**Reactive Power Compensation – New Sophia Substation**

**Draft Final Report**

August 3, 2018

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**Project 2: Reactive Power Compensation – New Sophia Substation**

* 1. **Introduction**

The Guyana Power and Light, Inc. (GPL) is a vertically integrated state-owned utility whose operations comprise generation, transmission and distribution. GPL’s nominal installed generating capacity is 172-MegaWatt (MW), with 136 MW effective and operable, delivering 762-GigaWatt-hour (GWh) of energy in 2017. GPL supplies electricity to nearly 189,000 customers in the coastal communities, serving a relatively small urban and suburban area of roughly 500-square kilometers (km2), where more than 80 percent (%) of the population resides. The power generation installed capacity is 90 per cent (%) based on heavy- fuel oil (83% of the total electricity supply) and 10% on diesel.

In addition to four small isolated systems in the Essequibo region, GPL operates the Demerara/Berbice Interconnected system (DBIS), a 60Hz system interconnecting the Demerara and Berbice regions at 69 kV. In 2017, the peak power demand in the Demerara Berbice Interconnected system was 115-MW. Electricity demand in Guyana is expected to continue growing on a 4.8% yearly average based on GPL’s 2017-2021 Development & Expansion (D&E) plan, mainly due to the positive trend in economic growth. New developments in the commercial, industrial and residential sectors are expected to contribute to the increase in electricity demand.

Key operational results and indicators show critical weaknesses in GPL’s operations, such as: (i) the persistence of high electricity losses after several years of trying different strategies to curb them; and (ii) low quality of service, partly due to an aged, weak and overloaded transmission and distribution network. These factors, together with low technical and executing capacities of GPL, high generation costs, and constraints to raising already-high tariffs, all contribute to poor financial results, which in turn, limit the company’s ability to finance its capital expenditures.

In order to address problems in the transmission and distribution network and to cope with projected increases in electricity demand, GPL has been considering a wide range of infrastructure investments in its recent D&E Plans. However, persistent delays in the preparation and execution of such plans have hindered the achievement of substantial results. Key technical challenges in GPL can therefore be identified in two inter-related areas: (i) low operational efficiency; and (ii) weak and limited infrastructure to meet the expected growth in demand. These deficiencies have caused many industries to self-generate their electricity.

It is therefore essential for GPL’s output to be of suitable quality and reliability and for electricity prices to be lower than the marginal cost of self-generation in order for the self-generators to switch to GPL’s supply. Two important measures to achieve these improvements are to improve its voltage supply and quality and to reduce the system’s technical losses. The efficient operation of the Demerara/Berbice interconnected system is critical to these improvements.

* 1. **Problem**

The 69 kV Demerara/Berbice interconnected transmission system (DBIS) consists of 276 km of transmission circuits interconnecting 6 power stations and 14 substations from Skeldon in the East Corentyne to Edinburgh, West Demerara. (See Schematic in Appendix I). An important link in this system is the interconnection of the 58 MW Kingston power station, via a 5 km 69 kV transmission line (L5), to a major substation at Sophia, which functions as the distribution hub of the power system supplying substations at North Ruimveldt, Good Hope, Columbia and Onverwagt. Recent records (2018) show transmission levels of up to 47 MVA along this line.

In the period between the mid 1970’s and 2016, GPL’s interconnected system operated at both 11 kV, 50 Hz and 13.8 kV, 60 Hz and frequency converters at Sophia substation were operated to balance the supply of generation and loads at the two frequencies. An important function of the converters was their ability to provide voltage support at both the 50Hz and 60 Hz busbars. When the DBIS system was standardised at 60 Hz in 2016, the frequency converters operated as synchronous condensers to provide reactive compensation to the system. However, when the frequency converter station was decommissioned in 2017 because all the machines became inoperable, this voltage support to the DBIS system was no longer available.

With no voltage support at Sophia substation, the Kingston power station is expected to provide the required reactive vars, however it is unable to do this and supply the necessary real power and this has meant that the voltage levels at Sophia are now low. Recent data recorded by the SCADA system have been used to produce the following graphs. Figure 1 below shows typical levels of voltage at Kingston and Sophia 69 kV busbars.

