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Contingency Analysis in thePort-Harcourt 132kV Sub-Transmission Network

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ABSTRACT:
In electrical power systems, reliability and efficiency are crucial; thus, there is a need for contingency analysis, which helps determine the operating status of power systems under various conditions, such as outages. This research work is focused on performing a contingency analysis on a transmission network using the Port Harcourt 132kV sub-transmission network as a case study. The power system network under investigation is a 21-bus system that was modeled and analyzed using software known as the Electrical Transient Analyzer Program (ETAP). A load flow analysis was performed using Newton Raphson's method, which revealed the existing bus voltage profile and power losses in the power system in a critical condition. Thus, shunt capacitor banks were introduced, which improved the voltage profile of the buses and reduced the active and reactive power losses from a total of 40030.0 to 23867.7 kW and 115534.0 to 6552.6 kvar, respectively. Furthermore, a contingency analysis was performed using the Fast-Decoupled Method in order to determine how the power system will operate during outages. Contingency analysis was performed for single and double outages, and the results revealed that the power system network under study has sufficient redundancy to withstand single outages; however, it does not have sufficient redundancy to withstand double outages.

Keywords: *contingency analysis, load flow analysis, shunt capacitor banks, active power, reactive power.*

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1. INTRODUCTION

Electricity is an essential form of energy in modern cultures, with demand increasing year after year. An efficient power system can assure the optimal supply and consumption of this type of energy. The power system's success in performing this duty is measured in terms of voltage regulation, service continuity, flexibility, efficiency, and cost. The electricity system is extremely important economically, and the amount of investment required necessitates careful planning, design, construction, and operation [10]. A continuous, uninterrupted supply of electricity is crucial due to the rising reliance of the modern world on it for electronics, industrial output, and other daily activities. Even a brief blackout of all electricity can cause major disruptions to the region's essential infrastructure, including transportation, hospitals, water supplies, and even emergency services like fire, ambulances, and police. On the other hand, the odds of the transmission lines failing are increasing as a result of the increased strain placed on them. In recent years, blackouts have increased in frequency across the globe. Therefore, the biggest problem facing the world now is the creation of an efficient system for managing contingencies [2].

Contingencies are characterized as potentially dangerous disturbances that happen while a power system is operating in its steady state. Contingencies can cause irregularities like overvoltage at specific buses and overload on the lines, which, if left unchecked, can cause the entire system to collapse. Modern energy management systems (EMS) provide a function known as contingency analysis. When parts of a power system, like transmission lines, transformers, and generators break down, what happens to the remaining system's line power flows and bus voltages? This is called a contingency analysis. It serves as a crucial instrument for researching the impact of elemental outages on the operation and planning of the security of the power system [14]. In general, an outage of one transmission line or transformer may lead to overloads in other branches and/or a sudden system voltage rise or drop. Contingency analysis is used to calculate violations [25].

The importance of power flow studies in electrical power systems cannot be overemphasized, as both power system engineers and researchers depend on their outcomes to know the true state of the system under investigation [17]. The purpose of a power flow study is to calculate the voltage and its angle at each bus, the actual and reactive power flow in each line, and the line losses in the power system for a given bus or terminal condition. Power flow studies are carried out for the purposes of planning (short, medium, and long-range planning), operation, and control. The study also aims to determine the power system's steady-state operating point, or the voltage magnitudes and phase angles at the buses. By knowing these numbers, it is possible to determine other numbers as well, such as line flow (MW and MVAR), real and reactive power delivered by the generators, and the loading of the transformers. This study can also be used to identify any existing overload, undervoltage, or overvoltage situations in the system's component sections [16].

The power system is a complex network that includes many components such as generators, isolators, switches, bus bars, transmission lines, relays, transformers, and circuit breakers. If a malfunction occurs in any of these apparatuses in the power system during its operation, it affects the consistency of the power system and causes transmission problems and outages [21]. Large flow violations on transmission lines can induce line outages, which can have a cascading effect and overload other lines. If such an overload is caused by a line failure, it is urgent to start the control operation to reduce the overload on the line. Therefore, one of the most crucial tasks for power system planners and operation engineers to do is contingency analysis, which will be used in this research.

