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Load Flow Study of Nigeria Liquefied Natural Gas (NLNG) Residential Area, Bonny Island, Using Fast Decoupled Technique

[1] Amuno Joy Aghogho [2] D.C. Idoniboyeobu and [3] C. O Ahiakwo
[1,2,3] Department of Electrical Engineering, Power Option Rivers State University, Port Harcourt.[1]amunoj2013@yahoo.com,[2]idoniboyeobu.*d*@ust.edu.ng[3]ahiakwo.christopher@ust.edu.ng

ABSTRACT

The Load Flow Study of Nigeria Liquefied Natural Gas (NLNG) Residential Area, Bonny Island is a research conducted which is necessary for the planning, operation future expression and improvement of the distribution network for the area. The analysis was conducted to tackle and solve the problem of the over loaded nature of the distribution transformers in the area under study. A detailed survey was done and the line and bus input, distribution transformer's ratings and loading, ratings of the various lump loads (consumer terminals), short-circuit capacity of the supply to the area were found. The network was modelled and simulated in Electrical Transient Analyser Program (ETAP) 16.00, using the Fast-Decouple Load Flow Method for analysis in ETAP 16.00. Simulation results of analysis of the network showed that one of the distribution transformers feeding the area under study to be marginally (almost) overloading. This, thus, causes enormous stress and losses (I^2R) in the transformer, bringing about loss or shortage of electrical supply to the area under study. Load bifurcation on the overloading transformer was the optimization method done; to improve supply 500KVA sized transformer was installed to alleviate the load on the overloaded transformer. Simulation results showed that the active and reactive losses along the overloaded branch (transformer) before load bifurcation were 10.8KW and 16.3KVar respectively. Also, the percentage voltage drop was seen to be 3.74%. But a significant improvement was noticed after the bifurcation of load on the overloaded branch. After optimization, the real and reactive power loss from the overloaded transformer became 3.3KW and5.0KVar respectively, with a percentage voltage drop of 2.07%. Similarly, the real and reactive power losses along the new transformer were 2.2KW and 3.3KVar with a percentage voltage drop of 1.68%, which are all very much within the safety limits of operation.

Keywords: Load Flow Study, Nigeria Liquefied Natural Gas (NLNG) Residential Area, Bonny Island, Fast Decoupled Technique

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Load flow study is a numerical analysis of the flow of electric power in an interconnected system, load flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing system (Barboza et al,2004).

The load flow analysis is the backbone of power system. For distribution system the load flow analysis is a very important and fundamental tool. Its results play the major role during the operational stages of any system for its control and economic schedule, as well as during expansion and design stages. The purpose of any load flow analysis is to compute precise steady-state voltages and voltage angles of all buses in the network, Load flow studies is one of the most vital study for power systems, it provides mathematical calculation to determine the bus voltages, Phase angle, active and reactive load flows through power system components. During the second half of the twentieth century, and after the large technological developments in the fields of digital computers and high-level programming languages, many methods for solving the load flow problem have been developed, such as Gauss-Seidel, Newton-Raphson‘s (NR) and its decoupled versions. Nowadays, many improvements have been added to all these methods involving as assumptions and approximations of the transmission lines and bus data, based on real systems conditions (Kriti, 2014). The Fast Decoupled Load flow Method (FDPFM) is one of these improved methods, which were based on as amplification of the Newton-Raphson‘s method.

This method due to its calculations simplifications and reliable results became the most widely used method in load flow analysis. However, FDPFM for some cases, where heavy loading (Low Voltage) at some buses are present, does not converge well. For these cases, many efforts and developments have been made to overcome these obstacles. In this

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research work, the Newton-Raphson method shall be use because is one of the accurate and fast method. Load flow studies are important in planning, operation and future expansion of power systems. The study gives steady state solutions of the voltages at all the buses, for a particular load condition. Different steady state solutions can be obtained, for different operating conditions, to help in planning, designing and operation, economic scheduling and exchange of power between utilities. Load- flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power-flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive load flowing in each transmission line. The load flow problem consist of finding the load flow (real and reactive) and voltages of a network for a given bus conditions. Because of the non-linearity of the algebraic equations, describing the given power system, their solutions are obvious, based on the iterative methods only. Load flow studies are mostly done in the radial distribution network, but in this project Load flow studies will be done on ring distribution system. The drawback of radial electrical power distribution system can be overcome by introducing a ring main electrical power distribution system**.** Here one ring network of distributors is fed by more than one feeder. In this case, if one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it. In this way, the supply to the consumers is not affected even when any feeder becomes out of service. The ring main system is also provided with different section isolates at different suitable points. If any fault occurs on any section of the ring, this section can easily be isolated by opening the associated section isolators on both sides of the faulty zone transformer directly (Serrican, et al, 2009).

In NLNG residential area the ring distribution network is applicable on like the mostly used radial distribution network used for commercial purposes. Ring distribution network is very reliable but expensive. Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic

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(Vishal et al 2015; Jos & Arrillaga, 2001). Conventional techniques for solving the load flow problem are iterative, using the Newton-Raphson or the Gauss-Seidel methods (Nisar, et al, 2015; Czumbil, et al, 2017). Load flow analysis forms an essential prerequisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary.

There are many solution techniques for load flow analysis. The solution procedures and formulations can be precise or approximate, with values adjusted or unadjusted, intended for either on-line or off-line application, and designed for either single-case or multiple-case applications. Since an engineer is always concerned with the cost of products and services, the efficient optimum economic operation and planning of electric power generation system have always occupied an important position in the electric power industry. With large interconnection of the electric networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running charges of the electric energy (Mozina, 2007). A saving in the operation of the system of a small percent represents a significant reduction in operating cost as well as in the quantities of fuel consumed. The classic problem is the economic load dispatch of generating systems to achieve minimum operating cost.

1.2 Statement of the Problem

Acknowledging the steady growth of population in NLNG residential area Bonny Island which has tremendously made the energy demand requirement in terms of consumption pattern of electric power to be over stressed beyond its designed thermal limits, NLNG Residential Area Bonny is closely associated with the problem of Overload conditions on the distribution transformers in the network, giving rise to losses in supply of electricity to the area under study.

1.3 Aims of the Study

The research work is aimed at analysing the Load Flow Study of Nigeria Liquefied Natural Gas (NLNG) Residential Area Bonny Island for Improved Distribution using Fast-Decoupled Technique.

1.4 Objectives of the Study

The objectives of this research work shall be:

(i) To collect appropriate data from field survey from NLNG Substation 7.

(ii) To use the data collected for modelling of the network in ETAP 16.00 software.

(iii) To analyse and run simulations using Fast-Decoupled Load Flow Technique, thereby obtaining the steady state operational values of the existing network.

(iv) To carry out an optimization technique for the improvement of the electrical distribution for the are under study

1.5 Significance of the Study

The significance of this research work is that, it will give the steady state operational values - the real and reactive power flows, the voltage profiles and the losses and drops along the branches of the existing network; and as well solve the problem of distribution transformer overload, shortage of electrical power supply to NLNG residential area, and at the long run provide adequate information for the planning of future expansion and upgrade of NLNG residential Area Bonny Island distribution network.

