A System Line Overload Index for Contingency Assessment of Nigeria's 330kV Transmission System

Ganiyu A. Ajenikoko, Anthony, A. Olaomi
Department of Electronic & Electrical Engineering, LadokeAkintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria

ABSTRACT

Contingency analysis is an abnormal condition in electrical network. It puts the whole system or a part of the system under stress. It occurs due to sudden opening of a transmission line, generator tripping, sudden change in generation and sudden change in load value.

This paper presents a System Line Overload Index (SLOI) for contingency assessment of Nigeria's 330kV transmission system. The analysis started with the determination of the receiving and sending end voltages of the buses in order to compare their values for safety operation. The ratio of the receiving and sending end voltages of the buses was determined as a basis for the mathematical computation of the System Line Outage Index (SLOI).

The results of the work showed that the outage of Osogbo to Aiyede had the most critical effect on the system because, at this line, a peak SLOI value of 0.99998 was obtained with sending and receiving end voltages of 1.84V and 1.81192V respectively. The outage of Osogbo to Ikeja West line had the least SLOI value of 0.069, hence the least critical effect on the system. This SLOI value gave a corresponding receiving and sending end voltages of 1.04272V and 1.12V respectively. Additional lines should be used to connect Osogbo to Aiyede to create more links for power to be transmitted to Lagos area so as to reduce the SLOI value of Osogbo to Aiyede line.

The work will stress the importance of operating the transmission system defensively to avoid system collapse due to overloading so as to improve the lines' active power capability contingency event using Flexible AC Transmission (FACT) devices because of their fast switching ability.

Keywords: Contingency, SLOI, Sending End Voltage, Receiving End Voltage, Transmission System, Power Grid.

I. INTRODUCTION

A contingency is a failure of any one piece of equipment (line or transformer), which can be caused by either external or internal disturbances. Power system should be able to withstand the failure of any one piece of equipment and still function normally. Contingency analysis in power system area refers to the study of different situations where one or more of the system components, including a transmission line, generator, transformer, etc., are out of service either intentionally or due to fault[13], [19].

Contingencies are defined as harmful disturbances that occur during the steady state operation of a power system.

Contingencies can lead to some disturbances such as over voltage at some buses, overloading on the lines, which if are unloaded can lead to total system collapse [9], [17].

Power system engineers use contingency analysis to predict the effect of any component failure. Periodically, maintenance operations are carried out on generating units or transmission lines. During this period, a unit is taken offline for servicing. The effect of this forced outage on other parts of the system can be observed using contingency analysis [4], [15].

Furthermore, contingency analysis is the study of the outage of elements such as transmission lines, transformers and generators, and investigation of the resulting effect on line power flows and bus voltages of the remaining system. It represents an important tool to study the effect of elements outages in power system security during operation and planning [11], [18]. Contingencies referring to disturbances such as transmission element outages or generator outages may cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the operating constraints. Consequently, planning for contingencies forms an important aspect of secure operation. Contingency analysis allows the system to be operated defensively [12], [20]. Many of the problems which occur in the power system can cause serious troubles within a short time if the operator could not take fast corrective action Therefore, modern computers are equipped with contingency analysis programs which model the power system and are used for outage events and alert the operators of potential overloads and voltage violations [2],[6],[7].

The most difficult methodological problem to cope with in contingency analysis is the accuracy of the method and the speed of the solution of the model used. Then operator usually needs to know if the present operation of the system is secured and what will happen if a particular outage occurs [1],[3],[8].Operations personnel must recognise which line or generator outages will cause power flows or voltages to go out of their limits. In order to predict the effect of outages, contingency analysis technique is used. Contingency analysis procedures model a single equipment failure, that is one line or one generator outage, or multiple equipment failure events, that is to transmission lines, a transmission line and a generator, one after another in sequence until all credible outages have been studied. For each outage tested, the contingency analysis procedure checks all power flows and voltage levels in the network against their respective limits [16], [21].

1.1 Classification of Contingencies.

Contingency analysis involves abnormal conditions in electrical network, it puts the whole system or part of the system under stress.

