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Cost Analysis of Power Loss in a Distribution Network by the Application of Distributed Generation and Static Var Compensator

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ABSTRACT

Energy losses happen during the process of supplying electricity to consumers due to technical and commercial losses. The technical losses are due to energy disseminated in the conductors and equipment utilized for transmission, transformation, sub transmission and distribution of power. These technical losses are inherent in a system and can be decreased to an optimum level. These days distributed generation is frequently connected to the distribution network. Distributed power supply willimportantly have an impact on the system network loss when it connects to the distribution network. Cost of annual energy loss occurs in distribution networks are a vital issue in distribution systems planning, design and operation.In this paper, the impact of optimal placement of Distributed Generators and Static Var Compensator (SVC) ona distribution network is investigated. It has determined the cost of technical losses in the network and savings that would be made by optimally deploying DG sources and Flexible Alternating Current Transmission Systems (FACTS) Devices.

Keywords*: Energy loss; Distributed Generation (DG); Flexible Alternating Current Transmission (FACTS) Devices; Power Tools for Window (PTW); Static Var Compensators (SVC).*

INTRODUCTION

Power is generated for the consumer utilization. From when power is generated it is transmitted through transmission lines via grids & then distributed to the consumer. Power distribution is the final and most crucial link in the electricity supply chain, it's also the most visible part of the electricity sector, Presently, the Nigeria electrical power system is facing a lot of challenges as a whole. From generation to distribution, the reliability of the system is far belowthe expectation [1]. A nation whose energy need is epileptic in supply prolongs her development and risks losing potential investors. After over 50 years of independence, Nigeria, a country of over 160 million people and richly endowed with various sources of energy such as; natural gas, hydro power, solar, coal and wind etc, are still mired in the dark. Poor electricity supply has been a serious problem in Nigeria. Despite the huge amount of money said to have been expended by successive administrations to revamp the power sector,there is no obvious change as not much seems to have been achieved as the country still witnesses frequent and persistent power outages.[2, 3]. Nigeria's power generation fluctuates between 4,000MW and 2,000MW. This unsteady power supply is attributed to general system failure, which has caused nearly all the power generating plants in thecountry to operate at less than 40 percentcapacity. About 45 percent of the population is connected to the national grid, but only 30 percent of their power demand is met. About 35 percent of Nigerians enjoy regular electricity for up to 50 percent of the time, which adversely impacts on the standard of living and industrial productivity. This causes the increasing number of industrial and residential customers provide electrical power privately at huge costs to themselves and the Nigerian economy [4]. The peak demand that is required by the Nigeria Power sector is 14,630 MW; peak generated power is 3874.1 MW; there are twenty three (23) generating stations (3 Hydro, 2 Steam and 18 Gas) in the country [5]. Distributed Generation (DG) is developing rapidly and is gradually reshaping and adding value to the conventional power systems in recent times globally. They range from small hydropower plants, micro turbines, and wind power. The majority of DG infrastructures use asynchronous generators for electric power generation [6]. A farmer using the waste from his own animals to generate electricity is DG. An emergency generator sitting behind a convenience store is DG. Solar panels installed in homes are DG. A hospital using a gas turbine for electricity and recycling the waste heat to wash bedding or provide hot showers is DG. The terms "cogeneration" or "small power production" seem to be used to depict types of this broader industry term "DG," which applies to energy systems that produce electricity and/or thermal energy at or close to the point of use. Since such installations are typically situated within or near homes, buildings or industrial plants, the terms "dispersed generation", "DG," "cogeneration" and "small power production" are interchangeable. [7]. Figure 1 shows the conventional power grid and power grid with DGs included. Very high efficiency and reliability, environmental friendliness, modularity, high controllability, and noiseless operation make fuel cell-driven power plants a nice competitor for the future financial and power market. DG is taken as a means for solving environmental concerns and the need to secure an efficient electricity supply and reliability in supporting sustainable development [8]. Voltage is a standout amongst the most essential parameters for the control of electric power systems. In a radial distribution feeder, voltage diminishes towards the end of the feeder, as loads cause a voltage drop. Notwithstanding, it will be modified by the presence of DG. DG will build the voltage at its connection point, which thusly will increase the voltage profile along the feeder [9, 10]. This increase may surpass the maximum permitted voltage when the DG power is high. In this paper, Static Var Compensators will be introduced to help control the voltage in the network in the presence of DGs.

