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Minimizing Transmission Line Power Losses in Port Harcourt, Southern Nigeria: An Optimization-Based Approach

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Abstract

In Nigeria, frequent power outages can be attributed to under frequency, low power factor, overcurrent, overvoltage, and under voltage causes. Improving the quality of electric power supply means improving voltage transients and frequency instability. This epileptic power source could be improved estimating the following parameters: Line losses, the phase values of the voltages at load buses, the real and reactive power of slack buses; optimizing these values to determine active power loss reduction in the buses, and designing the model using a workable optimization technique. When compared to proportional integral, proportional integral, proportional integral derivative (PID), and other traditional techniques, the result of the optimization technique is approximately 67% better.

Subject Areas

Electrical and Electronic Engineering

Keywords

Power Losses, Transmission Network, Optimization

1. Introduction

Optimization technique is one of the better alternatives to meet the ever-increasing energy demand, which is growing faster than the growth of the electricity demand. Additionally, it lessens system energy loss, eases transmission congestion, enhances reliability, improves voltage profile, and offers lower operating costs. When compared to conventional generation units, optimization is smaller, making installation more cost and time-efficient. As a result, the integration of Transmitted Energy Resources (TER) with the transmission network presents a promising solution. To fully comprehend how transmitted resources affect the transmission system, extensive research is therefore required. It is important to properly analyze various technical, environmental, commercial, and regulatory issues before operating transmitted and dispersed generation in a power system. Protection, power quality, stability, and outstanding operation are the biggest technical obstacles. To maximize these technical advantages, however, there are a few other issues that need to be examined first. Previous research has shown that different Distributed Energy Resources (DER) placements and penetration levels will have different effects on the transmission system [1]. Additionally, improper DER allocation and fuzzy size optimization may result in higher power loss than if there is no distributed generation at all in the system [2]. To accurately determine the proper location and size of optimization, a detailed and exact analysis method is needed. It is important to allocate optimization in transmission systems in a way that minimizes system losses and, as a result, improves voltage profile [3]. In our study, we concentrated on the best spot and amount of optimization to reduce overall system power loss. The majority of earlier studies on optimization have a direct connection between the grid and the optimization's size and location. Directly connecting such equipment to a utility transmission system carries significant risks. The machines' insulation levels might not match the insulation level of the system. As a result, direct fuzzy optimization connections are frequently discouraged [4]. In Nigeria, the issue of intermittent power supply has taken on a life of its own. Power losses in the transmission network, distortion, harmonics, short circuits, and the burning of feeder pillars are a few of the causes of this. This paper focuses on the power losses caused by distortion and harmonics in the transmission network. The unfortunate situation of our nation's inconsistent power supply has discouraged investors from investing, which has increased the rate of unemployment in Nigeria. Applying proper techniques of optimization, the endemic problem could be minimized as proposed in this work. In the real world, the distribution system's Distributed Generation (DG) needs to be provided in the best possible way to reduce system losses and enhance the voltage profile [5].

The goal of the study is to have a reliable supply of electricity through the measurement of line losses in transmission networks using the Newton-Raphson method, the phase values of the voltage at load buses, the real and reactive powers of slack buses, the optimization of power losses in transmission networks, active power loss reduction in the buses, and the design of a model that reduces power losses in transmission networks using these methods.

Last but not least, it was discovered that a gap needed to be filled during Loss reduction in transmission network using Newton Raphson method after following the aforementioned steps. Diverse technologies and sources are available for distributed generation. Different kinds of "generator groups" can be taken into consideration when analyzing the effects of DER [5] [6]. Because proportional integral controllers (PI) controllers and regular Transmission statcom (TSTATCOM) cannot reduce transmission network loss quickly, optimization was used instead. The transmission system that uses the optimization described in this work performs better than the PI controller in terms of adaptability, speed, and dependability for lowering harmonic distortions, low power factor, and voltage fluctuations to their lowest possible levels. Analysis techniques for radial and network distribution systems with various systems having different load configurations are given in [6] [7].

