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|---|---|---|

Title: **SUB-TRANSMISSION BUILDING BLOCKS FOR IPP INTEGRATION**

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# 1. Introduction

A guideline is required to assist network planners in making informed choices regarding the capability of different line configurations, under different loading levels and distances, based on regulatory requirements and costs associated with such designs. It is also aimed at promoting standardized network development and configuration for the integration of IPP's to the Grid.

# 2. Supporting Clauses

## 2.1 Scope

### 2.1.1 Purpose

The purpose of the guideline is to recommend standard line configurations (taking into account regulatory requirements and life cycle cost considerations) to connect collector stations to a 132kV transmission busbar, satellite substations to collector stations and IPPs to collector stations/satellite substations under various power evacuation levels and line lengths. The recommendations from the study also incorporate the economic loading limits of the line configurations over a period of 25 years to ensure that the recommended line configurations are the most optimal in terms of operation and cost.

### 2.1.2 Applicability

This document shall apply throughout Eskom Distribution.

### 2.1.3 Effective Date

This document shall be effective once authorised.

## 2.2 Normative/Informative References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

### 2.2.1 Normative

[1] Distribution Voltage Regulation and Apportionment Limits Standard – 240-70465489.

[2] Network Planning Guideline for Lines and Cables – 240-61227438.

[3] Distribution Network Planning Standard – 240-75757028.

[4] Network and Grid Planning Standard for Generation Grid Connection – Generators Technology Overview and Effects on Networks – 240-61227305.

[5] Network and Grid Planning Standard for Generation Grid Connection – Application for Planning Studies – 240-61227308.

### 2.2.2 Informative

None

## 2.3 Definitions

### 2.3.1 General

| Definition | Description |
|---|---|
| **Collector Station** | Switching station into which multiple generation sources feed, which in turn feeds into a Main Transmission Substation via a single line or power corridor. |
| **Satellite Station** | Similar to a collector station but smaller in capacity and feeding into a collector station. |
| **External Grid** | Represents the upstream transmission network. |

### 2.3.2 Disclosure classification

**Controlled disclosure:** controlled disclosure to external parties (either enforced by law, or discretionary).

## 2.4 Abbreviations

| Abbreviation | Description |
|---|---|
| **BB** | Busbar |
| **HV** | High Voltage |
| **IPP(s)** | Independent Power Producer(s) |
| **km** | Kilometres |
| **kN** | Kilo-Newton |
| **kV** | Kilovolts |
| **LV** | Low Voltage |
| **mm** | Millimetre |
| **MTS** | Main Transmission Station |
| **MV** | Medium Voltage |
| **MW** | Megawatt |
| **PF** | Power Factor |
| **POC** | Point of Connection |
| **pu** | Per Unit |
| **PV** | Photovoltaic |
| **UTS** | Ultimate Tensile Strength |

## 2.5 Roles and Responsibilities

Not applicable.

## 2.6 Process for Monitoring

Not applicable.

## 2.7 Related/Supporting Documents

Not applicable.

# 3. Network Concept Model for IPP Integration

The network concept model proposes the integration of IPP's via satellite and collector stations to the main transmission stations (MTS). The proposed model representing the connection of an IPP to an MTS can thus be expressed as follows:

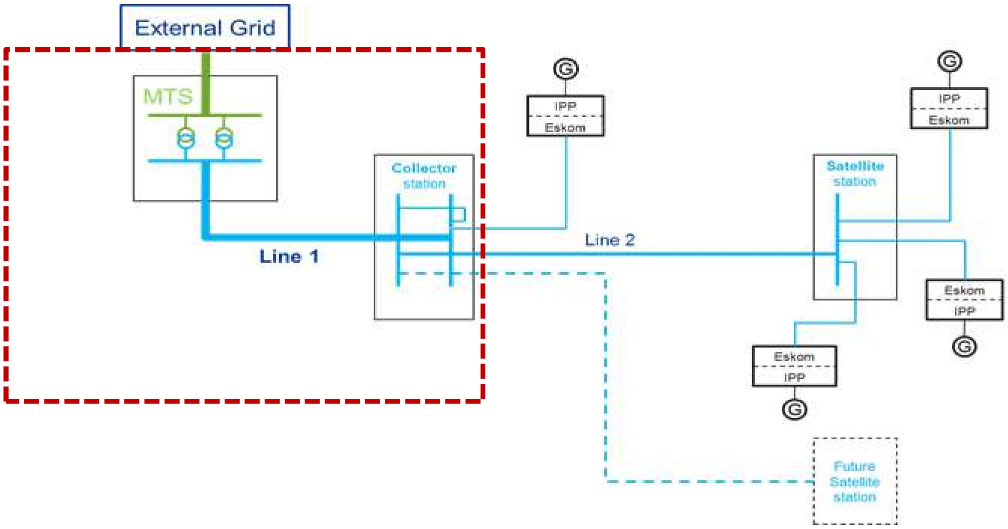


**Figure 1: Network Concept Model**

# 4. Technical Study Scope

The technical study is focused mainly on the connection between the collector station and the MTS which is shown within the dotted outline in Figure 1. The study looks at the operating losses, the voltage change at the collector station and the thermal loading of the conductors for several line configurations over a range of lengths and loading levels.

Based on the extensive amount of possible scenarios and with the aim of making the study as generic as possible, the technical study is limited to the following:

- A minimum collector station capacity of 25 MW and a maximum collector station capacity of 600 MW.
- Line configurations capable of transferring a minimum of 100 MW and a maximum of 800 MW.
- A maximum line length of 100 km.
- Line operating voltage of 132 kV.
- IPPs operating in power factor control mode with the POC (at the 132 kV collector station busbar) at 0.98 leading PF and assuming a constant supply profile.
- Line thermal loading limit of 100% of Rate A. (Ratings derived from the probabilistic method).
- The Transmission 132 kV BB operating at a set-point voltage of 1.05pu.
- Maximum 1% allowed voltage rise at the collector station busbar.
- Minimum voltage level at the collector station busbar of 0.95pu.

## 5. Line Configurations

There are numerous line configurations that can be used to cater for the various power evacuation levels (100 MW – 800 MW) at 132kV. The conductor configurations chosen for the study are based on the most commonly available conductors in Eskom together with non-standard configurations for comparison. Tower types listed for each line configuration are plausible however the planner is still required to investigate new and/or cheaper alternatives. For each power evacuation level, a set of plausible conductor configurations were grouped according to their Rate A ampacity rating and are tabled below:

**Table 1: Line Configurations @ 132kV**

| **Power Evacuation Level** Dependant on length | **Conductor Configuration** *Non-standard conductor | **Template Temperature (°C)** | **Rate A (MVA)** | **Tower Type** | **Conductor Diameter (single circuit) mm** | **UTS (Single Circuit) kN** | **Positive sequence resistance at 1km (Ω)** |
|---|---|---|---|---|---|---|---|
| **800MW** | Double Circuit Twin Bersfort | 50 | 882 | 247 | 71.12 | 360 | 0.01092 |
| | *Double Circuit Twin Zebra | 70 | 858 | 247 | 57.24 | 266 | 0.01707 |
| | *Double Circuit Twin Dinosaur | 50 | 858 | 247 | 71.88 | 411 | 0.01125 |
| | Double Circuit Twin Tern | 70 | 818 | 247 | 54 | 197.4 | 0.01819 |
| **700MW** | Double Circuit Twin Tern | 70 | 818 | 247 | 54 | 197.4 | 0.01819 |
| | Double Circuit Twin Kingbird | 70 | 706 | 247 | 47.76 | 139.6 | 0.02259 |
| **600MW** | Double Circuit Twin Kingbird | 70 | 706 | 247 | 47.76 | 139.6 | 0.02259 |
| | Double Circuit Twin Tern | 50 | 608 | 247 | 54 | 197.4 | 0.01819 |
| **500MW** | Double Circuit Twin Tern | 50 | 608 | 247 | 54 | 197.4 | 0.01819 |
| **400MW** | Double Circuit Twin Chickadee | 60 | 454 | 247 | 37.74 | 89.8 | 0.03582 |
| | Twin Tern | 70 | 409 | 224 | 54 | 197.4 | 0.03638 |
| **300MW** | Double Circuit Twin Chickadee | 50 | 384 | 247 | 37.74 | 89.8 | 0.03582 |
| | Twin Kingbird | 70 | 353 | 224 | 47.76 | 139.6 | 0.04519 |
| | Twin Tern | 50 | 304 | 224 | 54 | 197.4 | 0.03638 |
| **200MW** | Twin Chickadee | 60 | 227 | 248 | 37.74 | 89.8 | 0.07165 |
| | Tern | 70 | 204 | 248 | 27 | 98.7 | 0.07275 |
| **100MW** | Twin Chickadee | 50 | 192 | 248 | 37.74 | 89.8 | 0.07165 |
| | Chickadee | 70 | 128 | 255 | 18.87 | 44.9 | 0.14329 |

