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Voltage Stability Analysis of 86-Bus 330KV Nigeria Power Grid Based on Reserved Energy Potential via Continuation Power Flow Technique

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Abstract— **The Nigeria power system is being confronted by myriad of problems ranging from inadequate power generation capacity to meet demand, limited transmission corridor to evacuate generated power and insufficient reserves to sustain the existing capacity in times of sudden transients such as loss of generator/power plant. The objectives of this work include overview analysis of the procedures taken for the conversion of reserved energy resources of coal, natural gas and large hydro potentials into its equivalent electric power resource, evaluation of the reserved-based electric power resource, deployment of the reserved-based electric power resource into existing installed power generating capacity and voltage stability simulation of upgraded reserved-based electric power generating capacity model to enhance the totality of Nigeria power network stability. To meet the ever increasing power demand with increasing population, several megawatts (63,876.96 MW) from the reserved energy resources of large coal deposits (2,559 million tonnes or 12,081.96MW), unlimited reserved quantity of natural gas (5.4 trillion cubic meters or 39,270 MW) and abundant hydro reserve (12,525 MW) are deployed into the existing installed power generation capacity (12,682 MW) to form the reserved power potential injected Nigeria power network of 76,558.96 MW capacity. The introduction of 8,442 Km new transmission lines to the existing grid transmission lines of 5,988 Km were equally considered in this research in order to provide sufficient power evacuation corridor for efficient power flow management of the new network. The continuation power flow method which uses predictor, corrector and tangent techniques to generate the power – voltage (P – V) curves for the estimation of load ability limits to quantify voltage stability indices and determine the weak buses in the power network was deployed in the analysis. The results showed that majority of the network bus voltages met the acceptable voltage profile level of ±5 % tolerance of rated voltage value, that is, (0.95 PU, 313.5 KV) < V < (1.05 PU, 346.5 KV), with reduced transmission line congestion.**

Keywords— 86-bus 330 kV Nigeria power grid, voltage stability analysis, reserved energy resources, installed power generation capacity, voltage stability indices.component; formatting; style; styling; insert (key words)

I. INTRODUCTION

The existing Nigeria power network which comprises 5,988Km grid transmission lines (330 KV) is facing with the following problems: inability to effectively dispatch generated energy to meet the load demand; large number of uncompleted transmission line projects, reinforcement expansion projects in the power industry; poor voltage profile at the bus; inability of the existing transmission lines to wheel more than 4000 MW of power at present operational problems, voltage and frequency controls [1-5]. The grid system in Nigeria is almost radial single circuit lines, fragile and very long transmission line. Many of these lines experience total or partial system collapse when subjected to major disturbance and this makes voltage control difficult. Other problems include: poor network configuration in some regional work centres; ineffective control of the transmission line parameters; large numbers of overloaded transformers in the grid systems; the use of transmission lines beyond their thermal limits and frequent vandalism of 330KV transmission lines in various parts of the country [6,7]. Transmission-line voltage decreases when heavily loaded and increases when lightly loaded. This is line loadability. The line-loading limits are the thermal limits, the voltage-drop limit, and the steady-state stability limit. The existing power network must be transformed and expanded from radial to ring because of the high power losses associated with it and this help to maintain acceptable or allowable voltage violation drop of ±5 % of nominal value in the system.

Nigeria has sufficient reserved energy resources of coal, natural gas and new discovered hydro potentials that can serve as an input to all economic activities. Reserved energy resources of coal, natural gas and new discovered hydro potentials are the energy producing installations basket that contains power plants fired by fossil fuels (coal and natural gas) and hydro potentials[8,9]. The proven reserved coal in Nigeria is about 445 millions tones, consisting approximately of 81.05 % sub-bituminous, 4.81 % bituminous and 14.14 % lignite coals. The estimated reserved coal in Nigeria is about 2,559 million tonnes, consisting approximately of 42.32 % sub-bituminous, 45.17 % bituminous and 12.51 % lignite coals. The reserved proven coal and estimated coal can contribute 1,964 MW and 12,082 MW respectively to the grid system at 60 % capacity utilization for over 100 years. The total reserved proven natural gas in Nigeria are 4 trillion cubic meters (or 142 trillion standard cubic feet) and 5.4 trillion cubic meters (or 189 trillion standard feet) respectively. The reserved proven natural gas and estimated natural gas can contribute 29,505 MW and 39,270 MW respectively to the grid system at a capacity of 60 % for 100 years. The new discovered hydro potentials and the existing electricity generation capacity in Nigeria are about 12,525 MW and 12,682 MW respectively. The reserved estimated energy resources of coal, natural gas and new hydro potentials can contribute a total of 63,876.96 MW to the grid system, and when added to the existing installed capacity of 12,682 MW will give a total of 76,558.96 MW. Only 60.4 %

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(46,207 MW) of 76,558.96 MW is utilized in the current generation and transmission capacities expansion that gives expanded 86-bus network with the reserved energy resources.

