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Loss Minimization in Nigerian Power System Network

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Original Research Article

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Abstract: Proper reactive power management for improving the a.c power system performance always result in loss minimization. It is all about the supply of reactive power in a transmission line to increase the transmittable power thereby making it compatible with the prevailing load demand. In this paper, various factors contributing to loss minimization in a.c networks were examined, and include the use of: shunt capacitors and reactors, synchronous capacitors, tap changing transformers, series capacitors e.t.c. Recommendations to minimize losses in the system were proffered in this study to ensure good power quality and security in the network.

Keywords: Reactive power, loss minimization, voltage, transmission line, capacitors, reactors.

INTRODUCTION

The transmission network in Nigeria is characterized by losses leading to several outages that cause disruption in the lives of the citizenry. In Nigeria, the available energy generated is about 6400MW and this is not enough to meet the demands of the people thus, leading to constant load shedding and blackouts.

The consequences of poor reactive power management in 330KV grid systems in Nigeria cannot be over-emphasized. The reactive power which almost runs in all the grid systems, throughout the nation, rises and falls (very unsteady) and may result in high power loss, when the reactive power is high, with mostly low output voltages [1]. This has resulted in the loss of high voltage components/equipment, ranging from transformers, insulator transmission lines to total loss of high voltage power substation with fire outbreak if the reactive power continues to rise with current upsurge [1].

Most multinational industries in Nigeria have relocated to other West African countries such as Ghana, Togo, and Benin Republic to mention but a few, because of poor quality of power supply in the country [1].

The economic recession in Nigeria today are not far-fetched from poor quality of power supply hence, poor management of reactive power will continue to frustrate the operators of high voltage systems.

Relevance and Significance of this Work

Electricity is used for lighting, heating, cooking, driving machinery and for a whole lot of other operations. It is intangible (without physical existence) yet very potent. It is one single scientific invention that has completely revolutionized the whole world from a basically rural and primitive existence to a modern and sophisticated society. Electricity is such variable commodity that every country, city or homes are striving to have because it has major political, economic and strategic importance [2]. In fact, the advancement of a country is measured in terms of per capita consumption of electrical energy. Unfortunately, Nigeria has not been able to come into limelight in his life giving blood of civilization in electricity [2].

The acute power shortage and massive load suppression in the country is as a result of insufficient generation capacity, transmission losses and fragility of the radial grid. This condition gave rise to government’s current proposed intervention in the power industry by way of boosting the generation capacity to 20,000MW [1].

The importance of evacuation study therefore, cannot be overstressed as it complements government's effort at improving electricity supply in the country. When electricity is generated, it has to be transmitted successfully to the load centres before it can be distributed for consumption by domestic and industrial loads [2].

Methods of Voltage Control in Nigerian Power System (Or Loss Minimization)

Use of Shunt Capacitors and Reactors

Shunt capacitor compensation are used for lagging power factor (p.f) circuits created by heavy loads. The effect is to supply the requisite reactive power to maintain the receiving end voltage at a satisfactory level. Capacitors are connected directly to a bus bar or to a tertiary winding of a main transformer and are disposed along the route to minimize the losses and voltage drops [5].

Shunt reactors act on the undesirable voltage effects associated with line capacitance. They are used for leading p.f. circuits created by line capacitance and light loads. The effect is to absorb the reactive power under light load condition to maintain satisfactory voltage level at the receiving end. In both cases, it is the circuit breaker that coordinates these activities in a transmission line but these have some limitations:

- The switching operation of the circuit breaker is slow because of the greater time required for its activities (3-4 cycles).
- They are not suitable for switching operation during the variation of the voltage.

These limitations can be overcome by the use of Static Var System (SVS). In SVS, thyristors are employed as switching devices instead of circuit breakers. Thyristor switching is faster than mechanical switching and is also possible to have transient-free operation by controlling the instant of switching. In effect, SVS compensators should be able to minimize the line over voltage under light load condition and maintain voltage levels under heavy load condition.

Use of Series Capacitors

Series compensators are used to reduce series reactance between the load and the supply point. That is to say that in a.c transmission lines, series capacitors are connected in series with the line to reduce the effect of inductive reactance X_L between the sending end and receiving end of the line [2]. The result is improved transient and steady state stability, more economic loading and minimum voltage dip on load buses. They are series capacitors connected in series with the line and usually located at the midpoint of a transmission line. In all, an ideal compensator should be lossless, that is active power is the same both at the sending end, midpoint and at the receiving end. These are banks of inductors and capacitors in a transmission line [1].