2. Extent of Past Related Work on the Subject

This work described the analysis of an electrical distribution network's radial distribution system to determine the voltage status at the buses and to choose the size and type of reactive power control distributed generation that would be able to maintain power on the network. In the era of computer simulations, the power system can be controlled using programmable controllers (PLC); the significance of energy systems cannot be overstated [8]. The network power fluctuations brought on by the increase in electricity demand are stabilized to some extent by distributed generation and reactive power compensation devices. Components of modern power systems have been used and subjected beyond their design limits and installed capacity [9]. To be sure that the transmission system can withstand sudden disturbances under load conditions, power system stability is a crucial component of the transmission system security assessment [9]. The integration of microgrid energy sources into the national grid could make up for the unstable power supply brought on by the slowly rotating hydro-turbine generators in the Kainji dam Hydropower station [10]. A hybrid configuration, which is used to feed microgrid sources into the grid, can provide improved performance and better financial values for the benefit of the customers and stakeholders [11]. A consistent power supply is a problem in Nigeria due to harmonics, short circuits, and power losses in the transmission network; the introduction of renewable energy sources may help solve this issue [12]. The optimization technique is desirable due to the accurate values obtained as compared to the Gaussian elimination approach which has drawbacks when the values are large.

3. Materials and Methods

3.1. Method

Newton Raphson method was applied in estimating the values of the required parameters. The National Control Center (NCC) in Osogbo, Osun State, Nigeria provided the data used in this analysis. The following base values were used to calculate the line impedances' per-unit values: The 330 KV network in northern Nigeria was created and the load flow was run using the Matlab programme. It shows a Newton-Raphson Power flow algorithm solution. **Figure 1** and **Figure 2** display, respectively, generator records and bus records after load flow. **Figure**

2's findings demonstrate voltage violation in the p.u. values of buses 1, 7, 8, 9, 10, and 13. The normal range of bus voltages is assumed to be 0.951.05 p.u. [7].

```
basemva = 330;  accuracy = 0.0001;  maxiter = 10;
% The impedances are expressed on a 100 MVA base.
%  the base is mistakenly stated as 100 MVA.
%         Bus  Bus   |V|  Ang   ---Load---       ---Gen---   Gen Mvar Injected
%         No.  code p.u.  Deg   MW       Mvar    MW   Mvar   Min   Max    Mvar
busdata=[1      1    1.04   0    00.0     0.0     0.0   0.0    0     0     0
         2      0    1.0    0    00.0     0.0     0.0   0.0    0     0     0
         3      0    1.0    0   150.0   120.0     0.0   0.0    0     0     0
         4      0    1.0    0     0.0     0.0     0.0   0.0    0     0     0
         5      0    1.0    0   120.0    60.0     0.0   0.0    0     0     0
         6      0    1.0    0   140.0    90.0     0.0   0.0    0     0     0
         7      0    1.0    0     0.0     0.0     0.0   0.0    0     0     0
         8      0    1.0    0   110.0    90.0     0.0   0.0    0     0     0
         9      0    1.0    0    80.0    50.0     0.0   0.0    0     0     0
        10      2    1.035  0     0.0     0.0   200.0   0.0    0   180     0
        11      2    1.03   0     0.0     0.0   160.0   0.0    0   120     0];

%          Bus   Bus      R        X        1/2B
%          No.   No.     p.u.     p.u.      p.u.
linedata=[1      2      0.00     0.06     0.0000     1
          2      3      0.08     0.30     0.0004     1
          2      6      0.12     0.45     0.0005     1
          3      4      0.10     0.40     0.0005     1
          3      6      0.04     0.40     0.0005     1
          4      6      0.15     0.60     0.0008     1
          4      9      0.18     0.70     0.0009     1
          4     10      0.00     0.08     0.0000     1
          5      7      0.05     0.43     0.0003     1
          6      8      0.06     0.48     0.0000     1
          7      8      0.06     0.35     0.0004     1
          7     11      0.00     0.10     0.0000     1
          8      9      0.052    0.48     0.0000     1];
```

```
%          Bus   Bus      R        X        1/2B
%          No.   No.     p.u.     p.u.      p.u.
linedata=[1      2      0.00     0.06     0.0000     1
          2      3      0.08     0.30     0.0004     1
          2      6      0.12     0.45     0.0005     1
          3      4      0.10     0.40     0.0005     1
          3      6      0.04     0.40     0.0005     1
          4      6      0.15     0.60     0.0008     1
          4      9      0.18     0.70     0.0009     1
          4     10      0.00     0.08     0.0000     1
          5      7      0.05     0.43     0.0003     1
          6      8      0.06     0.48     0.0000     1
          7      8      0.06     0.35     0.0004     1
          7     11      0.00     0.10     0.0000     1
          8      9      0.052    0.48     0.0000     1];
%          Gen.   Ra      Xd'
gendata=[ 1      0      0.20
          10     0      0.15
          11     0      0.25];
    lfybus                            % Forms the bus admittance matrix
    lfnewton                 % Power flow solution by Newton-Raphson method
    busout                   % Prints the power flow solution on the screen
    Zbus=zbuildpi(linedata, gendata, yload)%Forms Zbus including the load
    symfault(linedata, Zbus, V)     % 3-phase fault including load current
```

