Loadability Analysis of the Effect of Generation and Transmission Expansion in Southern Nigeria

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Abstract – Electrical energy demand in Nigeria has increased due to economic activities as a result of increase in population. The Southern region, experience stranded power due to the proximity of most of the gas thermal power stations and inadequacy of the tie lines for load evacuation. The southern buses also experience over voltage as a result of the reactive power generation from the various power plants within the vicinity. The existing 330kV Nigeria transmission network was enhanced by the introduction of new lines and power stations and the effect was analyzed.

Newton-Raphson algorithm in ETAP 12.6 was used to simulate and analyze the network. The parameters used for the study included bus data, transmission line power rating, generators active power, transformers rating and base load.

The base case operating condition as obtained from the power flow on which the various transfer cases were implemented, gives a fair generation and loading pattern of the Nigerian grid. The total installed generating capacity of the base case considered was 11,948MW out of which 4,420.4MW was available for load level of 3,633.6MW. Result shows that the maximum load the existing network can accommodate when all single circuits in the network is changed to double circuit and ten (10) transmission lines and four (4) power stations is inserted into the network is 12,342.296MW and 6,429.228MVar at a loading capacity of 12,059.054MW and 7,411.694MVar. When the Newton – Raphson iteration method was applied, the enhanced network evacuated 97.71% of the energy, while 82.2% was evacuated by the existing network.

Keywords – Transmission Line, Network, Loadability, Load Flow, Maximum Load, Power Station.

I. INTRODUCTION

Increase in economic activities resulting from increase in population and social advancement has led to increase in electrical energy demand. This has increased the burden on the existing transmission assets and in some cases, has caused the loading of the transmission assets beyond their design limits with consequent reduction in power quality and power outages in extreme cases [1]. The current transmission system in Nigeria comprises 5523.8 km of 330 kV, 6801.49 km of 132 kV, 32No. 330/132 kV substations with total installed transformer capacity of 7688 MVA. 105No. 132/33/11 kV substations with total installed transformer capacity of 9130 MVA. The average available capacity on 330/132 kV is 7364 MVA and 8448 MVA on 132/33 kV [2]. Some of the major challenges associated with the South-South, South East and South West regions (Edo, Delta, Bayelsa, Rivers, Akwa Ibom, Cross River, Abia, Enugu, Anambra, Imo, Ebonyi, Oyo, Osun, Ekiti, Ondo and Ogun states) of the transmission network are over voltages due to reactive power generation from the various power plants within the vicinity and power is stranded due to the proximity of most of the gas thermal power stations and inadequacy of the tie lines to evacuate load. Lagos (Lagos State) south west region is prone to transmission congestion [2] – [3]. The grid bus is characterized by poor voltage profile in most parts of the network, frequent system collapse and exceedingly high transmission losses [4] – [5]. Thus, there is need to have a sustainable, reliable and stable supply to create an enabling balanced economy [6]. The unreliability of the System Network has impacted on the nation’s socio-economic development and industrialization hence, the recent launch of the roadmap of the power sector reform by the Federal Government [7].

II. RELATED WORK

In [8], the authors considered power flow analysis of the Nigeria 330kV electrical power system using Newton-Raphson algorithm in MATLAB/SIMULINK software. The results obtained showed that out of the 30 buses in the network examined, 7 bus voltages were outside the statutory limit of 0.95 – 1.05p.u that is 313.5 – 346.5Kv which are buses 14 (Jos) with value 0.8171pu, bus 17 (Gombe) 0.8144p.u, bus 18 (Abuja) 0.9402pu, bus 19 (Maiduguri) 0.8268pu, bus 22 (Kano) 0.7690pu, bus 29 (Kaduna) 0.8738pu, and bus 30 (Makurdi) 0.8247p.u under normal uncompensated condition. Capacitive shunt compensation was carried out and appreciable values were recorded. Results obtained after compensation revealed acceptable voltage levels at the problem buses.

The analysis of power flow of Nigerian 330kV grid system (pre and post) using Matlab was examined by [9]. They assessed the reliability, stability and efficiency of the proposed (post reform) 10,000MW capacity 330kV grid and the volume to which it is going to offer option to the several issues that currently plague the prevailing (pre reform) grid. MATLAB was used; load flow studies was first conducted on both the 31 bus system pre reform grid and the 49 bus system post reform grid using both the Gauss-Seidel and Newton-Raphson iteration methods. The network was discovered to have significant deficiencies in voltage level and power flow along the transmission lines. The affected lines which were single circuits were replaced with double circuit transmission lines and the simulation results showed that this was able to lower the power evacuation burden on these lines well below their thermal ratings; it also showed reduction in line losses. Reactive power compensations were also applied at the buses that experienced high voltages and results revealed very high
improvement in voltage levels at affected buses as no bus voltage exceeded the acceptable limits (-15% to +10% of nominal value) after compensation.

