International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 7 Issue 2, February - 2023, Pages: 18-28

A Load Flow Analysis on Medium Scale Consumers: A Case Study of Kapeka Namunkekera Industrial Area, Uganda

Kibirige David[1], Kanyana Ruth[2],Nakitto Immaculate[3], Kitone Isaac[4],Njubo Nelson[5], Makumbi David[6], **Baguma Abdul Majid**[7], **Twikirize Michael**[8], **Namulawa Hawa**[9], **Muyunga Godfrey**[10], **Afam Uzorka[11]**

1-6 Ndejje University, Department of Electrical and Electronics
semkibirige@gmail.com[1], kanyanaruth@gmail.com[2], nakittoimmy@gmail.com[3], kitonei@gmail.com[4], tag.nnt@gmail.com[5], makumbidavid92@gmail.com[6]
7,8Ministry of Energy and Mineral Development
abdulbaguma15@gamil.com[7], tinkahjr@gmail.com[8]
9 Umeme Ltd, Network assets management
hawanamulawa@gmail.com
10 I Engineering, gmuyunga4@gmail.com
11Kampala International University
School of Natural and Applied Sciences

Abstract*—Uganda has over the years embarked on a rural electrification project to help extend electricity from the national grid to communities currently unable to access clean energy. This project has enhanced economic and social development in areas outside Kampala, the capital city; however, as the infrastructure and industrial development gained ground, there has been a strain on the load flow in the established industrial parks. Power flow analysis equips power system engineers with all the essential data for building a secure, stable, and reliable power system. Power flow analysis talks about the line flows of active and reactive power and bus bar values of voltage magnitude and phase difference, and it also explains ways of overcoming such problems like adding parallel transformers, transmission lines in parallel with the installed lines, and also adding parallel generators. In this paper, a numerical method for contingency analysis was used to predict contingencies that cause system violations and rank the contingencies according to their relative severity. A simulation of the network of 8 buses in the Kapeka Namunkekera industrial area was done, and the results showed that the network was heavily loaded due to the new factories that were established in that region, thus affecting the small-scale consumers.*

Keywords—Power flow, Load flow, contingency analysis, distributed power systems, N-R algorithm, Digsilent software, Industrial Area

1. INTRODUCTION

The analysis of load flow to medium consumers is the most important of all network calculations because it concerns network performance under normal operating conditions [1]. It is carried out to investigate the magnitude and phase angle of the voltage at each bus, as well as the real and reactive power flows in the system components, so that the capacities or ratings of the components can sustain the available loads on the network, and if not, then new lines are extended and other solutions, such as parallel transformers and mini lines, are implemented Load flow analysis has great importance in future expansion planning, stability studies, and determining the most economical operation for existing systems. Also, load flow results are very valuable for setting proper protection devices to ensure the security of the system [2]. In order to perform a load flow study, full data must be provided about the studied system, such as a connection diagram, the parameters of transformers and lines, the rated values of each piece of equipment, and the assumed values of real and reactive power for each load. We should be able to analyze the performance of power systems both in normal operating conditions and under fault (short circuit) conditions. The analysis in normal steady-state operation is called a power flow study (load flow study), and it targets determining the voltages, currents, and real and reactive power flows in the system under given load conditions [3] [4].The purpose of power flow studies is to develop an optimized voltage-dependent load model in which active and reactive powers vary as a function of voltage. For example, what if power system distribution lines that properly supply load must be taken offline for maintenance? Can the remaining lines in the system handle the required loads without exceeding their rated parameters? Nowadays, load flow (LF) is one of the important tools utilized by electrical experts for planning and control to determine the best operation for distributed power systems (DPS) and the exchange of power between utility companies [5]. In the last decade, electrical and systems engineers have been dealing with power system studies by using new software tools. Recent advances in electrical engineering sciences have brought a revolution to the field after the development of powerful computer-based software. Load flow methods might take a long time to be calculated; therefore, they prevent achieving an inaccurate result for a load flow solution because of continuous changes in power demand and generation. The magnitude and phase angle of the voltage at each bus, as well as the real and reactive load flowing in each line, are the primary results of a load flow analysis. Commercial power systems are typically too complex to allow for load flow handling solutions [2]. Large-scale digital computers have replaced analogous methods with numerical solutions. Besides, in order to perform the load flow analysis, computer programs perform related calculations such as short-circuit fault assessment, stability studies with a focus on transient and steady-state behavior, unit commitment, and economic dispatch. Maintaining a high level of system security is one of the more important aspects of power systems that should be noted, as should be the economic operation of these systems. There is a tendency for commercial consumer loads such as motors, compressors, and inductors to consume a lot of reactive power, which increases the wasted power and power deficit among consumers on the same network [3]. For instance, the expansion of the Mineral Water Company by creating a new industrial plant of 12 MVA at Kapeka has resulted in power instability at the existing 15 MVA Luweero Substation [6][7]. This results in multiple power quality impacts on the side of consumers on the same network or feeder, such as voltage surge, voltage swell, flickers, and so on, and reliability impacts on network components such as transformers in terms of early aging, wear, and stress. There is a need to develop an optimized voltage-dependent load model in which the active and reactive powers will vary as a function of voltage [1]. There is a primary requirement for designing a new power system and planning for an extension of the existing power system to increase the demand for power by medium- and large-scale consumers and also to improve the efficiency of capacitor banks to reduce the reactive power that the machines consume.

2. METHODOLOGY

In this paper, digsilent software was used to model the Kapeka Namunkekera industrial area, and load flow analysis was done on a network of 8 buses in the Kapeka Namunkekera industrial area. The following steps were used in computing the N-R algorithm in Digsilent software, and the flow chart is shown in the figures below:

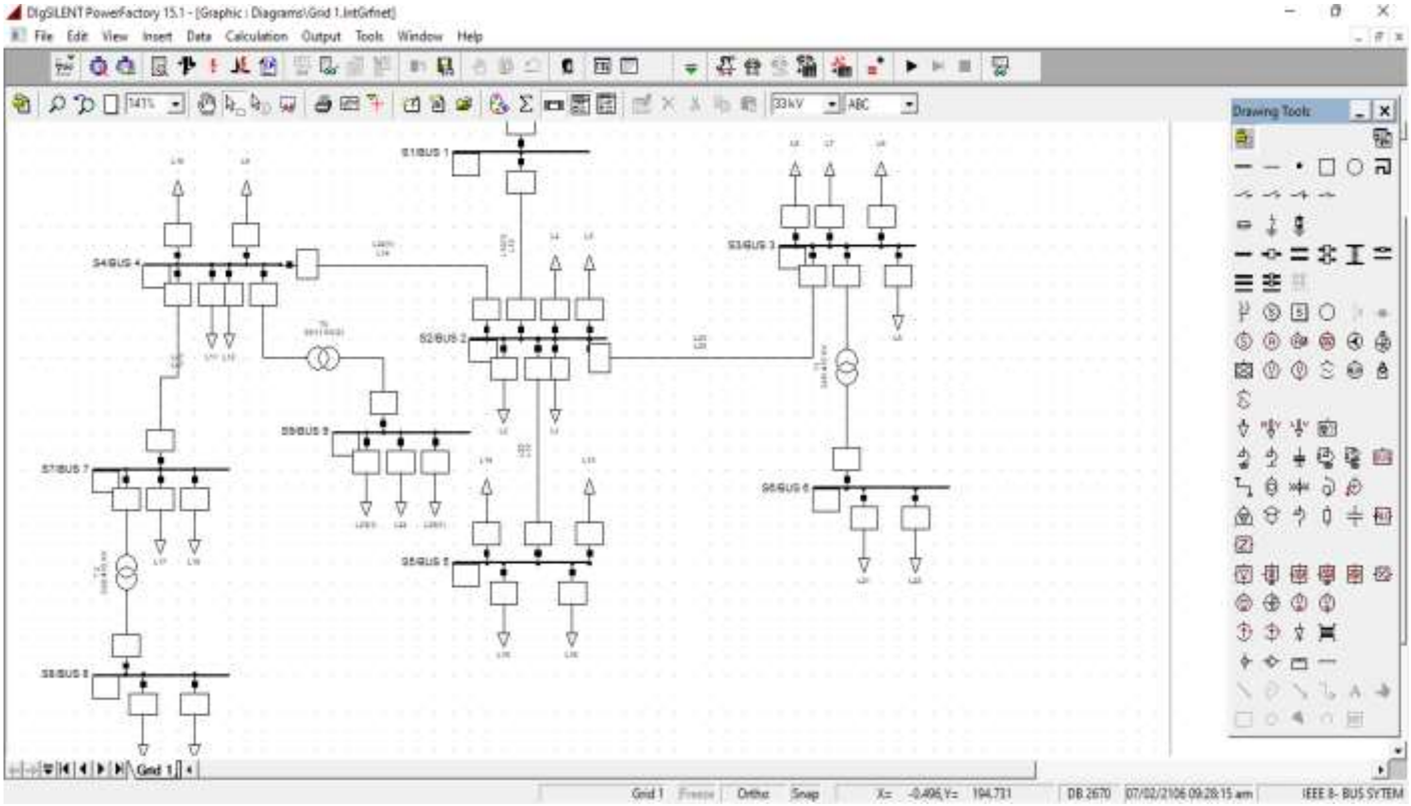


Figure 1: Kapeka Industrial Area Power System Network

The input data to the above power system are as follows

The input data of the power system network above include the bus voltages, resistance per kilometer, reactance per kilometer, length and sometime capacitance per kilometer of the distribution line, current flow within the line, apparent power of the transformers, primary and secondary voltages of the transformers, active power of the loads, and finally the power factor at which these loads are working.

Table 1: Line characteristic of 8 bus system data

Line characteristics of 8 bus system

Bus-Bus	Voltage (Kv)	R (ohm/km)	X (ohm/km)	Length (km)	Current (KA)
1 to 2	33	0.09	0.1	6	0.87
2 to 3	33	0.11	0.12	2	0.75
2 to 4	33	0.1	0.53	6	0.83
4 to 7	33	0.402	0.47	3	0.72
2 to 5	33	0.503	0.58	2	0.8

Table 2: Transformers data of 8 bus system

Transformers data of 8 bus system

Bus-Bus	Sn (MVA)	Vp (KV)	Vs (KV)
7 to 8	1	33	0.415
4 to 9	0.5	33	11
3 to 6	1	33	0.415

Above is the data that was entered in the transformers within power system network.