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1.6 Scope of the Work

The scope of this research work is limited to the areas covered by the National grid supply to Nigeria Liquified Natural Gas (NLNG) residential Area Bonny Island distribution network.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Survey

Load flow analysis forms an essential pre-requisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. There are many solution techniques for load flow calculations. However, an acceptable load flow method should meet the requirements such as high speed and low storage requirements, highly reliable, and accepted versatility and simplicity. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and hence, development of a special program for distribution studies becomes necessary. There are many solution techniques for load flow analysis such as: Gauss Seidel, Newton-Raphson, Fast Decoupled algorithm etc.

According to the scholar (Ahmed, 2013) that load flow analysis is the solution for the operating condition of a power system. Load flow analysis is used for power system planning, operational planning and operations/construct (Brown, 2013) also employed in multiple assessments, stability analysis and system optimization.

2.2 An Efficient Load Flow Algorithm for Radial Distribution Network (RDN)

The efficient load flow method is used to model the characteristics features of Radial Distribution Networks (RDN) in the area of distributed system automation such as Volt/Var

Planning (VVP), optimal sizing and placement of distributed generators and network reconfiguration flow profile. The load flow calculation studies which started with the Ward and Hale method in 1956 form a very important and basic tool in the field of power system engineering, used both in planning and operational stages. Since the invention and widespread use of digital computers in the 1950s and 1960s, many methods for solving the load flow problem have been developed (Stott, 1974). Most of the methods have 'grown up'

around the transmission systems and, over the years, variations of the Newton method such as the fast decoupled method have become the most widely used. Popular methods like the Gauss Seidel, Newton-Raphson, Fast Decoupled load flow and other versions might be unsuitable for solving load flow program and sometimes fail to converge because distribution feeders have a high R/X ratio, huge number of buses and radial structure topology which makes the system ill-conditioned when solving for the respective load.

In the view of these scholars (Li et al., 2014) they stated that algorithm have been developed to tackle the load flow power, where the authors have formed node-branch incidence matrix that depict the relationship between the bus injection powers and branch powers, then an estimated voltage drop and angle formulas were used along with the incidence matrix to solve the load flow power. (Li et. al., 2016) modifies the previously mentioned algorithm to counter the fundamental error problem resulting in high precision results for both weakly-meshed/meshed networks.

2.3 Review of Previous Work

2.3.1 Determination of Bus Voltages, Power Losses and Load Flow in the Northern Nigeria 33KV Transmission Sub-Grid

According to the scholar (Izuegbunam et al., 2011) researchers, the Nigerian Electric Power Transmission network operated by Transmission Company of Nigeria (TCN) operates at a very high pressure of 330kv while its lower transmission pressure is 132kv.The planning,

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design and operation of power systems requires load flow computations to analyse the steady state performance of the power system under various operating conditions and to study the effects of changes in the configuration of equipment. In their view, the very low bus voltage and poor power magnitude obtained from this study without voltage compensation revealed the reality of the perpetual poor power supply to the North West part of Nigeria. The analysis of distribution systems is an important area of activity as distribution systems is the final link between a bulk power system and consumers.

2.3.2 Load Flow Analysis Using ETAP Software for Network Simulation

Jayaprakash, et. al., (2016) in their work on load flow analysis to investigate the performance of electrical system during normal and abnormal operating conditions, provided information needed to: minimize MW and MVar losses; optimize circuit usage; develop practical voltage profiles; develop equipment specification guidelines and identifies transformer tap settings. ETAP is a computer based software that simulates real time steady-state power system operations, enabling the computation of system bus voltage profiles, real and reactive load flow and line losses etc.(Jayaprakash, et al,2016).

2.3.3 Performance of Newton-Raphson Technique in Load Flow Analysis Using MATLAB

Load flow study is a tool in power system analysis, and as such balanced conditions and single phase analysis are determined using this tool. It also solve the problems in the voltage magnitude and phase angle at each bus, the active and reactive load flow voltage magnitude, voltage phase angle, real power injection and reactive power injections. The sinusoidal steady state condition of the fully system voltages, real power and reactive power generated, and line losses are also determined using this analysis.

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In the view of Klingman and HimmeIbau (2008) the slack bus set the angle difference between two voltages, the angle of the slack bus is not important, although it sets the reference angles of all the other bus voltages.

The main objective for the calculation of load flow study is to find the magnitude of voltage /V/ and the phase angle (δ) of the power losses at each bus section, the real and reactive load flowing in each line of the power system. It was observed that Newton-Raphson's approach has made the calculations easier because the number of buses increased while the number of iterations decreased.

2.3.4 Load Flow Analysis of Abule-Egba 33KV Distribution Grid System with Real Network Simulations

Load flows are required to analyse the steady state performance of the power system during planning, design and operation of electrical power systems. These load flow studies can be done using computer programs designed specifically for this purpose.

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According to (Abdulkareem,et al, 2014) model and doing simulation are methods used to overcome the computational problems of load flow solution using load flow iterative technique such as Newton-Raphson and Gauss-Seidel. It needs a model based on real condition. The making of this model must be based on real and valid data so that the model can represent real condition.

In their view they stated that the very low bus voltages and poor power magnitude obtained from their study without voltage compensation at Agbefa 11KV feeder emphasize the reality of the epileptic poor power supply at the Abule-Egba part of Lagos State, Nigeria. In a view to supplement this disturbing situation, it was recommended that relevant parties engage in the reduction of power loss on the distribution network via correct sizing and location of

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reactive power support. If not properly applied or sized, the reactive power from capacitor banks can create even more losses and high voltage that can damage light load.

2.3.5 Impact of Distributed Generation on the Quality of Power Supply in Nigeria; Port Harcourt Network Case Study

According to Ajabuego, Okafor, Izuegbunam, & Olubiwe, (2017). In their work considered the impact of distributed generation (DG) on the quality of electricity supply in Port Harcourt network. They gave account on the impact of both the present and the future load demand. In achieving this, load flow analysis and continuous load flow (CPF) optimization method was used to achieve the simulation. The simulation was done using MATLAB 7.9 Power System Analysis Toolbox (PSAT) Simulink environment to analyse the network (Ajabuego et al., 2017). The result shows that the dispersion level of DG's among the buses increases, there was a very remarkable improvement in the voltage profile, real and reactive power and load ability of the network.

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2.3.6 Comparison between Load Flow Analysis Methods in Power System Using MATLAB

According to Kriti (2014), in his work on the 'Comparison between Load Flow Analysis, Methods in Power System Using MATLAB'. He stated that the analysis, designing, and comparison between different load flow system techniques such as Newton-Raphson, Gauss-Seidel etc. in power system using MATLAB was done successfully and the desired results were obtained. In Gauss-Seidel method, it was found that the rate of convergence was slow, it can be easily programmed and the number of iterations increases directly with the number of buses in the system whereas in the Newton-Raphson method, the convergence was very fast and the number of iterations is independent of the size of the system; the solution is high as obtained. It was stated as observed that in Newton Raphson method, convergence is not sensitive to the choice of slack bus. In conclusion it was practical that only the Newton-

Raphson and the Fast decoupled load flow methods were the most popular methods. The fast decoupled load flow is definitely superior to the Newton-Raphson method because of its speed and storage capability (Kriti, 2014).

2.3.7 Application of Fast Decoupled Load Flow Method for Distribution Systems with High R/X Ratio Lines

(Ochi, et. al., 2013) in their view proposed a fast-decoupled load flow calculation method for distribution systems with high R/X ratio'. The method was based on a coordinate transformation in Y-Matrix for Jacobian Matrix in the load flow method. But comparing it with the Newton-Raphson's method, it was found that a short computational time was realized although its convergence characteristics worsen. In a bid to solve the problem, a coordinate transformation in Y-matrix of the fast decoupled method for better convergence was employed (Ochi et. al., 2013).

