Optimal solutions for a 33 KV loop supplied by infinite source

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ABSTRACT

This paper presents an analysis and explores the potential an infinite generation system to accommodate the domestic load growth of the 33 KV loop network from 2025 to 2040. The study involves assessing the current state of the network, focusing on voltage levels, loading lines, and transformers, to ensure they operate within the permissible loading limits of the system. It is assumed that the loop is supplied by an infinite source. A numerical model using the Gauss-Seidel method is implemented and executed on the PSS/E simulator. We will simulate the current network state and analyze the voltage profile, which should range between 0.95 and 1.05 pu. Next, we forecast the demand based on the industrial growth of the cities interconnected to this 33 kV loop. Analysis the simulation results will demonstrate the possibility of increasing the transit active power and controlling the reactive power in the system at 2040 year. Indeed, we propose solutions to address the identified critical issues to meet the projected demand. These solutions involve doubling the power capacity of the existing transformers. The proposed system will provide industrial consumers with reduced load imbalances and better control over voltage fluctuations caused by rapid variations in reactive power demand.

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1. INTRODUCTION

Effective power system management involves more than ensuring that the power transits remain below transmission capacity. Several technical parameters must also be monitored, including voltage levels. The voltage must be maintained within a permissible range at all points in the grid under all anticipated production and consumption scenarios. In this context, we also propose analyzing the feasibility of an infinite source generation system to meet the domestic demand of the 33 kV network. The goal is to achieve and maintain a voltage profile within the range of 0.95 to 1.05 per unit (pu). To achieve this, we modeled the power grid based on its transit capacities and analyzed the simulation results using PSSE and MATLAB.

This modelling is also conducted to ensure the voltage profile remains within the limits established by the grid operator. Another objective is to propose a methodology for managing and controlling transit power and voltage to optimize system efficiency under varying conditions. In this context, a reactive energy compensation system is proposed [1]-[11]. To achieve the predetermined objectives, we undertake the following steps:

First, we provide a schematic diagram of the 33 kV loop network, including its various parameters for the year 2022 [12]-[16]. This is followed by calculating the power system admittance matrix and analyzing the load flow results. In the second step, we provide the forecasted demand for the years 2025 to 2040 [17], [18]. In the third step, a numerical model using the gauss-seidel (GS) method is implemented and run in the MATLAB environment and PSS/E simulator. The simulation results will be analyzed and discussed to address any identified issues. In the fourth step, we implement the proposed solutions to optimize the power flow and voltage profiles of the studied network. A conclusion is then drawn based on the proposed work. It is important to note at the end of this introduction that increasing transformer capacity aims to establish a stable electrical energy network capable of delivering the required power to consumers, even during disturbances [19]-[23].

2. METHOD

Figure 1 illustrates the single-line diagram of the 33 kV loop network. The line data, injected powers at the buses, and load information are provided in Tables 1 and 2, respectively. The electrical network comprises four transmission lines, four transformer substations fed by an infinite source, and four loads connected to buses 1, 2, 3, and 4 as shown in Figure 1. The active and reactive powers generated are expressed in MW and MVAR. The voltage at each bus (i) is given in per unit. Each load bus is characterized by its active power P and reactive power Q, with (P, Q) specified and(V) to be calculated. In this context, bus 3 is proposed to be the slack bus. Additionally, it should be noted that a bus numbered (i) is connected to (k) other buses, as depicted in Figure 1.

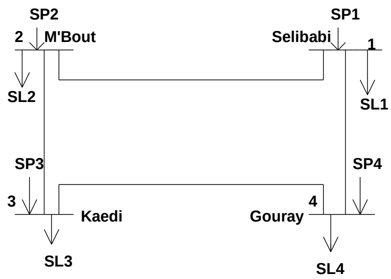

Figure 1. Line diagram of the 33 KV loop system

2.1. Lines parameters

Table 1 illustrates the given data, including the active resistances and reactances of the lines in per unit, the node voltages, and the corresponding lengths of each line. This dataset is essential for evaluating the electrical characteristics and performance of the network. Analyzing these parameters allows for a thorough assessment of the system's efficiency and stability.