Table 3: Loads data of 8 bus system

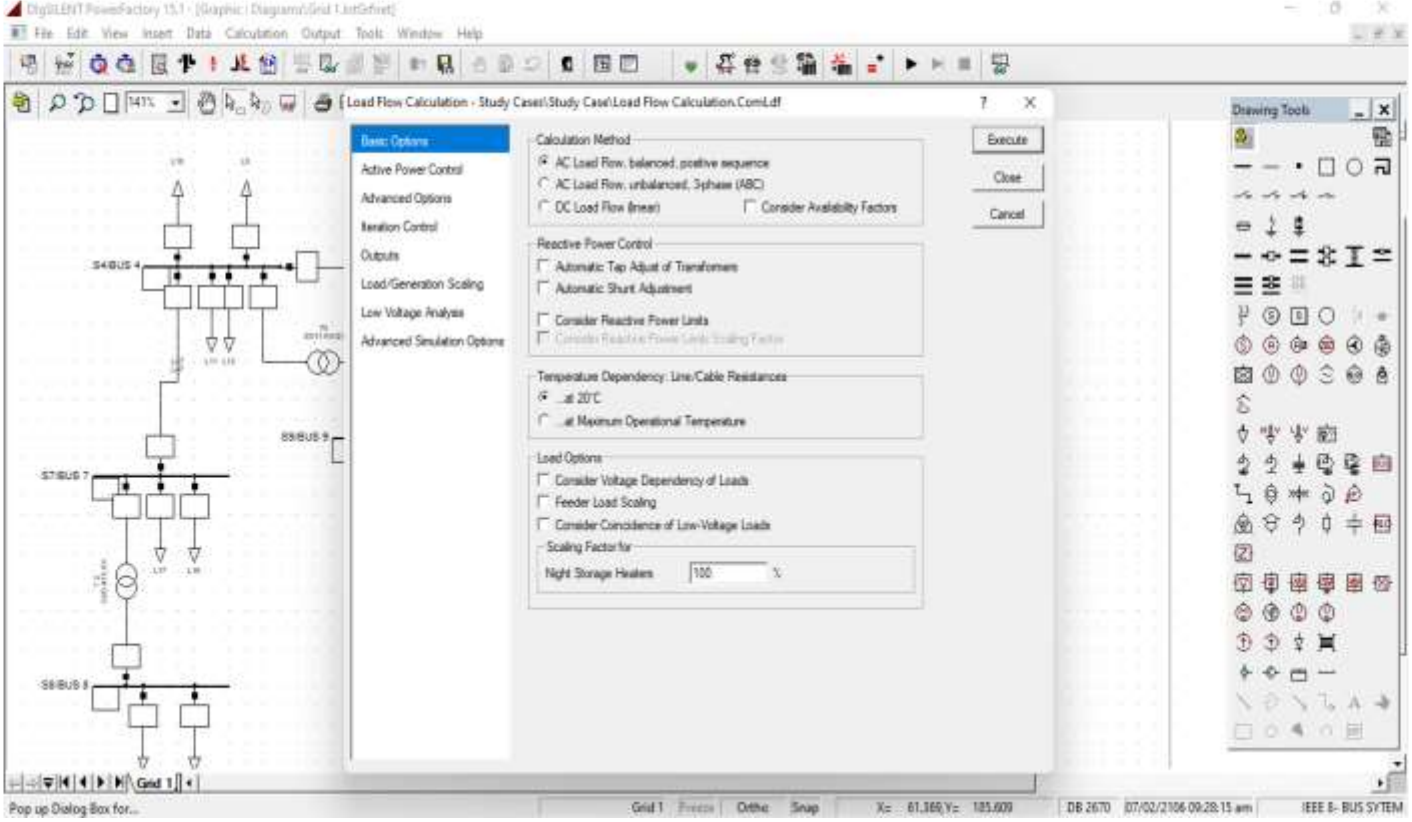
Loads data of 8 bus system

Bus	Load	P (MW)	Pf
2	L1	3.5	0.7
	L2	2	0.8
	L3	3	0.8
	L4	1.3	0.8
3	L8	0.33	0.67
	L7	0.5	0.9
	L6	0.67	0.9
	L5	0.67	0.5
4	L9	2	0.9
	L10	2	0.9
	L11	1.33	0.7
	L12	1.33	0.8
5	L13	0.67	0.5
	L14	3.32	0.6
	L15	1.67	0.6
	L16	0.67	0.5
6	L21	0.33	0.5
	L22	0.33	0.6
7	L17	1	0.4
	L18	1.5	0.5
8	L19	0.33	0.5
	L20	0.05	0.65
9	L23	0.5	0.6
	L24	1.33	0.7
	L25	0.67	0.75

The loads incorporated in this project are connected to the buses as shown in the above figure.

Power flow solution in digsilent software

After entering the data into the appropriate tabs, the load flow can be obtained, and the various unknown data will be supplied in the power flow solution. The power flow solution is obtained through Digsilent Software [3].



Load Flow Calculation - Study Cases\Study Case\Load Flow Calculation.ComLdf

Calculation Method
- ● AC Load Flow, balanced, positive sequence
- ○ AC Load Flow, unbalanced, 3phase (ABC)
- ○ DC Load Flow (linear)
- ☐ Consider Availability Factors

Reactive Power Control
- ☐ Automatic Tap Adjust of Transformers
- ☐ Automatic Shunt Adjustment
- ☐ Consider Reactive Power Limits
- ☐ Consider Reactive Power Limits Scaling Factor

Temperature Dependency: Line/Cable Resistances
- ● ...at 20°C
- ○ ...at Maximum Operational Temperature

Load Options
- ☐ Consider Voltage Dependency of Loads
- ☐ Feeder Load Scaling
- ☐ Consider Coincidence of Low-Voltage Loads

Scaling Factor for
Night Storage Heaters 100 %

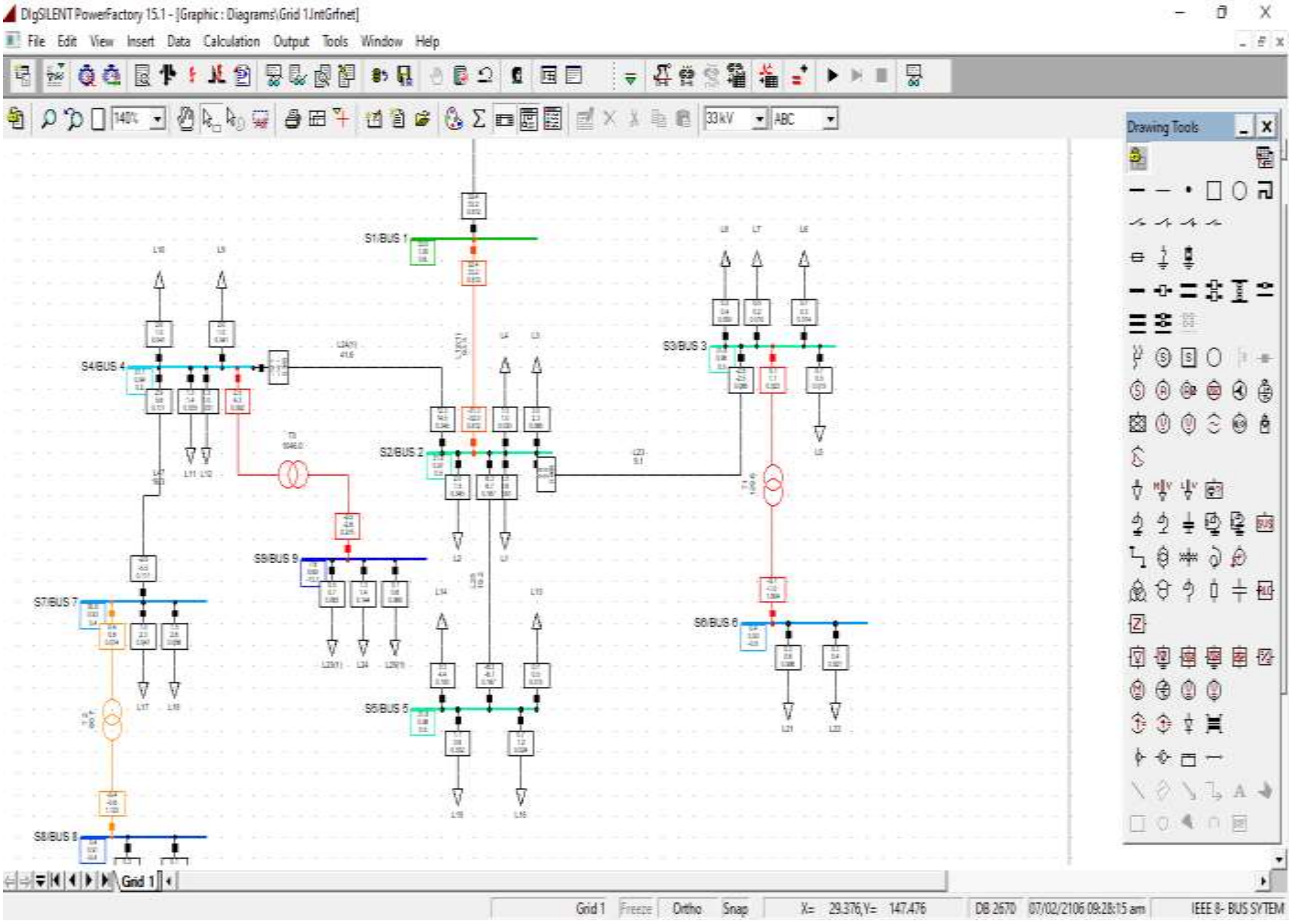
Figure 2: Entering data into the model system