2.4 A Promising Method for Uncertain Load Flow Studies

The load flow studies is a tool used to find the steady or operating conditions of power systems for given sets of load and generation value. But when the input conditions are uncertain, different incidence are considered for the required range of uncertainty, and reliable solution algorithms that accept the effect of data uncertainty into the load flow analysis will be required.

According to (Su, 2005) and (Chen et al., 2008), probabilistic methods are tools for planning studies. Though there are different short comings as a result of non-normal probability distribution and the statistical dependence of the input data as well as the problems associated with identifying probability distribution for some input data accurately.

In their view (Zian Wang et al., 2009) suggested a method for solving the load flow using interval arithmetic taking the uncertainty at the nodal values. Their articles also stated that

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the required solution to the non-linear equations can be obtained by interval Newton operator, Krawczyk operator or Hansen-Sengupta operator.

(Barboza et al., 2004) and (Barboza et al., 2005) also gave the methodology for solving the uncertain load flow problems and a mathematical representation was applied to the load flow analysis by considering Krawczyk's method to solve the non-linear equations. It is mentioned that the existing problem of excessive conservation in solving the interval linear equation could be overcome by Krawczyk's method. In this method the linearized load flow equations should be preconditioned by an M-matrix in order to guarantee convergence. The scholar also said that (Wang et al., 2005) the set of non-linear equations were solved by Gauss-Seidel method. Preconditioning is required but if interval input is too cumbersome, convergence is not guaranteed, that is why this method cannot give an exact solution. (Yu et al., 2009) Fast Decoupled load flow using interval arithmetic has been used to obtain the solution to the load flow with uncertainty.

This algorithm converges very fast and considers retaining the midpoint of the load flow studies. This is a specific feature that ensures the convergence in accordance with the punctual load flow studies. The algorithm is effective and avoids unnecessary computation effort like preconditioning.

2.5 Analysis of the Load Flow Problem in Power System Planning Studies

In an electrical Power system, load flows from generating station to the load through different branches of the network. According to (Afolabi, et al., 2015) that the flow of active and reactive power is known as load flow or load flow. Load flow analysis is an important tool used by mostly power engineers for planning and determining the steady state operations of a power system. Also (Mageshvaran et al., 2008) said that load flow studies is to determine the various bus voltages/phase angles, active and reactive load flow through different branches, generators, transformers, settings and load under steady state conditions.

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The power system is modelled by an electric circuit which consist of generation, transmission and distribution networks. The researchers (Elgerd, 2012) and (Kothari and Nagreth, 2007) said that the main information obtained from the load flow or load flow analysis consist of phase angles of load flow bus voltage and magnitude, reactive powers and voltage phase angles of generator buses, real and reactive load flow on transmission lines and power of the reference bus; other variables also being specified.

The load flow problem equations are non-linear and as such it requires iterative techniques such as Newton-Raphson, Gauss- seidel etc in solving it. According to (Aroop et al., 2015) and (Milano, 2009), the development of these methods mainly led to the basic requirement of load flow calculation such as convergence properties, memory requirement, computing efficiency, convenience and flexibility of the implementation. However, it was concluded that in planning of a power system, Gauss-Seidel method can be used especially for a small system with less computational complexity due to the good computational characteristics it exhibited. The effective and most reliable amongst the three load flow methods is the Newton-Raphson method because it converges fast and is more accurate.

2.6 Ring Distribution Network

The loop or ring distribution system is one that starts at distribution substation, run through or around an area serving one or more distribution transformer or load centre And returns to the same substation.

The ring main system has the following advantages:

(a) There are very less voltage fluctuations at consumer’ terminals.

(b) The system is very reliable as each distributor is fed with two feeders.

In case of fault in any section of feeder, the continuity of supply is maintained. The drawback of radial electrical power distribution system can be overcome by introducing a ring main electrical power distribution system**.** Here one ring network of distributors is fed by more

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than one feeder. In this case, if one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it. In this way, the supply to the consumers is not affected even when any feeder becomes out of service. The ring main system is also provided with different section isolates at different suitable points. If any fault occurs on any section of the ring, this section can easily be isolated by opening the associated section isolators on both sides of the faulty zone transformer directly.

Ring main distribution system is a method of power distribution system in which different parts of the power distribution network have an option to feed power from the same source through more than one route, a ring main distribution system is a loop of cable run from the generating station to the distribution station and back to the generating station. In NLNG residential area the ring distribution network is applicable on like the mostly used radial distribution network used for commercial purposes. Ring distribution network is very reliable but expensive.

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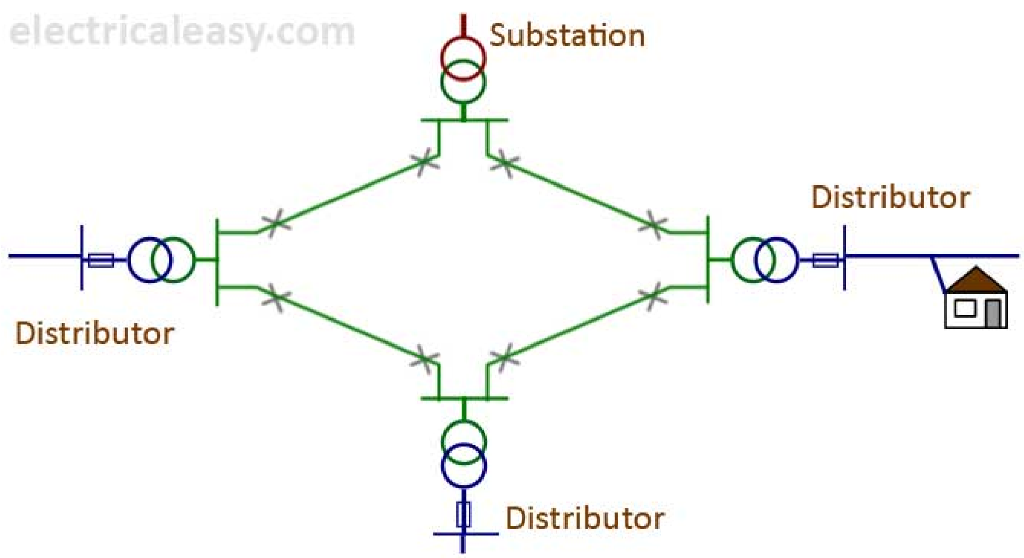
Below is a Ring distribution system



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2.7 Load Flow Overview

The load flow analysis (also known as load-flow study) is an importance tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a load flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various form of AC power (i.e. reactive, real and apparent) rather than voltage and current. The advantage in studying load flow analysis is in planning the future expansion of power systems as well as in determining the best operation of existing systems. Load flow analysis is being used for solving load flow problem by Newton-Raphson method and Gauss Seidel method. This sub-chapter will discuss all two methods generally on formula or mathematical step in order to solve load flow problem.

CHAPTER 3

MATERIALS AND METHODS

3.1 Material Used for Solving Static Load Flow Problems

The material required for the analysis of the network under study shall be line input and bus data, ratings and loadings of distribution transformers, short-circuit capacity of supply to the area of study, ratings of lump loads (consumer terminals) and Electrical Transient Analyser Program (ETAP) software. Load bifurcation by additional transformer shall be the optimization technique used in this research work. The network shall be modelled in ETAP 16.00 for simulation purposes using fast decoupled load flow method FDLFM.