Table 1. Line parameters

Bus (i – k)	Resistance (Ω)	Rpu=R/Z_B	Reactance (Ω)	Xpu=X/Z_B	Voltage (kV)	Length (km)
1-2	2.147	0.0015	2.9380	0.00215	33	113
2-3	2.0805	0.00152	2.847	0.00207	33	109.5
3-4	3.8247	0.00281	5.2338	0.00384	33	201.3
4-1	0.84816	0.00061	1.16064	0.000852	33	44.64

2.2. Calculation of bases values

Table 2 provides data for 2022, including initial voltages, their angles, injected powers, and power demands. This information is vital for assessing the performance and efficiency of the power distribution system. Analyzing these metrics helps ensure the reliability of the network.

$$Z_B = \frac{U_B^2}{S_B} = \frac{33^2}{800} = 1361\ \Omega\ with\ U_B = 33\ KV\ and\ S_B = 800\ KVA$$

Table 3 shows the projected system demand from 2025 to 2040 using extrapolation. This forecast is crucial for strategic planning and resource allocation. It helps anticipate future needs and prepare accordingly. Table 4 presents the simulation results for the admittance matrix involving buses 1, 2, 3, and 4. This data highlights the interactions and performance of these buses within the system. Analyzing these results is crucial for understanding system dynamics.

Table 2. Initial given data of the network

Bus no.	Bus voltage		Injected power		Load	
	Voltage magnitude (pu)	Angle (deg)	P (kW)	Q (kVAr)	P (kW)	Q (kVAr)
1	1.05	0	634.5	310.2	564	423
2	1	0	333	162.8	296	222
3	1	0	720	352	640	480
4	1	0	288	140.8	256	192

Table 3. Projected demand of the system between 2022 and 2040 years

Country	2025 - 2030		2030- 2035		2035-2040	
	P_D (Mw)	Q_D (Mvar)	P_D (Mw)	Q_D (Mvar)	P_D (Mw)	Q_D (Mvar)
Sélibabi	10.33	7.524	11.537	8.653	13.268	9.951
M'Bout	4.751	4.345	5.464	4.997	6.284	5.746
Kaédi	11.385	8.538	13.09	9.819	15.056	11.292
Gouray	4.109	3.42	4.726	3.93	5.435	4.523

Table 4. Admittance matrix of system

	1	2	3	4
1	0.7807 - j1.0695	-0.2206 + j0.3016	0	-0.5601 + j0.7679
2	-0.2206+ j0.3016	0.4472 - j0.6127	-0.2206+ j0.3016	0
3	0	-0.2267 +j 0.3111	0.3507 - j0.4807	-0.1241+ j0.1696
4	-0.5601 + j0.7679	0	-0.1241+ j0.1696	0.6842 - j09375

2.3. Numerical model of resolution

Load flow studies are crucial for power system planning and operation. The primary objective of a load flow study is to determine the voltage magnitude and angle at each bus given specified generation and load conditions. To address the load flow problem, we employ the iterative Gauss-Seidel method due to the system's size. The simulation was conducted using MATLAB and PSSE.

2.3.1. Gauss Seidel resolution

Using Kirchhoff's Current Law (KCL) from Figure 1, we obtain the (1).

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{ii}V_i + \cdots + Y_{in}V_n = \sum_{k=1}^{n} Y_{ik}V_k \quad (1)$$

The conjugate complex power at bus (i) is given by (2).

$$P_i - jQ_i = V_i^* I_i \quad (2)$$

Substituting in (1) into (3), we obtain:

$$P_{i,inj} - jQ_{i,inj} = V_i^* \sum_{k=1}^{n} V_{ik}V_k = V_i^*[Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{ii}V_i + \cdots + Y_{in}V_n] \quad (3)$$

Then, the voltage at bus(i) is defined by (4).