Figure 1. Newton Raphson 330 kv power flow result.

```
                   Power Flow Solution by Newton-Raphson Method
                      Maximum Power Mismatch = 2.83789e-007
                             No. of Iterations = 10

 Bus  Voltage  Angle    ------Load------    ---Generation---   Injected
 No.  Mag.     Degree     MW       Mvar       MW       Mvar      Mvar

  1   1.040    0.000     0.000     0.000   280.945   234.260    0.000
  2   1.000   -2.815     0.000     0.000     0.000     0.000    0.000
  3   0.865   -9.857   150.000   120.000     0.000     0.000    0.000
  4   0.957   -7.229     0.000     0.000     0.000     0.000    0.000
  5   0.764  -32.321   120.000    60.000     0.000     0.000    0.000
  6   0.835  -12.945   140.000    90.000     0.000     0.000    0.000
  7   0.911  -20.108     0.000     0.000     0.000     0.000    0.000
  8   0.784  -21.606   110.000    90.000     0.000     0.000    0.000
  9   0.763  -20.335    80.000    50.000     0.000     0.000    0.000
 10   1.005   -4.339     0.000     0.000   200.000   204.496    0.000
 11   0.980  -16.995     0.000     0.000   160.000   227.795    0.000

 Total                 600.000   410.000   640.945   666.550    0.000
```

Figure 2. Power flow solution by Newton-Raphson method.

3.2. Evaluating the Phasor Magnitudes of the Voltage at No Loads Buses

One-line diagram of a simple three-bus power system with generation at bus 1 is shown in Figure 3; the value of voltage at bus 1 is manipulated to 1.05 per unit. The allocated loads at buses 2 and 3 are as stated on the diagram. Line impedances are shown in per unit on a 100 MVA base and initial power loss in the network before using optimization are PL_{12} = 150 mw PL_{13} = 153.94 mw and PL_{23} = 120 mw.

To convert line impedance to admittance

$$Z_{12} = 0.02 + j0.04$$

$$Z_{13} = 0.01 + j0.03$$

$$Z_{23} = 0.0125 + j0.025$$

To find Y_{12}

$$Y_{12} = \frac{1}{Z_{12}}$$

$$Y_{12} = \frac{1}{0.02 + j0.04}$$

$$Y_{12} = \frac{1}{0.02 + j0.04} \times \frac{0.02 - j0.04}{0.02 - j0.04}$$

$$Y_{12} = \frac{0.02 - j0.04}{0.004 - j0.0008 + j0.0008 - j^2 0.0016}$$

$$Y_{12} = \frac{0.02 - j0.04}{0.004 - 0.0016}$$

$$Y_{12} = \frac{0.02 - j0.04}{0.002}$$

$$Y_{12} = 10 - j20$$

Similarly $Y_{13} = 10 - j30$ and $Y_{23} = 16 - j32$.