3.2 Fast-Decoupled Load Flow Method (FDLFM)

Power does not change appreciably. Thus, the load flow equation from the Newton-Raphson method can be simplified into two separate decoupled sets of load flow equation, which can be solved iteratively:

$$\begin{aligned}[\Delta P] &= [J_1][\Delta \delta] \\ [\Delta Q] &= [J_4][\Delta V]\end{aligned} \tag{3.1}$$

The FDLFM reduces computer memory storage by approximately half, compared to the Newton-Raphson method. It also solves the load flow equation using significantly less computer time than that required by the Newton-Raphson method, since the Jacobian matrices are constant. The savings is computer time and the far more favourable convergence criteria make for a very good overall performance.

3.3 Line Parameter for the Modelling of the Nigeria Liquefied Natural Gas (NLNG) Network

Length of 11KV crossbar $= 6\,ft = 1.8288m$. Spacing between adjacent conductors that are horizontally equally placed $= \frac{1.8288}{3}$

$$D = 0.6096m$$

Conductor cross sectional area, $A = 150mm^2\,AAC$ (All Aluminum conductor)

Radius of conductor, $r = \sqrt{\frac{A}{\pi}m}$ (3.2)

$$r = \sqrt{\frac{150\times10^{-6}}{\pi}}0.00691m$$

Geometric mean distance, $D_{GMD} = 3\sqrt{D_{RY}D_{YR}D_{RB}}$ (3.3)

$$\begin{aligned}&= \sqrt[3]{2\times D^3} \\ &= \sqrt[3]{2\times D} \\ &= 1.26D \\ D_{GMD} &= 1.26\times0.6096 \\ &= 0.7681m\end{aligned} \tag{3.4}$$

Resistivity of Aluminum, $\ell = 2.826\times10^{-8}\,\Omega m$ at 20°C

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3.3.1 Per-Kilometre Resistance of line, R_0

$$R_0 = \frac{1000 \times \ell}{A(m^2)} \tag{3.5}$$

$$R_0 = \frac{1000 \times 2.826 \times 10^{-8}}{150 \times 10^{-6}} = 0 \cdot 1884\Omega / km$$

3.3.2 Per-Kilometer Reactant of Line, $\mathbf{X}_0$

$$\mathbf{X}_0 = 0.1445 Log_{10}\left[\frac{D_{GMD}}{r}\right] + 0.0157 \tag{3.6}$$

$$\mathbf{X}_0 = 0.1445 Log_{10}\left[\frac{D_{GMD}}{r}\right] + 0.0157$$

$$X_0 = 0.2956 + 0.0157$$
$$X_0 = 0.3113\Omega/km$$

3.3.3 Per-Kilometer Capacity Susceptance, b_0

$$b_0 = \frac{7.58}{Log_{10}\left[\frac{D_{GMD}}{r}\right]} \times 10^{-6}\, 1/\Omega km \tag{3.7}$$

$$b_0 = \frac{7.58}{Log_{10}\left[\frac{0.7681}{0.0061}\right]} \times 10^{-6}$$

$$b_0 = 3.7049 \times 10^{-6}\, siemens$$
$$b_0/2 = 1.85245x10^{-6}\, siemen$$

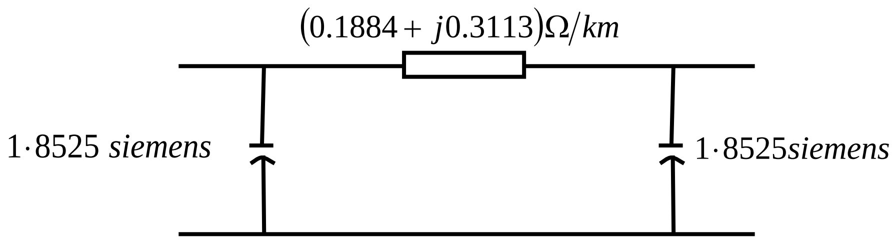

Fig. 3.1 Per-Kilometer π-equivalent circuit representation of line

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3.4 Power in Balance 3-Phase System

$$S_{3\theta} = \sqrt{3} \times V_{LL} \times I^{*} \quad (3.8)$$

$$S_{3\theta q=} = P + jQ \quad (3.9)$$

$$P = S_{3\theta} Cos\theta \quad (3.10)$$

$$Q = S_{3\theta} Sin\left[Cos^{-1}\theta\right] \quad (3.11)$$

3.5 Bus Percentage Operating Voltage

$$V\% = \frac{KV_{calculated}}{KV_{no\min al}} \times 100 \quad (3.12)$$

Transformation Ratio

$$\frac{KV_1}{KV_2} = \frac{N_1}{N_2}$$

Where $N_1 =$ Primary turns $V_1 =$ Voltage at primary side of transformer

$N_2 =$ Secondary turns $V_2 =$ Voltage at secondary side of transformer

3.6 Voltage Drop (V_n)

$$V_D = V_5 - V_R \quad (3.13)$$

$$V_D = I_R R + I_x X \quad (3.14)$$

Where $V_5 =$ Sending end voltage $V_R =$ Receiving end voltage

$I_R =$ In phase real current $I_x =$ Out of phase reactive current

$I =$ Average current flow $\cancel{Z} =$ Line impedance

Percentage voltage drop $= \frac{V_D}{V_5} \times 100\%$ (3.15)

3.7 Transformer Loading

Complex load demand = Transformer capacity x percentage loading on transformer.

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$$\text{Percentage Loading} = \frac{I_R + I_Y + I_B}{3I_n} \times 100 \qquad (3.16)$$