Ahmed et al. [1] performed a contingency analysis using the Newton-Raphson Load Flow (NRLF) algorithm, which was simulated in DIgSILENT software by forced component outages, in order to detect all outages causing system violations. The contingency screening method and the PI ranking method were also performed on the IEEE 9 bus system to select and rank all severe contingencies. The results obtained show that the L_1 outage is the most severe contingency case; L_2 and L_6 outages have a serious impact on the system. These outages were classified as critical contingencies. The performance indices and contingency ranking using BP-ANN were performed to verify the validity of the proposed algorithm.

James et al. [8] carried out a comparative study of the contingency assessment of the reformed Nigerian 330 kV power network under normal and fortified conditions. This contingency analysis allows operators to be better prepared to react to outages by using pre-planned recovery scenarios. The results obtained show that there are fewer violations in the system during contingencies when compared to previous works done on the pre-reform grid. This is a result of the availability of more than one transmission link between most stations (buses) in the system.

For their study, Hrvoje et al. [9] used an enhanced contingency analysis (ECA) that adds static voltage analysis to the traditional contingency analysis (CA). The study dedicated methodology for the proposed ECA tool, with special emphasis on the analysis of corrective measures provided by the system operator, intended for enhancing power system security (regulation of transformer action, distributed generation, and energy storage). Also, the influence of the load model was analyzed by simulation. The study demonstrated the advantages that distributed generation resources and energy storage can provide in the context of voltage stability. Also, the simulations acknowledged the importance of correct load modeling, since over- or under-estimation of a certain load-type component can result in too optimistic or too pessimistic power system operation limits.

Rohimi et al. [19] conducted a contingency selection by calculating two kinds of performance indices: voltage performance index (PIV) and line performance index (PIF) for single transmission line outages with the help of the fast decoupled method in MI power software. The obtained result shows that transmission line contingency in line number 16 is the most critical contingency. It was also shown that an outage in these lines has the highest potential to make the system parameters go beyond their limits. It can be further concluded that these lines require extra attention, which can be done by providing more

Braide and Idoniboyeobu [5] investigated network overload using the development of an improved contingency analysis model for a proper transmission expansion system with the view of addressing the power transfer capability (PTC) of transmission line addition or removal. The investigation was achieved by considering the system impedance matrix of Z_{bus} and Ybus, which characterizes the system properties and behaviors. It was shown that the system can be adjusted to compensate for an overload line. The technique of generation or phase shifter can be calculated to compensate for or correct an overloaded line for improved power quality. The model was developed to identify overloaded lines and select one or more lines to be removed in order to reduce overload in the power system.

Neelesh and Chaturvedi [12] proposed contingency analysis and security of a six-bus power system network. The results obtained concluded that the performance indices calculated indicate how severe a possible line outage is and thus define the severity of each line outage in the system. The performance index with the highest value indicates the severity of that particular line outage and also indicates that it has the maximum chances of making system parameters operate beyond the operating limits. Thus, it helps the operational engineers of the power system take the necessary and prior actions to mitigate the problem and thus helps in ensuring a safe, secure, reliable, and continuous supply from the power system.

Salah et al. [20] carried out a contingency analysis for the Sudan National Grid. The results obtained show the weaknesses of the transmission system, and new capacities were suggested for better power system security.

Dhiraj et al. [6] reviewed a paper on power system contingency analysis using an artificial neural network. Various strategies of contingency analysis were given in this review, and additionally, the utilization of artificial neural networks for contingency analysis was cited.

Nnonyelu& Theophilus [14] conducted a study on power system contingency analysis: a study of Nigeria's 330 kV transmission grid. In the study, it was shown, with values, the importance of operating the transmission system defensively to avoid system collapse due to overloading. Also, the researchers suggest that the Transmission Company of Nigeria (TCN) should adopt flexible AC transmission (FACT) devices, as they can improve the line's active power capability in any contingency event as they are faster switched than traditional compensation devices. Also, additional lines should be used to connect Oshogbo to Aiyede through different routes to create more links for power to be transmitted through the Lagos area in order to reduce the SLOI value of the Oshogbo to Aiyede line.

Niraj and Raju [13] conducted a study on power system disturbances and sensitivity analysis methods as part of contingency analysis. The study focused mainly on the types of changes and disturbances in the electrically deregulated market, solution methods for contingency analysis, load flow studies, and sensitivity factor analysis methods. Also, a case study of the IEEE-14 bus test system was carried out with the solution mentioned by sensitivity analysis under the condition of contingency to improve the GSF and LODF of lines. The obtained results show AC load flow and a real power flow performance index.

