.7 | | 7.8 | 0.9 | 32.5 | 0.4 |
| | Counter-poise | 5.2 | | 1.7 | 0.2 | 7.1 | 0.1 |
| | **Total** | **1,233.9** | **193.9** | **410.0** | **29.1** | **1,867.0** | **21.3** |

(Prepared by JPST)

Table-2.4.3 Grid Extension Project Cost

## Annual Fund Requirement

| | |
|---|---|
| Base Year for Cost Estimation: | Nov, 2010 |
| Exchange Rates | Nu = Yen 1.88 |
| Price Escalation: | FC: 1.8% LC: 2.4% |
| Physical Contingency | 10% |
| Physical Contingency for Consultant | 10% |

| | Item | Total | | | | |
|---|---|---|---|---|---|---|
| | | FC (Million JPY) | LC (Million BTN) | Total (Million JPY) | Total (Million USD) | Percentage to grand total |
| **A. ELIGIBLE PORTION** | | | | | | |
| Ⅰ) | Procurement / Construction | 1,348 | 395 | 2,091 | 23.8 | 76.2% |
| | 1. Substation and Line Materials | 1,212 | 12 | 1,234 | 14.1 | 45.0% |
| | 2. Transportation Cost | 0 | 15 | 29 | 0.3 | 1.1% |
| | 3. Erection Cost | 0 | 321 | 604 | 6.9 | 22.0% |
| | Base cost for JICA financing | 1,212 | 348 | 1,867 | 21.3 | 68.0% |
| | Price escalation | 13 | 11 | 34 | 0.4 | 1.2% |
| | Physical contingency | 123 | 36 | 190 | 2.2 | 6.9% |
| Ⅱ) | Consulting services | 38 | 3 | 43 | 0.5 | 1.6% |
| | Base cost | 34 | 2 | 38 | 0.4 | 1.4% |
| | Price escalation | 1 | 0 | 1 | 0.01 | 0.0% |
| | Physical contingency | 3 | 0 | 4 | 0.05 | 0.1% |
| Total ( Ⅰ + Ⅱ ) | | 1,386 | 398 | 2,134 | 24.3 | 77.8% |
| **B. NON ELIGIBLE PORTION** | | | | | | |
| a | Procurement / Construction | 0 | 51 | 97 | 1.1 | 3.5% |
| | 5. Compensation including the removal of orchard trees | 0 | 40 | 76 | 0.9 | 2.8% |
| | 6. Envirenmental Monitoring | 0 | 5 | 10 | 0.1 | 0.4% |
| | Base cost for RGoB financing | 0 | 46 | 86 | 1.0 | 3.1% |
| | Price escalation | 0 | 1 | 2 | 0.02 | 0.1% |
| | Physical contingency | 0 | 5 | 9 | 0.1 | 0.3% |
| b | Land Acquisition | 0 | 0 | 0 | 0.0 | 0.0% |
| | Base cost | 0 | 0 | 0 | 0.0 | 0.0% |
| | Price escalation | 0 | 0 | 0 | 0.0 | 0.0% |
| | Physical contingency | 0 | 0 | 0 | 0.0 | 0.0% |
| c | Administration cost | 0 | 119 | 223 | 2.5 | 8.1% |
| d | BIT (local) | 0 | 8 | 15 | 0.2 | 0.5% |
| e | BIT (foreign) | 0 | 1 | 1 | 0.01 | 0.0% |
| f | Duties and Sales Tax | 0 | 129 | 242 | 2.8 | 8.8% |
| Total (a+b+c+d+e+f) | | 0 | 308 | 578 | 6.6 | 21.1% |
| **TOTAL (A+B)** | | 1,386 | 706 | 2,713 | 30.9 | 98.9% |
| | | | | | | |
| **C. Interest during Construction** | | 25 | 0 | 25 | 0.3 | 0.9% |
| | Interest during Construction(Const.) | 25 | 0 | 25 | 0.3 | 0.9% |
| | Interest during Construction (Consul.) | 0 | 0 | 0 | 0.0 | 0.0% |
| **D. Commitment Charge** | | 6 | 0 | 6 | 0.1 | 0.2% |
| **GRAND TOTAL (A+B+C+D)** | | 1,417 | 706 | 2,744 | 31.3 | 100.0% |
| | | | | | | |
| **E. JICA finance portion incl. IDC (A + C + D)** | | 1,417 | 398 | 2,166 | 24.7 | 78.9% |

(Prepared by JPST)

## 2.5 Lightning Damage Prevention Program Cost

The costs for shield wire and counterpoise installation is estimated at USD 491,476 as shown in Table -2.5.1. The cost for ARCB installation is estimated at USD 1,186,692 as shown in Table -2.5.2.

Table-2.5.1 Cost Estimate for Shield Wire and Counterpoise Installation

Unit: USD

| | Quantity | Unit | Unit Price | Cost |
|---|---|---|---|---|
| Shield Wire Installation | 290 | km | 933 | 270,570 |
| Counter-poise | 700 | nos | 84 | 58,800 |
| Civil | | | 30% | 143,035 |
| Transportation Cost | | | 4% | 19,071 |
| | Total | | | 491,476 |

(Prepared by JPST)