3.8 Total Equivalent Losses on Transformer

$$L_{Total} = P^2 F_u L_{Load} + L_{no-load} \qquad (3.17)$$

Where L_{Total} = Average losses KW $L_{no-load}$ = rated no-load

P = Peak transformer Load, permit losses, KW

F_u = Losses factor, per unit L_{Load} = rated load losses, KW

3.9 Load Calculator

$$KVA = \sqrt{(KW)^2 + (KVar)^2} \qquad (3.18)$$

$$PF = \frac{KW}{KVA} \qquad (3.19)$$

$$I_{3\theta} = \frac{KVA}{\left(\sqrt{3} \times KV\right)} \qquad (3.20)$$

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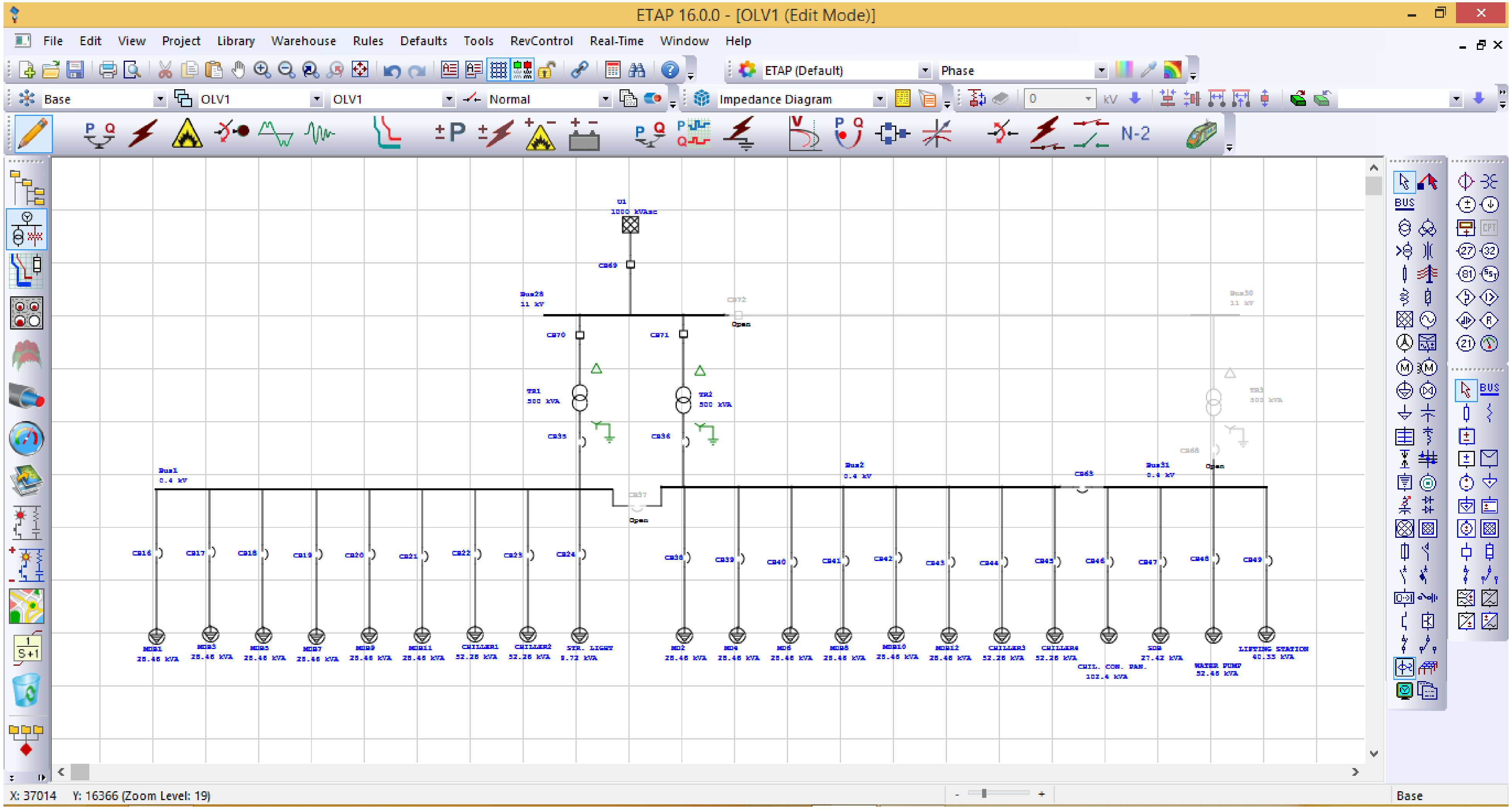

Figure 3.2 Existing Network of Nigeria Liquefied Natural Gas (NLNG) Residential Area, Bonny Island

CHAPTER 4

RESULTS AND DISCUSSION

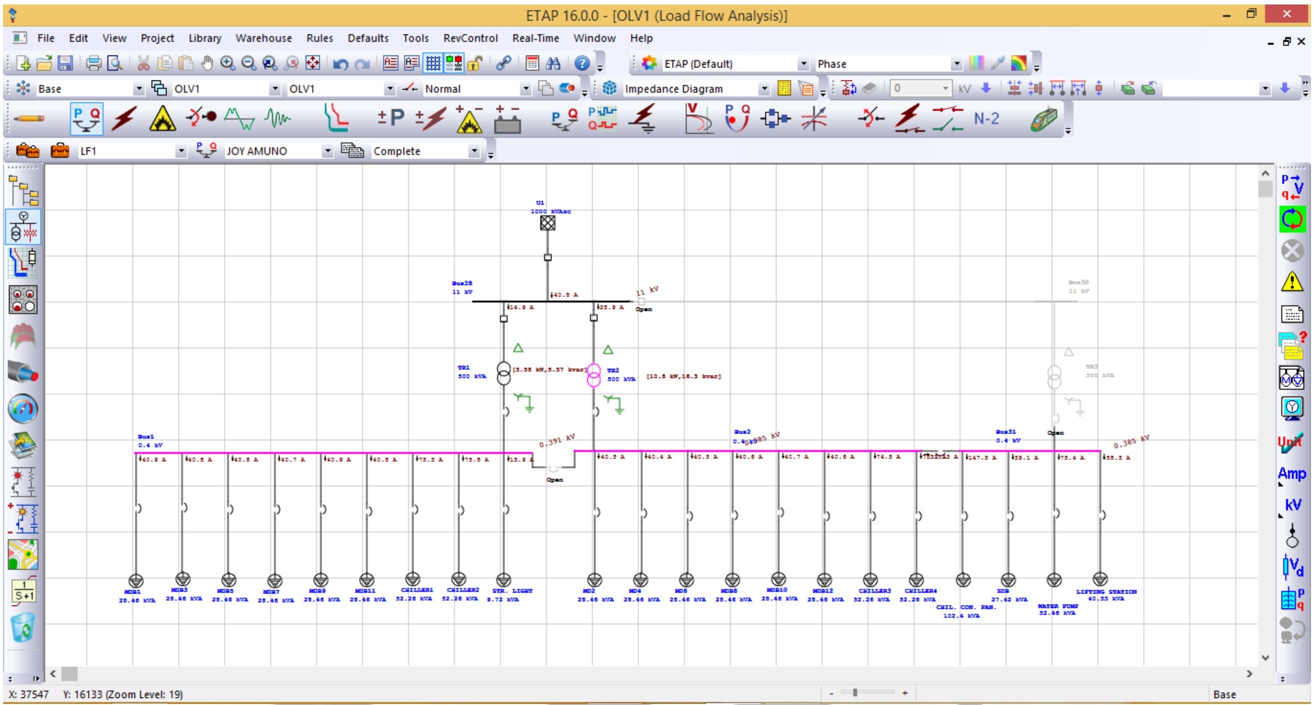

Figure 4.1: Flow Analysis of Existing Network before Optimization (Current Flow).

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The figure above shows the current flow into various branches, busses and loads in the existing network before optimization observed that Bus 1 and Bus 2 are marginally under voltage, due to the losses and drops along the branches (Transformers). From analysis, it is seen that transformer 2 is operating at marginally overloaded condition.