# 6. Power System Analysis

## 6.1 System Model

A typical system model of the network depicted in figure 1 is shown below in which an IPP is integrated to the Bacchus 400kV/132kV MTS:

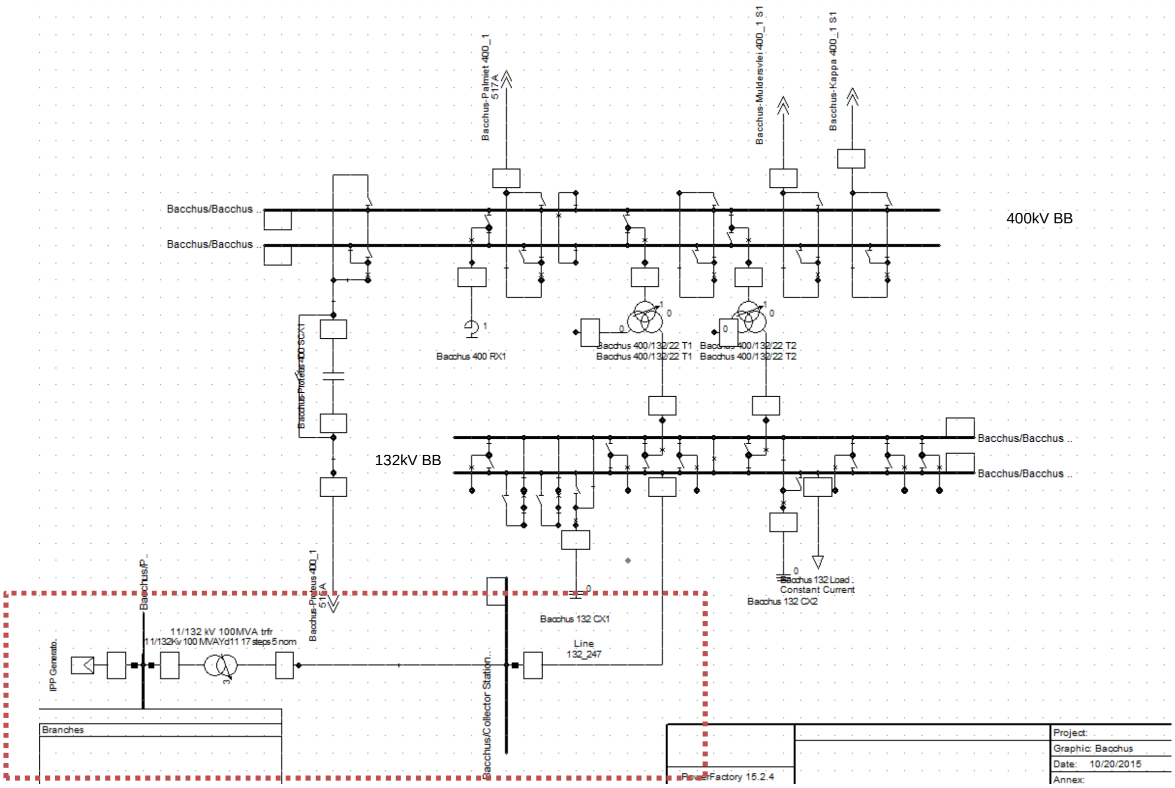


**Figure 2: System Model – IPP Connected to Bacchus 400kV/132kV MTS**

Due to the nature of the study and the main focus being between the collector station and the MTS, the above system model was simplified accordingly and is shown in the figure below:

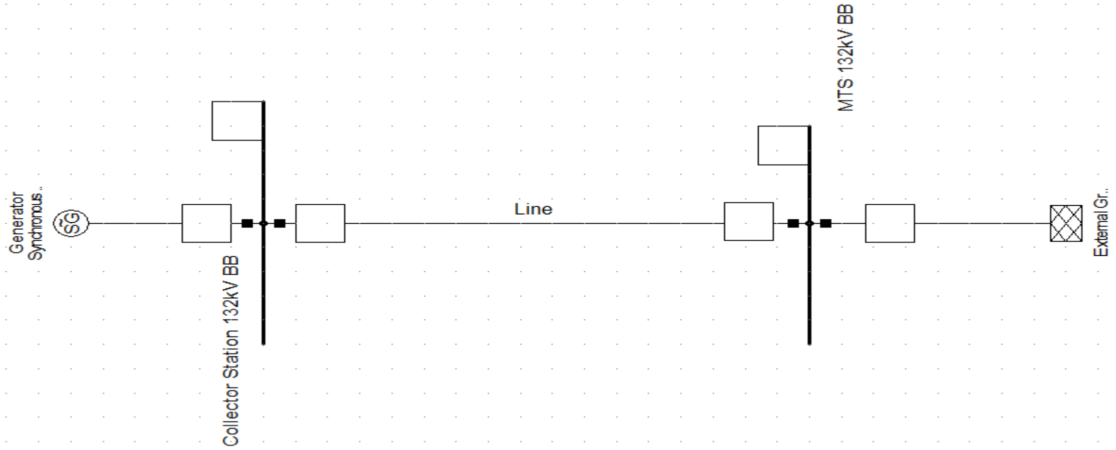


**Figure 3: Simplified System Model**

The simplified model consists of a synchronous generator (operating at a 0.98 capacitive power factor) connected directly to a 132 kV collector station. The collector station is connected to the 132 kV BB at an MTS via a 132 kV line. An external grid is connected to the MTS to keep the set-point voltage at the 132 kV BB at 1.05pu which provides the worst scenario in the case of voltage rise.

## 6.2 Study Parameters, Assumptions & Exclusions

### 6.2.1 Parameters

Based on the study scope, the study parameters for the network model are summarised in the table below:

**Table 2: Study Parameters**

| Element | Parameters |
|---|---|
| MTS 132 kV Busbar | 1. Voltage set-point: 1.05pu. |
| Line | 1. Voltage: 132 kV.<br>2. Thermal Loading Limit: 100% Rate A.<br>3. Tower Family: Various.<br>4. Conductor Type: Various.<br>5. Length: 1 – 100 km. |
| Generator | 1. Type: Synchronous Generator.<br>2. Load Profile: Flat.<br>3. PF: 0.98 Leading. |
| Collector Station | 1. Capacity: 100 – 600 MW. |

### 6.2.2 Assumptions

- The network was analysed under system healthy conditions (i.e. no contingency and a system healthy fault level).
- The IPP was modelled as a single node which ignores internal losses.
- The IPP operates at peak output.

### 6.2.3 Exclusions

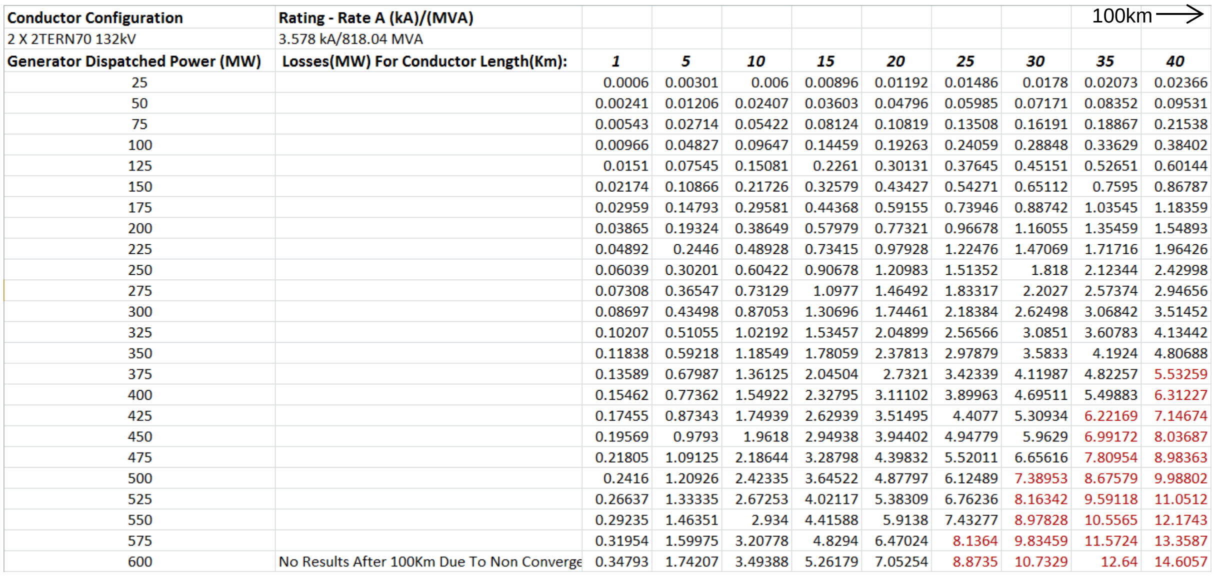
- Varying fault levels.
- IPP generation profiles.