Table-2.5.2 Cost Estimate for ARCB Installation

Unit: USD

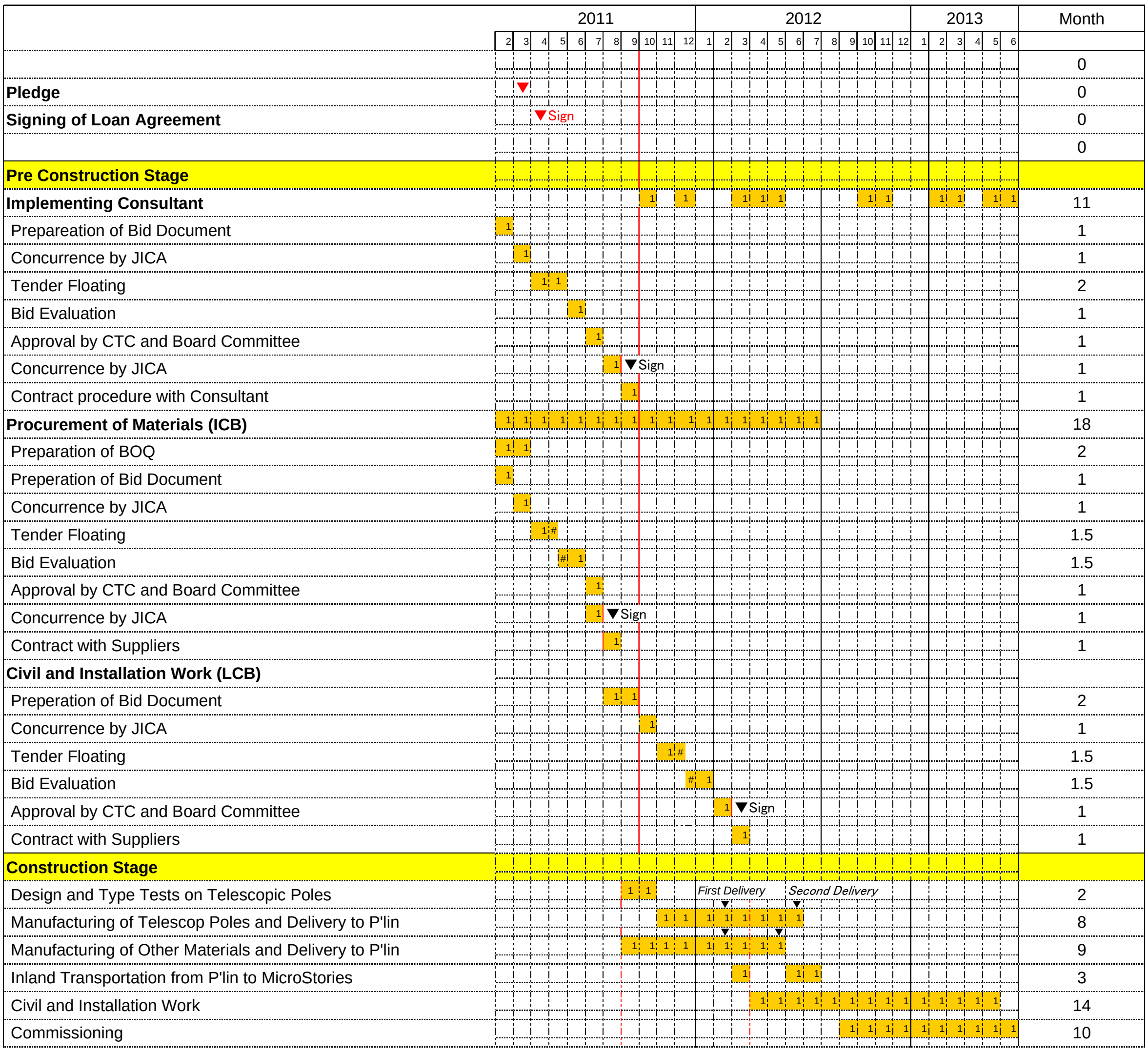
| | Quantity | Unit | Unit Price | Cost |
|---|---|---|---|---|
| 33kV ARCB | 20 | nos | 35,200 | 704,000 |
| 11kV ARCB | 13 | nos | 24,100 | 313,300 |
| Civil 33kV ARCB | 20 | nos | 3,900 | 78,000 |
| Civil 11kV ARCB | 13 | nos | 3,900 | 50,700 |
| Transportation Cost | | | 4% | 40,692 |
| | | | 4% | 1,186,692 |

(Prepared by JPST)

# CHAPTER 3 IMPLEMENTATION

## 3.1 Implementation Schedule and Project Sub-Packages

The target completion of the Project is end of June 2013. Accordingly, the entire implementation period would only be 29 months since the Project is supposed to commence in February 2011. In order to achieve this target completion, an implementation schedule is recommended based on the past experience and the consensus between BPC and JPST as shown in Figure-3.1.1.




(Prepared by JPST)

Figure-3.1.1 Implementation Schedule

### 3.1.1 Loan Agreement

The signing of the Exchange of Notes (E/N) for the loan agreement is scheduled to be in

March 2011.

### 3.1.2 Lightning Damage Prevention Program Cost

BPC may commence the preparation works, such as preparation of bidding documents for selection of implementing consultant and procurement of materials, in February 2011 after prior notification (pledge), while waiting for the signing of the loan agreement.

### 3.1.3 Pre-Construction Stage

(1) Implementing Consultant

The procedure for the selection of implementing consultants will commence immediately when the project starts in February 2011. The consultancy services are scheduled to start after JICA concurs with the contract in the beginning of September 2011, and intermittently implemented until June 2013.

(2) Procurement of Materials

The distribution line materials like transformers, conductors, insulators, poles, etc., will be procured under one-phase bidding. The bidding procedures are undertaken through ICB in accordance with JICA Procurement Guideline.

The period for the whole bidding process (from the preparation of bidding documents to signing of contracts) is expected to be approximately seven months, including the bid floating period of 45 days.

(3) Civil and Installation Work

Selection of local contractors for the civil and installation works will be carried out under one-phase bidding, through LCB. It will consist of approximately 52 packages, based on the number of MV feeders planned to be developed under the Project. A recommendation of erection packages proposed by JPST is shown in Appendix-Q in the main report.

### 3.1.4 Construction Stage

The design and manufacturing of materials will start immediately after the signing of the contract for procurement of materials. The delivery of materials to BPC’s warehouse in P’ling is scheduled during the period from February 2012 to December 2012, depending on the materials.

The work is managed by packages on feeder-wise basis. The period for the entire construction work is scheduled to be within 15 months, depending on the volume of works for each package, which is generally longer than the previous project. This also takes into account the difficulty in transporting materials to the project sites in remote mountainous regions.

### 3.1.5 Summary of Project Sub-packages

(1) Procurement of Materials

The bidding procedures for the procurement of materials will be undertaken through international competitive bidding (ICB). The following 14 sub-packages for these procurements are recommended as summarized in Table 3.1.1 below.