3. TESTS AND RESULTS

Load flow results for the power system after simulation

The simulation output and the Newton-Raphson load flow solution with the data obtained is as follows

Figure 3: Simulation output and the Newton-Raphson load flow solution for optimized model



Load flow results analysis

After performing the load flow, the equipment on the model is color-coded. For this study, lines were considered, and in the backwash of the load, the lines were color coded. The color codes are according to the three critical different loading levels: the red lines show that the line has a loading range of over 100% and is hence overloaded. Orange indicates the line has a loading range of over 80%, and black lines indicate a loading range of less than 80%, thus being underloaded. The bus-based reports for the network buses are obtained after the load flow problem has been solved. The bus voltages and angles are obtained from the N-R load flow solution and are shown below in the table below.

Table 4: Bus voltages and angles are obtained from the N-R load flow solution

BUS NO	VOLTAGE(PU)	ANGLES(DEGREE)
2	0.97	0.5
3	0.96	0.5
4	0.94	0.2
5	0.96	0.5
6	0.93	-0.8
7	0.93	0.4
8	0.91	-0.4
9	0.69	-13.1

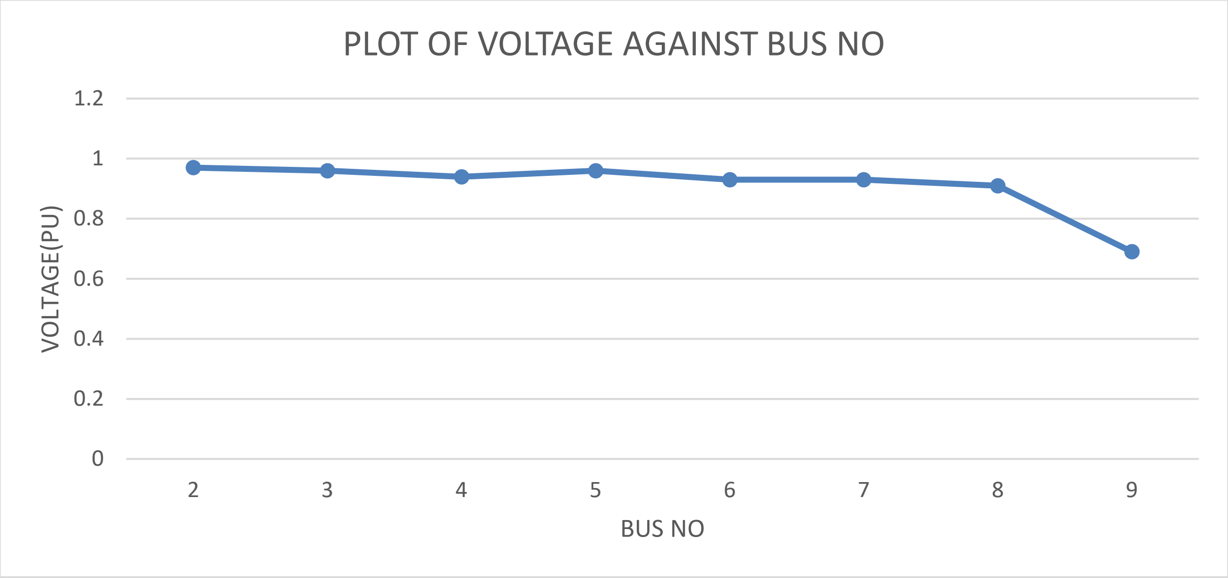


Figure 4: The plot of voltage against buses on N-R load Analysis

Table 5: The power flow for the distribution lines for Kapeka Network before optimisation

CONNECTED BUS		SENDING END		RECEIVING END		LOSSES	
FROM	**TO**	**P(MW)**	**Q(MVAR**	**P(MW)**	**Q(MVAR)**	**P(MW)**	**Q(MVAR)**
1	2	32.4	33.2	-31.3	-32	1.1	1.2
2	3	2.8	2.5	-2.8	-2.5	0	0
2	4	12.3	14.5	-12.1	-14.1	0.2	0.4
4	7	2.9	5.6	-2.9	-5.5	0	0.1
2	5	6.3	6.7	-6.3	-6.7	0	0
4	9	2.5	4.3	-2.5	-2.6	0	1.7
7	8	0.4	0.6	-0.4	-0.6	0	0
3	6	0.7	1.1	-0.7	-1	0	0.1
TOTAL POWER LOSS						**1.3**	**3.5**

Different Optimization Scenarios

Here we optimized the power system network while considering the different operation scenarios that were used to make the system stable.