At P-Q buses, the complex loads expressed in per units are

For bus 2

$$S_2^{ach} = \frac{P + jQ}{Sb}$$

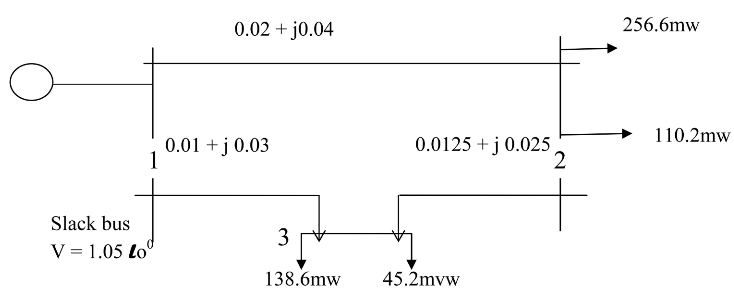

Figure 3. One-line diagram of a simple three-bus power system with generation at bus 1.

$$S_2^{ach} = \frac{256.6 + j1102}{100}$$

$$S_2^{ach} = 2.566 - j1.102\,pu$$

To convert load to per unit in bus 3

$$S_3^{ach} = \frac{p + jQ}{Sb}$$

$$S_3^{ach} = \frac{138.6 + j45.2}{100}$$

$$S_3^{ach} = 1.386 - j0.452$$

3.3. Estimating the Slack Bus Real and Reactive Powers

The slack real and reactive power powers are

$$P_1 = 5.3139\,pu = 5.3139 \times 100$$

$$P_{1\,\text{ToTAL}} = 531.39 \text{ mw}$$

$$Q_1 = 0.7652\,pu = 0.7652 \times 100$$

$$Q_1 = 76.52 \text{ Mvar}$$

Similarly P_2 when calculated gave $P_{2\,\text{total}} = 117$ mw.

The result gotten are $P_{1\,\text{total}} = 531.31$ KW and $P_{2\,\text{total}} = 117$ kW.

3.4. Maximizing Power Loss Reduction in a Transmission Network Using Optimization Approach

The utility company generates two types of power supply for transmission; lines A and B require power P_1 and P_2 respectively. One unit of type A requires 1 kW of P_1 and 2 kW of P_2. Type B requires 2 KW of P_1 and 1 KW of P_2 (Each unit). The utility company has only 531.31 KW of P_1 and 117 KW of P_2. Each unit of type A brings a profit of ₦500 Million and each unit of type B brings a profit of ₦400 Million for 330 Kva (Table 1). It is required maximize profit through optimization that would result in total power loss reduction in the transmission network.

The optimization equation becomes

$$\text{Maximize } z = 500x + 400y \tag{1}$$

Subject to

$$x + 2y \le 531.31 \tag{2}$$

$$2x + y \le 117 \tag{3}$$

Figure 4 shows the result of power loss optimization.

Table 1. Optimization data.