It occurs due to [5], [10], [14]:

- Sudden opening of a transmission line.
- Generator tripping.
- Sudden change in generation.
- Sudden change in load value

1.2 The Nigerian National Grid Systems.

The Nigerian National Grid System is made up of various buses with assigned numbers. Figure 1 shows the grid map of Nigeria while Figure 2 shows the single line diagram of the Nigerian power grid.It shows the various bus numbers and their numbers. The buses include Kainji G.S, Birnin-Kebbi, Kano, Jos, Gombe, Kaduna, Shiroro, Jebba G.S, Jebba T.S, Katampe, Osogbo, Ajaokuta, New-Haven, Aiyede, Ikeja-West, Benin, Onitsha, Alaoji, Akangba, Sapele, Egbin, Afam, Aja and Aladja.

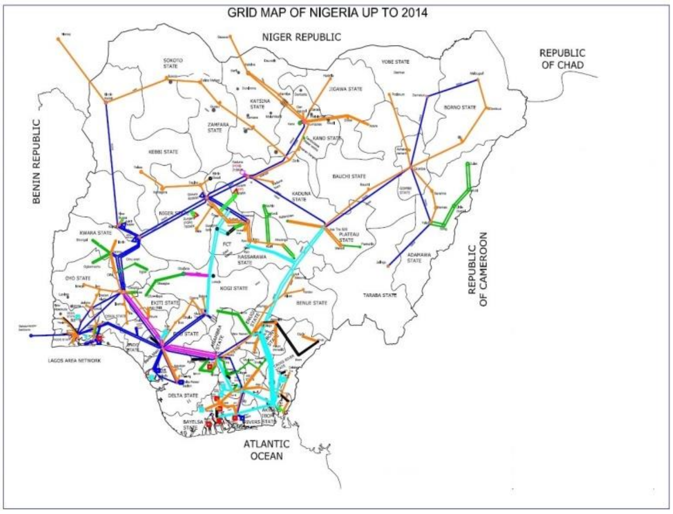

Figure 1: Grid Map of Nigeria

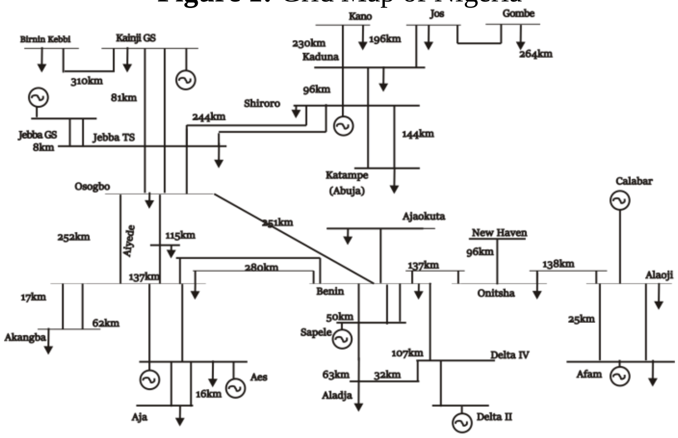

Figure 2: Single line diagram of the Nigerian Power grid

II. METHODS AND MATERIAL

- **i** Computation of the bus receiving-end voltage $V_{R.}$
- ii Determination of the bus sending-end voltage V_S.
- iii Compute $\frac{V_r}{V_s}$
- iv Compare V_R and V_S to ensure that $\frac{V_r}{V_s} < 0.95$ for safety operation.
- v Compute System Line Outage Index (SLOI)as

$$SLOI = 1 - \left(\frac{V_r}{V_s}\right)^k$$

where

V_r= Bus Receiving end voltage
V_s= Bus Sending end voltage
k = Number of lines whose $\frac{V_r}{V_s} < 0.95$.

III. RESULT AND DISCUSSION

The variation of the receiving end voltages with the sending end voltage is illustrated in Figure 3. From Osogbo to Ikeja-West, the sending and receiving-end voltages were 1.12V and 1.04272V respectively indicating that the sending end voltage was greater than the receiving end voltage thus making the ratio of the receiving end voltage to the sending end voltage to be 0.931. Thus at this instance, Osogbo to Ikeja-West line recorded the least value of the sending end voltages. These two buses appeared to be the least critical line.

From Osogbo to Ikeja-West line, the receiving and sending end voltages were 1.81192V and 2.84V respectively because, the outage of the line between these two buses appeared to be the most critical lines.
Figure 4 illustrates how the receiving end voltages varied with the System Line Outage Index. Observations showed that the receiving end voltages varied linearly as the System Line Outage Index Thus as the receiving end voltage increased, the System Line Outage Index also increased.