### III. METHODOLOGY

Data was collected from Transmission Company of Nigeria (TCN) for load flow analysis. The analysis on the data was done using Newton – Raphson algorithm in Etap 12.6 load flow analyzer which is a power system modeling, design, analysis, optimization, control, and automation software.

Newton – Raphson method or techniques for load flow studies was used to simulate and investigate the generated power of the network. The load flow program calculates the magnitude and phase angle of the voltage at each bus, real and reactive power flowing in each line respectively.

A number of methods for power flow calculation use equations in different forms considering sending end \(i^{th}\) end or receiving end \(j^{th}\) end. In this work, we used the same method in section 2.26 of [10] where a detailed explanation of Newton-Raphson method as applicable to power flow problem was given.

The linear equation in compact form used is given as:

\[
\frac{\Delta P}{\Delta Q} = \begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{pmatrix} \begin{pmatrix} j_1 \\ j_2 \\ \vdots \\ j_n \end{pmatrix} \Delta V
\]

### IV. PRESENTATION OF SYSTEM DATA

The data used in this work is as presented in Tables 1 and 2. We considered 20 generating stations, 67 transmission lines and a total of 59 buses stations for the existing network. While the expanded network consist of sixty six (66) buses, seventy nine (79) transmission lines and twenty four (24) generating stations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Station</th>
<th>S/N</th>
<th>To Station</th>
<th>Location</th>
<th>No of circuits</th>
<th>Length (Km)</th>
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</thead>
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<td>PH main T.S</td>
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<td>Gbarian G.S</td>
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<td>Maiduguri T.S</td>
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<td>Yola T.S</td>
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<td>Shiroro G.S</td>
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<td>Ihovbor G.S</td>
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<tr>
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<td>Omotosho T.S</td>
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<td>Okearo T.S</td>
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<td>65</td>
<td>7875.87</td>
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<td>Ikeja west T.S</td>
<td>Egbin T.S</td>
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<td>62</td>
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<td>7875.87</td>
<td></td>
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<tr>
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<td>Olrunosogo G.S</td>
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<td>67</td>
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</tr>
<tr>
<td>Ikot - Ekpene T.S</td>
<td>Ugwaju T.S</td>
<td>34</td>
<td>174</td>
<td>Total</td>
<td>8717.67</td>
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</table>
V. DISCUSSION OF RESULT FROM THE ANALYZED NETWORK

Analyzing the network to determine the performance effect when the Southern region was enhanced to allow more power to be evacuated within the network was done. To determine the load carrying capacity of the network, ETAP 12.6 Load flow Analyzer was used to simulate the 330kV expanded network consisting of sixty six (66) buses, seventy nine (79) transmission lines and twenty four (24) generating stations (13,290MW installed generating capacity). Meanwhile generating stations which has more than one stations in one place like Olorunsogo I and II were grouped together. The input data used in the simulation of the maximum load capacity are the various line loading and generation as obtained from Transmission Company of Nigeria (TCN) which represents the base case for the model. Electric power transfer was investigated by the insertion of the following power station; Calabar 561MW, Ibom 191MW, Aba 140 and Azura 450MW into the network which increased the total installed capacity to 13,290MW. The network was further expanded by transmission lines shown in table 3 to ascertain the maximum load capacity. Results shows that the network was able to evacuate 12,342,296MW and 6,429,228MVar at a loading capacity of 12,059.054MW and 7,411.694MVar. However, only Jos T.S (0.80p.u) was out of the statutory voltage limit of 0.85p.u – 1.05p.u. While Okearo T.S – Egbin G.S had the highest load as shown in the power flow and line flow result as presented in Table 4-5.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Terminal Bus</th>
<th>Rating (MVA)</th>
<th>S/N</th>
<th>Terminal Bus</th>
<th>Rating (MVA)</th>
<th>S/N</th>
<th>Terminal Bus</th>
<th>Rating (MVA)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>Afam</td>
<td>105.882</td>
<td>11</td>
<td>Delta</td>
<td>75.647</td>
<td>21</td>
<td>Kainji G.S</td>
<td>117.647</td>
</tr>
<tr>
<td>2</td>
<td>Aiyede T.S</td>
<td>117.647</td>
<td>12</td>
<td>Egbin G.S</td>
<td>1176.471</td>
<td>22</td>
<td>Kano T.S</td>
<td>217.529</td>
</tr>
<tr>
<td>4</td>
<td>Ajaokuta T.S</td>
<td>117.647</td>
<td>14</td>
<td>Geregu NIPP &amp; G.S</td>
<td>164.706</td>
<td>24</td>
<td>Maiduguri T.S</td>
<td>58.824</td>
</tr>
<tr>
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<td>96.588</td>
<td>16</td>
<td>Ikeja West T.S</td>
<td>352.941</td>
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<td>Okearo T.S</td>
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</tr>
<tr>
<td>8</td>
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<td>52.588</td>
<td>18</td>
<td>Jebba G.S</td>
<td>117.647</td>
<td>28</td>
<td>Onitsa T.S</td>
<td>135.529</td>
</tr>
<tr>
<td>10</td>
<td>Birni-Kebbi T.S</td>
<td>117.647</td>
<td>20</td>
<td>Kaduna T.S</td>
<td>195.529</td>
<td>30</td>
<td>Shioro G.S</td>
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</table>