## 6.3 Analysis & Results

A script was developed and used in the analysis to study each of the listed line configurations in table 1 above using the simplified model and the results were written to excel spreadsheets.

The study monitored the generation dispatched at the IPP and recorded the operational losses along the conductors, the thermal loading of the conductors and the voltage level at the collector station busbar. The results for each of these tests were recorded under different line lengths from the collector station to the MTS.

A typical example of a result spreadsheet can be seen in the figure below:



| **Conductor Configuration** | **Rating - Rate A (kA)/(MVA)** | | | | | | | | 100km → | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 X 2TERN70 132kV | 3.578 kA/818.04 MVA | | | | | | | | | |
| **Generator Dispatched Power (MW)** | **Losses(MW) For Conductor Length(Km):** | ***1*** | ***5*** | ***10*** | ***15*** | ***20*** | ***25*** | ***30*** | ***35*** | ***40*** |
| 25 | | 0.0006 | 0.00301 | 0.006 | 0.00896 | 0.01192 | 0.01486 | 0.0178 | 0.02073 | 0.02366 |
| 50 | | 0.00241 | 0.01206 | 0.02407 | 0.03603 | 0.04796 | 0.05985 | 0.07171 | 0.08352 | 0.09531 |
| 75 | | 0.00543 | 0.02714 | 0.05422 | 0.08124 | 0.10819 | 0.13508 | 0.16191 | 0.18867 | 0.21538 |
| 100 | | 0.00966 | 0.04827 | 0.09647 | 0.14459 | 0.19263 | 0.24059 | 0.28848 | 0.33629 | 0.38402 |
| 125 | | 0.0151 | 0.07545 | 0.15081 | 0.2261 | 0.30131 | 0.37645 | 0.45151 | 0.52651 | 0.60144 |
| 150 | | 0.02174 | 0.10866 | 0.21726 | 0.32579 | 0.43427 | 0.54271 | 0.65112 | 0.7595 | 0.86787 |
| 175 | | 0.02959 | 0.14793 | 0.29581 | 0.44368 | 0.59155 | 0.73946 | 0.88742 | 1.03545 | 1.18359 |
| 200 | | 0.03865 | 0.19324 | 0.38649 | 0.57979 | 0.77321 | 0.96678 | 1.16055 | 1.35459 | 1.54893 |
| 225 | | 0.04892 | 0.2446 | 0.48928 | 0.73415 | 0.97928 | 1.22476 | 1.47069 | 1.71716 | 1.96426 |
| 250 | | 0.06039 | 0.30201 | 0.60422 | 0.90678 | 1.20983 | 1.51352 | 1.818 | 2.12344 | 2.42998 |
| 275 | | 0.07308 | 0.36547 | 0.73129 | 1.0977 | 1.46492 | 1.83317 | 2.2027 | 2.57374 | 2.94656 |
| 300 | | 0.08697 | 0.43498 | 0.87053 | 1.30696 | 1.74461 | 2.18384 | 2.62498 | 3.06842 | 3.51452 |
| 325 | | 0.10207 | 0.51055 | 1.02192 | 1.53457 | 2.04899 | 2.56566 | 3.0851 | 3.60783 | 4.13442 |
| 350 | | 0.11838 | 0.59218 | 1.18549 | 1.78059 | 2.37813 | 2.97879 | 3.5833 | 4.1924 | 4.80688 |
| 375 | | 0.13589 | 0.67987 | 1.36125 | 2.04504 | 2.7321 | 3.42339 | 4.11987 | 4.82257 | 5.53259 |
| 400 | | 0.15462 | 0.77362 | 1.54922 | 2.32795 | 3.11102 | 3.89963 | 4.69511 | 5.49883 | 6.31227 |
| 425 | | 0.17455 | 0.87343 | 1.74939 | 2.62939 | 3.51495 | 4.4077 | 5.30934 | 6.22169 | 7.14674 |
| 450 | | 0.19569 | 0.9793 | 1.9618 | 2.94938 | 3.94402 | 4.94779 | 5.9629 | 6.99172 | 8.03687 |
| 475 | | 0.21805 | 1.09125 | 2.18644 | 3.28798 | 4.39832 | 5.52011 | 6.65616 | 7.80954 | 8.98363 |
| 500 | | 0.2416 | 1.20926 | 2.42335 | 3.64522 | 4.87797 | 6.12489 | 7.38953 | 8.67579 | 9.98802 |
| 525 | | 0.26637 | 1.33335 | 2.67253 | 4.02117 | 5.38309 | 6.76236 | 8.16342 | 9.59118 | 11.0512 |
| 550 | | 0.29235 | 1.46351 | 2.934 | 4.41588 | 5.9138 | 7.43277 | 8.97828 | 10.5565 | 12.1743 |
| 575 | | 0.31954 | 1.59975 | 3.20778 | 4.8294 | 6.47024 | 8.1364 | 9.83459 | 11.5724 | 13.3587 |
| 600 | No Results After 100Km Due To Non Converge | 0.34793 | 1.74207 | 3.49388 | 5.26179 | 7.05254 | 8.8735 | 10.7329 | 12.64 | 14.6057 |

**Figure 4: Result Spreadsheet (Operational Losses)**

Spreadsheets similar to the one above were created for the operational losses, voltage at the collector station busbars and the thermal loading for each line configuration.

## 6.4 Lookup-Table

In order to consolidate all of the attained information a lookup table was created to list the values, with evacuation capacity (MW) from 25 to 600 in steps of 25 and for distances (km) from 1 to 100 in steps of 5.

The intention of the lookup-table is to allow one to identify potential choices of line configurations for a mix of evacuation capacities and distances.

To populate the table, a macro was developed and used to browse through each result block in each result spreadsheet for all of the line configurations. The macro performed regulation checks to ensure that in each block the voltage rise at the collector station did not exceed 1%, the line thermal loading did not exceed 100% and the collector station busbar voltage did not go below 0.95pu. If all of these conditions were met (i.e. no limits/regulations were violated) the macro recorded that specific line configuration in the lookup-table as a possible option to be used for that specific loading level and distance.

The end result is a lookup-table consisting of various possible line configuration options for various loading levels and distances taking into account regulatory requirements and limits. The complete lookup-table can be found under section 13.1 in this report. A snapshot of the resultant table can be seen in the figure below:

| | 1km | 5km | 10km | 15km | 20km |
|---|---|---|---|---|---|
| **25MW** | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV<br>2 X 2KINGBIRD70 132kV<br>2 X 2BERSFORT50 132kV<br>2 X 2DINOSAUR50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV<br>2 X 2KINGBIRD70 132kV<br>2 X 2BERSFORT50 132kV<br>2 X 2DINOSAUR50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV |
| **50MW** | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV<br>2 X 2KINGBIRD70 132kV<br>2 X 2BERSFORT50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV<br>2 X 2TERN50 132kV<br>2 X 2KINGBIRD70 132kV<br>2 X 2BERSFORT50 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV | 1 X 2CHICKADEE50 132kV<br>2 X 2HARE60 132kV<br>2 X 2CHICKADEE50 132kV<br>2 X 2CHICKADEE60 132kV |

**Figure 5: Resultant Lookup Snapshot**

The above table consists of many possible choices of line configurations for various loading levels and distances however the life-cycle costing of the configurations are not taken into account at this stage (only regulatory requirements are currently considered). The next step is to thus determine the most economically feasible conductor configuration for each block by means of analysing the economic loading limits of each configuration.

# 7. Line Configuration Costing

## 7.1 Capital Costing Assumptions

The estimate costing of each of the line configurations was calculated using the 2014 cost estimation spreadsheet from Line Engineering Services and was based on the following common parameters for each configuration:

**Table 3: Line Capital Costing Assumptions**

| Parameter | Value |
|---|---|
| Construction duration | 12 Months |
| Line Voltage | 132 kV |
| Number of contractors | 2 |
| Greased/Ungreased conductors | Ungreased |
| Insulation type | Glass |
| Soil type | Type 1: 20%, Type 2: 20%, Type 3: 20%, Type 4: 20%, Soft Rock: 10%, Hard Rock: 10%. |
| Terrain Type | Flat: 25%, Moderate: 25%, Hilly: 25%, Mountainous: 25% |
| Tower Family Types (i.e. 247A/B/C) | A (70%), B (20%), C (10%) |

## 7.2 Capital Costing Components

The major components that contribute to the total estimate costing of each line configuration are listed below:

a) Construction Contract:

- Preliminaries and general
- Access & Environmental Rehabilitation
- Minor works
- Foundations
- Tower Supply
- Tower Construction
- Stringing & Tower Dressing

b) Material Supply:

- Hardware
- Insulators
- Conductors

## 7.3 Capital Costing Summary

The estimated unit capital cost/km of each line configuration is summarised in the table below:

**Table 4: Line Capital Costing Summary**

| Conductor | Tower Type | Unit Capital Cost (Rm/km) | | |
|---|---|---|---|---|
| | | 50°C | 60°C | 70°C |
| Double Circuit Twin Dinosaur | 247 | ≈ 5.89 | ≈ 5.91 | ≈ 5.92 |
| Double Circuit Twin Bersfort | 247 | ≈ 5.78 | ≈ 5.81 | ≈ 5.82 |
| Double Circuit Twin Zebra | 247 | ≈ 4.36 | ≈ 4.38 | ≈ 4.39 |
| Double Circuit Twin Tern | 247 | ≈ 3.94 | ≈ 3.97 | ≈ 3.98 |
| Double Circuit Twin Kingbird | 247 | ≈ 3.56 | ≈ 3.58 | ≈ 3.59 |
| Double Circuit Twin Chickadee | 247 | ≈ 3.13 | ≈ 3.16 | ≈ 3.17 |
| Twin Tern | 224 | ≈ 2.27 | ≈ 2.29 | ≈ 2.29 |
| Twin Kingbird | 224 | ≈ 2.05 | ≈ 2.07 | ≈ 2.07 |
| Twin Chickadee | 248 | ≈ 1.95 | ≈ 1.96 | ≈ 1.97 |
| Tern | 248 | ≈ 1.85 | ≈ 1.86 | ≈ 1.87 |
| Chickadee | 255 | ≈ 1.38 | ≈ 1.39 | ≈ 1.40 |

# 8. Economic Line Loading Limits

This section aims to find a balance between meeting minimum network requirements (i.e. thermal limits, fault level ratings and voltage limits) whilst minimising the total life-cycle cost of the line configurations (capital cost and technical losses).

## 8.1 Inputs and Assumptions

The DIgSILENT Power Factory simulation results of the model were used as inputs to the economic line loading limit study. In particular, the peak line technical losses for the different conductor configurations at different generation outputs as well as different conductor lengths were used. Given that line technical losses are directly proportional to the line length, losses were only calculated for a line length of 1 km.

The results of the Lines Engineering Service Cost Estimate Tool were also used as inputs to the study. The capital cost of construction of the line is assumed to be directly proportional to the line length. The capital cost of constructing a 1 km line structure for the different conductor configurations considered was used as an input to the study. The difference in operational and maintenance cost for the different conductor configurations was assumed to be negligible. As such, the operational and maintenance cost was excluded from the study.

Due to the nature of the study, neither the intermittent nature of the generation nor the effects of seasonal changes on the generation output were investigated/ simulated in this study. A minimum generation output of 25 MW was used, with the maximum output capacity capped at 600 MW with 25 MW increments.

However, to factor in load (or generation in this case) diversification, a load factor (LF) of 0.35 was assumed.

The equipment/plant life cycle is assumed to be 25 years and the generation cost assumed to be 70 c/kWh irrespective of the technology. The net discount rate (NDR) over the 25 year period was assumed to be 0%.

## 8.2 Calculation Methodology

The fundamental objective was to assess the most economical conductor configuration to be used to transfer power ranging from 25 MW to 600 MW over a distance of 1 km. With the operational and maintenance cost assumed to be the same, the factors affecting the economic viability of a given conductor configuration are the cost of construction and the cost due to technical losses. For a 1 km line, the capital cost of a given conductor configuration will remain the same irrespective of the power transfer. However, the technical losses will vary with the varying power transfer.

The method presented here aims to quantify the Rand-value of the technical losses associated with the different conductor configurations at different line loadings. This together with the capital cost of the construction configuration will provide the total cost of the conductor configuration.

To quantify the Rand-value for technical losses, the MW value was converted to energy (megawatt-hour - MWh). Using the 70 c/kWh assumed generation cost, the Rand-value of the technical losses can be calculated over the 25 year period (219 000 hours). Table 5 shows the peak technical losses for the different conductor configurations at different generating capacity.

**Table 5: Line Peak Technical Losses at 1 km**

| Conductor Type / Line Loading [MW] | Line Peak Technical Losses [kW] | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 |
| Double Circuit Twin Tern 70°C | 0.6 | 2.4 | 5.4 | 9.7 | 15.1 | 21.7 | 29.6 | 38.6 | 48.9 | 60.4 | 73.1 | 87.0 | 102.1 | 118.4 | 135.9 | 154.6 | 174.6 | 195.7 | 218.0 | 241.6 | 266.4 | 292.3 | 319.5 | 347.9 |
| Double Circuit Twin Zebra 70°C | 0.6 | 2.3 | 5.1 | 9.1 | 14.2 | 20.4 | 27.8 | 36.3 | 45.9 | 56.7 | 68.6 | 81.6 | 95.8 | 111.1 | 127.5 | 145.1 | 163.8 | 183.7 | 204.7 | 226.8 | 250.0 | 274.4 | 299.9 | 326.6 |
| Double Circuit Twin Dinosaur 50°C | 0.4 | 1.5 | 3.4 | 6.0 | 9.3 | 13.5 | 18.3 | 23.9 | 30.3 | 37.4 | 45.2 | 53.8 | 63.2 | 73.3 | 84.1 | 95.7 | 108.0 | 121.1 | 135.0 | 149.6 | 164.9 | 181.0 | 197.8 | 215.4 |
| Double Circuit Twin Bersfort 50°C | 0.4 | 1.4 | 3.3 | 5.8 | 9.1 | 13.1 | 17.8 | 23.2 | 29.4 | 36.3 | 43.9 | 52.2 | 61.3 | 71.1 | 81.6 | 92.9 | 104.8 | 117.5 | 131.0 | 145.1 | 160.0 | 175.6 | 191.9 | 209.0 |
| Double Circuit Twin Kingbird 70°C | 0.7 | 3.0 | 6.7 | 12.0 | 18.7 | 27.0 | 36.7 | 48.0 | 60.8 | 75.0 | 90.8 | 108.0 | 126.8 | 147.0 | 168.8 | 192.0 | 216.8 | 243.0 | 270.8 | 300.0 | 330.8 | 363.0 | 396.8 | 432.0 |
| Double Circuit Twin Tern 50°C | 0.6 | 2.4 | 5.4 | 9.7 | 15.1 | 21.7 | 29.6 | 38.6 | 48.9 | 60.4 | 73.1 | 87.0 | 102.1 | 118.4 | 135.9 | 154.6 | 174.6 | 195.7 | 218.0 | 241.6 | 266.4 | 292.3 | 319.5 | 347.9 |
| Double Circuit Twin Chickadee 60°C | 1.2 | 4.8 | 10.7 | 19.0 | 29.7 | 42.8 | 58.3 | 76.1 | 96.3 | 118.9 | 143.8 | 171.2 | 200.9 | 233.0 | 267.5 | 304.3 | 343.5 | 385.1 | 429.1 | 475.4 | 524.1 | 575.2 | 628.7 | 684.5 |
| Double Circuit Twin | 1.2 | 4.8 | 10.7 | 19.0 | 29.7 | 42.8 | 58.3 | 76.1 | 96.3 | 118.9 | 143.8 | 171.2 | 200.9 | 233.0 | 267.5 | 304.3 | 343.5 | 385.1 | 429.1 | 475.4 | 524.1 | 575.2 | 628.7 | 684.5 |

| Conductor Type / Line Loading [MW] | **Line Peak Technical Losses [kW]** | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 |
| Chickadee 50°C | | | | | | | | | | | | | | | | | | | | | | | | |
| Twin Chickadee 50°C | 2.4 | 9.5 | 21.4 | 38.0 | 59.4 | 85.6 | 116.5 | 152.1 | 192.5 | 237.7 | 287.6 | 342.2 | 401.6 | 465.7 | 534.6 | 608.2 | 686.5 | 769.6 | 857.5 | 950.0 | 1047 | 1149 | 1256 | 1367 |
| Twin Kingbird 70°C | 1.5 | 6.0 | 13.5 | 24.0 | 37.5 | 54.0 | 73.5 | 96.0 | 121.5 | 150.0 | 181.5 | 216.0 | 253.5 | 294.0 | 337.5 | 384.0 | 433.5 | 486.0 | 541.5 | 600.0 | 661.5 | 726.0 | 793.5 | 864.0 |
| Twin Tern 50°C | 1.2 | 4.8 | 10.9 | 19.3 | 30.2 | 43.5 | 59.2 | 77.3 | 97.8 | 120.8 | 146.2 | 174.0 | 204.2 | 236.8 | 271.8 | 309.3 | 349.1 | 391.4 | 436.2 | 483.3 | 532.8 | 584.8 | 639.2 | 696.0 |
| Twin Tern 70°C | 1.2 | 4.8 | 10.9 | 19.3 | 30.2 | 43.5 | 59.2 | 77.3 | 97.8 | 120.8 | 146.2 | 174.0 | 204.2 | 236.8 | 271.8 | 309.3 | 349.1 | 391.4 | 436.2 | 483.3 | 532.8 | 584.8 | 639.2 | 696.0 |
| Chickadee 70°C | 4.8 | 19.0 | 42.8 | 76.0 | 118.8 | 171.0 | 232.7 | 303.9 | 384.6 | 474.7 | 574.2 | 683.2 | 801.7 | 929.5 | 1066 | 1213 | 1369 | 1535 | 1710 | 1894 | 2088 | 2291 | 2504 | 2726 |
| Tern 70°C | 2.4 | 9.7 | 21.7 | 38.6 | 60.4 | 86.9 | 118.3 | 154.5 | 195.6 | 241.4 | 292.1 | 347.6 | 408.0 | 473.1 | 543.1 | 617.9 | 697.6 | 782.0 | 871.3 | 965.4 | 1064 | 1168 | 1276 | 1390 |

In the same manner that load factor (LF) is used to effect load diversification when determining the energy demand in a power system, a load loss factor (LLF) is used when determining the energy loss of a power system.