Table 6: Operation scenario 1

Line$_{12}$	Conductor type	Unit cost/Km (Ugxshs)	Km	Parallel lines	Total cost (Ugxshs)
L$_{12}$	ACSR	17,024,000	6.0	2	204,288,000
TOTAL					**204,288,000**

Table 7: Operation scenario 2

TX NO	Types	Voltage level (KV)	Cost/TX (Ugxshs)	NO of parallel TX	Total cost (Ugxshs)
T$_1$	Distribution	33/0.415	30,000,000	2	60,000,000
T$_2$	Distribution	33/0.415	30,000,000	2	60,000,000
T$_3$	Distribution	33/11	50,000,000	2	100,000,000
TOTAL				**6**	**220,000,000**

Table 8: Operation scenario 3

Bus	NO of capacitors	Cost/capacitor (Ugxshs)	Total cost (Ugxshs)
8	4	850000	3,400,000
9	6	850000	5,100,000
6	4	850000	34,000,000
TOTAL			**11,900,000**

An improved power system network of Kapeka Industrial Area

Figure 5: The power flow for the optimized distribution line network for Kapeka Industrial Area

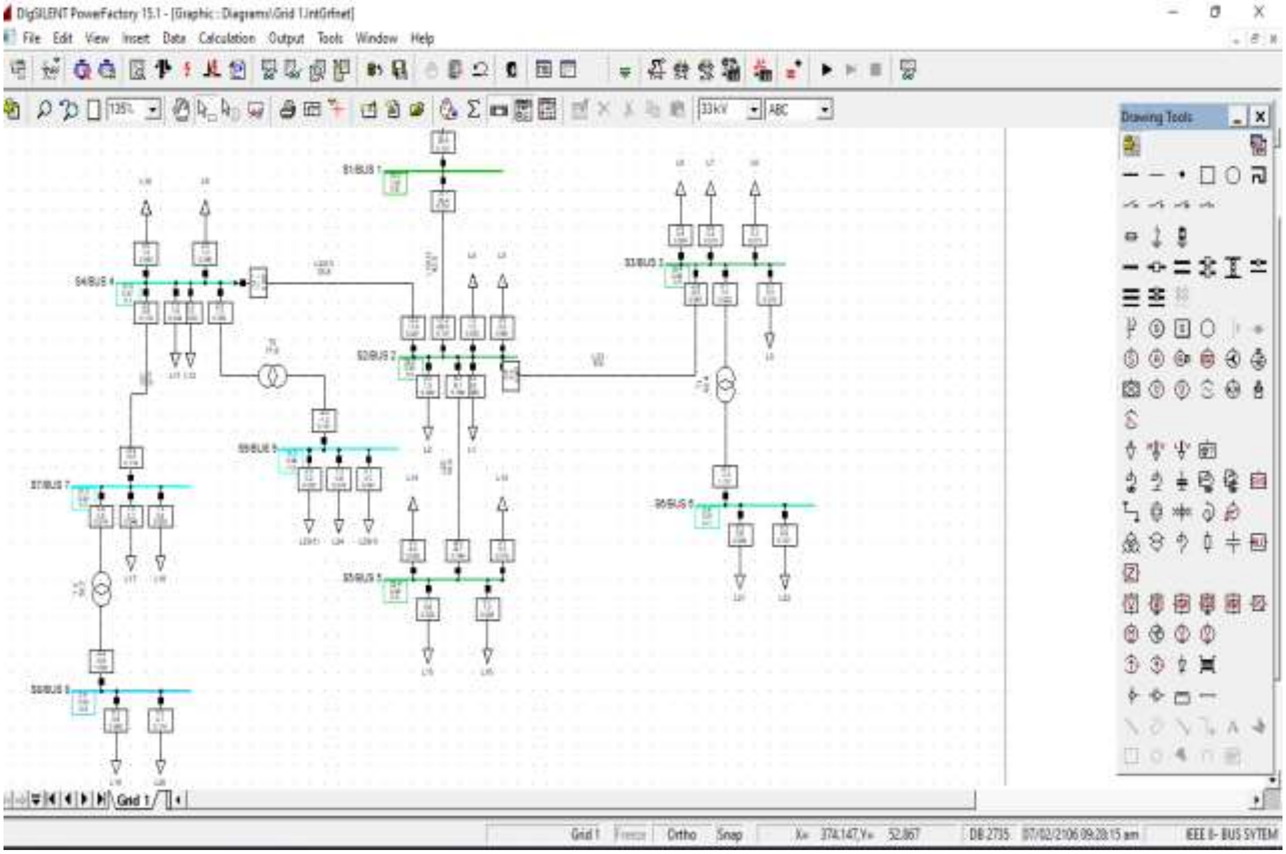


Table 9: Total power losses in the optimized system

CONNECTED BUS		SENDING END		RECEIVING END		LOSSES	
FROM	TO	P(MW)	Q(MVAR	P(MW)	Q(MVAR	P(MW)	Q(MVAR
1	2	31.7	28.5	-31.3	-28	0.4	0.5
2	3	2.8	1.9	-2.8	-1.9	0	0
2	4	12.3	11.1	-12.1	-10.8	0.2	0.3
4	7	3	5.3	-2.9	-5.2	0.1	0.1
2	5	6.3	6.7	-6.3	-6.7	0	0
4	9	2.5	1.3	-2.5	-1.2	0	0.1
7	8	0.4	0.3	-0.4	-0.3	0	0
3	6	0.7	0.5	-0.7	-0.5	0	0
TOTAL POWER LOSS						**0.7**	**1**

The bus voltages and angles data are obtained from N-R load flow solution for optimized Kapeka Network are shown in the table below.

Table 10: The bus voltages and angles data are obtained from N-R load flow solution.

BUS NO	VOLTAGE(PU)	ANGLES(DEGREE)
1	1	0.6
2	0.98	0.5
3	0.98	0.4
4	0.97	0.1
5	0.98	0.5
6	0.98	-0.1
7	0.96	0.2
8	0.95	-0.2
9	0.96	-1