Table 3: Transmission lines added to the existing network.

<table>
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<tr>
<th>S/N</th>
<th>Transmission line (From - To)</th>
<th>Length (Km)</th>
<th>No. of circuits</th>
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</thead>
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<td>1</td>
<td>Ikot Ekpene T.S - Ibom G.S</td>
<td>2.4</td>
<td>Double</td>
</tr>
<tr>
<td>2</td>
<td>Ikot Ekpene T.S - Afam G.S</td>
<td>107.8</td>
<td>Double</td>
</tr>
<tr>
<td>3</td>
<td>Aja G.S - Aja T.S</td>
<td>14</td>
<td>Double</td>
</tr>
<tr>
<td>4</td>
<td>Ibom G.S - Ekit T.S</td>
<td>37.4</td>
<td>Double</td>
</tr>
<tr>
<td>5</td>
<td>Ikot Ekpene T.S - Calabar G.S</td>
<td>71</td>
<td>Double</td>
</tr>
<tr>
<td>6</td>
<td>Egbema T.S - Owerri T.S</td>
<td>5</td>
<td>Double</td>
</tr>
<tr>
<td>7</td>
<td>Eket T.S - Itu T.S</td>
<td>75</td>
<td>Double</td>
</tr>
<tr>
<td>8</td>
<td>Itu T.S - Aba T.S</td>
<td>74.7</td>
<td>Double</td>
</tr>
<tr>
<td>9</td>
<td>Adiabor T.S - Itu T.S</td>
<td>10</td>
<td>Double</td>
</tr>
<tr>
<td>10</td>
<td>Omotosho G.S - Ajah T.S</td>
<td>145</td>
<td>Double</td>
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</tbody>
</table>

Table 4: Power flow result of the enhanced network

<table>
<thead>
<tr>
<th>S/N</th>
<th>Bus ID</th>
<th>V (pu)</th>
<th>Pgen (MW)</th>
<th>Qgen (Mvar)</th>
<th>Pload (MW)</th>
<th>Qload (Mvar)</th>
<th>S/N</th>
<th>Bus ID</th>
<th>V (pu)</th>
<th>Pgen (MW)</th>
<th>Qgen (Mvar)</th>
<th>Pload (MW)</th>
<th>Qload (Mvar)</th>
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<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>Itu T.S</td>
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<td>0.0</td>
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Table 5. Line flow result of the enhanced network

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<th>Q Flow (MW)</th>
<th>P Losses (MW)</th>
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Fig. 1. Voltage profile of the enhanced network
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<th>Q Flow (MW)</th>
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VI. CONCLUSION

In this work, the system profile analysis revealed that the existing network evacuated more power when more power station and transmission lines were added for the purpose of system enhancement. The maximum power the network evacuated was 12,342MW and 6,429MVar at a loading of 12,059.054MW and 7,411.694MVar. Nigeria grid network can only evacuate between 1,000MW and 4,000MW due to inefficiency, unreliability, not properly ringed network, high losses and power station breakdown. From the analysis, more generating stations and transmission lines should be built and added to the network and the single circuit lines should be upgraded to double circuit lines in order to boost generation and transmission, while control devices should be used in high and low voltage areas.

REFERENCES


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