The LLF is a function of the LF, and it is expressed as follows:

$$\boldsymbol{LLF = k \times LF + (1 - k) \times LF^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, [\mathbf{1}]$$

LLF : Load loss factor,

LF : Load factor,

k : A constant $0 < k \leq 1$

Load factor was assumed to be 0.35 and a value for k of 0.1 was assumed, resulting in a LLF of 0.145.

To calculate energy loss as a result of the technical losses, the following expression is used:

$$E_{Losses} = P_{Peak\ Losses} \times LLF \times T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, [2]$$

$E_{Losses}$ : Energy losses due to technical peak losses,

$P_{Peak\ Losses}$ : Peak technical losses,

LLF : load loss factor,

T : Period in hours

The energy loss equation above provides the energy (MWH) lost due to the conductor technical losses. The rand value of the energy loss is then calculated using the 70 c/kWh generation cost, which is equivalent to 700 R/MWh, as:

$$E_{Loss\ Cost} = E_{Losses} \times E_{Generation\ Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, [3]$$

$E_{Loss\ Cost}$ : Cost of energy in Rands due to technical losses,

$E_{Losses}$ : Energy losses due to technical peak losses,

$E_{Generation\ Cost}$ : Cost of energy generation in R/kWh, assumed to be 70 c/kWh (700 R/MWh)

The total cost of a 1 km line was then considered to be the summation of the capital cost and the line energy loss cost.

$$Total\ Cost = Capital\ Cost + E_{Loss\ Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, [4]$$

## 8.3 Line Energy Loss and Cost

Table 6 shows the calculated line energy loss results from equation 2. The cost of energy losses is then calculated with these results using equation 3 with the 700 R/MW cost of generation. The results are listed in Table 7.

.

## Table 6: Line Energy Losses at 1km

| Conductor Type / Line Loading [MW] | **Line Loss Energy [MWH]** | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **125** | **150** | **175** | **200** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| Double Circuit Twin Tern 70°C | 0.8 | 3.1 | 6.9 | 12.3 | 19.2 | 27.7 | 37.7 | 49.2 | 62.2 | 76.8 | 93.0 | 110.7 | 129.9 | 150.6 | 172.9 | 196.7 | 222.1 | 249.0 | 277.4 | 307.4 | 338.9 | 372.0 | 406.6 | 442.7 |
| Double Circuit Twin Zebra 70°C | 0.7 | 2.9 | 6.5 | 11.5 | 18.0 | 26.0 | 35.3 | 46.2 | 58.4 | 72.1 | 87.3 | 103.9 | 121.9 | 141.4 | 162.3 | 184.7 | 208.5 | 233.7 | 260.4 | 288.5 | 318.1 | 349.1 | 381.6 | 415.5 |
| Double Circuit Twin Dinosaur 50°C | 0.5 | 1.9 | 4.3 | 7.6 | 11.9 | 17.1 | 23.3 | 30.4 | 38.5 | 47.6 | 57.6 | 68.5 | 80.4 | 93.2 | 107.0 | 121.8 | 137.5 | 154.1 | 171.7 | 190.3 | 209.8 | 230.3 | 251.7 | 274.1 |
| Double Circuit Twin Bersfort 50°C | 0.5 | 1.8 | 4.2 | 7.4 | 11.5 | 16.6 | 22.6 | 29.5 | 37.4 | 46.1 | 55.8 | 66.5 | 78.0 | 90.5 | 103.8 | 118.1 | 133.4 | 149.5 | 166.6 | 184.6 | 203.6 | 223.4 | 244.2 | 265.9 |
| Double Circuit Twin Kingbird 70°C | 1.0 | 3.8 | 8.6 | 15.3 | 23.9 | 34.4 | 46.8 | 61.1 | 77.3 | 95.4 | 115.5 | 137.4 | 161.3 | 187.1 | 214.7 | 244.3 | 275.8 | 309.2 | 344.5 | 381.7 | 420.9 | 461.9 | 504.9 | 549.7 |
| Double Circuit Twin Tern 50°C | 0.8 | 3.1 | 6.9 | 12.3 | 19.2 | 27.7 | 37.7 | 49.2 | 62.2 | 76.8 | 93.0 | 110.7 | 129.9 | 150.6 | 172.9 | 196.7 | 222.1 | 249.0 | 277.4 | 307.4 | 338.9 | 372.0 | 406.6 | 442.7 |
| Double Circuit Twin Chickadee 60°C | 1.5 | 6.1 | 13.6 | 24.2 | 37.8 | 54.5 | 74.1 | 96.8 | 122.5 | 151.3 | 183.0 | 217.8 | 255.6 | 296.5 | 340.3 | 387.2 | 437.1 | 490.0 | 545.9 | 604.9 | 666.9 | 731.9 | 799.9 | 871.0 |
| Double Circuit Twin Chickadee 50°C | 1.5 | 6.1 | 13.6 | 24.2 | 37.8 | 54.5 | 74.1 | 96.8 | 122.5 | 151.3 | 183.0 | 217.8 | 255.6 | 296.5 | 340.3 | 387.2 | 437.1 | 490.0 | 545.9 | 604.9 | 666.9 | 731.9 | 799.9 | 871.0 |
| Twin Chickadee 50°C | 3.0 | 12.1 | 27.2 | 48.4 | 75.6 | 108.9 | 148.2 | 193.6 | 245.0 | 302.4 | 365.9 | 435.4 | 511.0 | 592.6 | 680.2 | 773.9 | 873.6 | 979.3 | 1091 | 1208 | 1332 | 1462 | 1598 | 1740 |
| Twin Kingbird 70°C | 1.9 | 7.6 | 17.2 | 30.5 | 47.7 | 68.7 | 93.5 | 122.1 | 154.6 | 190.9 | 230.9 | 274.8 | 322.6 | 374.1 | 429.4 | 488.6 | 551.6 | 618.4 | 689.0 | 763.5 | 841.7 | 923.8 | 1009 | 1099 |
| Twin Tern 50°C | 1.5 | 6.1 | 13.8 | 24.6 | 38.4 | 55.3 | 75.3 | 98.4 | 124.5 | 153.7 | 186.0 | 221.3 | 259.8 | 301.3 | 345.9 | 393.5 | 444.3 | 498.1 | 555.0 | 614.9 | 678.0 | 744.1 | 813.3 | 885.6 |

| Conductor Type / Line Loading [MW] | **Line Loss Energy [MWH]** | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **125** | **150** | **175** | **200** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| Twin Tern 70°C | 1.5 | 6.1 | 13.8 | 24.6 | 38.4 | 55.3 | 75.3 | 98.4 | 124.5 | 153.7 | 186.0 | 221.3 | 259.8 | 301.3 | 345.9 | 393.5 | 444.3 | 498.1 | 555.0 | 614.9 | 678.0 | 744.1 | 813.3 | 885.6 |
| Chickadee 70°C | 6.0 | 24.2 | 54.4 | 96.8 | 151.1 | 217.6 | 296.1 | 386.7 | 489.3 | 603.9 | 730.6 | 869.3 | 1020 | 1182 | 1357 | 1544 | 1742 | 1953 | 2176 | 2410 | 2657 | 2915 | 3186 | 3468 |
| Tern 70°C | 3.1 | 12.3 | 27.7 | 49.2 | 76.8 | 110.6 | 150.5 | 196.6 | 248.8 | 307.2 | 371.7 | 442.3 | 519.1 | 602.0 | 691.1 | 786.2 | 887.6 | 995 | 1108 | 1228 | 1354 | 1486 | 1624 | 1768 |