From Osogbo to Ikeja West line, the System Line Outage Index was 0.069 at a receiving end voltage of 1.04272 which appeared to be the least in the range and at a receiving end voltage of 1.08088, the System Line Outage Index was 0.16094. The highest SLOIvalue of 0.99998 was recorded from Osogbo to Ikeja West at a corresponding receiving end voltage of 1.81192V.

The relationship between the sending end voltage and the SLOI is illustrated in Figure 5. The sending end voltage increased as the SLOI increased. From Osogbo to Ikeja West line, the sending end voltage of 1.12V gave a SLOI value of 0.069 while at a SLOI value of 0.16094, the sending voltage was 1.18V. This trend continued throughout the study period until a sending end voltage of 2.84V obtained at an SLOI value of 0.99998 from Osogbo to Ikeja West line. This appeared to be the highest sending end voltage and SLOI in this range.

Figure 6 shows the variation of voltage ratio with SLOI. The voltage ratio decreased because of the inverse relationship between the quantities. Thus, at a voltage ratio of 0.931, the SLOI was 0.069 from Osogbo to Ikeja West line. The voltage ratio and the SLOI value at this instance appeared to be the highest and least values respectively in this range. When the voltage ratio was 0.894, the SLOI value was 0.36122 from Ikeja West to Afam line. A least voltage ratio of 0.638 was obtained from Osogbo to Ikeja West line with a corresponding SLOI value of 0.99998. At this instance, the SLOI value appeared to be the highest value so far in this range because, a reduction in the voltage ratio called for a boost in the value of the SLOI from Osogbo to Ikeja West line.

Figure 7 shows the variation of the receiving end voltage with the voltage ratio. As more voltages were received at one end, the voltage ratio decreased proportionately because the voltage ratio is a function of the receiving end voltage.

When the receiving end voltage was 1.04272V, the voltage ratio was 0.931 and at a voltage ratio of 0.695, the receiving end voltage was 1.43865V because the two quantities- receiving end voltage and the voltage ratio were inversely related. The least receiving end voltage value from Osogbo to Ikeja West line was 1.04272V which gave a corresponding highest voltage ratio of 0.931.

The highest receiving end voltage of 1.81192V gave a corresponding least voltage ratio of 0.638 because of the inverse relationship existing between the two quantities- receiving end voltage and voltage ratio. The relationship between the sending end voltages with the voltage ratio is shown in Figure 8. The voltage ratio decreased progressively as more voltages were sent at one end. At a voltage of 0.931V from Osogbo to Ikeja West, the sending end voltage was 12V. From Ikeja West to Egbin line, a voltage ratio of0.894 required a voltage of about 1.29V at the sending end because of the inverse relationship existing between the two quantities. From Osogbo to Ikeja West line, the least value of sending end voltage of 1.12V gave the highest voltage ratio of 0.931. From Benin to Sapele line a voltage ratio of 0.708 gave a corresponding sending end voltage of 1.99V. The highest sending end voltage of 2.84V gave rise to a corresponding voltage ratio of 0.638 which appeared to be the least voltage ratio from Osogbo to Aiyede line because of the inverse relationship existing between these two quantities.