Table-3.1.1 Bid Packages for Procurement of Materials

| Lot No. | Description of package | Cost Estimate (USD) |
|---|---|---|
| 1-A | MV STEEL TELESCOPIC POLEs, FITTINGS & ACCESSORIES<br>FOR THE WESTERN DZONGKHAGS (CHUKHA, HAA, PARO, PHUNAKA AND SAMTSE) | 3,087,325 |
| 1-B | MV STEEL TELESCOPIC POLEs, FITTINGS & ACCESSORIES<br>FOR THE EASTERN DZONGKHAGS (DAGANA, PEMAGATSHEL, SARPANG, TRONGSA, TSIRANG AND WANGDUEPHODRANG) | 1,943,038 |
| 2-A | MV OVERHEAD BARED CONDUCTORS | 1,057,728 |
| 2-B | MV OVERHEAD FITTINGS AND ACCESSORIES | 230,917 |
| 3 | INSULATORS AND FITTINGS | 548,843 |
| 4-A | MV COVERED CONDUCTOR, LV ABC CONDUCTORS & SERVICE CABLES | 1,576,623 |
| 4-B | LV TELESCOPIC POLES, ABC ACCESSORIES & DISTRIBUTION BOARDS | 2,659,066 |
| 5 | EARTHING EQUIPMENT | 144,289 |
| 6 | DISTRIBUTION TRANSFORMERS | 934,609 |
| 7 | SWITCHING EQUIPMENT, AUTO RECLOSER, AND ACCESSORIES | 1,244,419 |
| 8 | CUSTOMER EQUIPMENT - ENERGY METERS | 66,314 |
| 9 | MISCELLANEOUS CONSTRUCTION ITEMS | 247,267 |
| 10 | LIGHTNING DAMAGE PREVENTION | 329,370 |
| 11 | TOOLS AND VEHICLES | 265,957 |

(Prepared by JPST)

The above packaging is considered to be based on BPC's procurement experience in previous projects.

It is also recommended that the procurement of 11 m telescopic poles be separated into two packages since the total quantity will be more than 9,500 and the manufacturing period is limited to 11 months.

(2) Erection Works

The selection of contractors for erection works will be managed under the procedures for local competitive bidding (LCB). The bid packages will be split by BPC based on medium voltage (MV) main feeders during the preparation of bidding documents in the pre-construction stage.

Considering the contract volume and the geographical proximity of erection site, a recommendation of feeder-basis sub-packages of erection works is shown in Appendix-Q in the main report.

## 3.2 Implementation Method

The implementation for RE by BPC is vertically divided into three components, namely: procurement, transport, and civil works, instead of commissioning the entire work to a single or multiple contractors as a package. The method has been proved to work effectively especially in terms of controlling the material procurement costs, meeting timely delivery of the materials, and directly awarding the civil works to local contractors. In order to execute the work properly, BPC has set up a fairly large project implementation organization, involving the RED as well as the PSD. There is no merit in altering the work process that has worked relatively well in the past at this juncture.

## 3.3 Implementation Setup

### 3.3.1 Organization

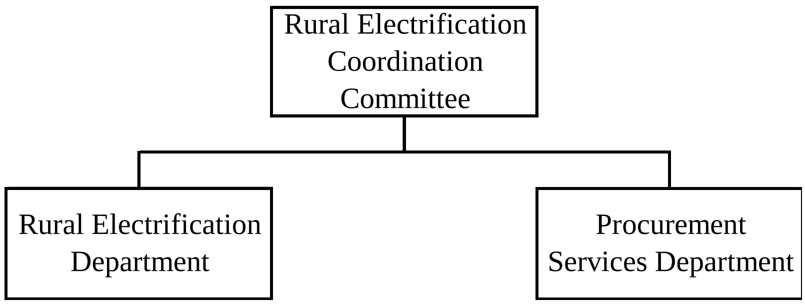
The project will constitute the last portion of RE in Bhutan. Prior to the last stage, the RGoB already received four loans from ADB and one loan from JBIC (now merged with JICA) to execute RE projects. During the implementation of the RE packages, BPC has established the RED as a permanent organization for the planning and execution of RE projects. Chapter 5 describes its function and setup in detail. Table-3.3.1 shows the summary of RE work and the responsible departments.

Table-3.3.1 Rural Electrification Work and Responsible Organizations

| Process | Organization in Charge |
|---|---|
| Material Procurement | Procurement Department |
| Inventory Control and Transport | Procurement Department |
| Construction Supervision | Rural Electrification Department |
| Operation and Maintenance | Electricity Service Division |

Source: BPC

As indicated in Section 6.3.3, there is a concern on meeting the deadline of completion in 2013. One of the critical measures is to minimize the procurement lot and synchronize the procurement-transport-installation work flow. Therefore, it is necessary to establish a closer coordination between PSD and RED. It is recommended to create an ad hoc coordination body above the two departments to realize the much needed coordination.




(Prepared by JPST)

Figure-3.3.1 Recommended RE Organization

### 3.3.2 Manpower

RED has some 160 staff in its headquarters and regional offices. Prior to the implementation of the first Japanese ODA loan, the SAPROF study recommended the expansion of RED staff from 44 to 170 to cope with increased workload for the JBIC package as well as ADB's RE-4. BPC has pursued the recommended staff increases earnestly. Although the work volume of the next phase of electrification may be somewhat less, it may be even larger than what is required at present due to the very tight implementation schedule. However, taking into account the demobilization of RED after the Project, it would be more advantageous not to alter the current size of the department.

### 3.3.3 Strategy to Meet 2013 Deadline: Just-In-Time to be Revisited

For the on-going Japanese ODA loan project, the SAPROF study recommended the introduction of just-in-time system to the procurement and inventory control in order to reduce delivery period as well as time wasted arising from inflated inventories. However, the recommendation was not taken up, hence, the conventional large lot based procurement was undertaken. As a result, there was no improvement in delivery period and large stagnant inventories. Sending the large order means that the manufacturers need to store the outputs and only after having met the required quantity that they ship the materials. In other words, the products produced in the beginning have to wait until the last product is produced before shipment. Reduced lot means reduced waiting period. If the first products were shipped immediately, construction using said products would have been shortened by the entire production period. Minimization of the lot size and synchronization of installation process should be an integral part to meeting the national deadline.