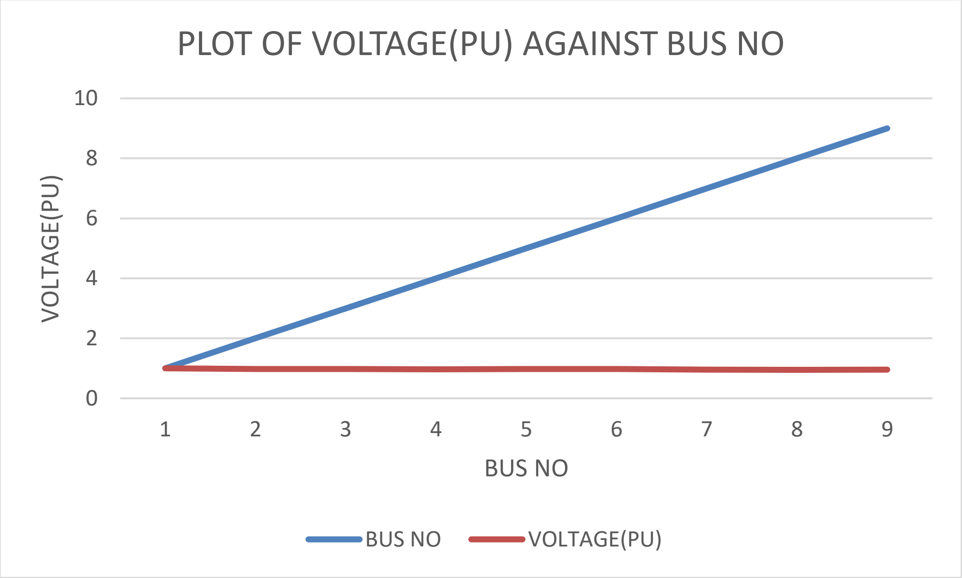


Figure 6: A graph of voltage against buses at different contingencies

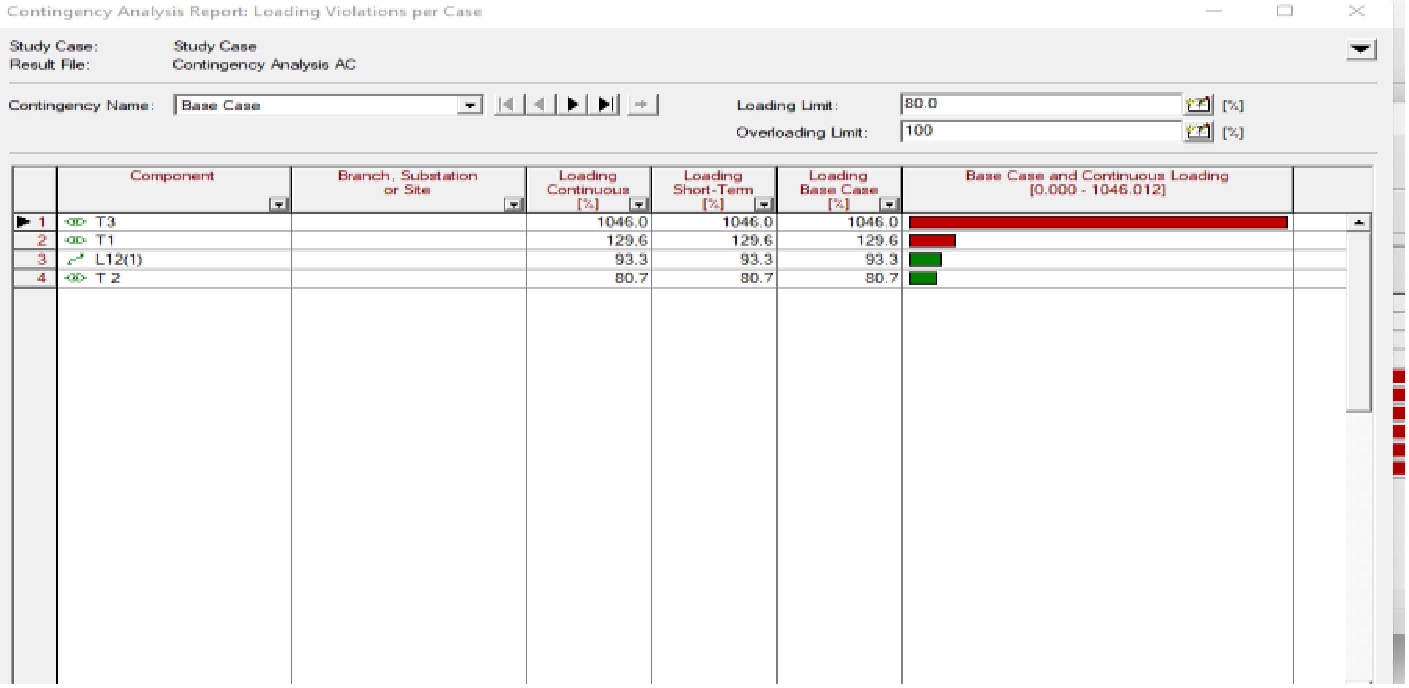
Contingency Analysis Results

During emergency situations such as an outage of the line, the thermal rating of other equipment should not be exceeded, and the voltage should not exceed the statutory limits. In this study, green indicates that the voltage and loading on a given system asset do not exceed 80% of the normal value. The color red is an indicator that the voltage and the loading of a system asset have exceeded 80%, which was the selected maximum standard after the contingencies occurred.

The Results from Contingency Analysis Are Obtained as Follow

The contingency report shows the following: maximum loadings, loading violations, voltage steps, maximum voltages, minimum voltages, maximum voltage violations, minimum voltage violations, loading violations per case, and voltage violations per case.

The following are different contingency cases.



Contingency Analysis Report: Loading Violations per Case

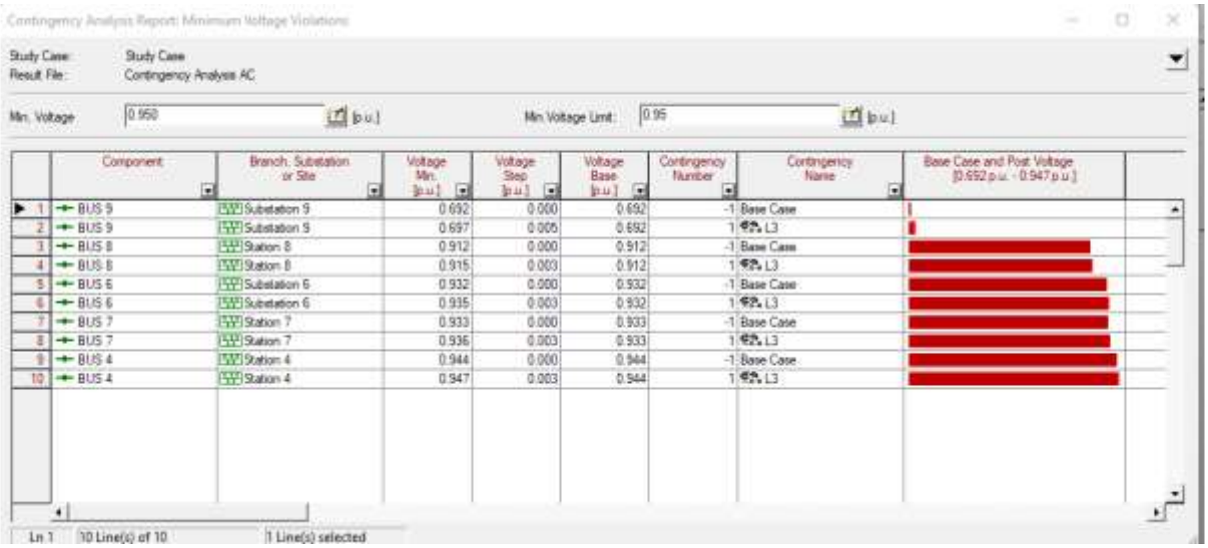
Study Case: Study Case
Result File: Contingency Analysis AC