Figure 1: Typical Voltage levels at Kingston and Sophia

The low voltage levels at Sophia are not only outside the accepted levels required at the transmission level but account for low receipt of power at the Sophia substation. Figure 2 shows (i) the power flow from Kingston, (ii) the calculated line losses and (iii) the power received at Sophia based on data at 10 July 2018. Further analysis shows that the total power losses is 5% which is at the higher end of the range for acceptable transmission losses. Increasing the voltage levels at Sophia can reduce these losses.

Figure 2: Daily Power Flows and Losses on the Kingston/Sophia Transmission Line

Calculations from the data show 4.2 MWh of line losses and 41.5 MWh losses due to low voltage for that day. Weekend records revealed similar data and confirm the above observations. Based on a generation cost of US$ 0.12 per kWh annual losses due to low voltage have been calculated at US$1.8 M.

Low transmission voltages result in low distribution voltages and reduce the quality of supply to the consumers. There have been numerous complaints of low supply voltages in the DBIS supply area.

* 1. **Base Line Definitions**

The base line definitions for this project are (i) the level and cost of power losses due to low voltage and (ii) the number of low voltage complaints recorded.

Voltage levels for power received at Sophia are on average 5% below the sending end Kingston voltage level. An increase in the voltage level at Sophia can reduce the level of losses in the transfer of power between Kingston and Sophia. These losses have been calculated at a daily average of 42 MWh accounting for US$1.8M annual financial losses to the Guyana Power and Light Inc.

The records of consumer complaints in the DBIS show that there were 2200 reports of low voltage in 2017. These complaints were made because the consumers’ equipment was malfunctioning. It is also to be noted that low distribution voltages are also a source of losses to the power company.

* 1. **Investment Solution and Components**

The ideal solution to this problem would be the installation of a ±10MVAr STATCOM at the Sophia 69kV bus-bar. However, because there is no space at the Sophia location to house this equipment the proposed solution is to locate the STATCOM equipment at the New Sophia 69 kV busbar which is 0.3 km away from the Sophia 69 kV busbar. (See Appendix I and II for schematic). It is necessary to extend the New Sophia 69 kV busbar and to install a 69 kV bay to accommodate the connection of the STATCOM.

STATCOM is a static synchronous compensator which continuously provides variable reactive power in response to voltage variations while supporting the stability of the grid. STATCOM operates according to voltage source converter (VSC) principles, combining unique PWM (pulse width modulation) with millisecond switching, and functions with a very limited need for harmonic filters and only contributing to a small physical footprint.  STATCOM increases power transfer capability by enhancing voltage stability and maintaining a smooth voltage profile under different network conditions. It is also able to perform active filtering which is also very useful for improvements in power quality. STATCOM controls can be integrated with the overall SCADA system control.

Load flow simulations of the DBIS with and without STATCOM show that with the STATCOM in service there is an average of 1.37% and 1.05% increase in voltage levels at Sophia and Kingston 69 kV busbars respectively. This would reduce the losses due to low voltage by approximately 1.5%. Table 1 below outlines the various components of the STATCOM reactive compensation system.