To solve the capacitor allocation problems in general means, the determination of optimal location, allocation of sizes and switching times for capacitor to be installed on the distribution feeder. The application of capacitors in electrical power system is intended to control the power flow, improve stability, voltage profile management, power factor correction and loss minimization [5].

Series Capacitor Model

Below is a schematic diagram and model of series capacitor in series with the line [2]. In high voltage (HV) transmission lines, series capacitors are connected in series with the line to reduce the effect of inductive reactance X_L between the sending end and the receiving end of the line.

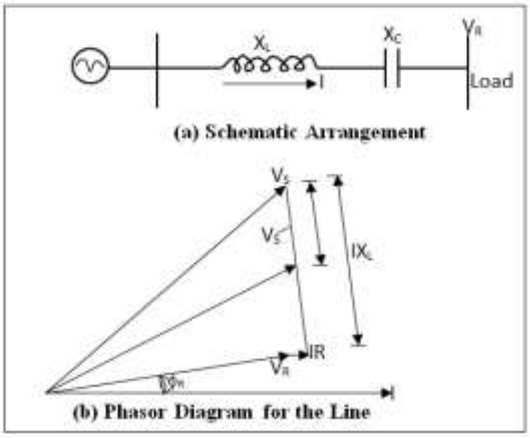

Fig-2.2: Effect of Series Capacitance in Series with the Line

Voltage drop in the line (2) is given as:

$$\Delta_V = IR\cos\phi_R + IX_L\sin\phi_R \qquad - \quad - \quad - \qquad (2.1)$$

(Without series capacitor)

And

$$\Delta_V = IR\cos\phi_R + I(X_L - X_C)\sin\phi_R \; - \quad - \qquad (2.2)$$

(With series capacitor)

Where I is the current flowing through the line

With series capacitors in the line, the voltage drop Δ_V in the line is reduced and the receiving end voltage Δ_R on load is improved. From the phasor diagram in fig. 2.2(b), it is clear that the voltage drop caused by the inductive load can be reduced particularly when the line has a large $\frac{X}{R}$ ratio. In practice however, X_C may be so chosen that the factor $(X_L - X_C)\sin\phi_R$ becomes negative and numerically equal to $R\cos\phi_R$ so that the voltage drop becomes zero. The ratio X_C/X_L expressed as a percentage is called the percentage compensation.

One drawback with this method is the high over-voltage produced across the capacitor terminals under short-circuit conditions. The drop across the capacitor under faulty condition may be 20 times larger than that caused by full load current under certain condition. For this reason, a spark gap with a high speed contactor is employed for the protection of the capacitor.

Use of Tap Changing or Ratio Adjuster Transformers

The flow of real power along the transmission line is determined by the angle difference of the terminal voltages while the flow of reactive power is determined mainly by the magnitude difference of the terminal voltages [3]. Real and reactive powers can be controlled by the use of tap changing or ratio adjuster transformers and regulating transformers. They can provide tight control of voltage levels by stimulating small changes of reactive power drawn from the network. Automatic tap changer can provide voltage control by matching the continual changes and/or consumers' demand without operator's intervention [3].

Tap Changing or Ratio Adjusting Transformer Model

This transformer is represented by a series admittance y_t when the ratio is at nominal value. When in off nominal ratio, the per unit admittance is different from both sides of the transformer and this admittance must be modified to include the effects of off nominal ratio. Consider a transformer with admittance y_t in series with an ideal transformer representing an off nominal ratio 1: ***a*** as shown in Fig-2.3. While y_t is the admittance in per unit based on the nominal turn ratio, ***a*** is the per unit off nominal tap position allowing for a small adjustment in voltage of about ±10% [3]. In the case of phase shifting transformers, ***a*** is a complex number and if we consider a fictitious bus x between its turn ratio and the admittance, and the complex power on either side of the ideal transformer is the same, it follows that if the voltage goes through a positive phase angle shift, the current will go through a negative phase angle shift [3]. For the assumed direction of current, we have:

$$V_x = 1/aV_j \qquad - \quad - \quad - \quad - \quad - \qquad (2.3)$$

$$I_i = -a^*I_j \qquad - \quad - \quad - \quad - \quad - \qquad (2.4)$$

The current I_i is given by

$$I_i = y_t(V_i - V_x) \quad - \quad - \quad - \quad - \quad - \qquad (2.5)$$

Substituting for V_x from (2.3), we have

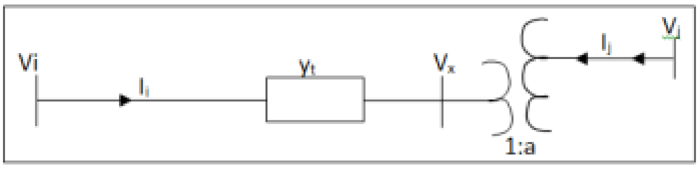

Fig-2.3: Transformer with Tap Setting Ratio 1:a

$$I_i = y_t V_i \frac{y_t}{-a} V_j \qquad - \quad - \quad - \quad - \qquad (2.6)$$

Also from (2.4), we have

$$I_j = \frac{1}{-a*} I_i \quad - \quad - \quad - \quad - \quad - \qquad (2.7)$$

Substituting for Ii from (2.6), we have

$$I_j = -\frac{y_t}{a*} V_i + \frac{y_t}{/a/^2} V_j \quad - \quad - \quad - \quad - \qquad (2.8)$$

Writing (2.6) and (2.8) in matrix form results in:

$$\begin{pmatrix} I_i \\ I_j \end{pmatrix} = \begin{pmatrix} y_t & -\frac{y_t}{a} \\ -\frac{y_t}{a*} & \frac{y_t}{/a/^2} \end{pmatrix} \begin{pmatrix} V_i \\ V_j \end{pmatrix} \quad - \quad - \quad - \qquad (2.9)$$

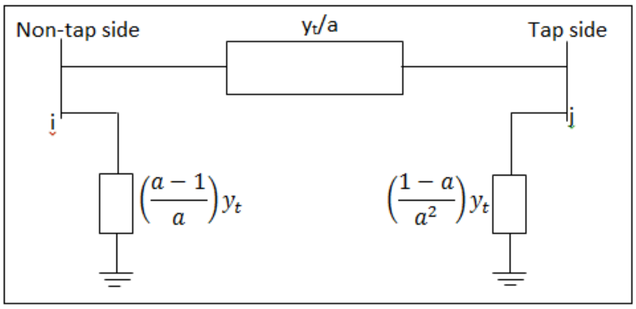

Fig-2.4: Equivalent Circuit for a Tap Changing Transformer

When ***a*** is real, the π model (Fig-2.4) represents the admittance matrix in (2.9). In the π model, the left side corresponds to the non-tap side while the right side corresponds to the tap side of the transformer.

Use of Synchronous Condensers

The voltage at the receiving end of a transmission line can be controlled by installing specially designed synchronous motors called synchronous condensers at the receiving end. The wattless leading KVA is automatically varied by the variation of its excitation according to the load on the transmission line [7]. The efficiencies of these machines are very high because values of the losses as a percentage of the KVA rating are very low (4 to 6 percent).

The synchronous motor or condenser is started and connected to the electrical network. It operates at full leading power factor and puts VARs on to the network as required to support a systems voltage or to maintain the system power factor at a specified level [7]. The condenser's installation and operation are identical to large electric motors. Its advantage is the ease with which amount of correction (p.f) can be adjusted and it behaves like an electrically variable capacitor [7].

Use of Shunt Capacitors and Reactors or SVS Method of Voltage Control Explained [6]

The results of load flow studies conducted by Ibekwe B. E *et al.*, (2014), in the paper tagged "Dynamic Compensation of Reactive Power in 330KV Transmission Line using Static Var Compensator (SVC)" exposed the following problem buses [6] shown in Table-1.

Table-1: Showing all the problems buses and their voltage magnitudes

Bus Nos	Bus Names	Voltage Magnitudes (P.U)
3	Okpai	1.090
14	Jos	0.9359
17	Gombe	0.9175
19	Maiduguri	0.9106
22	Kano	0.8849
28	Berni-Kebbi	-0.734
30	Makurdi	0.8247