Contingency Name: Base Case

Loading Limit: 80.0 [%]
Overloading Limit: 100 [%]

	Component	Branch, Substation or Site	Loading Continuous [%]	Loading Short-Term [%]	Loading Base Case [%]	Base Case and Continuous Loading [0.000 - 1046.012]
1	T3		1046.0	1046.0	1046.0	🟥
2	T1		129.6	129.6	129.6	🟥
3	L12(1)		93.3	93.3	93.3	🟩
4	T 2		80.7	80.7	80.7	🟩

Figure 7: Contingency Analysis Report: Loading Violations per case



Contingency Analysis Report: Minimum Voltage Violations

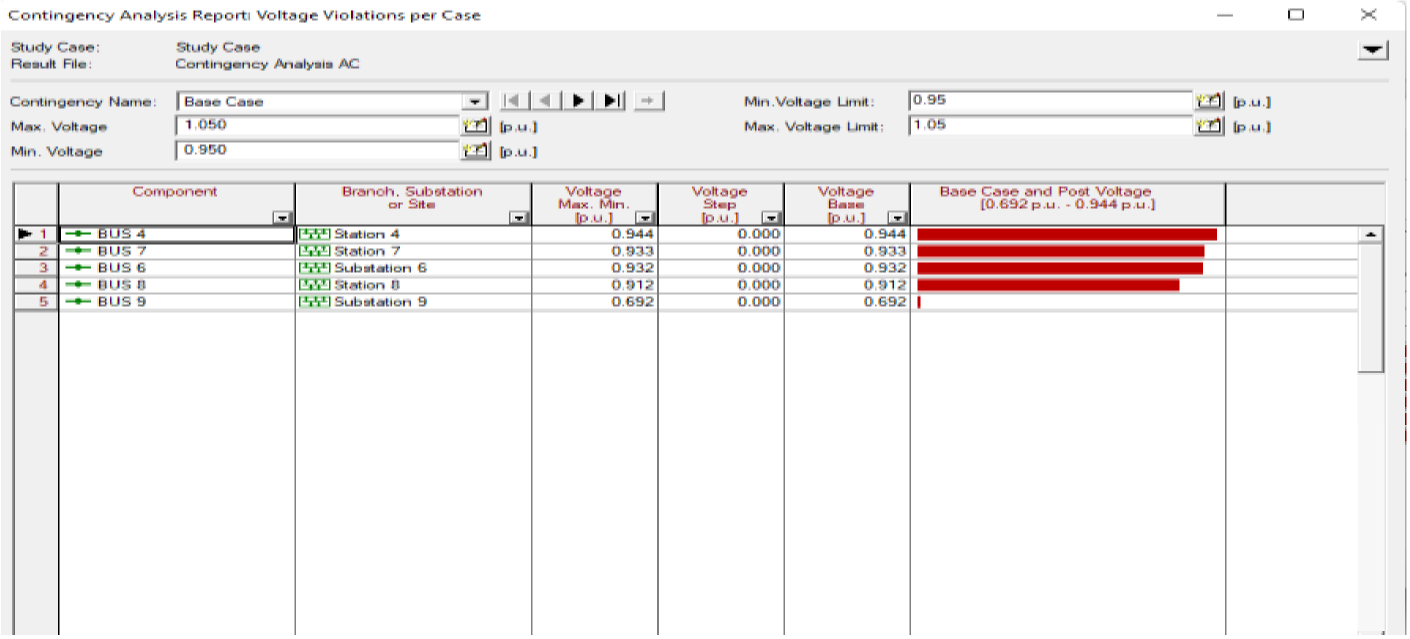
Study Case: Study Case
Result File: Contingency Analysis AC

Min. Voltage 0.950 [p.u.]
Min. Voltage Limit: 0.95 [p.u.]

	Component	Branch, Substation or Site	Voltage Min. [p.u.]	Voltage Step [p.u.]	Voltage Base [p.u.]	Contingency Number	Contingency Name	Base Case and Post Voltage [0.692 p.u. - 0.947 p.u.]
1	BUS 9	Substation 9	0.692	0.000	0.692	-1	Base Case	🟥
2	BUS 9	Substation 9	0.697	0.005	0.692	1	L3	🟥
3	BUS 8	Station 8	0.912	0.000	0.912	-1	Base Case	🟥
4	BUS 8	Station 8	0.915	0.003	0.912	1	L3	🟥
5	BUS 6	Substation 6	0.932	0.000	0.932	-1	Base Case	🟥
6	BUS 6	Substation 6	0.935	0.003	0.932	1	L3	🟥
7	BUS 7	Station 7	0.933	0.000	0.933	-1	Base Case	🟥
8	BUS 7	Station 7	0.936	0.003	0.933	1	L3	🟥
9	BUS 4	Station 4	0.944	0.000	0.944	-1	Base Case	🟥
10	BUS 4	Station 4	0.947	0.003	0.944	1	L3	🟥