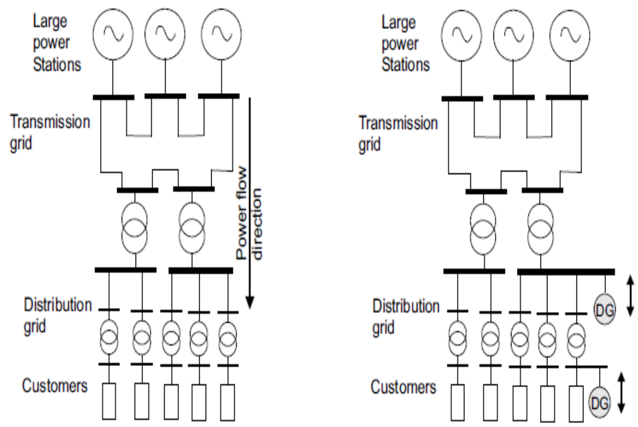

Figure 1: (a) Traditional power system (b) Penetration of Distributed Generator

Benefits of DG

- **Economic Benefits**
  a) Installation of DG units close to the load centers defers the need for new expansive feeders to circulate power of consumer, evade the construction of a new substation.
  b) Installation time for DG is very low.
  c) Implementation DGs for distribution system planning minimizes the investment hazard due to reduced capital cost and less installation time.
  d) Integration of DGs enhances the system proficiently by improving the system voltage profile and decreases the feeder's power losses and furthermore reducing the loadings on existing electric equipment.
  e) The capital expense of DG is low furthermore, it returns back the benefit withina short period of time.

- **OperationalBenefits**
  a) When DGs is introduced in the distribution system, it decreases the cost of the distribution system in light of the fact that there is a reduction in the number of electric elements such as feeders, transformers, capacitors etc.
  b) DGs with their modern power electronic interface devices can be interconnected to the grid to accomplish special reliability,

power quality and voltage profile necessities.

c) Customer-owned DGs can help customers by sharing some portion of their demands during their peak load periods and by feeding the excess power to the grid during their light loads periods. This way, they can recover some income back from the electric utility.
d) The production of efficient, safe, clean and reliable electrical energy is possible through DGs. Alongside that cost of electrical energy is very low, with no or low emissions.
e) DGs specifically provide power in the vicinity of the loads and help in decreasing the loadings on the feeders [11, 12].

Voltage Control in the Presence of DG.

In the past, distribution networks were intended to be passive systems, i.e., without Distributed Generation (DG) connected.Power injections at medium and low voltage level present new issues for network management to address: the quick development of DG can influence thequality of supply as well as the user's safety.DG plants have effects on power flows along distribution feeders:specifically thevoltage profile along the feeder is no longer monotonous and over-voltages at the DG Point of Common Coupling (PCC) might happen[13]. An active distribution network is defined as distributionnetwork with system set up to control a mix ofdistributed energy resource including that of generator andstorage.Voltage controls in active distribution system have beenbroken down into three various level i.e.primary,secondary and tertiary levels. The primary control isperformed by AVR (Automatic Voltage Regulator), thesecondary control is performed by on load tap changer(OLTCs),in the interim, tertiary control is a short operationplanning is produced to coordinatethe action of primary&secondary control device indicated to securedoperation and economic criteria based on load andgeneration estimate [14]. Voltage control of distribution networks with DG can beaccomplished by applying control routineslike those usedin transmission systems. This includes the use ofcoordinated voltage control through dispatch of DG output,OLTCs and reactive power support [15]. The classifications ofcoordinated voltage management in distribution networksfusing DG are centralised or decentralised. Voltagecontrol with DGs is just possible with DG technologiesthat permit dispatching, such as fossil fuel-burning generators, combined heat and power[16]. Most renewableenergy sources such as wind and PV have outputs whichare not effectively controllable. Centralized distribution management system controlsa few distribution substations. Such management systemsrequire broad communications networks in order tooperate. It isseen that there are three parameters used to control voltagein distribution systems with DG.These are DG plants, transformers andreactive power devices. Transformers areutilized to incorporate the voltage directly.OLTCs at substations canraise or bring down the voltage level in the distribution network.Reactive power devices incorporate shunt reactors, shuntcapacitors and power electronics-based devices for example staticVar compensators.They control voltage by infusingleading or lagging reactive power at various pointsthroughout the system. Finally, DGs themselves can beutilized to control voltage. This is accomplished by changing theamount of real and reactive power generated. Likewise, DGscan vary the power factor at which they generate power[17].