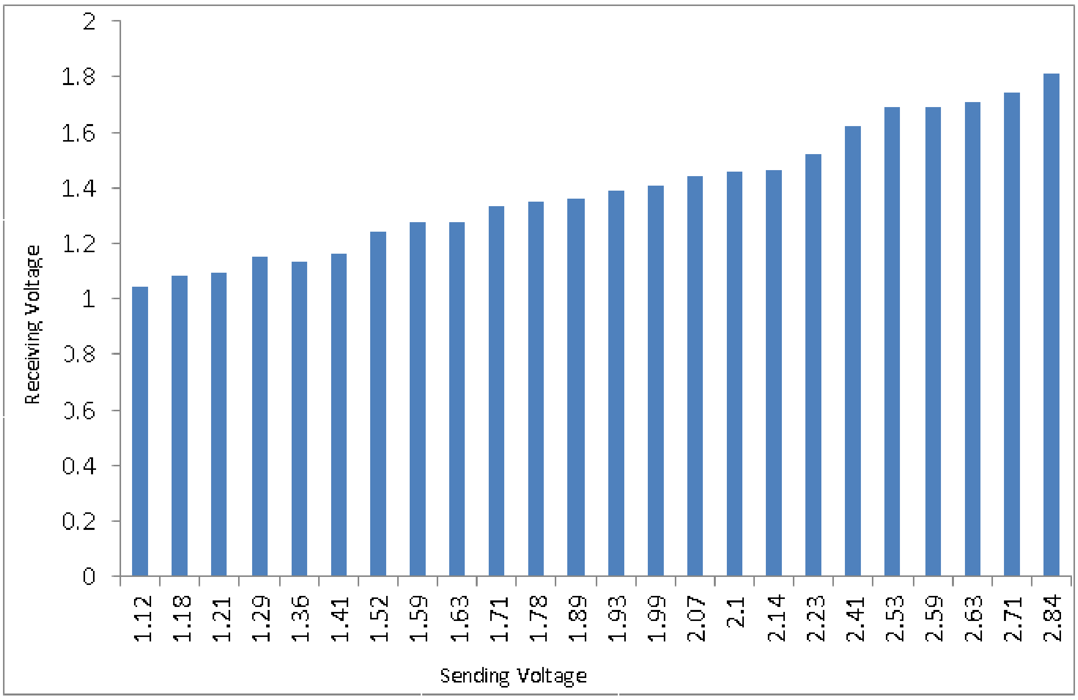

Figure 3: Variation of Receiving End Voltage with Sending Voltage

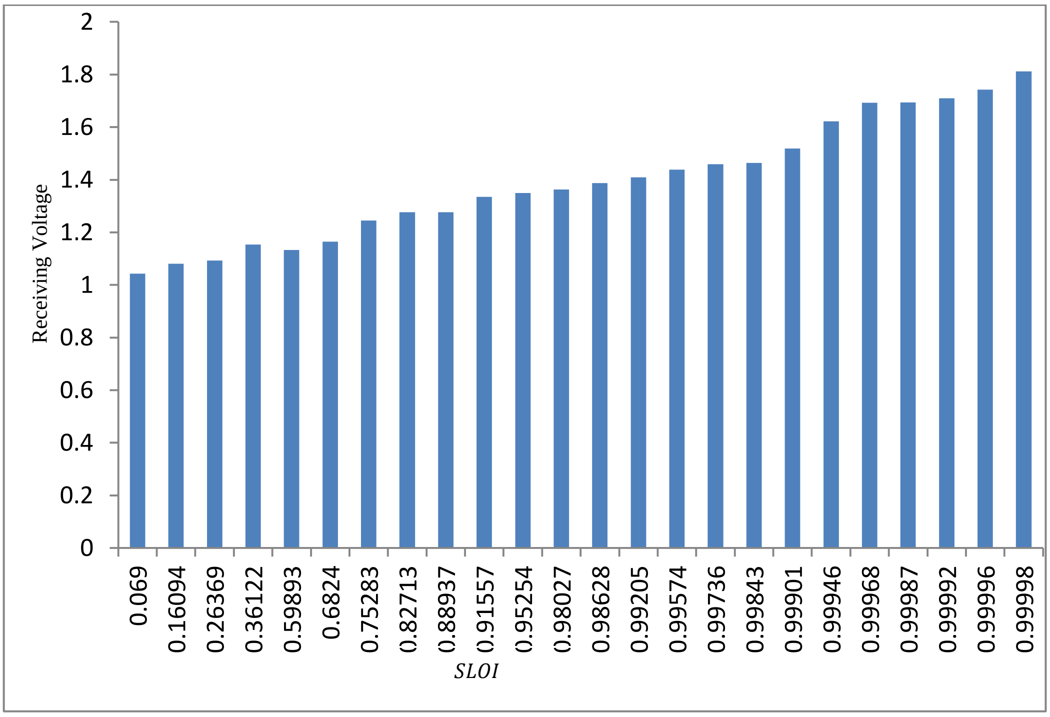

Figure 4: Variation of Receiving End Voltage with SLOI

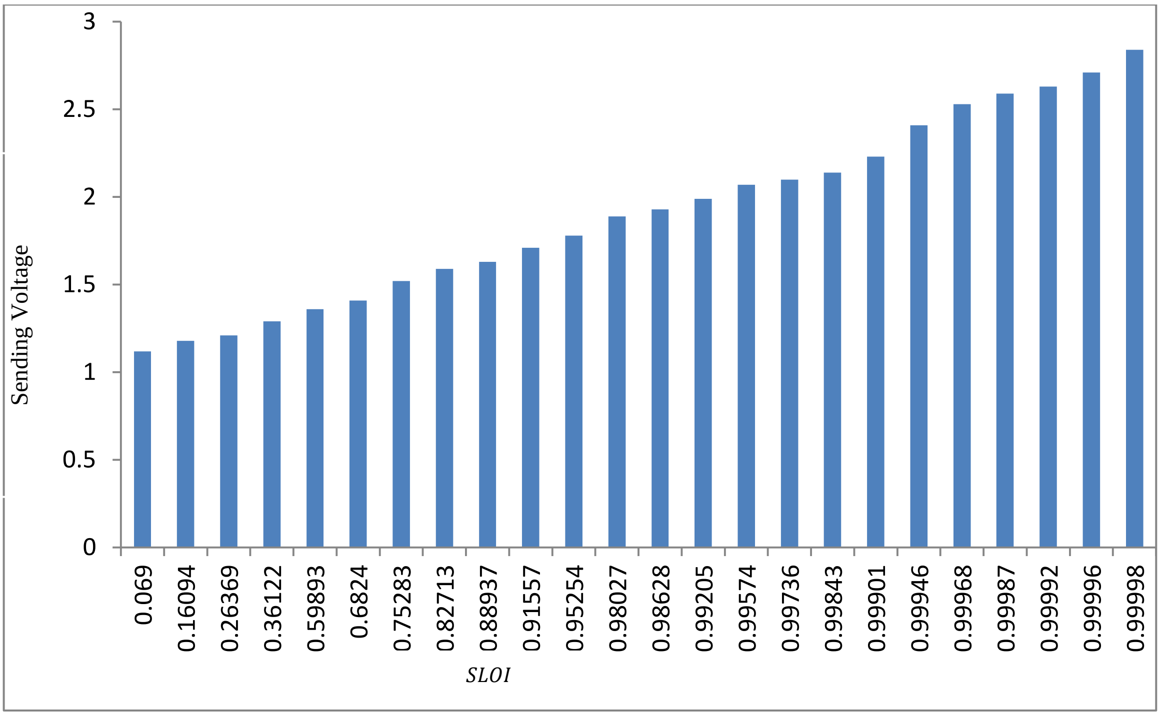

Figure 5: Variation of Sending End Voltage with SLOI

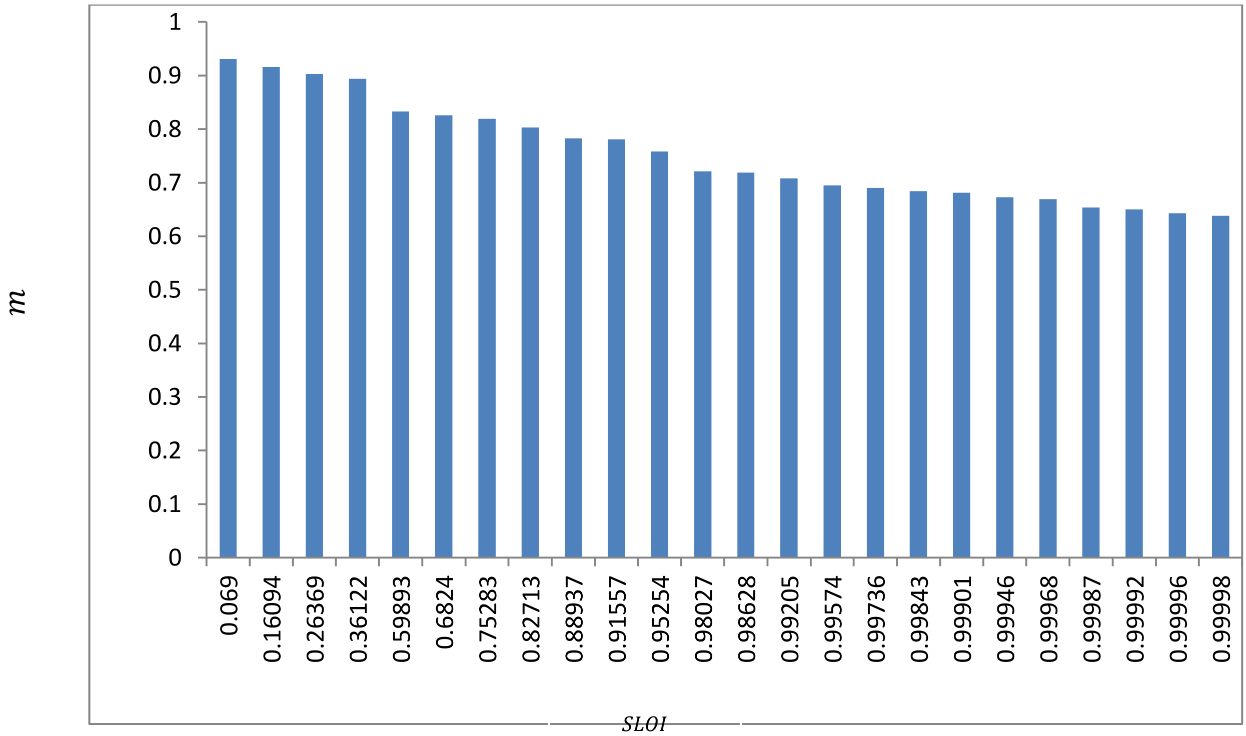