Naturally, each product cannot be shipped on a single basis, thus, a minimum lot size that does not inflate transport and handling costs need to be sought out. Discussion with PSD has revealed that there are both visible administrative and hidden costs in cross-border shipment such as waiting time. This transaction costs need to be factored into the determination of lot sizes. One suggestion that has emerged from the discussion is to adopt one month cycle of production and shipment. For most of the products, one month production would generate more than one truckload. This transportation cost would not be increased by lot size reduction. In addition, monthly delivery will have a standardization effect on administration including documentation, and also logistics. The manufacturer would need less space for inventory and the freight transporter needs fewer vehicles or less capacity for each trip, but which should be more frequent. Therefore, it could lead to reduction of costs as well. Lot size optimization needs to be studied for each procurement package before tendering, in consultation with the vendors in order to create a win-win situation.

### 3.3.4 Contractor Education and Information Sharing: Reforming Tender Documents and Consultation

The last package of rural electrification is supposed to have a larger proportion of civil costs within the total project budget due to more remote locations of the project feeders. The largest contributor in the cost escalation is the human transport of materials to construction sites, so called head-loading work. At present, the tender documents require the bidder to provide costs per unit length of conductor line or unit costs per transformer which include local transport (from the regional store to the road end nearest to the construction site), head-loading, and installation. JPST conducted unit cost analyses for civil works; however, the tender results did not provide any information with regard to costs associated with each type of work such as transport or erection. Moreover, the results of analysis show some inconsistencies such as no statistically meaningful deviation in costs between single phase and three-phase conductor line work, despite the fact that the total weight of conductors is 50% more for three-phase compared to single phase. Or, a larger transformer had fetched lesser prices. These statistical anomaly leads to a hypothesis that the contractor is bidding without detailed examination of transport loads and required manpower. There are numerous reports of contractors' complaints on excessive difficulties arising from head-loading work. JPST's conjecture is that these complaints are emanating from those uninformed and underprepared contractors without knowing how many people and how long it takes to carry heavy and long equipment on mountainous terrain.

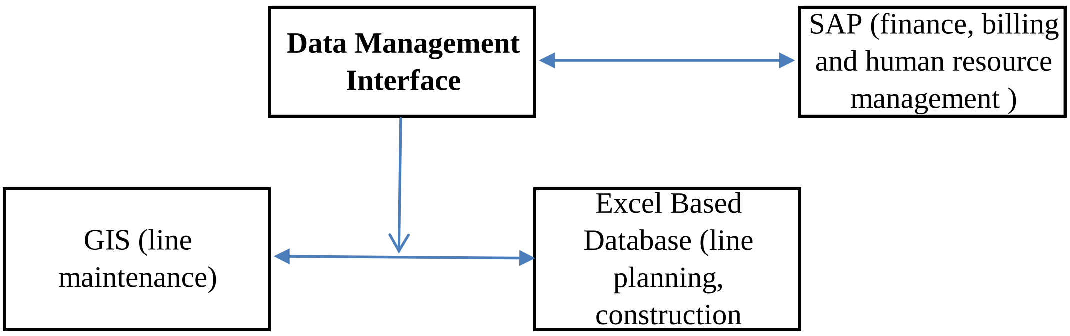
Given the priority, which is to meet the deadline in 2013, and to ensure proper installation of equipment and facilities, it is reasonable to employ well-informed contractors with well-prepared logistical plans for transport and erection. The contractor should be informed about the length, volume and weight of the materials to be transported and installed for better planning on their part. Detailed information sharing will do some justice by avoiding unnecessary losses on the part of the contractor or delays in construction. Therefore, it is recommended that the bid documents should contain all the relevant planning data for the contractors including the weights of the materials to be used in construction as well as the transportation distance. Some workshops related to past experience and best practices may be given by BPC to contractors to enhance their planning capacity.

### 3.3.5 Data Management

There are currently three data management systems working within BPC. One is much centrally controlled and so-called data management for financial transactions and customer database management; the second is the GIS database introduced since the beginning of JICA RE-1 project; and the third consists of numerous reports compiled in excel formats such as progress monitoring sheets and fault records. BPC has decided to introduce SAP as the main application to handle most of the critical and centrally controlled database. GIS is now fully utilized in the planning of both MV and LV lines in conjunction with GPS.

Given the ease of use, familiarity and wide availability of excel within the BPC, it would be most efficient and cost-effective to use excel as the basic platform for data entry interface. There will be less need for human resource development and less costs associated with the introduction of the software. It is envisaged that the next generation web computation will have similar format and style of commands, and thus, investment for human resource training will not lose continuity. The problems also come with ease and flexibility. The inconsistency in data entry formats and tabulation leaves the file formats to the whim of the data operators and in return, the aggregation process becomes extremely difficult and time consuming to rectify the individual variations as well as errors. The existence of decentralized files makes statistical or planning analysis very difficult. Often, the data are transferred from one file to another manually, requiring large wasteful manpower in data processing. The data file such as those containing fault records with tens of thousands of records are left without being utilized for strategic analyses. In most cases, the data in excel formats are used for the purpose of printing hard copies in standard formats and not for analyses or planning. Another problem for the decentralized data compilation is security. The maintenance of chronic file records and keeping the most updated data for common access is not easy while protecting the data from accidental or intentional losses.

BPC has developed an array of reporting data files which could potentially be a wealth of data for strategic planning. In order to achieve that purpose, there needs to be a mechanism or protocol to be developed for the transfer, aggregation and analyses. It is therefore recommended that as part of capacity building, data entry, management, security and analyses protocol, and software should be developed together with the human resources to manage the overall database system from management and strategic points of view. The database integration process with a purpose of integrated strategic monitoring and planning is a requisite for the subsequent capacity building.