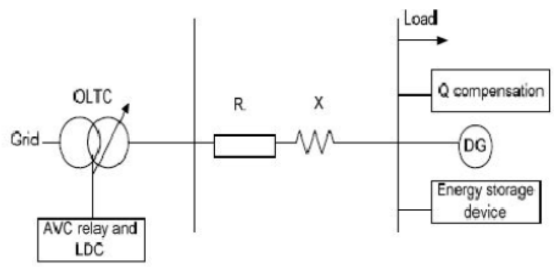

Figure 2. Simple Radial Feeder with Connected DG (14)

Figure 2 displays a simple radial feeder that is connected with DG. On Load Tap Changer transformer load anenergy storage device, automatic voltage controller, reactive power compensator andline drop compensator is also connected on the system. [14]. In this paper, a 15MVA injection Substation and the associated substations in Nigeria is analyzed, collection of various data (Substation locations, transformer ratings, line lengths, bus voltages, current, frequency, transmission line parameters and power factor) from the substations. The network was modeled Power Tools for Window (PTW 6.5) software using Newton - Raphson(N-R) power flow algorithm to determine bus voltages, power losses, total load demand and load flows. Furthermore the network was analyzed by sizing and optimal placement of DGs in the existing network. This was done by developing a Genetic Algorithm (GA) programme in Matrix Laboratory (MATLAB) and effecting the simulation in Electrical Transient Analyzer Programme (ETAP 7.0) environment. The voltage for the entire network needed to be controlled in the presence of DGs, so introducing Flexible Alternating Current Transmission (FACT) Device; the SVC further improved the voltage profile and reduced the distribution losses. The introduction of DGs and SVC was used in determining cost of technical losses in the network and savings that would be made.

METHODOLOGY

Power tools for windows (PTW 6.5) software program were used in carrying out the load flow studies. With the data (route lengths, transformer ratings, conductor (ACSR) size of existing Network, peak load readings, off peak load readings, power factor) obtained from the field for the 85 substations they were fed into the software. The load flow was analyzed using Newton-Raphson method which is embedded in the software. Table 1.0 presents summary from the software. Appendix A presents a section of the existing network modeled in PTW.

Table 1:Summary of Load Flow Results for Peak and Off Peak Period.

	Peak	Off Peak
Voltage Profile	0.8645 – 0.9560pu	0.889 – 0.9799pu
Active Load Demand	25.210MW	17.273MW
Reactive Load Demand	10.243Mvar	9.93Mvar
Losses (Real)	6.59MW	3.78MW
Losses (Reactive)	2.218Mvar	2.10Mvar

Equation (1) is a multi-objective function. Multi-objective function is an objective function with many parameters considered. In this paper, there are three objective functions put together; these include:

1. Lossequation
2. DG size equation
3. Voltage equation

$$f = \sum_{k=1}^{n}\left(a\frac{P_{loss}^{With\ DG}}{P_{loss}^{WithoutDG}} + b(V_{bus,k}^{With\ DG} - 1)^2 + c\frac{CG_k}{S_{base}}\right) \quad (1)$$

Using the multi-objective function equation and various constraints in equations (2), (3) and (4) (Voltage, DG capacity and Power factor) as a GA code developed in MATLAB Environment and implemented in ETAP 7.0 Environment. The code provided the optimum places where DGs can be located.

$$V_{min} < V_{bus,k}^{With\ DG} < V_{max} \quad (2)$$

$$\sum_{k=1}^{NDG} CG_k \leq P_{load} \quad (3)$$

$$0.8 \leq PF_{DG,k} \leq 1, \quad (4)$$

Appendix B provides the Matlab Environment showing all DG sizes and

Locations while Appendix C shows Etap Environment showing DG locations being implemented.