Power	P_1 (KW)	P_2 (KW)	Profit (#)
A	1	2	500
B	2	1	400
	531.31	117	

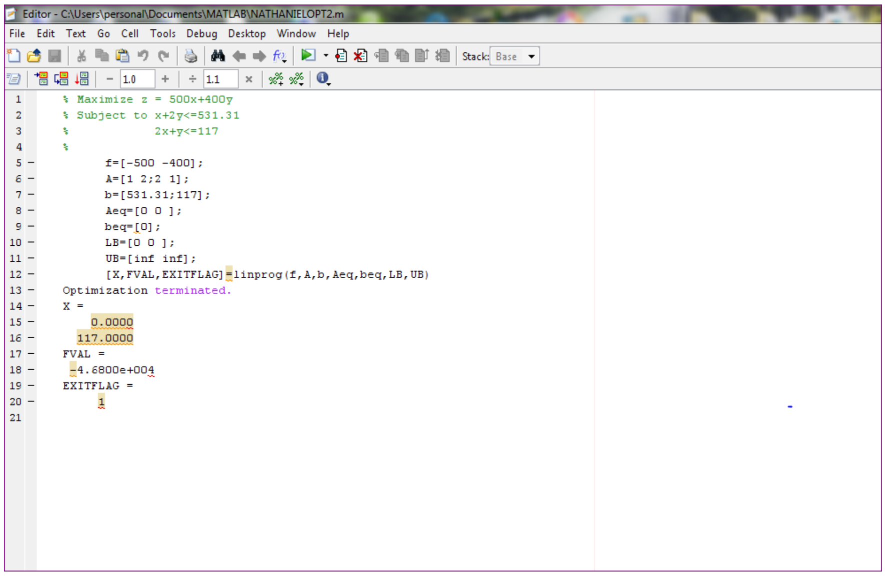

Figure 4. Result of power loss optimization.

3.5. Determination of Active Power Loss Reduction in the Buses

The optimized values were used for the power loss reduction as shown in Table 2.

3.6. Estimating the Active Power Loss Reduction by Transmitted Generator

To find active power loss reduction PLR in Bus 12.

Applying formula for active power loss reduction PLR

$$PLR_{12} = \frac{PL_{12}^{inital} - PL_{12}^{final}}{PL_{12}^{inital}} \times \frac{100}{1}$$

$$PLR_{12} = \frac{531.31 - 117}{531.31} \times \frac{100}{1}$$

$$PLR_{12} = \frac{414.31}{531.31} \times 100$$

$$PLR_{12} = 77.97\%$$

3.7. Designing a Model That Reduces Power Losses in Transmission Network Using Optimization Technique

The optimized power loss reduction Simulink model was designed as shown in Figure 5.

4. Results and Discussion

Figure 2 displays the outcome of a simulation of Newton Raphson's 330 kv transmission loss reduction. The 640 kVA is the load that was achieved in this case. The optimization method is being used to achieve a significant loss reduction in the 330 kV transmission network because this result shows that the reduction is insufficient. An easy three-bus power system with bus 1 as the power source is shown in a one-line diagram for the purpose of calculating the voltage