### Table 7: Line Loss Energy Cost at 1 km

| **Conductor Type /** Line Loading [MW] | **Line Loss Energy Cost [R x 1000]** | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **125** | **150** | **175** | **200** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| Double Circuit Twin Tern 70°C | 0.5 | 2.2 | 4.8 | 8.6 | 13.4 | 19.4 | 26.4 | 34.4 | 43.6 | 53.8 | 65.1 | 77.5 | 90.9 | 105 | 121 | 137 | 155 | 174 | 194 | 215 | 237 | 260 | 284 | 309 |
| Double Circuit Twin Zebra 70°C | 0.5 | 2.0 | 4.5 | 8.1 | 12.6 | 18.2 | 24.7 | 32.3 | 40.9 | 50.5 | 61.1 | 72.7 | 85.3 | 99.0 | 113 | 129 | 145 | 163 | 182 | 202 | 222 | 244 | 267 | 290 |
| Double Circuit Twin Dinosaur 50°C | 0.3 | 1.3 | 3.0 | 5.3 | 8.3 | 12.0 | 16.3 | 21.3 | 27.0 | 33.3 | 40.3 | 47.9 | 56.3 | 65.3 | 74.9 | 85.2 | 96.2 | 107. | 120 | 133 | 146 | 161 | 176 | 191 |
| Double Circuit Twin Bersfort 50°C | 0.3 | 1.3 | 2.9 | 5.2 | 8.1 | 11.6 | 15.8 | 20.7 | 26.2 | 32.3 | 39.1 | 46.5 | 54.6 | 63.3 | 72.7 | 82.7 | 93.4 | 104 | 116 | 129 | 142 | 156 | 170 | 186 |
| Double Circuit Twin Kingbird 70°C | 0.7 | 2.7 | 6.0 | 10.7 | 16.7 | 24.0 | 32.7 | 42.8 | 54.1 | 66.8 | 80.8 | 96.2 | 112 | 130 | 150 | 171 | 193 | 216 | 241 | 267 | 294 | 323 | 353 | 384 |

| **Conductor Type /** Line Loading [MW] | **Line Loss Energy Cost [R x 1000]** | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **25** | **50** | **75** | **100** | **125** | **150** | **175** | **200** | **225** | **250** | **275** | **300** | **325** | **350** | **375** | **400** | **425** | **450** | **475** | **500** | **525** | **550** | **575** | **600** |
| Double Circuit Twin Tern 50°C | 0.5 | 2.2 | 4.8 | 8.6 | 13.4 | 19.4 | 26.4 | 34.4 | 43.6 | 53.8 | 65.1 | 77.5 | 90.9 | 105 | 121 | 137 | 155 | 174 | 194 | 215 | 237 | 260 | 284 | 309 |
| Double Circuit Twin Chickadee 60°C | 1.1 | 4.2 | 9.5 | 16.9 | 26.5 | 38.1 | 51.9 | 67.8 | 85.8 | 105 | 128 | 152 | 178 | 207 | 238 | 271 | 306 | 343 | 382 | 423 | 466 | 512 | 559 | 609 |
| Double Circuit Twin Chickadee 50°C | 1.1 | 4.2 | 9.5 | 16.9 | 26.5 | 38.1 | 51.9 | 67.8 | 85.8 | 105 | 128 | 152 | 178 | 207 | 238 | 271 | 306 | 343 | 382 | 423 | 466 | 512 | 559 | 609 |
| Twin Chickadee 50°C | 2.1 | 8.5 | 19.1 | 33.9 | 52.9 | 76.2 | 103 | 135 | 171 | 211 | 256 | 304 | 357 | 414 | 476 | 541 | 611 | 685 | 763 | 846 | 932 | 1,023 | 1,118 | 1,218 |
| Twin Kingbird 70°C | 1.3 | 5.3 | 12.0 | 21.4 | 33.4 | 48.1 | 65.5 | 85.5 | 108 | 133 | 161 | 192 | 225 | 261 | 300 | 342 | 386 | 432 | 482 | 534 | 589 | 646 | 706 | 769 |
| Twin Tern 50°C | 1.1 | 4.3 | 9.7 | 17.2 | 26.9 | 38.7 | 52.7 | 68.9 | 87.1 | 107 | 130 | 154 | 181 | 210 | 242 | 275 | 311 | 348 | 388 | 430 | 474 | 520 | 569 | 619 |
| Twin Tern 70°C | 1.1 | 4.3 | 9.7 | 17.2 | 26.9 | 38.7 | 52.7 | 68.9 | 87.1 | 107 | 130 | 154 | 181 | 210 | 242 | 275 | 311 | 348 | 388 | 430 | 474 | 520 | 569 | 619 |
| Chickadee 70°C | 4.2 | 16.9 | 38.1 | 67.7 | 105 | 152 | 207 | 270 | 342 | 422 | 511 | 608 | 714 | 827 | 950 | 1,080 | 1,220 | 1,367 | 1,523 | 1,687 | 1,860 | 2,041 | 2,230 | 2,428 |
| Tern 70°C | 2.2 | 8.6 | 19.4 | 34.4 | 53.8 | 77.4 | 105 | 137 | 174 | 215 | 260 | 309 | 363 | 421 | 483 | 550 | 621 | 696 | 776 | 859 | 948 | 1,040 | 1,137 | 1,238 |

# 9. Collector Stations and Satellite Stations

## 9.1 Configuration

The collector stations and satellite stations will be designed as six and three feeder bay configurations respectively as shown in the figures below.

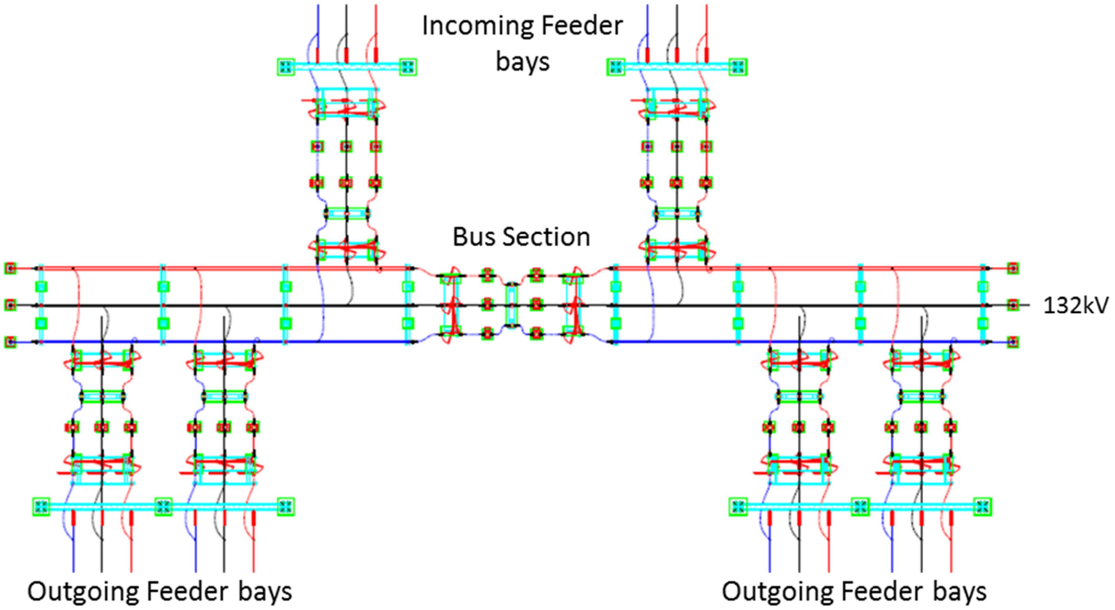


**Figure 6 Six feeder bay configuration – Collector Station**

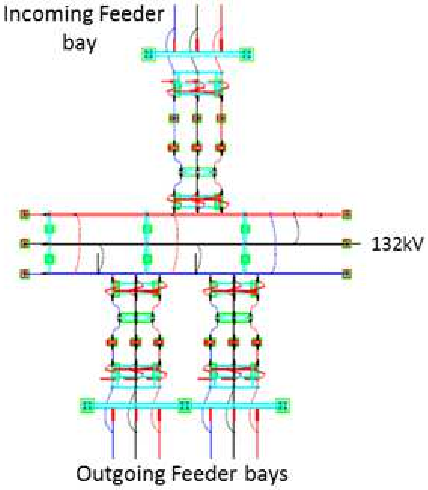


**Figure 7 Three feeder bay configuration – Satellite Station**

## 9.2 Costs

The estimated cost for the station configurations shown in Figures 7 and 8 are tabulated below.

**Table 8: Estimated Costs of Collector and Satellite Stations**

| Station Type | Feeder Bay | Bus Section | Busbar (up to 7 Feeders) | Total Cost | Additional Feeder-Bay |
|---|---|---|---|---|---|
| Collector Station | 6 x R3.3m | 1 x R5.5m | 1 x R4.1m | R29.4m | R3.3m |
| Satellite Station | 3 x R3.3m | 0 | 1 x R4.1m | R14.0m | R3.3m |
| MTS (132kV) | N/A | N/A | N/A | N/A | R7.8m |

The estimated cost is based on the cost estimation guideline from Eskom Grid Planning (GC PDD – EST01) and cost estimations from Eskom Distribution Planning.