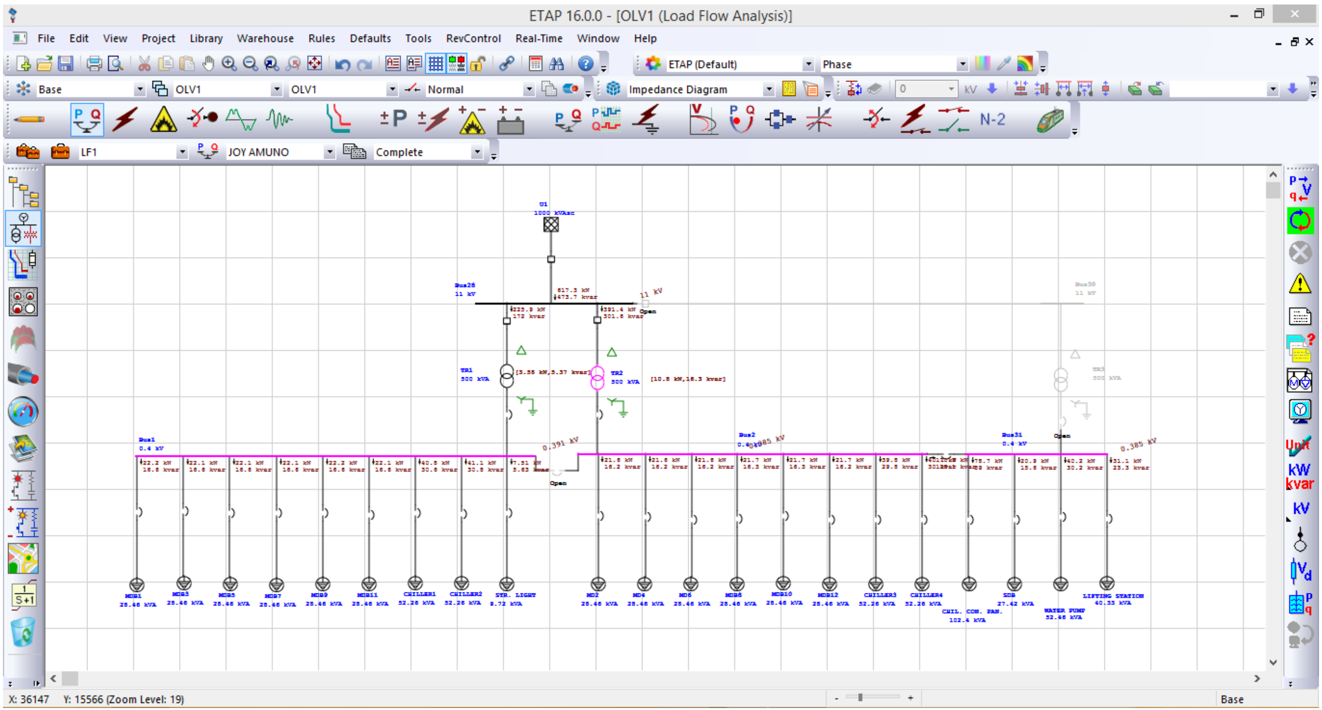

Figure 4.2: Load Flow Analysis of Network before Optimization

(Active and Reactive Power Flow)

Figure 4.2 shows the active and reactive power flow into the branches, buses and loads in the network before optimization.

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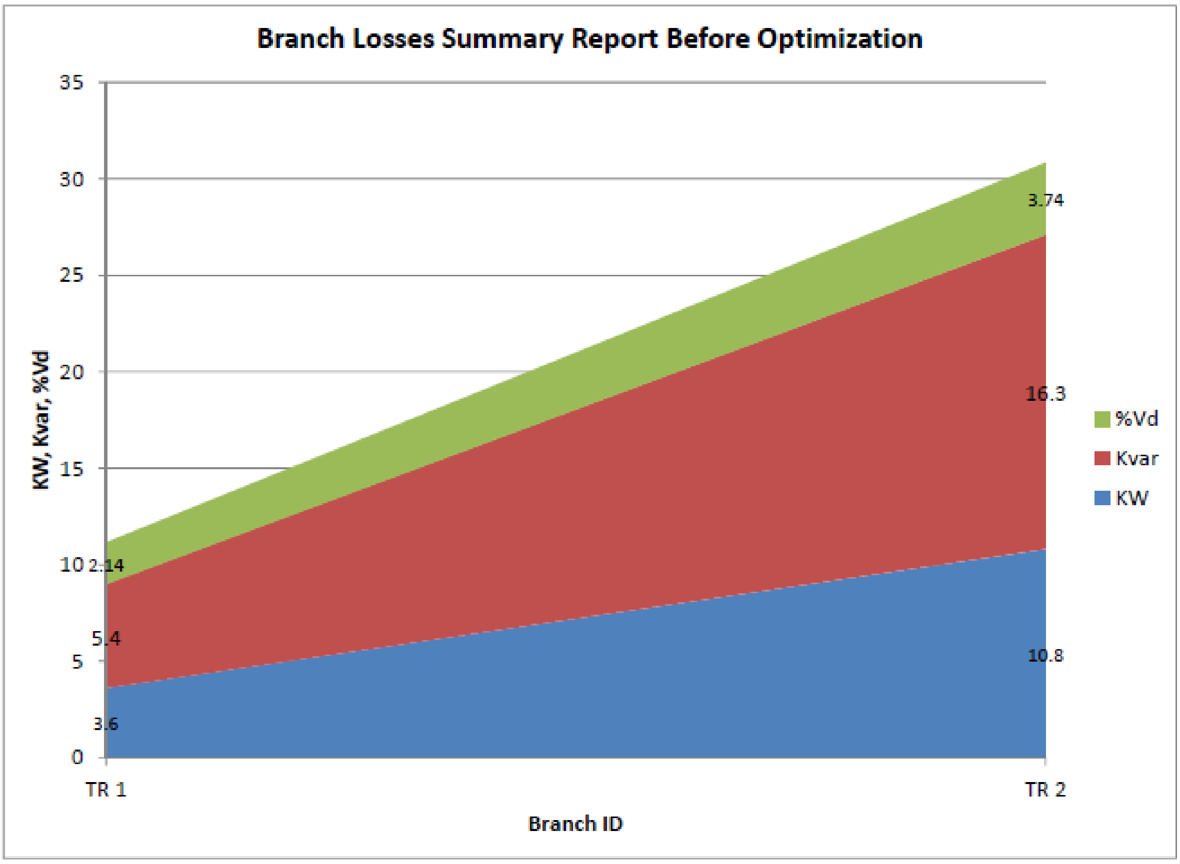

Figure 4.3 Branch Losses Summary Report before Optimization

The graph above shows the power losses and voltage drops along the transformer before optimization. Notice the high power losses from transformer 2. This is actually due to the overloaded nature of transformer 2. As a result, more load is being drawn into the windings of the transformer, thereby overheating them. Hence, more losses are experience from transformer 2.

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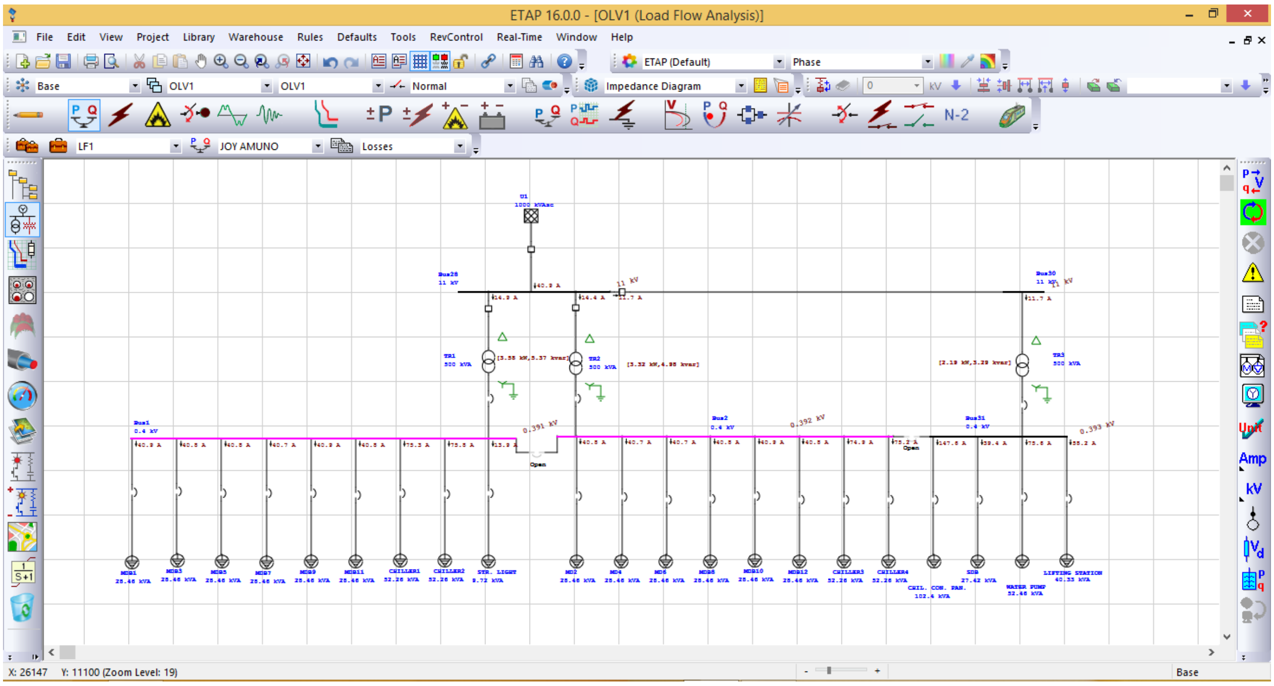