Table 2 presents the summary of results from the network with DGs in place.

Table 2: Summary of Results for Peak and Off Peak in the Presence of DGs.

	Peak	Off Peak
Voltage Profile	0.9202 – 0.9776pu	0.9329 – 1.004pu
Active Load Demand	27.169MW	18.403MW
Reactive Load Demand	10.965Mvar	10.12Mvar
Losses (Real)	2.73MW	2.02MW
Losses (Reactive)	1.59Mvar	1.09Mvar

In placing the SVC, three (3) 11 kV buses were considered; using deviation from ideal voltage profile equation in equation (5)

$$VPI_{tot} = \sum_{n=1}^{n_{load}} \sum_{l} (1 - V_n^l)^{2} \qquad (5)$$

Appendix D shows DGs and SVC in the existing network.
Table 3 presents the summary of results from the network with DGs and SVC in place.

Table 3: Summary of Results of DG and SVC Placement

	Peak	Off Peak
Voltage Profile	0.9402 – 0.9873pu	0.9502 – 1.0458pu
Active Load Demand	27.169MW	18.469MW
Reactive Load Demand	11.913Mvar	11.09Mvar
Losses (Real)	1.45MW	1.26MW
Losses (Reactive)	1.05Mvar	0.09Mvar

Cost of Power Loss in Network

As seen from Table 1, 2 and 3, the loss in the network without DG was 6.59MW; 2.218Mvar (Peak), 3.78MW; 2.01Mvar (Off Peak) with DG was 2.73MW; 1.59 Mvar (Peak), 2.02MW; 1.09Mvar (Off Peak) and with DG and SVC was 1.45MW; 1.05Mvar (Peak) 1.26MW; 0.90Mvar.

The amount of revenue lost as a result of the distribution losses in the network is;

- For 6.59MW (6.59 x 10^3 kW for Peak Period)

Tariff per kilowatt-hour is ₦14.82

Cost per Hour for 6.59 x 10^3 kW is 6.59 x 10^3 kW x ₦14.82 = ₦97,664 per Hour

Cost per Day = ₦97,664 per Hour x 24 = ₦2, 343931 per Day

Cost a year = ₦2, 343931 per Day x 365 = ₦855, 534888.P.A.

As seen from the above calculation revenue lost as a result of distribution losses in the 15 MVA, 33/11kV Injection Substation for peak period is eight hundred and fifty five million, five hundred and thirty four thousand, eight hundred and eight-eight naira per annum (₦855, 534,888.P.A).

RESULTS AND CONCLUSION

When the load flow simulated for the Network, the total losses during peak are 6.59MW, 2.22Mvar and off peak were 3.78MW, 2.01Mvar.

When DGs were introduced in the Network, the loss was reduced, for peak it was 2.73MW, 1.59Mvar and for off peak 2.02MW, 1.09Mvar.

When SVC was placed with DGs, the losses were further reduced to 1.45MW, 1.05Mvar for peak and 1.26MW, 0.90Mvar.

The sum of six hundred and sixty seven million, two hundred and ninety one thousand two hundred and forty eight Naira per annum (₦667, 291,248) for peak period and four hundred and fifty six million, nine hundred and seventy seven thousand six hundred and sixty four Naira per annum (₦456, 977664) for an off peak period is saved as a result of the deployment of DG and FACTs device.

In the placement of DGs and SVC in the network, distribution losses can be reduced and savings in terms of revenue could also be achieved.