Nagendra et al. [11] conducted a contingency analysis of the power system using a fuzzy approach. fuzzy approach gives effective contingency ranking under different loading conditions. Fuzzy provides an effective framework for the analysis. Through proper tuning of the membership functions in fuzzy, it was shown that the method can mimic operator performance by conducting contingency ranking.

Taofik and Gafari [24] carried out contingency analysis of line components of a standard IEEE-30 bus and a real 330-kV Nigerian Transmission Company of Nigeria (TCN) network. 28-bus systems were investigated using the Radial Basis Function Neural Network (RBF-NN), which is artificial intelligence-based. The contingency analysis was carried out by solving the non-linear algebraic equations of the steady-state model for the standard IEEE-30 Bus and TCN-28 Bus power networks using the Newton-Raphson (N-R) power flow method. The RBF-NN-NNthod was used for the computation of reactive and active performance indices (PIR and PIA), which were ranked in order to reveal the criticality of each line outage. Simulation was carried out using the MATLAB R2013a version. The non-converged lines in both systems were reinforced and re-analyzed. The results of the contingency analyses of the reinforced systems obtained show more robust systems with a complete line ranking.

Sathish et al. [21] conducted a contingency analysis of faults and minimized power system outages using fuzzy controllers. It calculates the violation in the transmission line. The computational controller fuzzy system handled the transmission line outage and overload in other branch kinds of problems in the power system. The efficiency of a power transmission system with a fuzzy controller is determined by the computation of various parameters of the transmission bus under different loading situations. Several methods were developed for the transmission power flow of the contingency analysis.

Nur et al. [15] proposed a network splitting strategy following critical line outages based on N-1 contingency analysis. The work determines the optimal splitting solution for each of the critical line outages using the discrete evolutionary programming (DEP) optimization technique assisted by the heuristic initialization approach, whose initialization provides the best initial cut-sets that will guide the optimization technique to find the optimal splitting solution. Generation-load balance and transmission line overloading analysis were carried out on each island to ensure steady-state stability. A load-shedding scheme was initiated when the power balance criterion was violated on any island to sustain the generation-load balance. The proposed technique is validated on the IEEE 118 bus system. Results obtained show that the proposed approach produces an optimal splitting solution with lower power flow disruption during network splitting execution.

Lekshmi and Nagaraj [10] reviewed electrical power system contingency ranking using artificial intelligence techniques. In the work, a bibliography of all the artificial intelligence techniques, like fuzzy logic, artificial neural networks, genetic algorithms, and particle swarm optimization techniques used for contingency analysis, were listed. It was also shown that the data mining techniques used in the contingency analysis were also listed.

Akanksha et al. [2] proposed a probability of severity-based placement strategy for the Interline Power Flow Controller (IPFC) based on the Composite Severity Index (CSI). It was seen from the work that the composite severity index provides an exact measure of stress in the line in terms of megawatt overloading and voltage instability. IPFC was placed on the line that has the highest probability of severity during the occurrence of different outages. The IPFC has been tuned for a multi-objective function using Differential Evolution (DE), and the obtained results have been compared with genetic algorithms (GA), which were tested and implemented on IEEE 14 and 57 bus systems.

Anika et al. [3] proposed a complementary network-based framework, DIHEN, for power system CA to identify a set of contingencies (trigger nodes) using a heterogeneous network. The work provided a capability within power system inter-dependency analysis that identifies critical nodes within an inter-dependent network without using network connectivity (similar to baseline model IC1); instead, the knowledge provided by the subject matter experts was used. The speed and applicability of the results obtained were promising for real-time use of DIHEN in evaluating geographically expansive threats, where large failures are expected but cannot be predicted or assessed in reasonable time frames or with any expectation of solution convergence using traditional CA tools.

Fatima et al. [7] proposed a distributed spatiotemporal contingency analysis for the Lebanese power grid. The obtained results revealed that failures in the power grid were spatially long-range correlated, and correlations decayed with distance. In a couple of attack scenarios, the Spark implementation achieved a significant speedup on 16 cores for a graph with about 9×105 nodes. Scalability toward 32 nodes improved when experimenting with replicas of the power grid graph, which are double and quadruple the original size. This renders this paper suitable for larger networks at many vital levels beyond the power grid.