Ln 1 | 10 Line(s) of 10 | 1 Line(s) selected

Figure 8: Contingency Analysis Report: Minimum Voltage Violations



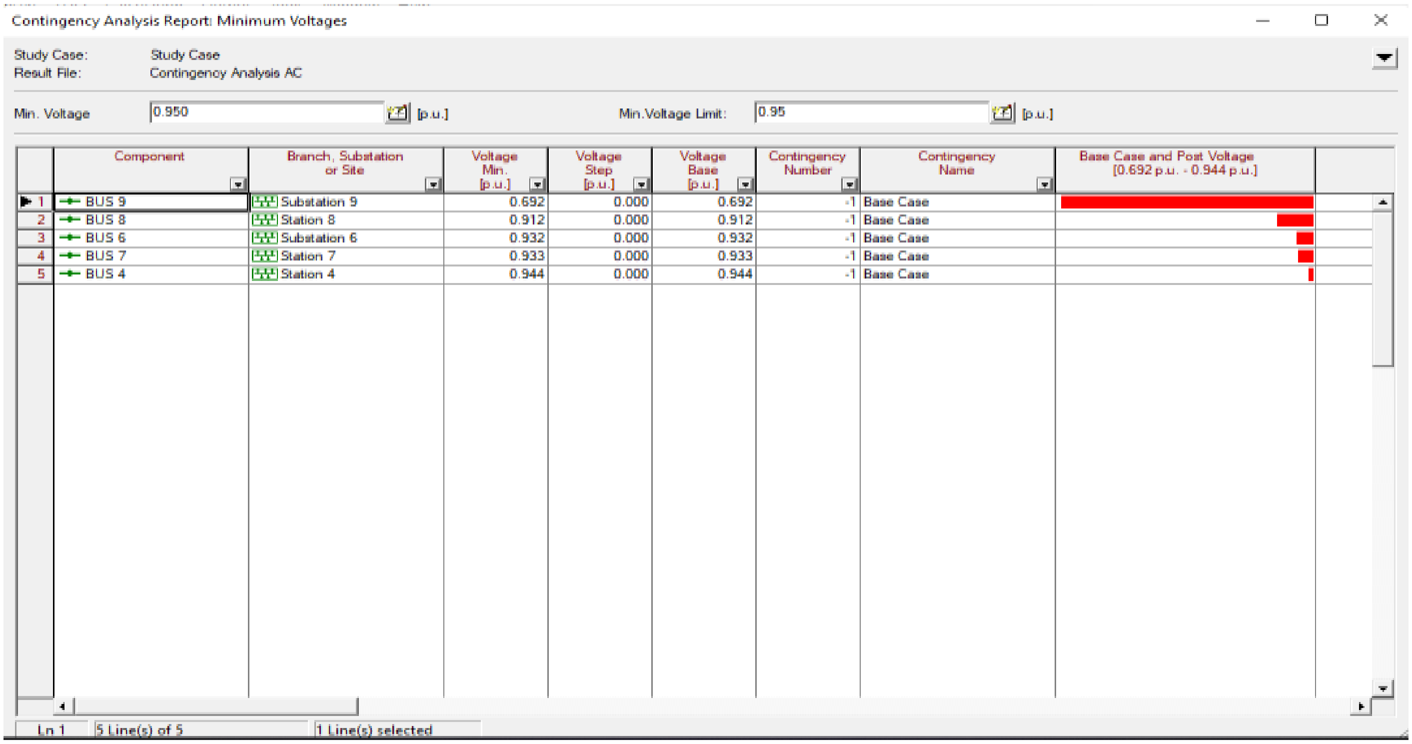
Contingency Analysis Report: Voltage Violations per Case

Study Case: Study Case
Result File: Contingency Analysis AC

Contingency Name: Base Case
Max. Voltage: 1.050 [p.u.]
Min. Voltage: 0.950 [p.u.]
Min.Voltage Limit: 0.95 [p.u.]
Max. Voltage Limit: 1.05 [p.u.]

	Component	Branch, Substation or Site	Voltage Max. Min. [p.u.]	Voltage Step [p.u.]	Voltage Base [p.u.]	Base Case and Post Voltage [0.692 p.u. - 0.944 p.u.]
1	BUS 4	Station 4	0.944	0.000	0.944	
2	BUS 7	Station 7	0.933	0.000	0.933	
3	BUS 6	Substation 6	0.932	0.000	0.932	
4	BUS 8	Station 8	0.912	0.000	0.912	
5	BUS 9	Substation 9	0.692	0.000	0.692	

Figure 9: Contingency Analysis Report: Voltage Violations per case



Contingency Analysis Report: Minimum Voltages

Study Case: Study Case
Result File: Contingency Analysis AC

Min. Voltage: 0.950 [p.u.]
Min.Voltage Limit: 0.95 [p.u.]

	Component	Branch, Substation or Site	Voltage Min. [p.u.]	Voltage Step [p.u.]	Voltage Base [p.u.]	Contingency Number	Contingency Name	Base Case and Post Voltage [0.692 p.u. - 0.944 p.u.]
1	BUS 9	Substation 9	0.692	0.000	0.692	-1	Base Case	
2	BUS 8	Station 8	0.912	0.000	0.912	-1	Base Case	
3	BUS 6	Substation 6	0.932	0.000	0.932	-1	Base Case	
4	BUS 7	Station 7	0.933	0.000	0.933	-1	Base Case	
5	BUS 4	Station 4	0.944	0.000	0.944	-1	Base Case	

Ln 1 | 5 Line(s) of 5 | 1 Line(s) selected

Figure 10: Contingency Analysis Report: Minimum Voltage

4. Conclusion

Bus 9 from substation 9 had a minimum voltage per unit as well as a voltage base per unit totaling 0.692 per unit in this study, while Bus 8 from substation 8 had a minimum voltage base of 0.192 per unit. Bus 7 on branch substation seven had 0.933 as the voltage base minimum; it's imperative to note that Bus 6 had the same values as Bus 7; this is so because of the equal numbers of industries and power consumption in those two regions. Bus 4 on substation 4 had a voltage base minimum per unit of 0.944, and it was recorded as the maximum in this study. The changes in the voltage per unit are due to voltage variations and violations arising from theft of energy, substandard equipment used in the power sector, poor repair and maintenance practices, as well as overloading the power system, which are key factors in causing faults and failures. According to the findings of this study, load flow analysis should be performed on a regular basis to keep the system's performance in check.

REFRENCE

[1] M. Ghiasi, “Detailed study for load flow analysis in distributed power system,” vol. 10.22111/E, no. October, 2018.
[2] J. Guta, “Load flow (overview of the topic),” 2011.
[3] W. . Stevenson, “Elements of power system analysis, 4th edition,” vol. MCGraw-Hil, 1982.
[4] A. Dubey, “Load Flow Analysis of Power Systems,” *Int. J. Sci. Eng. Res.*, vol. 7, no. 5, 2016.
[5] A. Elrayyah, Y. Sozer, and M. E. Elbuluk, “A novel load-flow analysis for stable and optimized microgrid operation,” *IEEE Trans. Power Deliv.*, vol. 29, no. 4, 2014, doi: 10.1109/TPWRD.2014.2307279.
[6] Umeme, “Country and Macro Economic Overview.” https://www.umeme.co.ug/stories/1386
[7] UMEME, “Report 2020,” *NCSIoman*, vol. 31, no. 1, pp. 22–24, 2020, [Online]. Available: www.NCSI.gov.om