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| --- |
| **STATCOM COMPONENTS** |
|  | Land Space | 112 m2 |
|  | Civil Works (Foundation) |  |
|  | 3 phase 3 Winding Transformer | 10 MVA ON EACH WINDING69/0.69/0.69 kV |
|  | LV Cable Connection |  |
|  | 4 x APS units (IP 54) | * APS total reactive: ±10 MVA@1.0 pu/69 kV
* Direct Mounted cooling unit with pump unit
* Direct mounted water/air heat exchanger unit
 |
|  | Statcom Control, comprising: | * HMI for parameterization and operation
* Reference value controller (redundant system)
* SCADA interface ( DPN3 or equivalent)
 |
| **HIGH VOLTAGE CONNECTION** |
|  | 69 kV Busbar Expansion | Breaker and ½ configuration  |
|  | Metal structure | 9 meters height |
|  | 3 Pole circuit breaker type 3AP1 FG | SF6 630 Amps, 72.5 kV, Rated short time withstand current 20kA |
|  | 3 Disconnector | 630 Amps 72.5 kV |
|  | 3 Potential Transformer | Primary Voltage 69/√3, Sec Voltage 0.12/√3 |
|  | 6- current transformer | (Measurement & Protection core)1200-600-300/1, 72.5 kV, 630 Amps continuous |
|  | 3 Surge arrester | Rated Voltage 60 kV, Continuous Operating Voltage 48 kV, Discharge current 10 kA |
|  | Control & Protection System | Controller Type- 6MD8Main Protection: 87T, Rel Type 7UT85Back –up Protection Rel Type 7UJ85 (50/51)RTU SICAM AK3- 3 communication Protocols* IEC 61850 protocol to communicate with protection relays.
* IEC 60870-5-104 to communicate with the control center.
* MODBUS to receive the signals from STATCOM Solution.
 |
|  | Training |  |

Table 1: Components of the STATCOM Package

The New Sophia substation is an extension of the Sophia substation which became necessary with the development of GPL’s 69 kV network. It is 0.3 km away from Sophia and has the required space to house the STATCOM equipment and all its auxiliaries. Load flow simulations show a difference of 0.01% in the voltages between the two substations.

The STATCOM equipment comes as a complete package including a 69 kV, three phase, three winding transformer providing voltages for the apparent power systems (APS). Also included in the package are one (1) 69 kV circuit breaker, three (3) 69 kV disconnects and the current and voltage transformers required for measurement and protection. As this is a complete package, only a single cost is provided. GPL would need to provide the extension to the 69 kV busbar and also a de-energised busbar for 7 days to facilitate the connection. Civil works are required for the foundation of the equipment and the extension of the 69 kV busbar at New Sophia.

There would need to be an interface between the GPL and the STATCOM SCADA networks. The IEC communication protocol of the latter would make this a smooth interconnection. This would be the first installation of this type of equipment on the GPL’s network, however, the company has many skilled engineers and technicians, who with the relevant training would be able to operate and maintain this equipment.

* 1. **Expected results and impacts**

Load flow simulations of the DBIS at peak loads have shown that with a ±10MVAr STATCOM installed at the New Sophia 69 kV bus-bar, the voltages of all busbars on the DBIS system will increase. Table 2 shows the comparison of voltages with and without the installation of STATCOM. Increases vary between 1.38%, at New Sophia substation, the site of installation of the STATCOM, to 0.33% at the furthest location, the #53 Village substation. For low load conditions, these increases vary between 1.6% and 0.6%.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Bus ID | Nominal KV | Voltage kV- Without Statcom | Voltage kV- With Statcom | % Of Voltage Improvement ( Regulation) |
| Bus1 (GOE) | 69 | 67.748 | 68.508 | 1.12% |
| MAIN BUS1 (G/Grove) | 69 | 67.128 | 67.933 | 1.20% |
| Main Bus1 (New Sophia) | 69 | 66.521 | 67.439 | 1.38% |
| Main Bus1 (Sophia) | 69 | 66.527 | 67.44 | 1.37% |
| Main Bus 1 (# 53 Village) | 69 | 69.665 | 69.897 | 0.33% |
| Main Bus 1 (Canefield) | 69 | 69.055 | 69.417 | 0.52% |
| Main Bus 1 (Columbia) | 69 | 65.608 | 66.295 | 1.05% |
| Main Bus 1 (Goodhope) | 69 | 65.635 | 66.481 | 1.29% |
| Main Bus 1 (New G/town) | 69 | 66.132 | 67.04 | 1.37% |
| Main Bus 1 (Onverwagt) | 69 | 66.779 | 67.257 | 0.72% |
| Main Bus 1 (V/Hoop) | 69 | 67.731 | 68.438 | 1.04% |
| Main Bus 1(Edinburgh) | 69 | 66.915 | 67.614 | 1.04% |
| Main Bus1 (Kingston) | 69 | 67.598 | 68.308 | 1.05% |