Siddhartha and James [23] proposed an approach for parallelization and load balancing of contingency analysis (CA) in power systems using the D programming language. In the work, CA was parallelized using a multicore processor and proposed and employed work-stealing-based efficient scheduling to achieve load balancing. The work evaluated the features of D, which are important for the parallelization of CA and obtaining large performance gains. The approach promoted legacy code reuse and, hence, was suitable for modern control centers, which cannot afford to port their legacy code to other high-performance computing (HPC) platforms. Time domain simulation was conducted using a large 13029-bus test system with hundreds of contingencies and parallelized CA over 2, 4, 8, 12, and 16 cores. The obtained results confirmed that the approach outperforms a conventional scheduling technique and also offers large computational savings over serial execution. Index Terms: D programming language (dlang), high-performance computing, parallel programming, power system analysis computing, power system dynamics, power system simulation.

Shih-En et al. [22] carried out an automatic analysis program to help design the look-up tables for event-based SPSs. The performance shows that the program presented can enhance the contingency analysis process through automation, drastically reducing the cost of manually carrying out part of the task, as well as improving performance by removing human error from part of the process.

Rachana and Sudarshan [18] carried out contingency analysis to detect weak links in the network. This analysis was performed for a 35-bus system, and the weak links in the system were detected and new capacities were suggested. The new capacities ensure better power system security for both single contingencies and any of the set of multiple contingencies that are occurring in the system.

Bemdoo et al. [4] conducted a contingency analysis for the Abuja transmission network using DIgSILENT Power Factory software. The contingency analysis conducted showed the results for the worst loading violations, from the most severe to the least severe, for both the base case and the case study contingencies. It was also shown that for the base case condition, the most severe continuous loading condition was 200.2%, while the least severe continuous loading condition was 93.7%. After the reinforcement of the identified weak section of the network, the security and stability of the network improved greatly, with the most severe continuous loading condition of 138.9% and the least severe continuous loading condition of 80.4%. Contingency analysis for the Abuja transmission network was conducted to identify the weakest part of the network and then take measures to ensure its stability.

II. MATERIALS AND METHOD

Materials used in this research work are a single-line diagram of the Port Harcourt 132kV sub-transmission network, ETAP software, and a computer system. ETAP was used for representation of the electrical power system network under study, and the per-unit system was used for all calculations. The analysis presents the fundamental equations necessary for performing a load flow analysis as well as contingency analysis. The method used for load flow analysis in this research is Newton-Raphson.

Newton Raphson's (N-R) method is an iterative technique that employs Taylor's series expansion and partial derivatives for solving a set of various nonlinear equations with an equal number of unknowns. This method possesses a unique quadratic convergence characteristic (it usually has a very fast convergence speed compared to other methods for load flow calculation). The major advantages of using Newton Raphson's method for load flow analysis are its insensitivity to the choice of slack bus and the fact that the number of iterations required is independent of the size of the system.The Newton-Raphson method formulates and solves iteratively the following load flow equation:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2\\ J_3 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} \qquad (1)$$

Where ΔP and ΔQ are bus real power and reactive power mismatch vectors between specified value and calculated value, respectively; ΔV and $\Delta\delta$ represent bus voltage magnitude and angle vectors in an incremental form; and J1 through J4 are called Jacobean matrices.Contingency analysis is the computation of a load flow solution for every possible outage; thus, it is required to rank the outages that could cause system constraint violations. This rank of outages is known as the Performance Index.The equation for voltage violations of system constraints is given as follows:

$$P_{IV} = \sum_{i=1}^{L} \frac{1}{2n} \left| \frac{|V_i| - |V_i^{sp}|}{\Delta V_i^{lim}} \right|^{2n} \qquad (2)$$

Where;

$|V_i|$ = voltage magnitude at bus i

$|V_i^{sp}|$ = specified voltage magnitude at bus i

n = number of buses

Furthermore, the equation for active power violation of system constrains is given as;

$$P_{IP} = \sum_{i=1}^{L} \left(\frac{P_i}{P_{imax}}\right)^{2n} \qquad (3)$$

Where;

P_i = Active power flow in line i

P_{imax} = Maximum active power flow in line I

$$P_{imax} = \frac{V_i . V_j}{X} \qquad (4)$$

Figure 3.1 represents the single-line diagram of the Port-Harcourt 132kV sub-transmission network modeled using ETAP software and relevant data obtained from Port Harcourt Electricity Distribution Company (PHED).