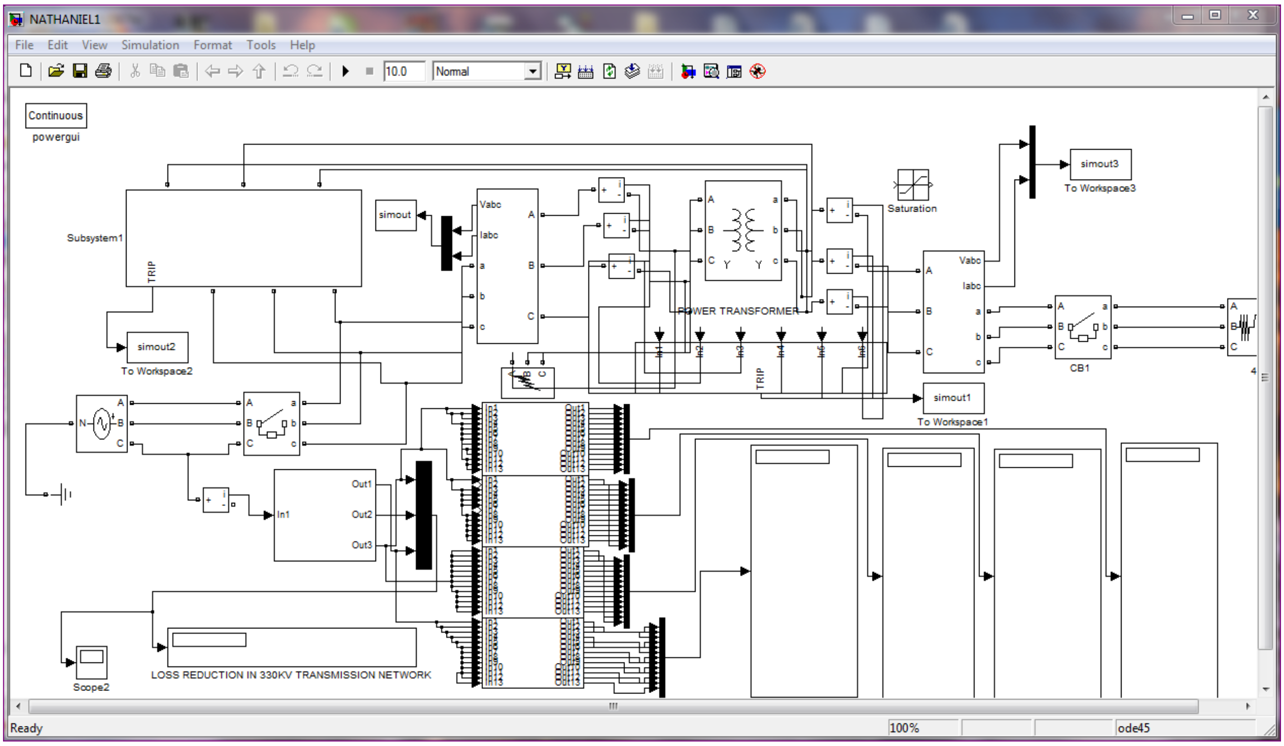

Figure 5. Designed model that reduces power losses in transmission network using optimization.

Table 2. Power losses.

Test system	Initial power losses in the Lines before using optimization (MW)	Final power losses in lines after using optimization (MW)
12 Bus	531.31	117
13 Bus	117	117

at load buses' phasor values. The voltage level on Bus 1 is changed to 1.05 per unit. The schedule loads for buses 2 and 3 are displayed in the diagram. Prior to using optimization, the system's initial power losses were PL_{12} = 150 mw, PL_{13} = 153.94 mw, and PL_{23} = 120 mw. On a base of 100 MVA, line impedances are marked in per unit.

Figure 3: One-line diagram of a straightforward three-bus power system with bus 1 serving as the generator The output of power loss optimization is shown in Figure 4, and the designed model for reducing power losses in transmission networks solely using optimization method is shown in Figure 5. Figure 5 depicts the power loss reduction after implementation. Figure 6 depicts a model that has been put into practice and uses optimization to lower power losses in the transmission network. When simulated, Figure 6 lowers the losses in the transmission network from 95.68 Kw to 91.37 Kw. Table 3 shows the final power losses in the lines after using optimization. The highest coordination percentage loss reduction in a transmission network and loss reduction transmission network (KW) occurred at (95.69%, 6.64 (KW)), and the lowest loss reduction is at (91.37%, 12.94 (KW)), according to Figure 7.

The simulated outcome for the model's designed method of using optimization to lower power losses in the transmission network is shown in Table 4 and Figure 8. When loss reduction in the transmission network and Time of (95.68, 5) are coordinated, the loss reduction in the transmission network becomes constant at P1 (95.68, 10). On the other hand, in a coordination of loss reduction in transmission network and Time of (94.21, 5) to P2, the loss reduction in transmission network becomes constant (94.21, 10).

