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 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 inte-
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 static compensator (STATCOM) 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.
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 0.95-1.05 p.u. [7].

Figure 1. Newton Raphson 330 kv power flow result.

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 \( \text{PL}_{12} = 150 \text{ mw} \), \( \text{PL}_{13} = 153.94 \text{ mw} \) and \( \text{PL}_{23} = 120 \text{ mw} \).

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 \( Y_{12} \)

\[
Y_{12} = \frac{1}{Z_{12}} = \frac{1}{0.02 + j0.04}
\]

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

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

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

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

\[
Y_{12} = 10 - j20
\]

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

\[
S_{2b} = \frac{P + jQ}{S_b}
\]

![Figure 3](image-url)
To convert load to per unit in bus 3

\[ S_{bus}^{ach} = \frac{256.6 + j1102}{100} \]

\[ S_{bus}^{ach} = 2.566 - j1.102 \text{pu} \]

3.3. Estimating the Slack Bus Real and Reactive Powers

The slack real and reactive power powers are

\[ P_1 = 5.3139 \text{pu} = 5.3139 \times 100 \]

\[ P_{1, \text{total}} = 531.39 \text{ mw} \]

\[ Q_1 = 0.7652 \text{pu} = 0.7652 \times 100 \]

\[ Q_1 = 76.52 \text{ Mvar} \]

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

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

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 \( \text{₦}500 \text{ Million} \) and each unit of type B brings a profit of \( \text{₦}400 \text{ Million} \) 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

\[ \text{Maximize } z = 500x + 400y \]  \hspace{1cm} (1)

Subject to

\[ x + 2y \leq 531.31 \]  \hspace{1cm} (2)

\[ 2x + y \leq 117 \]  \hspace{1cm} (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            |           |
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

\[
PLR_{12} = \frac{PL_{\text{initial}}^{12} - PL_{\text{final}}^{12}}{PL_{\text{initial}}^{12}} \times 100
\]

\[
PLR_{12} = \frac{531.31 - 117}{531.31} \times 100
\]

\[
PLR_{12} = 414.31 \times 100
\]

\[
PLR_{12} = 531.31
\]

\[
PLR_{12} = 77.97\%
\]

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.
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_{final}^{12} = 12.94 mw                             |
| PLR_{23} = 94.21%           | PL_{final}^{23} = 6.94 mw                              |
| PLR_{13} = 95.69%           | PL_{final}^{13} = 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 | 91.37 | 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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