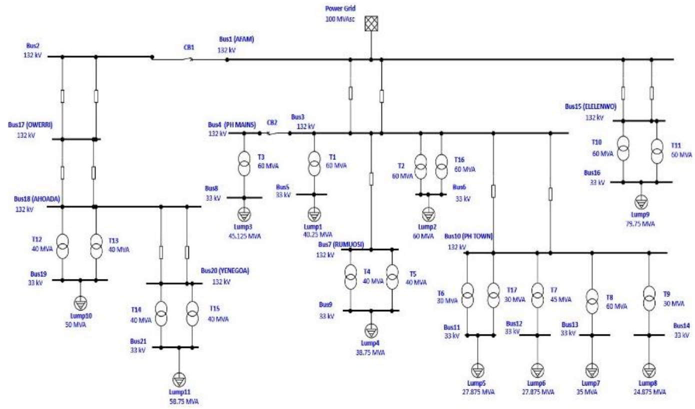

Figure1: ETAP Representation of Port-Harcourt 132kV Sub-Transmission Network

III. NETWORK DESCRIPTION AND OPERATION

A. Single Line Diagram

The power system network under investigation is a 21-bus system, which comprises a power grid, thirteen transmission lines, two high-voltage circuit breakers (used as tie-breakers or bus couplers), seventeen power transformers, and seven lump loads.

B. System Operation

Contingency analysis plays a vital role in power system studies as it helps to ascertain the operating condition of the power system under various conditions, such as outages on equipment. Furthermore, the results obtained can be used to propose adequate solutions to problems, if any, in order to ensure the efficiency and reliability of power supply in the power system network. This research work is focused on performing a contingency analysis on a power system network using the Port Harcourt 132kV Sub-Transmission Network as a case study. The sub-transmission network under study is a 21-bus system; it was modeled and analyzed using Electrical Transient Analyzer Program (ETAP) software.

They also did a load flow analysis to check how the power system network they were looking at was working at the time (looking at things like operating bus voltages, active and reactive power flow, and losses). Critical examination of the results obtained revealed that a total of 17 out of 21 buses were not operating within prescribed voltage limits; thus, they were flagged red (unhealthy). The unhealthy buses experienced a critical case of undervoltage; therefore, there is a crucial need for voltage regulation. Active and reactive power losses from branch elements like transformers and transmission lines were very high, at 4,030.0 kW and 115534.0 kV, respectively. This meant that measures had to be taken to reduce them. In this research work, tap-changing transformers and capacitor banks were used for voltage regulation and power loss mitigation.

After the insertion of capacitor banks at some weak buses, the high-voltage winding of some transformers was tapped in order to ensure voltage regulation and power loss mitigation. A load flow analysis was performed to verify the proposed method of voltage regulation and power loss mitigation, and the results obtained after the analysis revealed that all buses were operating within permissible voltage limits (no bus was flagged red); thus, the proposed method for voltage regulation was validated. Similarly, critical examination of the results obtained revealed a minimization in active and reactive power losses from 40030.0 kW to 23867.7 kW and 115534.0 kV to 65562.6 kV, respectively. Therefore, the proposed method for power loss mitigation was validated.