# 10. Results and Recommendations

This section outlines the results of the energy loss calculations. The results are compared for the different conductor configurations to provide suitable recommendations.

Using the results from Table 7 and the line capital cost from Table 4, the total cost for the different conductor configurations were calculated over a 25 year period and the results plotted as shown in Figure 8. The power transfer capacity of the conductors was used as the limit when plotting the total cost. Consequently, the total cost was only considered up to each individual conductor's power transfer capacity.

Figure 8 shows the total cost per conductor configuration plotted against the power transfer capacity. Using the economic line loading graphs of Figure 8, one can select the most economic conductor to be used for the size of generation capacity to be evacuated. The graph closest to the x-axis (Peak Loading / Generation) on Figure 8 indicates the most economic conductor for the power transfer considered.

The graphs in Figure 8 indicate that a Chickadee 70 $^0$C conductor is the most economical to transfer power less than 75 MW, whilst Twin Tern 70 $^0$C is the most economical for power transfer between 75 – 275 MW, etc.

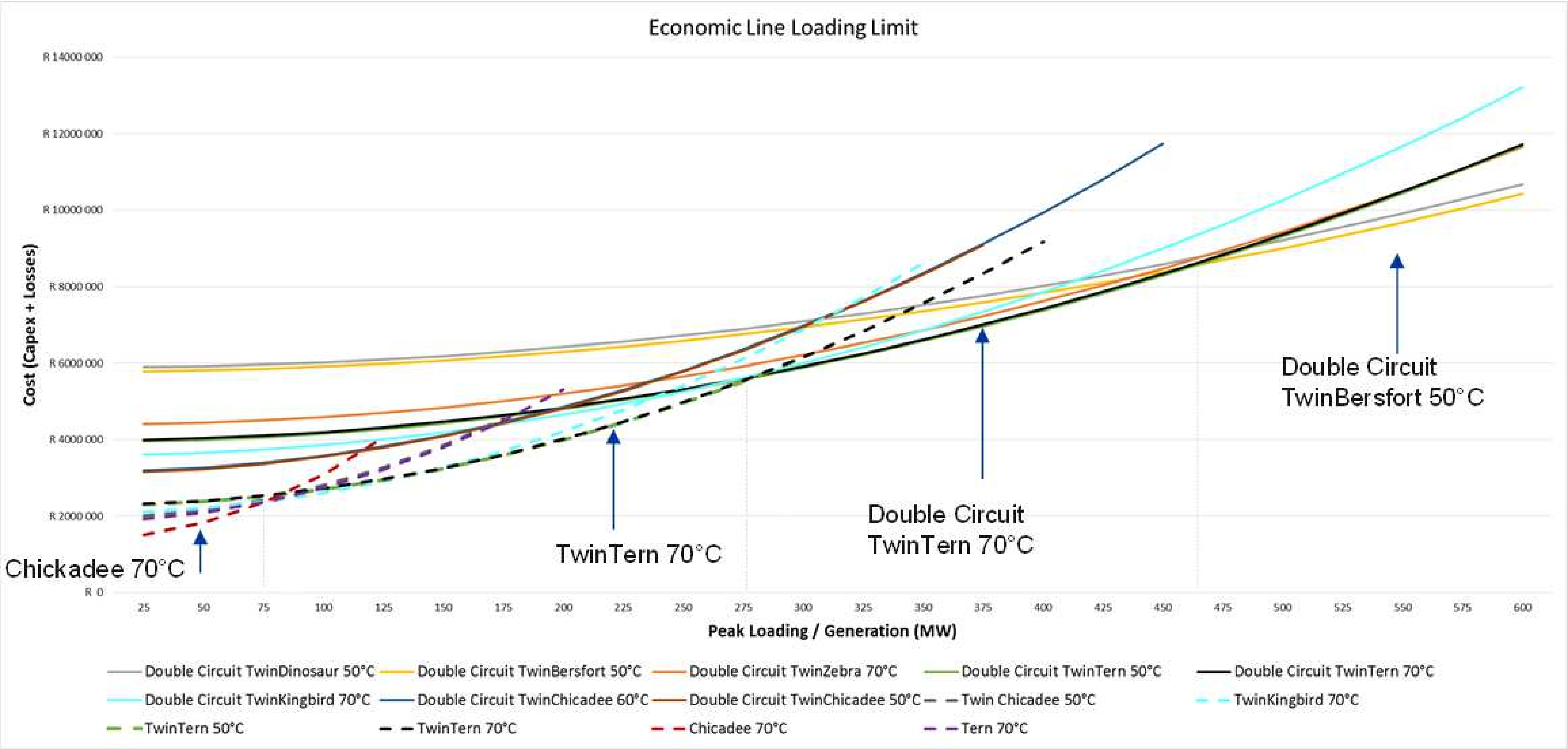


**Figure 8: Economic line loading result graphs**

In addition to the technical losses, voltage rise and thermal loading were also taken into consideration and the analysis was extended to 100 km with 25 km increments. The economic line loading results thereof are summarized in Table 9.

**Table 9: Economic line loading results for up to 100 km**

| | | **Distance (km)** | | | |
|---|---|---|---|---|---|
| | | **25** | **50** | **75** | **100** |
| **Generation Capacity (MW)** | **50** | Chickadee 70°C | Tern 70°C | Tern 70°C | Tern 70°C |
| | **75** | Chickadee 70°C | Tern 70°C | Tern 70°C | Tern 70°C |
| | **100** | Twin Kingbird 70°C | Twin Kingbird 70°C | Twin Kingbird 70°C | Twin Kingbird 70°C |
| | **150** | Twin Tern 70°C | Twin Tern 70°C | Twin Tern 70°C | Twin Tern 70°C |
| | **200** | Twin Tern 70°C | Twin Tern 70°C | Twin Tern 70°C | Twin Tern 70°C |
| | **250** | Twin Tern 70°C | Twin Tern 70°C | Twin Tern 70°C | Double Circuit Twin Tern 70°C |
| | **300** | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C |
| | **350** | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C |
| | **400** | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C |
| | **450** | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C | Double Circuit Twin Tern 70°C |
| | **500** | Double Circuit Twin Bersfort 50°C | Double Circuit Twin Bersfort 50°C | Double Circuit Twin Bersfort 70°C | |
| | **550** | Double Circuit Twin Bersfort 50°C | Double Circuit Twin Bersfort 50°C | | |
| | **600** | Double Circuit Twin Bersfort 50°C | Double Circuit Twin Bersfort 50°C | | |

Based on the results from Table 9, a number of line configurations are recommended for use within specific generation capacity ranges for a distance of up to 100 km from the point of common coupling (i.e. MTS). The results further indicate that for generation capacity of 500 MW a maximum transfer distance of 90 km applies, whilst maximum distances of 80 km and 75 km apply for 550 MW and 600 MW generation capacities respectively.

The recommended line configurations are shown in Table 10. The MVA capacity shows the conductor MVA rating. The distance limit is the cumulative distance from the furthest IPP generator point of connection to the point of common coupling (i.e. MTS).

**Table 10: Economic line loading recommendations**

| **Generation Capacity (MW)** | **Line Type** | **Capacity (MVA)** | **Distance Limit (km)** |
|---|---|---|---|
| 0 - 75 | Chickadee 70°C * | 128 | 30 |
| 0 - 75 | Tern 70°C | 204 | 100 |
| 75 – 275 | Twin Tern 70°C | 409 | 85 |
| 275 - 450 | Double Circuit Twin Tern 70°C | 818 | 100 |
| 450 - 500 | Double Circuit Twin Bersfort 50°C | 882 | 90 |
| 500 - 550 | Double Circuit Twin Bersfort 50°C | 882 | 80 |
| 550 - 600 | Double Circuit Twin Bersfort 50°C | 882 | 50 |

*Chickadee 70°C is recommended for evacuation capacities of 0 - 75MW up until a distance of 30km.

The network concept model of Figure 1 is redrawn as shown in Figure 9 with alignment to the results and recommendations.