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_{i,inj} - jQ_{i,inj}}{V_i^*} - Y_{i1}V_1 - Y_{i2}V_2 - \cdots - Y_{in}V_n\right] \quad (4)$$

Calculation of current flowing between bus(i) and bus (k) is defined by (5).

$$I_{ik} = -Y_{ik}(V_i - V_k),\ i \neq k \quad (5)$$

Hence, the voltage and the conjugate complex power at bus(i) is calculated by (6) and (7) respectively.

$$V_i = |V_i|\angle\delta_i,\ V_k = |V_k|\angle\delta_k,\ Y_{ii} = |Y_{ii}|\angle\theta_{ii},\ Y_{ik} = |Y_{ik}|\angle\theta_{ik} \quad (6)$$

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k = \sum_{k=1}^{n} |Y_{ik}V_iV_k| \left(\cos(\theta_{ik} + \delta_k - \delta_i) - j\sin(\theta_{ik} + \delta_k - \delta_i)\right) \quad (7)$$

The injected powers at bus (i) are defined by (8) and (9).

$$P_i = \sum_{k=1}^{n} |Y_{ik}V_iV_k| \cos(\theta_{ik} + \delta_k - \delta_i) \quad (8)$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}V_iV_k| \sin(\theta_{ik} + \delta_k - \delta_i) \quad (9)$$

Since the voltage at the buses must be maintained within certain specified statutory limits, the voltage bound constraint limit at bus (i) is defined by (10).

$$V_{i(\min)} \leq V_i \leq V_{i(\max)} \quad (10)$$

Where Vi (min) and Vi (max) are minimum and maximum voltage values at bus i. The reactive power supply constraint at bus (i) is specified by (11).

$$Q_{gi(\min)} \leq Q_{gi} \leq Q_{gi(\max)} \quad (11)$$

With Qgi(min) et Qgi(max) are minimum and maximum reactive power values generated at bus(i).

3. RESULTS AND DISCUSSION

3.1. Numerical model of resolution

Table 5 presents the simulation results obtained from the PSS/E simulator at the 2040 year, for the case before the insertion of the reactive power compensator into the system. We can observe the voltage magnitude profile and the voltage angles. The results indicate that the voltage magnitude values are below the stability range (0.95 to 1.05 pu) for the entire system, except at the slack bus.

3.2. Model of reactive power compensation

Table 5 shows the simulation results from the PSS/E simulator without reactive power compensation. We can observe that the voltage magnitude profile and the voltage angle are outside the stability margin. To address this issue, we have proposed the following mathematical model for reactive power compensation as in (12).

$$Q_C = 3 * \omega * U^2 * C \; Avec \; \omega = 2\pi f \quad (12)$$

Where, Qc- is a reactive power in MVAr, U - is a bus bar voltage, C - is a capacitance in µF, ω - is a pulse, F is a network frequency. Given that C= 20 µF, U=33 KV, F=50 Hz, we calculate the reactive power required to maintain the system within voltage constraints (0.95 and 1.05pu) substituting these values into (10) then applying in (13).

$$Q_C = 3 * 314 * 33^2 \, 10^6 * 20 * 10^{-6} = 20.51 \; MVAR \; with \; \omega = 314 \; rad/s \quad (13)$$

The injected reactive power at Selibabi bus bar (1) is Qc=20.51 MVAR. This represents a bank of capacitors shunt connected at bus (1).

3.3. Resolution of the problematic

Table 6 presents the simulation results for the voltage profile and angles after the insertion of the reactive power compensation system. The results indicate that the voltage values are within the stability constraints (0.95 and 1.05 pu). Figure 2 illustrates the voltage profile before and after reactive power compensation. It shows an increase in voltage magnitude at bus 1 from 0.90 (a value outside the limit of [0.95, 1.05 pu]) to 1 pu, at bus 2 from 0.93 to 0.98 pu, and at bus 4 from 0.93 to 0.99 pu. Note that the slack bus 3 maintained its voltage and angle values at 1 pu and 0°, respectively. Figure 3 shows the voltage angles before and after reactive power compensation. The results demonstrate an improvement in the voltage angle for bus 1 from -1.55° to -5.15°, for bus 2 from -0.89° to -2.69°, and for bus 4 from -1.37° to -4.33°.