(Prepared by JPST)

Figure-3.3.2 Database Integration Concept

### 3.3.6 Reinforcement of Operation and Maintenance Capacity

Given the geographical expanse of the next rural electrification and the difficulty in accessibility, there should be more reinforcement of operation and maintenance capacities. On the other hand the operation and maintenance for rural electrification in the next phase is purely a financial burden on the part of BPC. Thus there is a strong need for keeping the cost as low as possible at the same time. As discussed in the section on manpower above, the personnel size of ESD, RECD and RECSD should be maintained at the same level as of now. Strengthening should be focused on the management efficiency. One areas that is critical is to provide the field staff with adequate tools and means of communication.

As mentioned in 10.3.4, NLDC will be inaugurated in next year the data transmission and communication situation among generating and substation facilities and relevant offices which are covered by NLDC will be tremendously improved. Hence, it is required effective data transmission from ESD, RECD and RECSD to RED for the effective management and construction supervision/monitoring. The following issues are recommended for the reinforcement of O & M capacity..

- ✓ Vehicles: many field officers lack in means to travel efficiently. Appropriate motorcycles and automotive vehicles should be provided.
- ✓ Equipment and tools : necessary equipment and tools especially required for the emergency recovery work from power interruption should be provided to improve the system reliability.
- ✓ Measuring instrument and tools : measuring instrument such as earth resistance tester, digital multi-meter and tools such as torque wrench, etc. which are required for the commissioning test and regular maintenance work should be provide to execute these works on time.
- ✓ Items for safety : safety items such as safety helmet and safety belts, etc. should be provided for all field officers.
- ✓ Telecommunication: more mobile phone should be deployed to field officers as the coverage of the mobile network is covering the major part of the country soon.

And, BPC needs to give serious planning efforts to the coordination of the alignment of the MV routes to the future road alignments. This should provide large cost reduction in maintenance and operation costs.

Village Technician Program, initiated by ADB, should be reinforced as well to supplement the work to be done in remote areas.

## 3.4 Consulting Services

### 3.4.1 Necessity of Consulting Services

(1) Time Constraints and Facility Management

The RGoB had decided to supply electricity to all people in Bhutan by June 2013. For this purpose, ADB RE-5 and JICA RE-2 are planned to be implemented. The implementation schedule is plotted using critical path method which accordingly shows that no idle time is allowed to realize the completion date of the project as mentioned before. Time constraints is one of the main reason why foreign consultant is required to BPC, and as mentioned in (5) of this sub-clause, technical transfer on data arrangement for facility management is the most important issue to BPC.

(2) Coordination of Contract Packages

Procurement of the materials will be conducted through a number of contracts. Basically, one contract allotted is for one kind of material. The construction of distribution lines will also be carried out by a number of local contractors. During the peak period of the project, the total number of contracts will be around 50. Timely and well organized coordination among contract packages is significantly important to achieve efficient project implementation

(3) Material Delivery to the Project Site

Materials such as telescopic poles, insulators and conductors shall be delivered at the project site according to delivery schedule to complete the project on time. The timely material delivery to the site is also one of the most important issues for the idle-time free implementation of the project.

(4) Assistance for Bidding

Preparation of bid documents, bidding and bid evaluation process are subject to time constraints despite being the most significant works in the project implementation.

(5) Arrangement of feeder-wise Diagram

The line information such as support, kind of conductor, line length, etc., is arranged and controlled in the GIS. Also, the same information is used in the MI Power (Application Program for Load Flow Study).

The feeder-wise diagram, which may include number and capacity of transformers, kind of conductors, line length, etc., may be produced by extracting the necessary data from the database of MI Power.

Actually, handwritten diagrams have been prepared at some RECD or RECSD. Thus, only the person who prepared the diagram knows the distribution system.

JPST faced difficulty in reviewing the load flow study, and it was time-consuming work to know the feeder-wise information from the “Load Flow Study Diagram”.

(6) Ledger of Distribution Facilities

Together with the feeder-wise diagram, all feeder information should be arranged on the ledger so that all information on the distribution line can be commonly utilized by the personnel concerned.

### 3.4.2 Scope of Work

The scope of work of international consultant includes monitoring and construction schedule control, technical assistance and technical transfer for:

(1) Procurement of Materials

a. To review and endorse drawings and documents submitted by Suppliers for approval;
b. To carry out factory inspections on manufacturing equipment and materials, when necessary;
c. To assist BPC in monitoring the manufacturing and delivery by the Suppliers on schedule.

(2) Civil and Installation Work

a. Construction Supervision
   - Review and endorse all proposed plans, schedules and documents regarding Project implementation and construction work submitted by the Contractor for approval;
   - Check to ensure the Contractor's adherence to approved plans and schedules;
   - Check and inspect work quality and quantity;
   - Conduct additional field visits in order to assist BPC monitor the field works whenever necessary;
   - Advise on the methods of measurement and computation of work volume and provide assistance on the verification of the contract progress and payment;
   - Prepare reports of inspection, tests and supervision activities;
   - Supervise and approve as-built drawings prepared and submitted by the Contractors;
   - Conduct final inspection and witnessing tests to issue the Certificate of Completion to the contractor;

b. Design Modification
   The Consultant shall make revisions and adjustments of design from time to time when they become necessary due to findings in the field or to incorporate relevant comments from concerned agencies.

c. Coordination with other rural electrification programs
   The Consultant wil1 assist BPC in coordination with other rural electrification programs on-going simultaneously with the Project.

d. Preparation of feeder-wise single line diagram and ledger of distribution facilities
   The Consultant wil1 assist BPC in preparation of feeder-wise single line diagram and ledger of distribution facilities.

### 3.4.3 Requirement for Consultant

One of the major contribution to expected on the consultant is to streamline and optimize the procurement processes to meet the deadline of 2013. Therefore the consultant needs to fulfill the following qualification;

- ✓ At least five (5) projects of experience in consultancy services for supervision of implementation of power electricity projects in overseas countries (experience in Bhutan desirable), and
- ✓ At least one (1) project of experience as team leader or project manager for consultancy services under the project financed by JICA or JBIC.