Figure 6: Variation of Voltage Ratio with SLOI

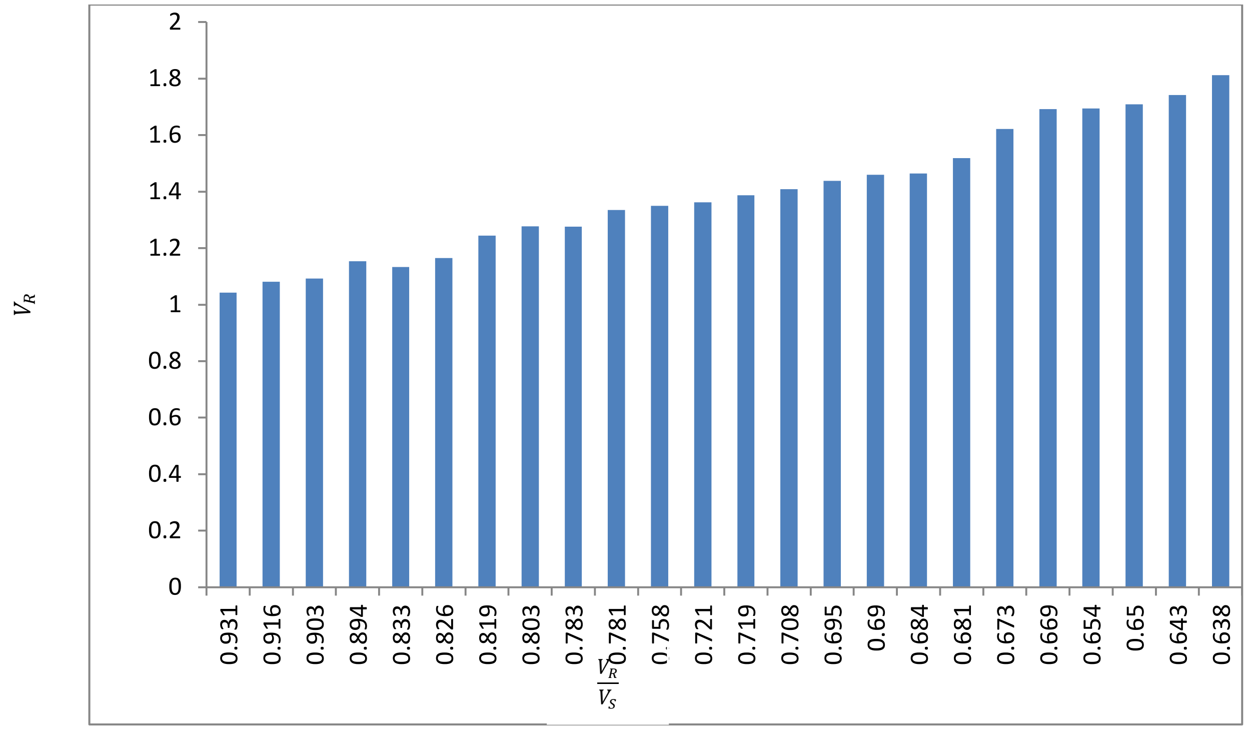

Figure 7: Variation of Receiving End Voltage with Voltage ratio

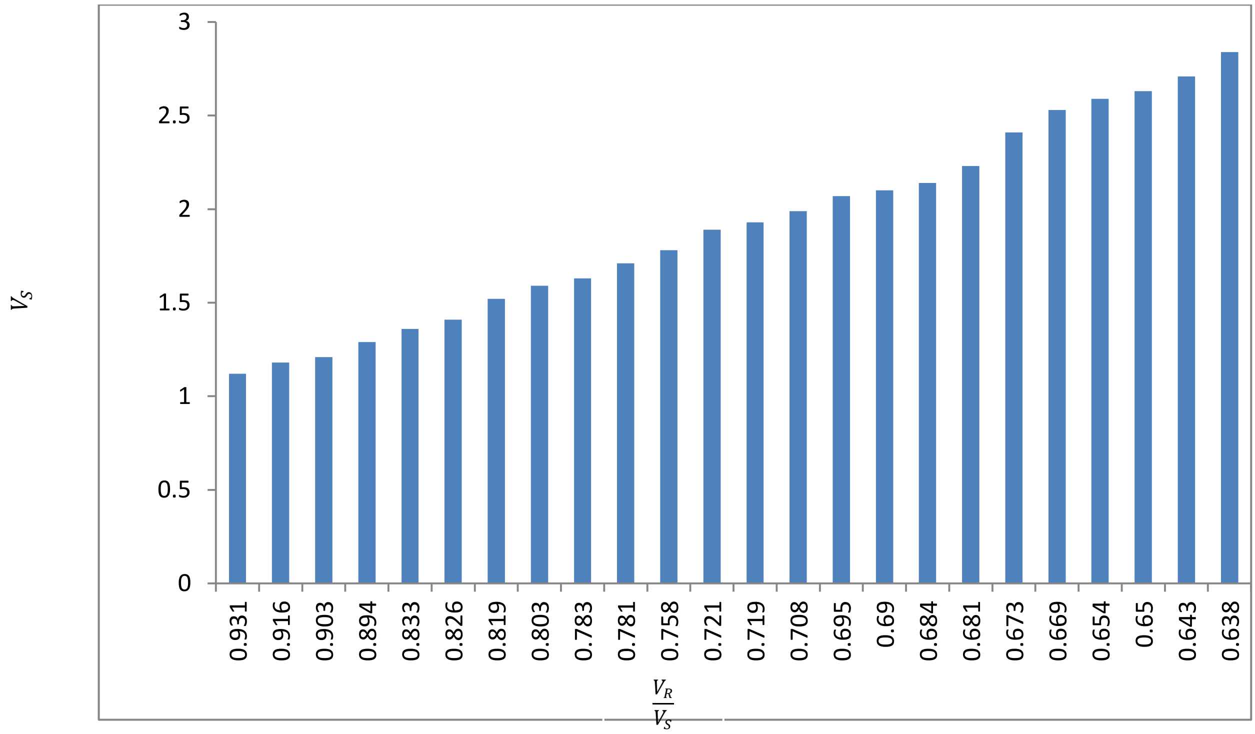

Figure 8: Variation of Sending Voltage with Voltage ratio

IV. CONCLUSION

A System Line Overload Index (SLOI) for contingency assessment of Nigeria’s 330kV transmission system has been presented.

The outage of Osogbo to Aiyede line had the most critical effect on the system because, on this line, a peak SLOI value of 0.99998 was obtained with sending and receiving end voltages of 1.84V and 1.81192V respectively. The outage of Osogbo to Ikeja West line had the least SLOI value of 0.069, hence the least critical effect on the system. This SLOI value gave a corresponding receiving and sending end voltages of 1.04272V and 1.12V respectively.

The lines active power capability contingency event can be improved using Flexible AC Transmission (FACT) devices because of their fast switching ability.