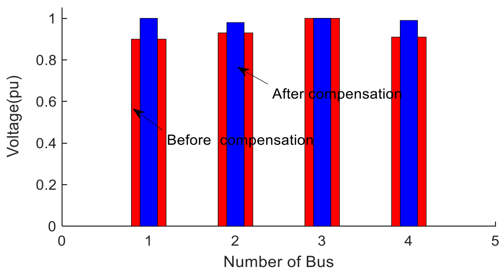

Figure 2. Curve of voltage magnitude in pu

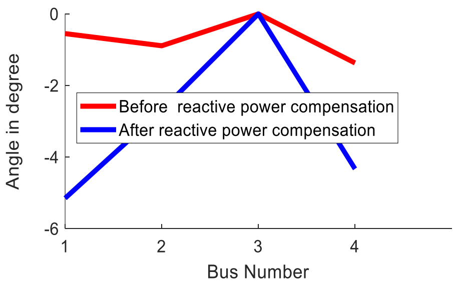

Figure 3. Curve of voltage angle in degrees

Table 5. Simulation results at 2040 year with using PSS/E

Name of bus	N°	Type	Vpu	ϕ °
Selibabi	1	PQ	0.9	-1.55
M'Bout	2	PQ	0.93	-0.89
Kaedi	3	Slack	1	0
Gouray	4	PQ	0.91	-1.37

Table 6. Simulation results after injected reactive power at bus 1

Bus N°	Type	Vpu	ϕ °
Selibabi 1	PQ	1	-5.15
M'Bout 2	PQ	0.985	-2.69
Kaedi 3	Slack	1	0
Gouray 4	PQ	0.99	-4.33

Table 7 presents the simulation results for total active and reactive power before and after the insertion of the reactive power compensation system at Selibabi bus (1). A reduction in total power losses is observed. This improvement highlights the effectiveness of the compensation system. Figure 4 shows a reduction in total active power loss from 1.8 MW to 1.5 MW. This indicates an improvement in active power transmission through the lines. The results highlight the effectiveness of the reactive power compensation system in enhancing voltage levels at buses and reducing active power losses.

Figure 5 shows a reduction in total reactive power loss from 2.5 MVAR to 2 MVAR. That indicates a decrease in reactive power loss through the transmission lines. These results demonstrate the effectiveness of the reactive power compensation system in enhancing voltage levels at buses and reducing reactive power losses in the power system.

Table 7. The total active and reactive power losses

Method	Active power losses (MW)	Reactive power losses (MVAR)
Before compensation	1.8	2.5
After compensation	1.5	2

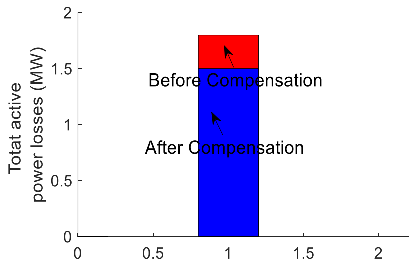

Figure 4. Total active power losses

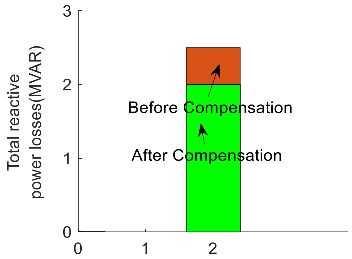

Figure 5. Total reactive power losses

3.4. Transformer model

To address the projected load growth of the 33 KV loop at the 2040 year, we propose enhancing the capacity of the transformers connected to various system buses. This can be achieved by connecting one or more additional transformers in parallel with the existing ones. Transformers are connected in parallel when the load on one transformer exceeds its capacity. Connecting transformers in parallel allows us to increase the available power without modifying the voltage, while sharing the demand power between the two transformers. This parallel operation enhances reliability compared to using a single larger unit [23]-[26]. The cost associated with maintaining spare parts is reduced when two transformers are connected in parallel. This setup ensures that at least half of the load can be supplied even if one transformer is out of service. The advantages of parallel transformer operation include meeting load demand, improved reliability, more efficient switching operations, and an uninterrupted power supply during the outage of one unit. The conditions for the parallel operation of transformers are as follows [27]-[31].