Figure 4.4: Load Flow Analysis of Network after Optimization (Current Flow)

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Figure 4.4 shows the flow of current into the branches, buses and loads in the network after load bifurcation has been carried out y erection of additional transformer. Observe the reduction in power losses along transformer 2, which is the direct result of the reduction of loading on the transformer. Also observe the increase in the operating voltages of Bus 1 and 2. The figure also shows how lump loads; chillers control panel, SDB substation, water pump control panel and lifting station control panel are bifurcated from transformer 2 and connected to the new erected transformer (3), so as to aid the improvement of the network.

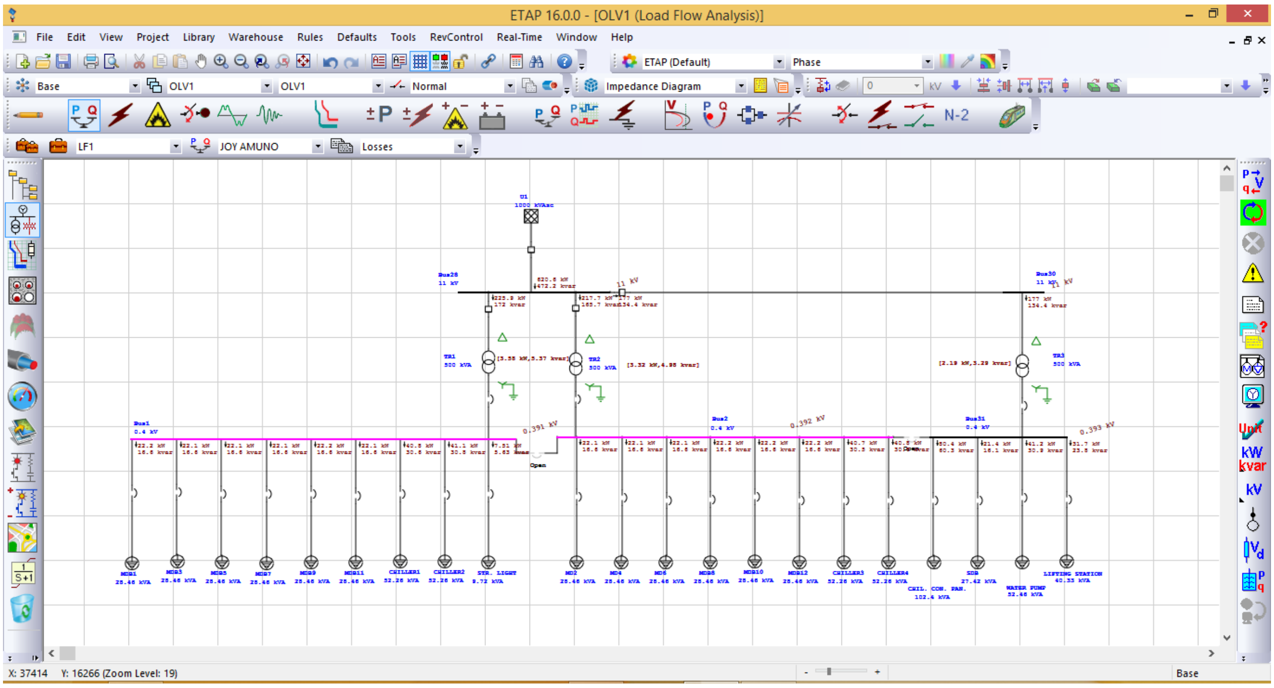

Figure 4.5: Load Flow Analysis of Network after Optimization

(Active and Reactive Power Flow)

Figure 4.5 shows the active and reactive power flow along the branches and into the various buses and loads after the load on bus 2 was split by erecting additional transformer.