Osogbo to Aiyede should be connected with additional lines through different routes to create more links for power to be transmitted to Lagos area so as to reduce the SLOI value of Osogbo to Aiyede line.

V. REFERENCES

[1] Ajjarapu V and Meliopoulos A.P.S (2008): Preventing voltage collapse with protection systems that incorporate Optimal Reactive Power Control," PSERC Publication, October 6-October 20, Pp 23-36.

[2] Ali N.A (2005): "An Overview of system collapses on the Nigerian Grid Network," Proceedings of the international conference on power systems operations and planning, Universidade Jean Piaget, May 22nd – May 26th, 2005, Pp 67-70.

[3] Bachar R (2009): "Graphical Interactions and visualization for the Analysis and interpretation of contingency analysis results," Proceedings of IEEE Power industry computer application conference, Pp 128-134.

[4] Brandwajn V (2008): "Efficient Bounding Method for Linear Contingency Analysis," IEEE Transactions on power systems, Vol. 3, No. 1, Pp 23-45.

[5] Chary, D.M (2011): "Contingency Analysis in power systems, Transfer Capability Computation and Enhancement Using FACTS devices in Deregulated Power systems," PhD Dissertation, Jawaharlal Nehru Technological University.

[6] Ejebe G.C and Wollenberg B.F (2009): " Automatic Contingency Selection," IEEE Trans on PAS-98, Pp 97-109

[7] Eldeen S, Mohammed G, Mohammed A.Y and Abdulrahim (2012): "Power system contingency analysis to detect network weaknesses," Zaytoonah University International Engineering Conference on Design and Innovation in infrastructure (ZEC Infrastructure 2012), June 18-20, Amman, Jordan.

[8] Enns M. Quada J.J and Sackett B(2012): " Fast Linear Contingency Analysis", IEEE Trans on PAS, Vol. PAS-101, No. 4, Pp 783-791.

[9] Glover J.D, Sarima M.S, Overbye T.I (2012): "Power System Analysis and Design," 5th Edition. Stanford Cengage Learning, Pp 78-92.

[10] Guler T, Gross G and Liu M (2011):" Generalized Line Outage Distribution Factor," Power Systems, IEEE Trans, Vol. 22, Issue 2, Pp 879- 881.

[11] Kundur P (1994): "Power system stability and control," New Delhi, Tata McGraw-Hill Publishing Company Ltd., Third Edition, Pp 234-246.

[12] Mohamed S.E.G, Mohamed A.Y and Abdelrahim Y.H (2012): "Power System Contingency Analysis to Detect Network weakness," Zaytoonah University International Engineering Conference on Design and Innovation in Infrastructure, Amman, Jordan Pp 13-41.

[13] Nara K, Tanaka K, Kadama H, Shoults R.R, Chen M.S, Olinda P.V and Bertangnolli D (1985): "On-line Contingency Selection for Voltage Security Analysis," ibid, Vol. PAS-104, Pp 847-856.

[14] Ogbuefi U.C (2013): "A Power flow Analysis of Nigeria Power system with compensation on some buses," PhD Thesis, University of Nigeria, Nsukka, Nigeria.

[15] Onohaebi O.S (2009): "Power outage in the Nigerian Grid," Research Journal of Applied Sciences 4(1) 1-9.

[16] Pentayya P, Mukhopadhyay P, Banerjee S and Thakur M.K (2010): " Contingency analysis for Eastern Regional Grid of India", 16th National Power Systems Conference, Pp 359-363.

[17] Radha K, Rani J and Kamaksharah S (2011): "Contingency Analysis under Deregulated Power Systems," ICOST –ACSE Journal, Volume 11, Issue 2, Pp 23-37.

[18] Saadat H (2002): "Power System Analysis," New Delhi, McGraw Hill, Pp 182-256

[19] Sule A.H (2010): "Major Factors affecting generation, transmission and distribution in Nigeria," International Journal of Engineering and Mathematical intelligence, Volume 1, Nos 1 & 2, Pp 23-34.

[20] Tinney W.F and Enns M.K (1994): "Controlling and Optimizing Power Systems," IEEE Spectrum, Pp 56-60.

[21] Wood A.J, Wallenberg B.F (1996): ‘Power Generation, Operation and Control," 2nd Edition, New York/USA: John Wiley and Sons, Pp 410-432.