Table 2: Voltage Levels at DBS 69 kV busbars with and without STATCOM

An analysis has been done of the effect of the increase in voltages on the entire GPL transmission network. The GPL transmission system on average transfers 3000 MWh of energy on a daily basis. Calculations on the Kingston/Sophia line show that the increased voltage at Sophia as a result of the STATCOM installation will cause a reduction in the transmission losses by 1.5%. If an average of 1.3% is used across the total network, then annual transmission line loss reduction would be 14,235 MWh. At a generation cost of US$0.12 per kWh, this would result in annual savings of US$1.7 M.

Higher transmission voltages will produce higher distribution voltages and therefore reduce the incidence of measured low voltages. It is expected that this project, together with the other project that will install larger conductors on the Kingston/Sophia transmission lines, will reduce low voltage incidence from the 2017 level of 2200 to 200 by the end of the project.

* 1. **Proposed Schedule of Implementation**

The following is the proposed implementation schedule of the project to install ±10MVAr STATCOM at the New Sophia 69kV bus-bar. Supply and delivery time will be twelve months after the signing of contract. The entire project will be completed in 24 months.



* 1. Budget Estimations

The following Table 3 indicates the main activities and costs for the installation of a ±10MVAr STATCOM at the New Sophia substation. The contractor will be providing all design, procurement, installation and commissioning works.

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| --- | --- |
| **Activity** | **Cost (US$)** |
| Design, installation and commissioning of one (1) ±10MVAr STATCOM at the **New Sophia** 69kV bus-bar with all cabling works to include:* 1, 69 kV, 3 phase, 3 winding transformer
* 2, Apparent Power Systems (APS)
* 1, 69 kV circuit breaker
* 3, 69 kV disconnects
* 3, 69 kV potential transformers
* 6, current transformers
* Protection and control systems
* Training
 | **6,150,000.00** |
| All electrical, civil and building works inclusive of all foundations and earthing works for 6 m, three phase, 60 Hz extension of **New Sophia** 69 kV outdoor busbar to house new ±10MVAr STATCOM. Busbar rated at 72.2 kV, 2000 A, BIL 350kV, fault rating 40 kA | **649,227.00** |
| Design, commissioning and all other services in connection with the extension of the **New Sophia** 69 kV outdoor busbar |
| 5% Contingency | **339,964.00** |
| TOTAL | **US$ 7,139,241.00** |

Table 3: Summary of Main Project Activities and Costs

**VIII.** **Financial Analysis**

The financial analysis for this project is based on the reduction of transmission line losses over the entire GPL 69 kV network. This is calculated to be 14,235 MWh annually using GPL’s average generation cost of US$120 per MWh. The analysis is based on (1) the existing system demand and (2) the projected increase in demand of 4% per year. The results of the financial analysis are shown in Table 4.

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 Table 4: Financial Analysis of the Reactive Compensation Project

The summary of the financial analysis is that it would be financially feasible to undertake the project. With an initial investment of US$7.13M the project was analyzed at discount rate of 12% which shows a positive Net Present Value (NPV) of US$6.6M with payback period of 6 years, 2 months and return on investment (ROI) of 93%. A growth in peak demand of 4% annually will result in a positive Net Present Value (NPV) of US$11.9M with payback period of 5 years, 6 months and return on investment (ROI) of 167% which is also financially feasible.

1. **Conclusion**

The project to install a ±10MVAr STATCOM at the New Sophia substation to provide more reactive compensation on the Demerara/Berbice interconnected system will significantly (i) improve the quality of the electrical power supplied and (ii) reduce the technical losses of DBIS.

Poor power quality remains one of the key considerations for self generators to remain off the DBIS and improvements in this area will serve to enhance one of the key operational objectives of the GPL.

Finally, the financial analysis of the project show that this is a financially feasible project to undertake with a reasonable NPV and payback period.

**Appendix I**

Schematic of the Demerara/Berbice 69 kV transmission network showing project area.



Appendix II – Schematic of STATCOM connection to New Sophia 69 kV busbar