### 3.4.4 Consulting Cost Estimate

Given the extension of the present consulting work to cover the tender documentation and its evaluation work, the main work for the consulting services is construction supervision. The workload for consulting work is one person team for consulting on construction supervision with 11 person-months in total. The estimated cost for consulting is 45 million yen inclusive of overhead and per diem.

### 3.4.3 Personnel Assignment and Schedule

The required personnel include a project manager. His assignment is shown in the Implementation Schedule in Figure-3.1.1.

## 3.5 Environmental and Social Considerations

In Sarpang and Wangduephodrang dzongkhag, the proposed distribution lines are located in Jigme Singye Wangchuck National Park or biological corridors. 34.2 km for Sarpang is located inside the protected area or biological corridor. 17.3km for Wangduephodrang is located inside the protected area. For these areas, the covered conductors with narrower arm span will be used with routes taken mostly on existing roads so as to minimize tree cutting needs and disturbance to animal habitats.

Electrification will bring many positive socio-economic impacts and households will have the opportunity to increase their incomes. Moreover, there will be tangible benefits to women by free them from chores with the use of electric appliance for more productive work. Electricity will reduce the consumption of firewood, thereby positively contributing to the protection of environment as well as public health. The provision of electricity will reduce indoor smoke pollution and will improve health condition of village people through reducing respiratory and eye ailments, which are more common to women, children and the elderly.

There will be no involuntary resettlement needs or land acquisition for the Project. There may be some compensation needs for the removal of orange and other orchard trees to clear the right-of-way for the conductor lines. The compensation cost is estimated to be BTN 40 million and the environmental monitoring cost at BTN 5 million.

# CHAPTER 4 MONITORING AND EVALUATION

## 4.1 Operation/Effect Indicators

### 4.1.1 Distribution OEI

Distribution OEI is indicated by Peak Load (kW), Sales Volume (MWh), Distribution Loss(%), System Average Interruption Duration Index (SAIDI), outage times, Bill Collection Rate (%), and Household Electrification ratio (%).

Table-4.1.1 below summarizes the distribution OEI.

Table-4.1.1 Summary of Distribution Operation/Effect Index[3]

| Indicator | Unit | Data Source | Current Value (Before Project) | Target Value (After Project)*1 |
|---|---|---|---|---|
| Peak Load | MW | Power Data, DOE | 211.0 MW*2 | 381.5 MW*4 |
| Electricity Consumption (Sales Volume) | GWh/year | Power Data Book, BPC | 1,368.17 GWh*2 | 2,293.5 GWh*5 |
| Distribution Loss | % | Power Data Book 2009, BPC | 9.81% (2009) | 9.8 %<br>(Current level) |
| SAIDI (System Average Interruption Duration Index) for distribution line | min/customer /year | Power Data Book 2009, BPC | 365.8 (2009) | 365.8<br>(Current level) |
| Outage Times | Number of times/year | CSD Reliability Data, BPC | 5,354 (2009) | 4,283<br>(20% reduction from current level) |
| Bill Collection Rate | % | BPC ESD | 95.7% (2009) | 100% |
| Energy Consumption per Household | kWh/HH /month | Power Data, DOE | 118.5 kWh | 234 kWh*6 |
| Household Electrification Ratio | % | BPC/PPTA report | 84.7% (2011)*3 | 100% (2013) |

*1: For the year 2013. *2: Actual value in 2008/09 *3 After JICA RE-1 and ADB RE-4 projects *4 Assume 12.5% of annual growth rate derived from the average growth rate from 2003 to 2009 *5 Assume 13.8% of annual growth rate derived from the average growth rate from 2003 to 2009 *6 Assume 14.6% of annual growth rate derived from the average growth rate of energy consumption per capita from 2003 to 2009

(Prepared by JPST)

### 4.1.2 Living Standard OEI

Table-4.1.2. below summarizes living standard indices for current (pre-electrification) and target post-electrification values.

3 The values of Electrification ratio, Bill Collection Rate and Electricity Consumption (Sales Volume) will be released as the JICA's Ex-ante Evaluation.

Table-4.1.2 Summary of Living Standard Index

| | Unit | Source | Current | Target |
|---|---|---|---|---|
| Social status and economic activity | | | | |
| Nos. of households | hh | JICA Study | 3,187 | 3,267 |
| Household income | Nu./hh/month | JICA Study | 1,967 | 2,557 |
| Consumption of firewood | ton/hh/year | JICA Study | 9.3 | 7.0 |
| Nos. of restaurants/shops | nos. | | - | 20% increase |
| Nos. of industry | nos. | | - | 20% increase |
| Education | | | | |
| Rural literacy rate | % | BLSS*2 | 49.0% | - |
| Rural school enrollment rate in middle/higher secondary school | % | BLSS*2 | middle: 44.6%<br>higher: 17.3% | - |

(Prepared by JPST)

## 4.2 Economic Evaluation

### (1) Economic Benefit from Grid Access

According to the technical specifications delineated in Appendix D.2 Economic Benefit Estimation Methodology in the main report, the JPST has estimated consumer benefits arising from five different activities, namely: 1) lighting, 2) radio listening, 3) TV viewing, 4) heating and power, and 5) mobile phone use, as well as cost savings permitted by grid electrification. Table-4.2.1 shows the summary of the estimated consumer benefits from grid electrification per household basis. The total benefit is estimated to be 1,168 Nu per household per month. The consumer benefit for each activity component is detailed in Appendix D.1 Economic Benefit Estimation in the main report.