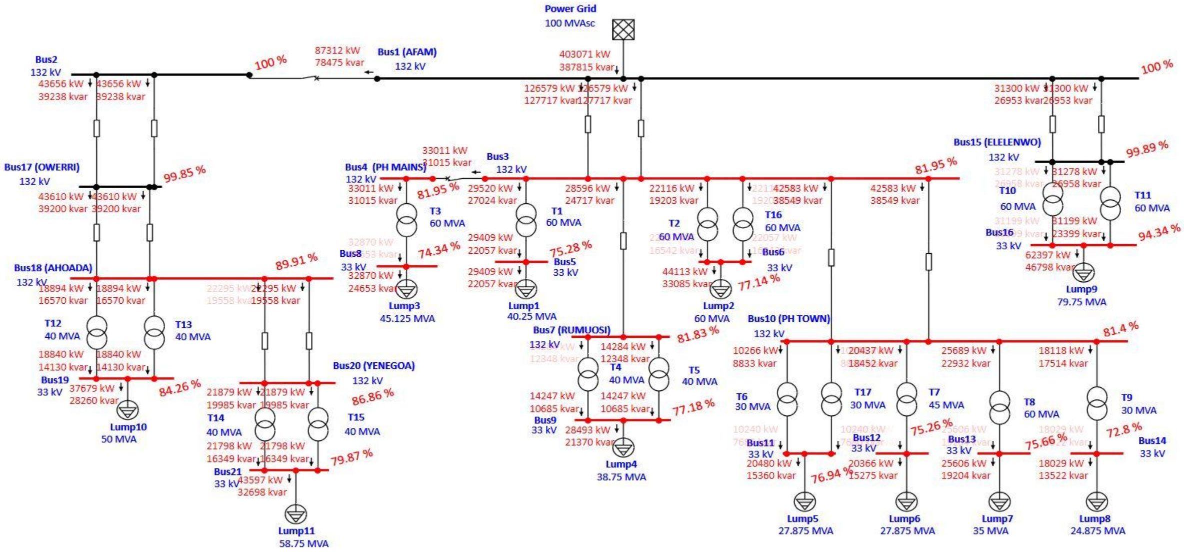

Figure 2: Load Flow Result of Port Harcourt 132kv Sub-Transmission Network

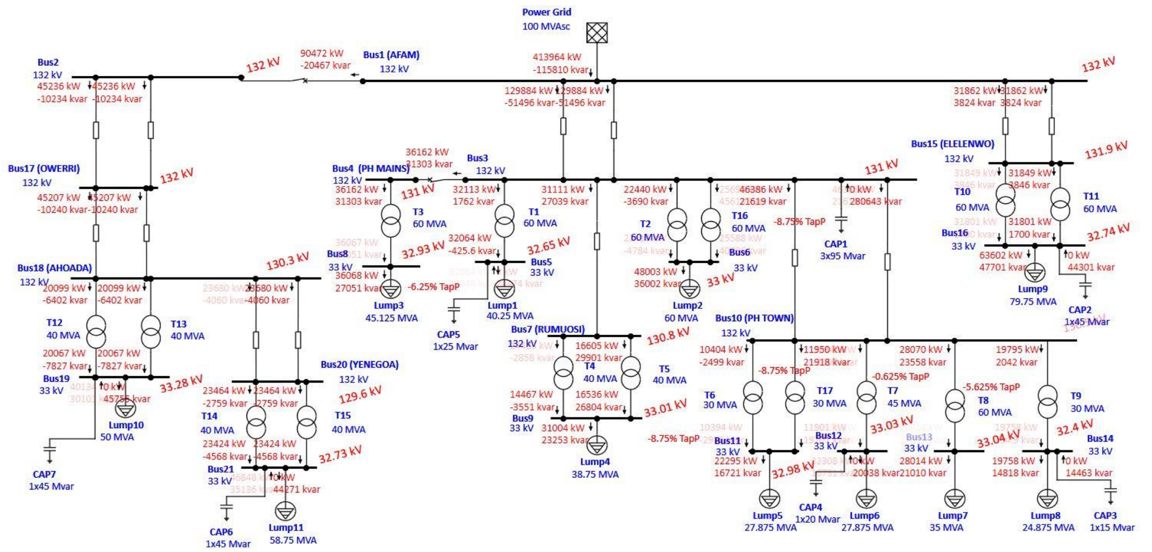

Figure 3: Load Flow Result of Port Harcourt 132kV Sub-Transmission Network after Improvement