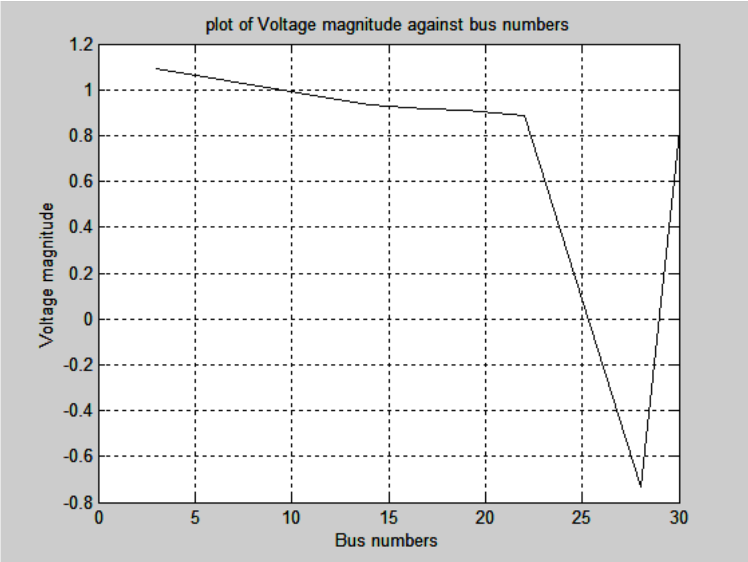

Fig-1: showing the plots of the problem buses against their voltage magnitudes

These low bus voltages were due to the losses in the 330KV grid system. From the "line flow and losses" [6], the real power loss was as high as 135.219MW while the reactive power loss was about 2983.320Mvar.

When shunt capacitors and reactors and/or SVC was employed as a method of voltage control and a "continuation load flow studies" and/or "validation" carried out, all the problem buses were corrected and conformed within the statutory limit of $0.95<vi<1.05$p.u. as stipulated by IEEE. From the "line flow and losses," the real power loss was found to have reduced to 93.796MW while the reactive power loss came down to 2691.54Mvar [6], showing a great improvement in loss minimization to the tune of 41.423MW and 301.78Mvar respectively after compensation.

Table-2: Showing the corrected buses after compensation

Bus Nos	Bus Names	Bus Voltage Magnitudes (P.U)
3	Okpai	1.05
14	Jos	1.05
17	Gombe	1.05
19	Maiduguri	1.049
22	Kano	1.049
28	Berni-Kebbi	1.05
30	Makurdi	1.05

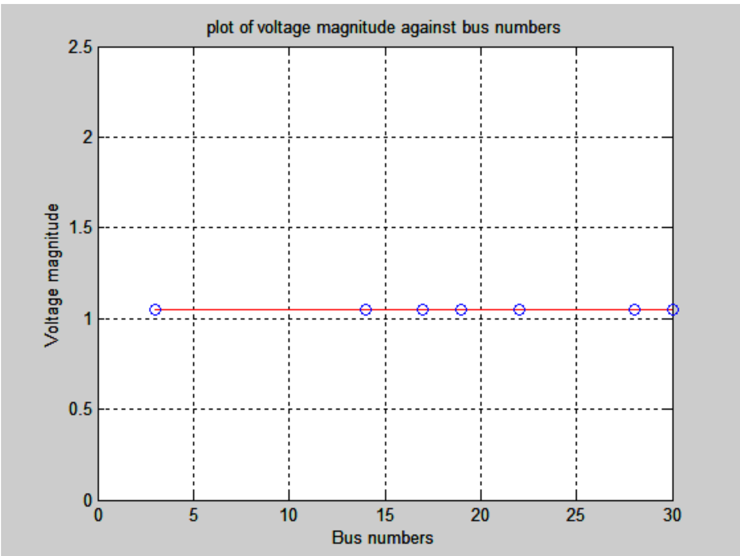

Fig-2: showing the corrected buses after compensation

ANALYSIS OF RESULTS

After the compensation, all the problem buses were corrected and improved as shown in figure 2 and moreover, the line losses were also improved by reducing to 93.796MW and 2681.54Mvar for real and reactive powers respectively [6], as against 135.219MW and 2983.320Mvar initially obtained. This showed percentage reduction in losses of 30.63% and 10.1% respectively for real and reactive power losses.

CONCLUSION AND RECOMMENDATIONS

As in the case of shunt capacitors and reactors or SVC demonstrated with Nigerian 330KV grid system, series capacitors, tap-changing or ratio adjuster transformers and/or synchronous condensers can also be recommended and employed. Series capacitors and shunt reactors are used to reduce artificially the series reactance and shunt susceptance of lines, thus, they act as line compensators. Compensation of lines result in improving the system stability and voltage control, increasing the efficiency of power transmission, facilitating line energisation and reducing temporary and transient over voltages [4], and is highly recommended in power system network.

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