Table-4.2.1 Summary of Grid Electrification Benefits

| Summary of Benefit | Unit | Consumption | | Price (Nu. Per unit) | | Benefit (Nu./Month) |
|---|---|---|---|---|---|---|
| | | Non-electrified | Electrified | Non-electrified | Electrified | |
| Lighting | k-lumens | 3.7 | 480.0 | 18.3 | 0.1 | 335 |
| Radio-listening | hours | 18 | 72 | 7.5 | 0.036 | 46 |
| TV-viewing | hours | 7.2 | 103.5 | 9.5 | 0.2 | 102 |
| Heat and power | kWh-equivalent | 125 | 78 | 6.8 | 4.2 | 128 |
| Mobile phone | minutes | 57.6 | 114 | 2.6 | 2.0 | 159 |
| Cost Saving from Electrification | | | | 879 | 481 | 398 |
| Total | | | | | | 1,168 |

(Prepared by JPST)

There are other intangible benefits to electrification. One particular importance is the increase in productivity of cottage industries. Also, it has brought educational impacts to children. A range of cottage industries are not thoroughly surveyed in Bhutan but kira and gho (national dress) production is an essential source of income for rural households. Studies on educational impacts have not yet substantiated. However, access to TV and radio will enhance the availability of information as well as provide entertainment for rural population at large. Another benefit is the promotion of public health. The use of firewood and its indoor air pollution contributes to respiratory diseases in non-electrified areas. A reduction in firewood is expected to reduce the prevalence of respiratory diseases in the rural areas

(2) Economic Benefit from Reliability Improvement

Based on the fault records compiled by BPC during 2007-2009, the following summary of lightning damages is obtained.

Table-4.2.2 Summary of Lightning Damages

| | Customer (nos) | Loss Duration (hours) | Lost Energy Consumption (kWh) | Economic Loss (USD thousand) |
|---|---|---|---|---|
| 2007 | 267 | 309.93 | 62,587 | 29 |
| 2008 | 195 | 210.1 | 44,193 | 20 |
| 2009 | 202 | 178.5 | 55,617 | 26 |
| Average | 221 | 233 | 54,132 | 25 |

Note: unit economic value for lost kWh is assumed at USD 0.46/kWh
The average kW load per customer is assumed at 0.4kW.

(Prepared by JPST)

It is presumed that the planned Reliability Improvement Program will have an effect to reduce the number of incidences in half, which, on the average, reduces the economic loss to approximately USD 12,500. The reduction will lead to the decrease in operation and maintenance costs but there is no unit cost calculation per such incidence. Thus, cost savings on maintenance is excluded from the economic benefit estimation.

## 4.3 Economic Evaluation Results for the Distribution Line Project

Economic cash flow analysis has been conducted for the Project period of 30 years with an investment program to be accomplished during 2011-2013. Procurement of materials for the Project will only be finished in 2011. The total number of customers to be added will be 3,701. It is assumed that one third of service connections are completed in 2012 and the remaining balance in 2013.

Table-4.3.1 Economic Evaluation Parameters

| | Unit | Parameters |
|---|---|---|
| Total Customers Under Plan | Nos | 3,701 |
| Investment Planned | USD million | 28 |
| Material Cost | USD million | 14 |
| Civil Cost | USD million | 7 |
| Transport Cost | USD million | 0.2 |
| Household Demand | kWh/month | 112 |
| Other | % | 30 |
| Total Demand Per HH | kWh | 145.6 |
| Willingness-To-Pay | USD | 0.23 |
| Reliability Improvement Benefit | USD million | 0.125 |
| Transmission Loss | % | 20% |
| Power Generation Cost | USD | 0.027 |
| Net Value of WTP | USD | 0.20 |
| Annual Growth to 2015 | % per annum | 5% |
| Annual Growth 2010-20 | % per annum | 5% |
| Annual Growth 2020-40 | % per annum | 3% |
| Grid Annual OM Cost | USD per Customer | 64 |
| Project Life for Grid | years | 30 |

(Prepared by JPST)

Based on the cash flow streams tabulated in Table-4.3.3, the EIRR has been calculated. The estimated EIRR is 7.3%, with an NPV discounted at 12% of USD -9.3million.

Table-4.3.2 Results of Economic Evaluation

Unit: USD Million

| | |
|---|---|
| NPV @12% (USD million) | -9.3 |
| EIRR | 7.3% |

(Prepared by JPST)

Table-4.3.3 Project Economic Cash Flow Table（Unit: Million USD）

| Year | **Number of Customer** | **Economic Benefit from Grid Access** | **Economic Benefit from Reliability Improvement** | **Investment** | **Power Generation Cost and Transmission Loss** | **Operation and Maintenance** | **Net Cash Flow** |
|---|---|---|---|---|---|---|---|
| 2010 | | | | | | | |
| 2011 | | | | 11.5 | | | -11.5 |
| 2012 | 1234 | 0.55 | | 11.7 | 0.07 | 0.08 | -11.3 |
| 2013 | 2468 | 1.15 | 0.06 | 4.4 | 0.1 | 0.16 | -3.5 |
| 2014 | 3,701 | 1.81 | 0.13 | | 0.21 | 0.24 | 1.5 |
| 2015 | 3,701 | 1.90 | 0.13 | | 0.21 | 0.24 | 1.6 |
| 2016 | 3,701 | 1.99 | 0.13 | | 0.21 | 0.24 | 1.7 |
| 2017 | 3,701 | 2.09 | 0.13 | | 0.21 | 0.24 | 1.8 |
| 2018 | 3,701 | 2.20 | 0.13 | | 0.21 | 0.24 | 1.9 |
| 2019 | 3,701 | 2.31 | 0.13 | | 0.21 | 0.24 | 2.0 |
| 2020 | 3,701 | 2.42 | 0.13 | | 0.21 | 0.24 | 2.1 |
| 2021 | 3,701 | 2.50 | 0.13 | | 0.21 | 0.24 | 2.2 |
| 2022 | 3,701 | 2.57 | 0.13 | | 0.21 | 0.24 | 2.3 |
| 2023 | 3,701 | 2.65 | 0.13 | | 0.21 | 0.24 | 2.3 |
| 2024 | 3,701 | 2.73 | 0.13 | | 0.21 | 0.24 | 2.4 |
| 2025 | 3,701 | 2.81 | 0.13 | | 0.21 | 0.24 | 2.5 |
| 2026 | 3,701 | 2.89 | 0.13 | | 0.21 | 0.24 | 2.6 |
| 2027 | 3,701 | 2.98 | 0.13 | | 0.21 | 0.24 | 2.7 |
| 2028 | 3,701 | 3.07 | 0.13 | | 0.21 | 0.24 | 2.7 |
| 2029 | 3,701 | 3.16 | 0.13 | | 0.21 | 0.24 | 2.8 |
| 2030 | 3,701 | 3.26 | 0.13 | | 0.21 | 0.24 | 2.9 |
| 2031 | 3,701 | 3.35 | 0.13 | | 0.21 | 0.24 | 3.0 |
| 2032 | 3,701 | 3.45 | 0.13 | | 0.21 | 0.24 | 3.1 |
| 2033 | 3,701 | 3.56 | 0.13 | | 0.21 | 0.24 | 3.2 |
| 2034 | 3,701 | 3.66 | 0.13 | | 0.21 | 0.24 | 3.3 |
| 2035 | 3,701 | 3.77 | 0.13 | | 0.21 | 0.24 | 3.5 |
| 2036 | 3,701 | 3.89 | 0.13 | | 0.21 | 0.24 | 3.6 |
| 2037 | 3,701 | 4.00 | 0.13 | | 0.21 | 0.24 | 3.7 |
| 2038 | 3,701 | 4.12 | 0.13 | | 0.21 | 0.24 | 3.8 |
| 2039 | 3,701 | 4.25 | 0.13 | | 0.21 | 0.24 | 3.9 |
| 2040 | 3,701 | 4.38 | 0.13 | | 0.21 | 0.24 | 4.1 |
| 2041 | 3,701 | 4.38 | 0.13 | | 0.21 | 0.24 | 4.1 |
| 2042 | 3,701 | 4.38 | 0.13 | | 0.21 | 0.24 | 4.1 |
| 2043 | 3,701 | 4.38 | 0.13 | | 0.21 | 0.24 | 4.1 |