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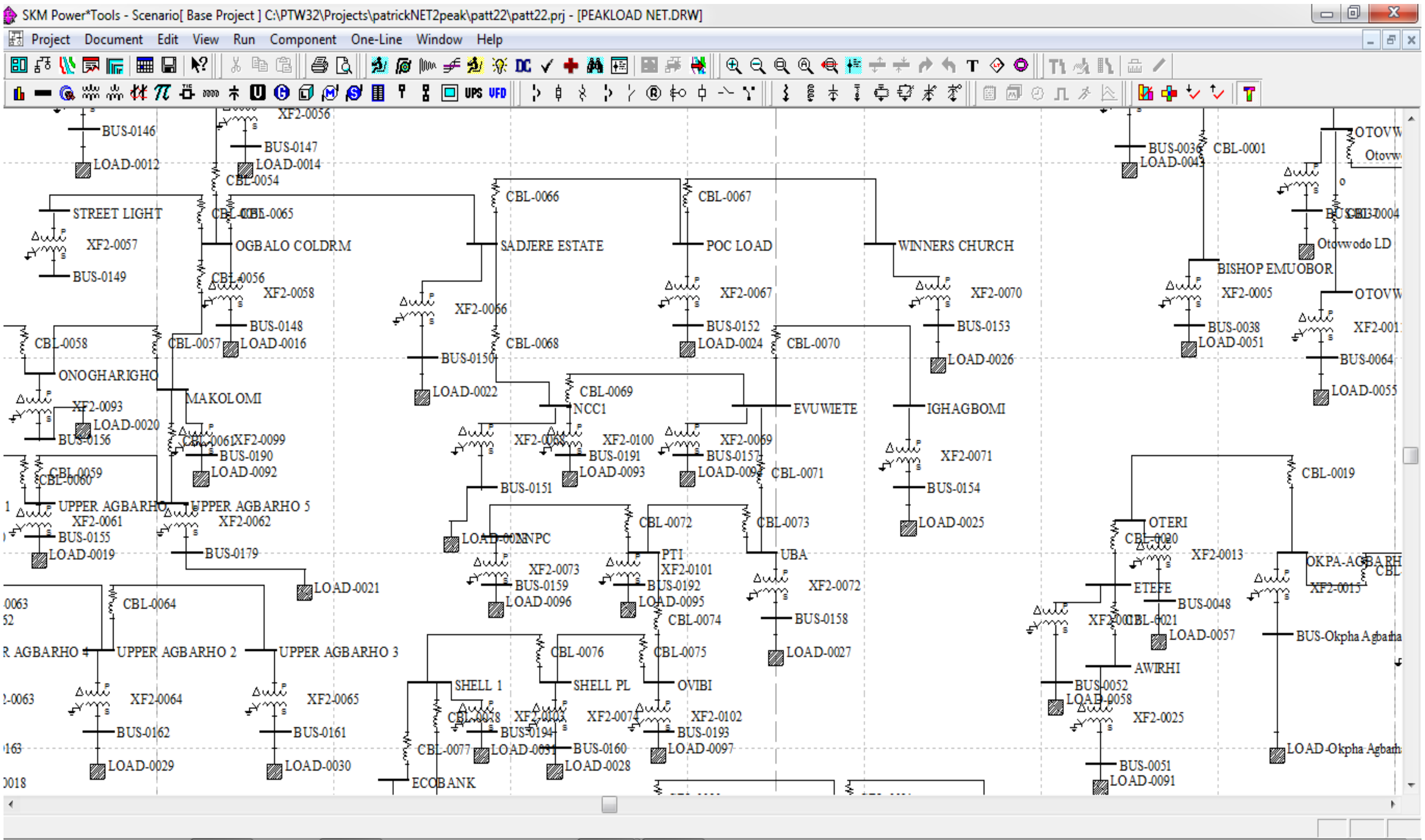
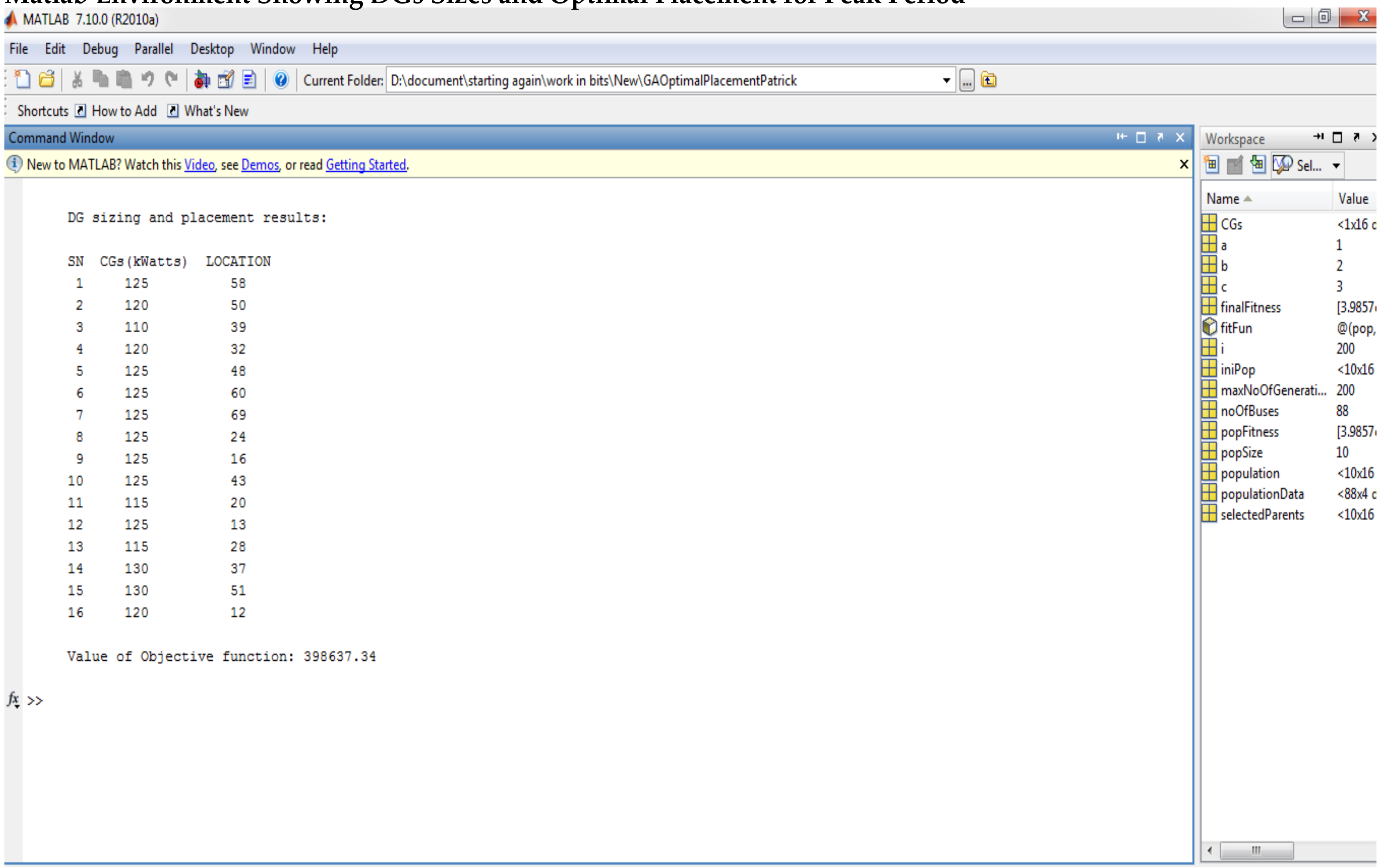
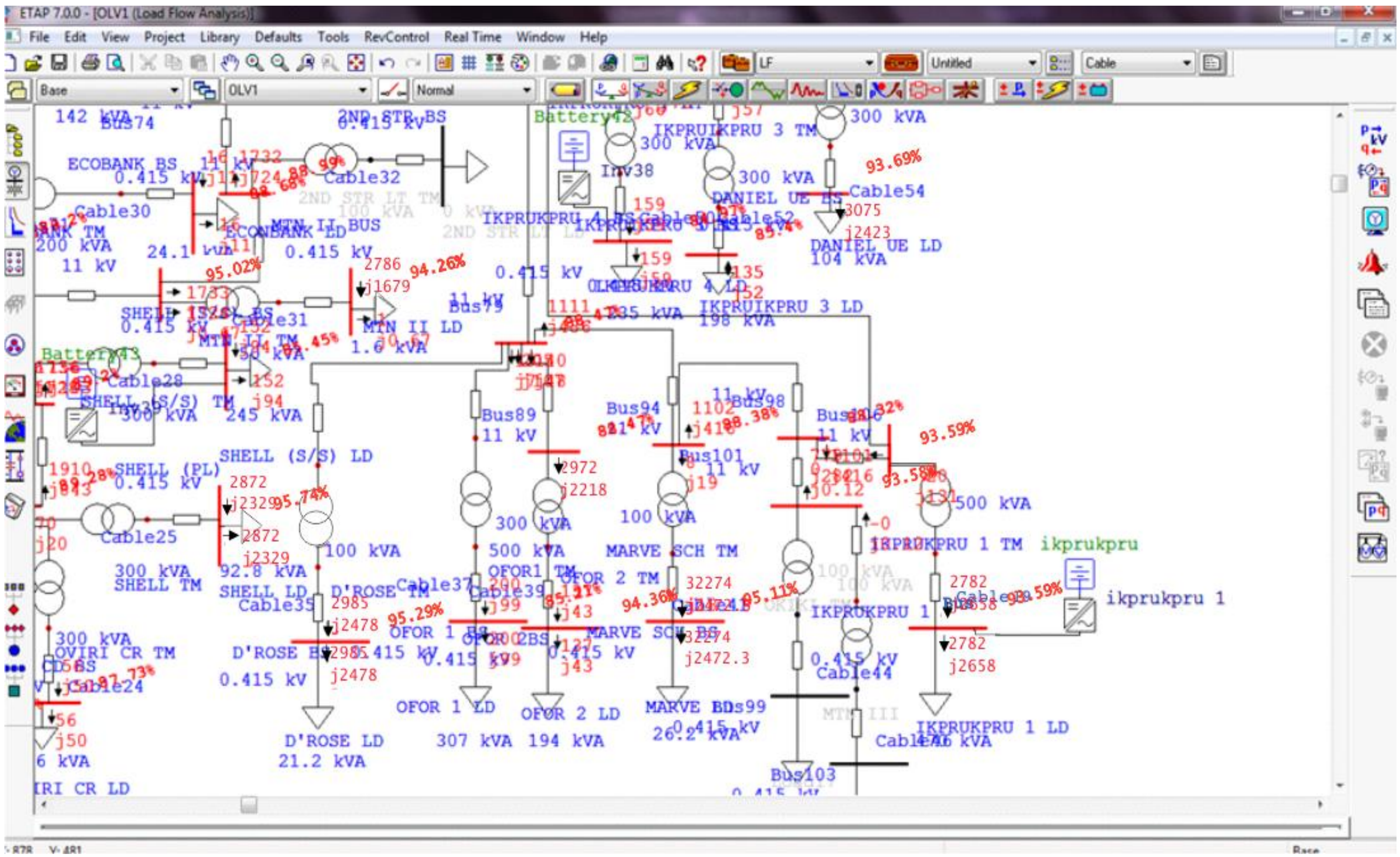
Appendix A
A Section of the Existing Network in PTW 65 Environment for Peak Period



Appendix B
Matlab Environment Showing DGs Sizes and Optimal Placement for Peak Period



Appendix C
ETAP Environment showing some of the DG locations in the existing network



Appendix D

ETAP 7.0 Environment Showing SVC in Place with DG for Peak Period.