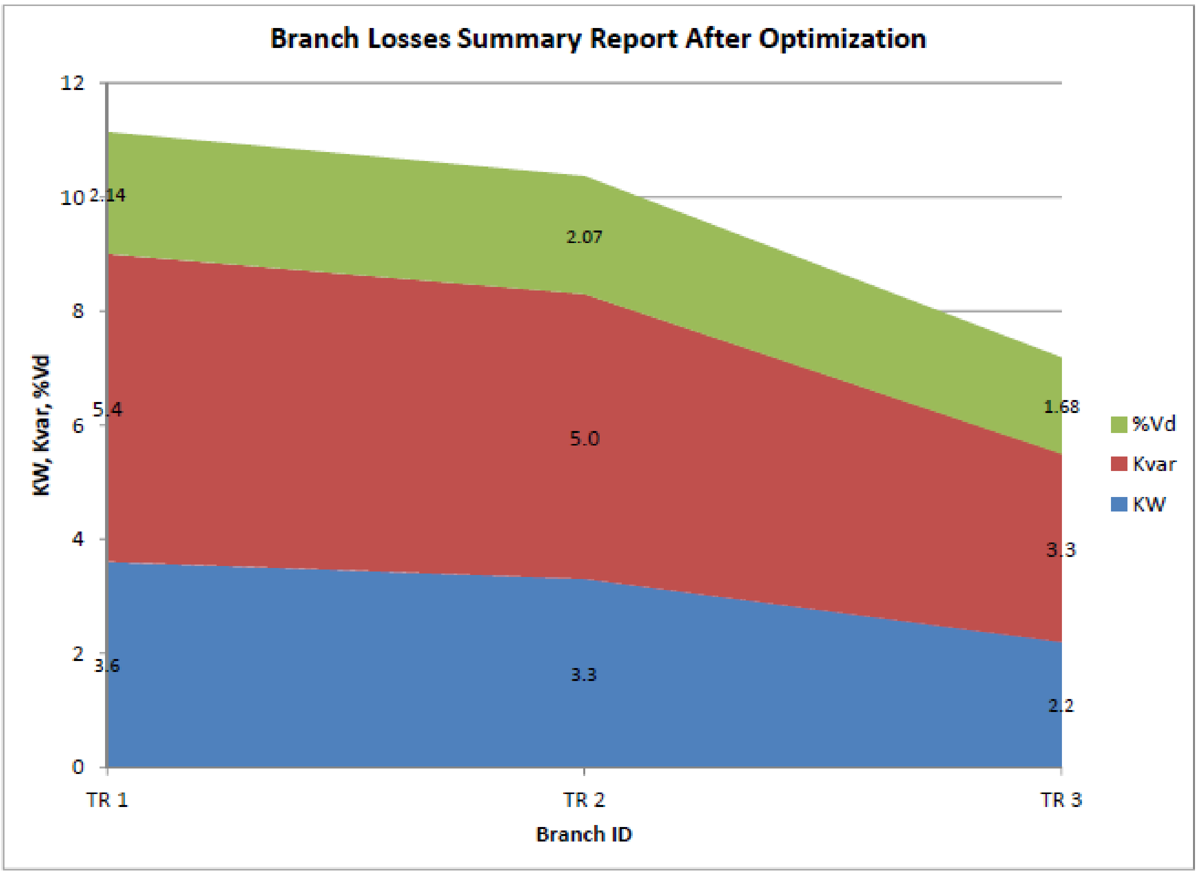

Figure 4.6: Branch Losses Summary Report after Optimization

The figure above shows the losses along the branches of the network after the addition of a new transformer 3. Observe the reduction in losses along transformer 2, due to the reduced loading on the transformer.

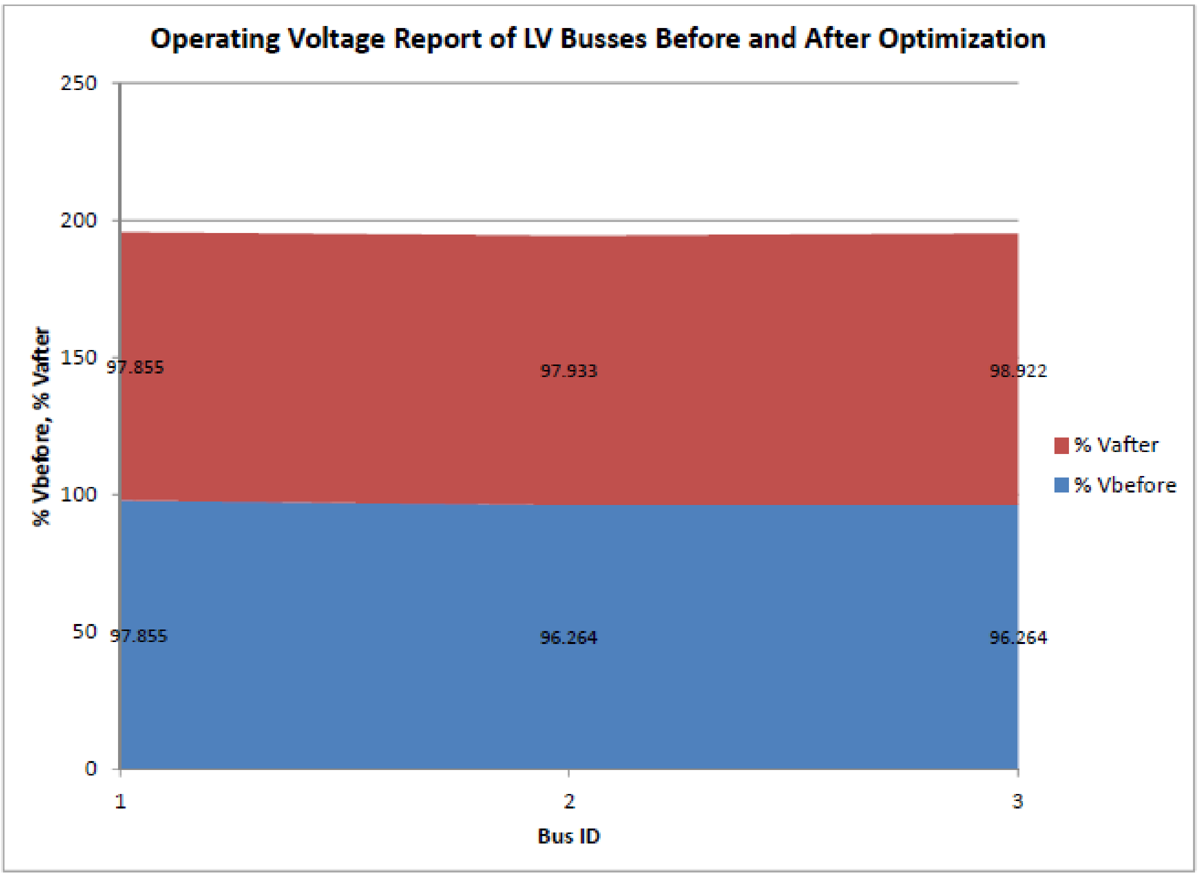

Figure 4.7: Load Flow Report of LV Buses; before and after Optimization

Figure 4.7 is a comparison between the operating voltages at the Low Voltage (LV) buses of the network, at before and after load bifurcation by erection of additional transformer. Notice that at before load bifurcation, the operating voltages of bus 2 and bus 31 are the same. This is because both buses are joined together by a LV circuit breaker, thus they operate as a single bus connected to transformer 2. When load bifurcation is implemented, the LV circuit breaker joining bus 2 and bus 31 is opened. Thus, bus 2 and bus 3 are connected to transformer 2 and 3 respectively, hence, the slight improvements of the operating voltage of these buses.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the Load flow analysis of the Nigerian Liquefied Natural Gas (NLNG) Residential Area, Bonny Island, it is obviously seen that the low voltage buses were flagged marginally under voltage due to the drop in voltage incurred along the branches of the network. Simulation results showed that transformer 2 (TR2) is marginally over loaded and thus, produces large amount of losses due to the increased load (power flow and current flow) along the windings of the transformation. Hence a considerable amount of power is fast in the form of I^2R.

The total power $\left(I^2R\right)$ losses along TRI and TR2 before improvement are (3.6+j54) KVA and (10.8+16.3) KVA respectively while the percentage voltage drop along same transformers are 2.14% and 3.74% of the nominal value.

To alleviate the stress on TR2, load bifurcation by addition of a new 500KVA transformer (TR3) was the optimization method induced into the network. Automatically this paved way for improvements both in the power losses and voltage drop along TR2. Results showed that the T^2R losses along TR2 was reduced to (3.3+j5.0) KVA and the percentage voltage drop also reduced to 2.07%, while the power losses and percentage voltage drop along the new transformer (TR3) and (2.2+j3.3) KVA and 1.66%, which are well within the permissible range by IEEE standard.

5.2 Contribution to Knowledge

This research work has contributed to knowledge as follows:

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(i) It examined the present state of the system and identified that transformer 2 was marginally overloaded.

(ii) The work also pre-empted the load bifurcation off transformer 2 by adding an addition 500KVA transformer to reduce the stress and losses along transformer 2.

(iii) The work creates a robust Distribution Network.

5.3 Recommendations

In line with the results gotten from the analysis of the Nigerian Liquefied Natural Gas (NLNG) residential area network, I hereby recommend that:

(i) Pressure testing should be done on the feeders of the network to correct all weak insulators.

(ii) A thorough inspection should be done to figure out all high resistance spots, including mechanically weak joints and terminations, which will enhance a proper maintenance to be done on the system.

(iii) Load bifurcation on transformer 2 by adding an additional 500KVA transformer should be carried out on the network, so as to reduce the stress and losses experienced by transformer 2.

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