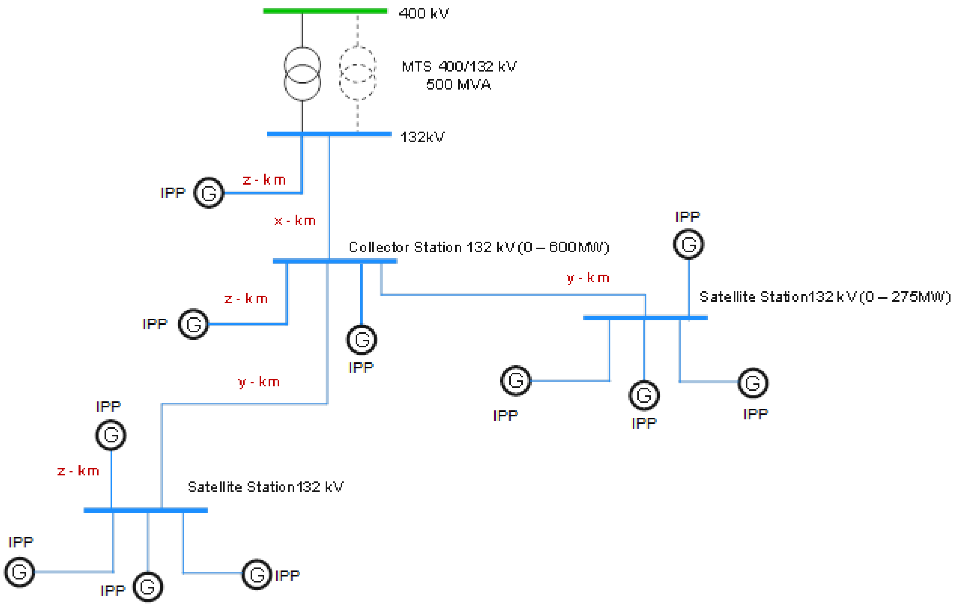


**Figure 9: Expanded network concept model**

Aligning the results from Table 9 and the recommendations from Table 10 with the network concept model in Figure 9, it can be deduced that a Collector Station will have a capacity of up to 600 MW at a maximum total distance of x ≤ 50 km from the MTS. A Satellite Station will have a capacity of up to 275 MW at a maximum total distance of y ≤ (85 – x) km from its point of connection. Lastly, an IPP Generator with a capacity of up to 150 MW will be at a maximum total distance of z ≤ (100 – y – x) km from its point of connection.

It must be noted that transient stability studies need to be done at the MTS to ensure that the specific MTS is capable of losing load with the additional capacity of the collector station without voltage rise violations.

## 10.1 Further Investigation

The current scope will be expanded in the next revision to cater for some of the arising matters listed below:

1) Running the line configurations at a higher voltage level (i.e. 275kV – 400kV) and investigating the economic benefits.

2) Having the IPP step up the operating voltage to either 275kV or 400kV instead of transformation at the satellite station.

3) Having the IPP metering point moved to either the position of the satellite station or the collector station so that the IPP is accountable for the incurred losses.

4) Running the study with different load diversification factors for wind and PV systems.

5) N-1 contingency and firm supply. What are the possible penalties if the IPP cannot supply power due to an outage on an Eskom line?.

# 11. Sample Case Study

Three IPPs would like to connect 150MW of PV generation and 140MW of wind generation to the grid. The figure below shows the location of the IPP's in relation to the closest MTS.

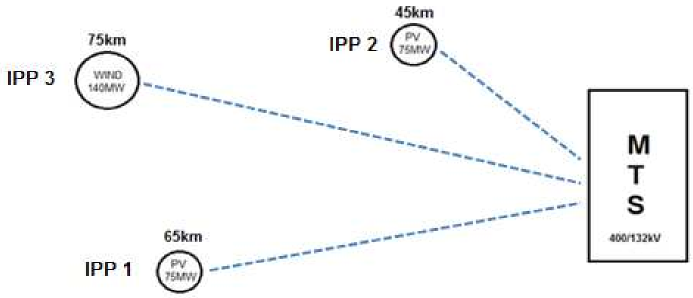


**Figure 10: Sample Case Study – IPP Locations**

The highest capacity IPP is 140MW which is below the threshold capacity of 150MW for a single IPP. The distance of the IPP furthest from the MTS is 75km which is below the recommended threshold of 100km. The total combined generation from the three IPPs is 290MW. This is above the recommended capacity threshold for a single satellite station (275MW), hence the need for a collector station. One of the PV IPPs falls within the threshold distance of a collector station (50km) however two of the IPPs fall outside the distance threshold for a collector station. These two IPPs however meet both the distance (85km) and capacity requirements of a single satellite station with a combined total capacity of 215MW.To minimise costs in this instance, the distance from IPP1 and IPP3 to the satellite station should be minimised and the distance between the satellite station to the collector station should be maximised (i.e. minimising the distance between the collector station and the MTS). The satellite station needs to be placed at 70km$\left(\frac{75km+65km}{2}\right)$. Fundamentally the satellite station can be placed closer to IPP3 as a bigger conductor will be used for this connection. The collector station can be placed between 1-50km from the MTS, taking into account that the distance between the collector station and the satellite station needs to be maximised. The satellite station will be a standard three feeder-bay configuration whilst the collector station will be the standard six feeder-bay configuration based on expected future capacity. In line with Table 10 above, the below conductor configuration recommendations at 132kV are made:

- The recommended conductor configuration between IPP1 and the satellite station is Chickadee 70°C.
- The recommended conductor configuration between IPP2 and the collector station is Chickadee 70°C.
- The recommended conductor configuration between IPP3 and the satellite station is Twin Tern 70°C.
- The recommended conductor configuration between the satellite station and the collector station is Twin Tern 70°C.
- The recommended conductor configuration between the collector station and the MTS is Double Circuit Twin Tern 70°C.

The figure below shows the recommended configuration to integrate the three IPPs mentioned above:

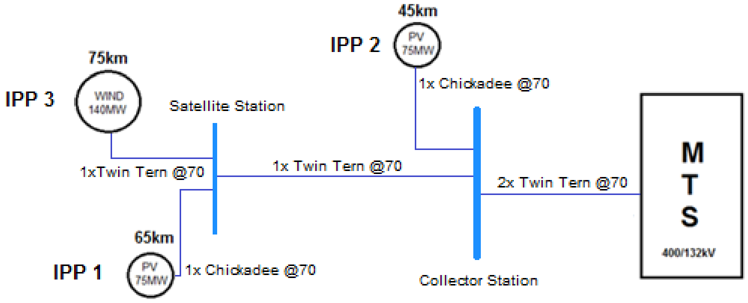


**Figure 11: Recommended Configuration for Sample Study Case**

* In the case of possible future capacity being added and the need of a second satellite station being required, the distance between the satellite station to the collector station should be minimised (i.e. maximising the distance between the collector station and the MTS).

It should be noted that transient studies must be conducted to determine if the specific MTS can handle the loss of load with the added generation connected at the 132kV busbar with no voltage rise violations.

## 12. Authorization

This document has been seen and accepted by:

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## 13. Revisions

| Date | Rev | Compiler | Remarks |
|---|---|---|---|
| April 2016 | 1 | Preshaan Jaglal | First issue |

## 14. Development Team

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## 15. Acknowledgements

Line Engineering Services (PDE)

# Annex A – Lookup Table

## Lookup-Table (0.95<Collector Voltage<1.06, Thermal Limit<100%, PF=0.98 Capacitive)

| | 1km | 5km | 10km | 15km | 20km | 25km | 30km | 35km | 40km | 45km | 50km | 55km | 60km | 65km | 70km | 75km | 80km | 85km | 90km | 95km | 100km | Key | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **25MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | 2x2 Bersfort @50°C | A |
| **50MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,M | 2x2 Zebra @70°C | B |
| **75MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,M | 2x2 Dinosaur @50°C | C |
| **100MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | 2x2 Tern @70°C | D |
| **125MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N,O | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | 2x2 Kingbird @70°C | E |
| **150MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | 2x2 Tern @50°C | F |
| **175MW** | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | 2x2 Chickadee @60°C | G |
| **200MW** | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M,N | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L,M | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | 2 Tern @70°C | H |
| **225MW** | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | A,B,C,D,E,F,G,H,I,J,K,L | 2x2 Chickadee @50°C | I |
| **250MW** | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,I | 2 Kingbird @70°C | J |
| **275MW** | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | 2 Tern @50°C | K |
| **300MW** | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J,K | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,I,J | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | 2 Chickadee @60°C | L |
| **325MW** | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,I,J | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | 1 Tern @70°C | M |
| **350MW** | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I,J | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | 2 Chickadee @50°C | N |
| **375MW** | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | A,B,C,D,E,F,G,I | 1 Chickadee @70°C | O |
| **400MW** | A,B,C,D,E,F,G,H | A,B,C,D,E,F,G,H | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H,I | A,B,C,D,E,F,G,H | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | | |
| **425MW** | A,B,C,D,E,F,G,H | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | | |
| **450MW** | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | A,B,C,D,E,F,G | B,D,E,F | | |
| **475MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | B,D,E,F | E | | |
| **500MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | B,D,E,F | | | | |
| **525MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | B,D,E,F | E | | | | |
| **550MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | B,D,E,F | E | | | | | |
| **575MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | B,D,E,F | E | | | | | | |
| **600MW** | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E | A,B,C,D,E | A,B,C,D,E | B,D,E | | | | | | | |