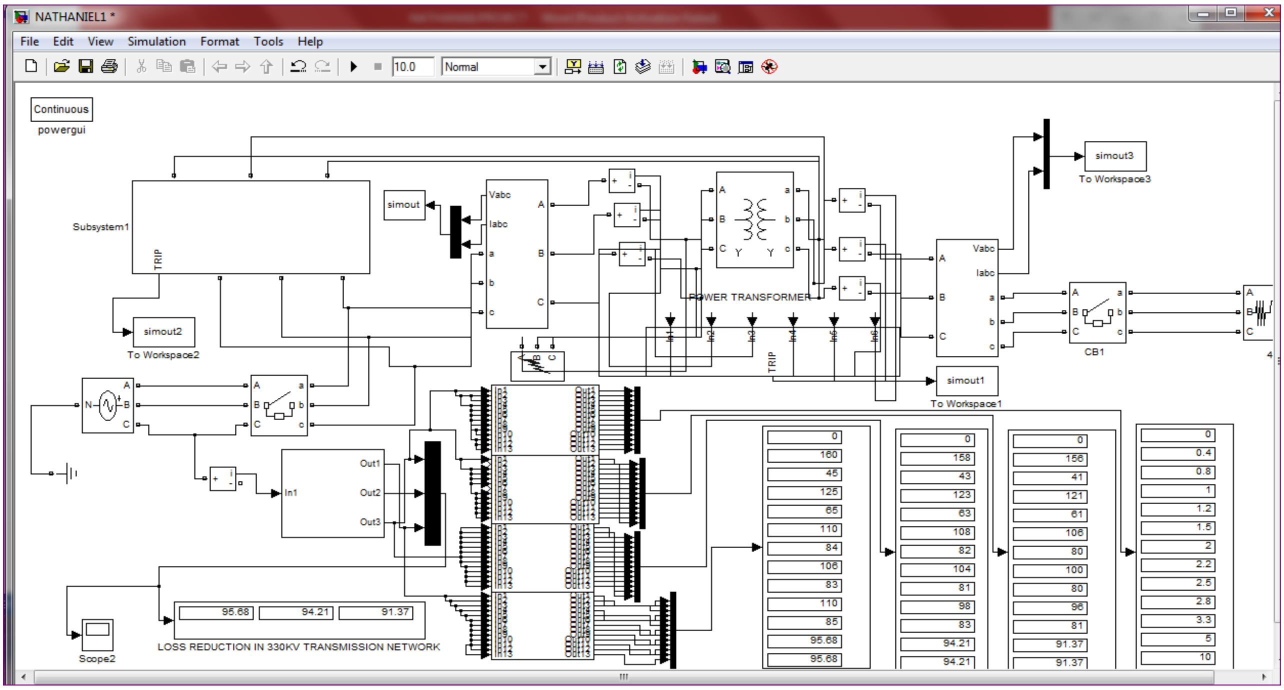

Figure 6. Implemented Designed model that reduces power losses in transmission network using optimization approach.

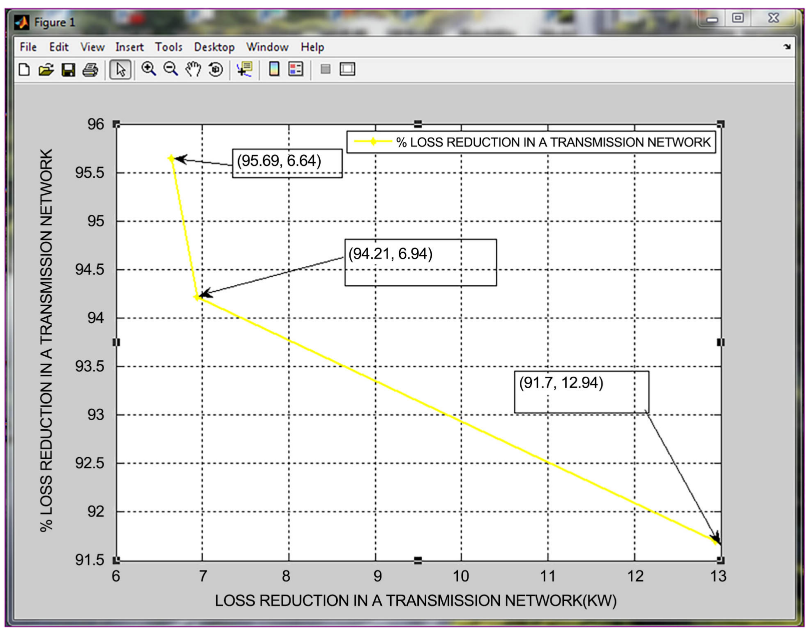

Figure 7. Power losses in transmission network using optimization.