(Prepared by JPST)

## 4.4 Financial Evaluation

Financial evaluation was undertaken to explore financial sustainability of further rural electrification. The cash flow as shown in **Table-4.3.3** was created in order to simulate financial impacts of rural electrification on BPC. The parameters for the simulation are summarized in **Table-4.4.1**.

Table-4.4.1 Parameters for Financial Cash Flow Simulation

| | Unit | Parameters |
|---|---|---|
| Total Customers Under Plan | Nos | 3,701 |
| Investment Planned | USD million | 31 |
| Material Cost | USD million | 14 |
| Civil Cost | USD million | 7 |
| Transport Cost | USD million | 0.2 |
| Household Demand | kWh/month | 112 |
| Other | % | 30 |
| Total Demand Per HH | kWh | 145.6 |
| Tariff | USD | 0.024 |
| Reliability Improvement Benefit | USD million | 0.075 |
| Transmission Loss | % | 20% |
| Power Purchase Cost | USD | 0.003 |
| Annual Growth 2010-20 | % per annum | 2% |
| Annual Growth 2020-40 | % per annum | 2% |
| Grid Annual OM Cost | USD per Customer | 64 |
| Project Life for Grid | years | 30 |

(Prepared by JPST)

The assumed parameters are synonymous to those used for economic evaluation. Instead of WTP increases, the increases in the demand for power are assumed to continue at the rate of 2% per year until 2040. Operation and maintenance costs are estimated at USD 64 per customer basis as shown in Appendix-D in the main report for OM Cost Analysis. It is assumed that BPC is able to purchase the generated energy at the cost of Nu 0.13 per kWh from the Royal Energy at a subsidized price.

The simulated cash flows are shown in Table-4.4.3. The net cash flow marginally turns surplus after 2014. In the end, NPV calculation shows a negative value for the Project and a financial rate of return on investment with also a negative value at -11.7%. Rural electrification power demand comprises less than 4% of total power demand in Bhutan. Thus negative return on the investment in rural electrification does not affect the overall financial situation of BPC. Thus BPC regards rural electrification as part of their corporate social contribution. In addition, BEA evaluates every activity of BPC including rural electrification to make sure it does not incur direct financial losses.

Table-4.4.2 Financial Evaluation Summary

Unit: USD Million

| | |
|---|---|
| NPV @12% (USD million) | -25.6 |
| FIRR | -11.7% |

(Prepared by JPST)

Table-4.4.3 Financial Cash Flow Analysis of Rural Electrification Work

Unit: Million USD

| Year | Number of Customer | Economic Benefit from Grid Access | Economic Benefit from Reliability Improvement | Investment | Power Generation Cost and Transmission Loss | Operation and Maintenance | Net Cash Flow |
|---|---|---|---|---|---|---|---|
| 2010 | | | | | | | |
| 2011 | | | | 12.7 | | | -12.7 |
| 2012 | 1234 | 0.05 | | 13.0 | 0.01 | 0.08 | -13.0 |
| 2013 | 2468 | 0.11 | 0.04 | 5.6 | 0.0 | 0.16 | -5.6 |
| 2014 | 3,701 | 0.17 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2015 | 3,701 | 0.17 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2016 | 3,701 | 0.18 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2017 | 3,701 | 0.18 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2018 | 3,701 | 0.18 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2019 | 3,701 | 0.19 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2020 | 3,701 | 0.19 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2021 | 3,701 | 0.19 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2022 | 3,701 | 0.20 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2023 | 3,701 | 0.20 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2024 | 3,701 | 0.21 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2025 | 3,701 | 0.21 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2026 | 3,701 | 0.22 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2027 | 3,701 | 0.22 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2028 | 3,701 | 0.22 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2029 | 3,701 | 0.23 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2030 | 3,701 | 0.23 | 0.08 | | 0.02 | 0.24 | 0.0 |
| 2031 | 3,701 | 0.24 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2032 | 3,701 | 0.24 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2033 | 3,701 | 0.25 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2034 | 3,701 | 0.25 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2035 | 3,701 | 0.26 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2036 | 3,701 | 0.26 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2037 | 3,701 | 0.27 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2038 | 3,701 | 0.27 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2039 | 3,701 | 0.28 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2040 | 3,701 | 0.28 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2041 | 3,701 | 0.28 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2042 | 3,701 | 0.28 | 0.08 | | 0.02 | 0.24 | 0.1 |
| 2043 | 3,701 | 0.28 | 0.08 | | 0.02 | 0.24 | 0.1 |

(Prepared by JPST)