For transformers to be connected in parallel, their primary windings must be connected to the source bus-bars, and their secondary windings must be connected to the load bus-bars. Several conditions must be met for the successful parallel operation of transformers. They are: i) Both the primary and secondary voltage ratings must be the same (same voltage ratio and turns ratio); ii) The same transformation ratio (k) must be maintained; iii) The short circuit voltage should be equal to or less than 10%; and iv) The phase angle shift should be the same (vector groups must be the same or compatible).

3.4.1. Model parallel operation of transformers

To share the total load between two transformers connected in parallel, the following information is required: i) The power rating of transformer T1 (MVA1) and its percentage impedance (%Z1); ii) The power

rating of transformer T2 (MVA2) and its percentage impedance (%Z2); iii) The total demand power (MVA); and iv) With these parameters, the load can be appropriately distributed between the two transformers.
Load sharing by T1 as in (14).

$$T1 = \frac{\frac{MVA1}{Z1}}{\frac{MVA1}{Z1}+\frac{MVA2}{Z2}} * MVA \tag{14}$$

Load sharing by T2 as in (15).

$$T2 = \frac{\frac{MVA2}{Z2}}{\frac{MVA1}{Z1}+\frac{MVA2}{Z2}} * MVA \tag{15}$$

To determine the power values shared between connected transformers in parallel at bus 3 (Kaedi) in the year 2040, you can use (14) and (15). These equations will allow you to calculate the distribution of power between the transformers based on their ratings and impedances. Noting that one of the transformers is already existing in the system with a rating of T1=10 MVA, the load shared by the second transformer (T2) can be determined as the following:

- The total load demand (MVA) minus the power rating of the existing transformer (MVA1) gives the load that needs to be handled by the second transformer (MVA2).
- Mathematically: MVA2 = total load demand (MVA) − MVA1
- Where: MVA1 is the power rating of the existing transformer (10 MVA). MVA2 is the power rating required for the second transformer. To carry out this analysis, we will examine two cases:
- Simulation Case: Use PSSE software to determine the total load demand of the system.
- Analytical Case: Calculate the shared load between transformers T1 and T2 using (14) and (15), as detailed in Table 8.
- This approach allows for a comparison between the simulated load demand and the theoretical calculations for load distribution.
- Based on Table 8, we can determine and fix the shared load between the two transformers, with T1=10 MVA and T2 = 31 MVA. Operating the transformers in parallel is more economical compared to replacing them, as this approach allows for scaling with load increases.

Table 8. Simulations and calculation results of load shared at Kaedi bus (3)

Bus	Total load (T) (MVA)	Load of existing (T1) (MVA1)	Load shared by (T2) (MVA2)	Impedances of T1 and T2		Calculation results in MVA		Simulations results in MVA	
				%Z1	%Z2	T1	T2	T1	T2
Kaedi	41	10	31	8	10	15.25	25.62	20.5	20.5
Year	2040	< 2030	> 2030	-	-	-	-	-	-

4. CONCLUSION

In this paper, we examined the state of a 33 KV loop for two distinct periods: First Period: The state of the network parameters (voltages, powers) for the year 2022. During this period, the system is stable, and all parameters are within the required standards. In the second period, we projected the demand forecast from 2025 to 2040. The results indicated that the system would exceed stability constraints. To address the increasing demand, we proposed injecting reactive power using a capacitor bank at the Selibabi bus (1). This intervention allows the system to remain within the voltage stability margin (0.95 to 1.05 per unit) and reduces power mismatches. As a result, the system achieves stability in both voltage and power at each busbar.

In the second case, where the existing transformers become overloaded, it is more economical to operate the transformers in parallel. This approach allows for accommodating load increases by adding transformers in parallel rather than replacing them. As a result, the system becomes stable in both voltage and power. Furthermore, when the load decreases, one of the two transformers can be deactivated to prevent low-efficiency operation at reduced loads.

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