Table 3. Illustrating loss reduction in transmission power system.

Active Power Loss Reduction	Final power loss in the lines after using optimization
$PLR_{12} = 91.37\%$	$PL_{12}^{final} = 12.94$ mw
$PLR_{23} = 94.21\%$	$PL_{23}^{final} = 6.94$ mw
$PLR_{13} = 95.69\%$	$PL_{13}^{final} = 6.64$ mw

Table 4. Simulated data for designed model that reduces power losses in transmission network using optimization.

P_1	P_2	P_3	TIME
0	0	0	0
160	158	156	0.4
45	43	41	0.8
125	123	121	1
65	63	61	1.2
110	108	106	1.5
84	82	80	2
106	104	100	2.2
83	81	80	2.5
110	98	96	2.8
85	83	81	3.3
95.68	94.21	91.37	5
95.68	94.21	91.37	10

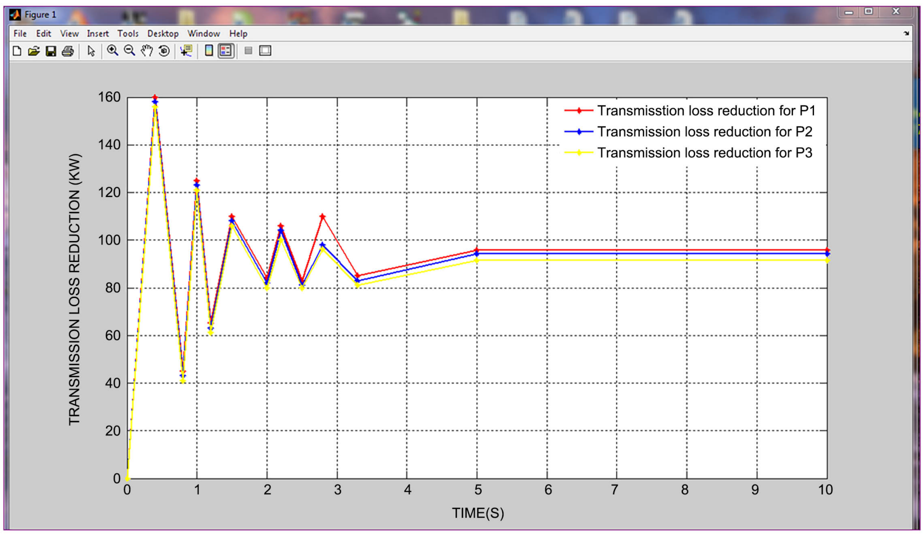

Figure 8. Simulated result for designed model that reduces power losses in transmission network using optimization.

When loss reduction in the transmission network and Time of (91.37, 5) are coordinated, the loss reduction in the transmission network becomes constant at

P3 (91.37, 10).

This demonstrates that a transmission network's loss reduction decreases from 95.68 to 91.37 Kw.

5. Conclusion

The importance of using optimization to calculate power loss properly in a transmission network cannot be overstated. Transmission system power loss drives up system costs overall and has a significant impact on power system management. Our analysis reveals that using the optimization method results in less power loss in the transmission network than using other methods of power reduction. In other words, when compared to other methods like the Gaussian method, the optimization method offers a higher reduction of losses. As a result, an efficient loss reduction in a power system's transmission network (optimization method) must be used. When different reactive power compensation devices of various capacities are installed in all the buses of the power system, there would be improvement in the quality of the Nigerian power system in general.

Conflicts of Interest

The authors declare no conflicts of interest.

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