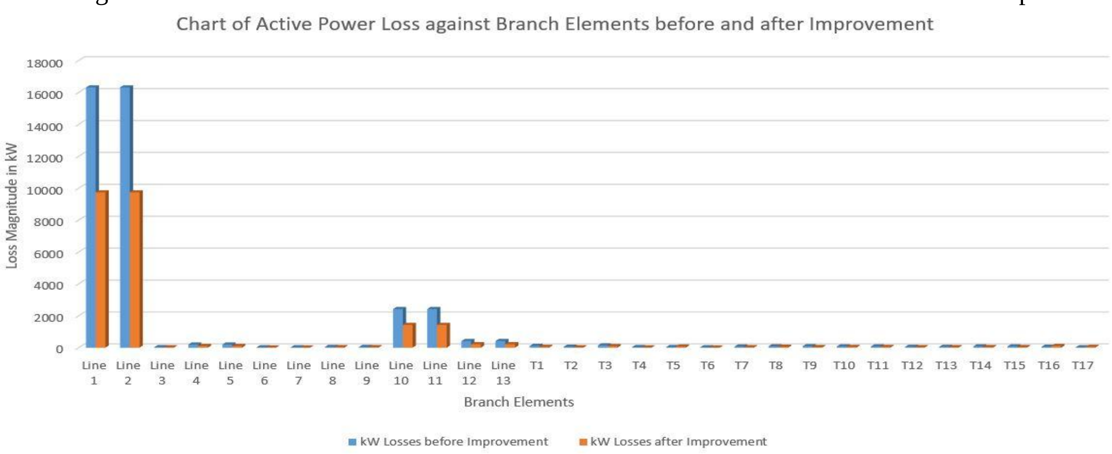

Figure 4: Comparison of Active Power Loss before and after Improvement

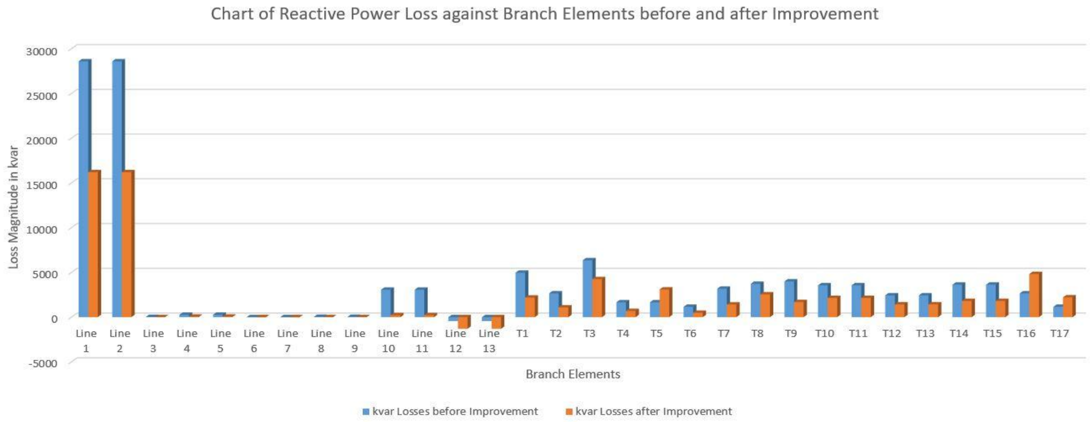

Figure 5: Comparison of Reactive Power Loss before and after Improvement

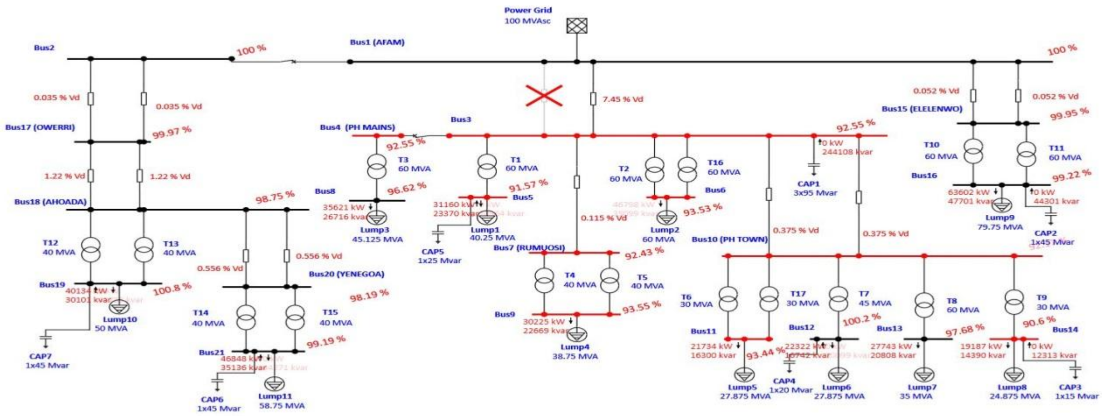

Figure 6: Single Outage on Line 1

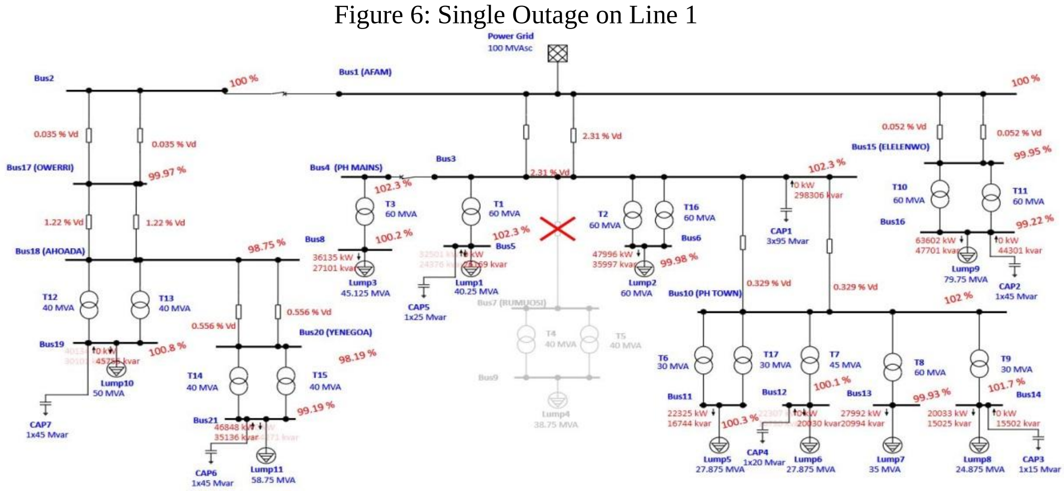

Figure 7: Single Outage on Line 3

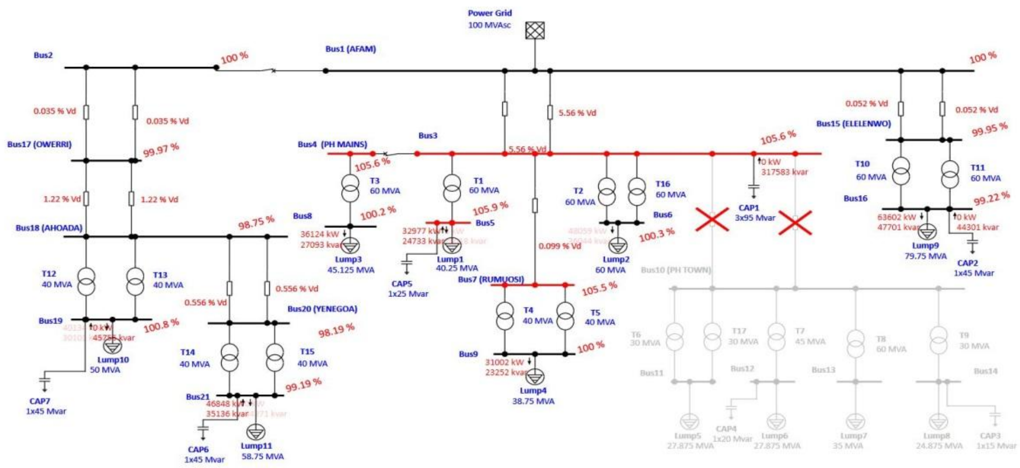

Figure 8: Outage on Lines 4 and 5

IV. CONCLUSION

A contingency analysis was performed using the Fast-Decoupled Method in order to ascertain how the power system will operate during outages. N-1 contingency analysis was performed for single outages on a transmission line, while N-2 contingency analysis was performed for double outages (outages on two transmission lines simultaneously). The results obtained were recorded, displayed, and explained. It was observed that the power system did not have sufficient redundancy to withstand outages on two transmission lines simultaneously (N-2 contingency).

V. RECOMMENDATION

In the process of carrying out this research work, some observations were made, which led to the following recommendations:

i. Enhancement of the existing network for improved efficiency and reliability of power supply.
ii. Shunt capacitor banks should be deployed as a medium for voltage profile improvement.
iii. Introduction of Distributed Generation (DG) at load centers, which will serve as a backup power source during maintenance or outages of the generator.

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