The continuation power-flow (CPF) techniques are used to investigate the voltage stability analysis of reserved power potential injected Nigeria power network. The continuation power-flow network is formulated, and then implemented using MATLAB SIMULINK Power System Analysis (PSAT) program. The purpose of the continuation power-flow is to find a continuum of power-flow solution for any change in load. The general principle behind the continuation power-flow is simple. It employs a predictor – corrector scheme to find a solution path of a set of power-flow equations that have been reformulated to include a load parameter. It starts from a known solution corresponding to a different value of the load parameter. This estimate is then corrected using the same Newton – Raphson technique employed by a conventional power flow. The local parameterization provides a means of identifying each point along the solution path and plays an integral path in avoiding singularity in the Jacobian [10-12].

The solution power-voltage (P-V) curve is an important element in voltage stability analysis, which can be computed by continuation power flow method. The continuation power flow method is powerful and useful tool for obtaining solution power-voltage (P-V) curves for general non-linear algebraic equation by automatically changing the value of a parameter. These solutions power-voltage (P-V) curves are used to find the knee or critical point of voltage stability limit of a certain bus, which is at the nose of the curve. Voltage stability limit is the maximum loading point (MLP), which is computed by the continuation power flow method.

Power Generation and Load Projection Capacities

Power supply is either a source of generation or transformation from which the power is available to meet the load demand in megawatts. Presently, the total installed and on - going generating capacities in Nigeria is 12,682 MW whilst the available capacity is 3,863.5 MW or 31 %.This low average availability of the power plant is due to faulty generators, lack of machine maintenance and generally aging generators in the old power plants e.g. Kainji hydro power plant which was commissioned in 1968.

There are a number of government owned and independent power plant projects under way to expand the generation and consequently the grid. The available installed capacities of existing and ongoing Nigerian power plants are estimated at 12,682 MW. This means that even with new plants and transmission lines being added, there may still be inefficient generation and transmission capacities due to demand increase.

The word load is used to represent the present power consumption in the system and demand is used to represent the actual power need and future power consumption of the country. Load demand arises from the sudden load growth from industrial, commercial or residential development. The total load demand allocation for Nigeria power network estimation based on the total available generation capacity is about 3,152.31 MW with the total peak load demand of 3,927.5 7MW. The load allocation capacity in Nigeria is regional, comprising eight transmission regions of Lagos, Enugu, Osogbo, Port-Harcourt, Kaduna, Shiroro, Bauchi and Benin.

Since this load allocation is regional, there was a need to adopt it to the network such that regions are associated with nodes. **Table 1** shows the load nodal distribution for the demand forecast for years 2015, 2020 and 2025 with total load capacity of 3,603.47 MW. The total projected load capacities for 2015, 2020 and 2025 years are 13,157 MW, 18,280MW and 31,684 MW respectively, as shown in **Table 1**.

Table 1 Nigeria power network 330KV voltage level load projection.

Station	Current Load (MW)	% total load	2015	2020	2025
B.kebbi	124.40	3.45	454.21	631.07	1093.80
Jebba T.S	7.47	0.21	27.27	37.89	65.68
Osogbo	129.77	3.60	473.82	658.31	1141.02
Ayede	190.43	5.28	695.30	966.03	1674.38
Sakete	140.43	3.89	511.17	710.20	1230.97
Ikeja west	230.78	6.40	842.62	1170.72	2029.16
Akangba	247.62	6.87	904.11	1256.15	2177.23
Aja	200.00	5.55	730.24	1014.58	1758.53
Egbin	200.00	5.55	730.24	1014.58	1758.53
Ganmo	42.83	1.19	156.38	217.27	376.59
Kaduna	203.71	5.65	743.79	1033.40	1791.15
Shiroro	73.39	2.04	267.96	372.30	645.29
Katampe	280.00	7.77	1022.34	1420.41	2461.94
Jos	82.59	2.29	301.55	418.97	726.18
Kano	292.66	8.12	1068.56	1484.63	2573.25
Benin	173.08	4.80	631.95	878.02	1521.83
Ajaokuta	68.16	1.89	248.87	345.77	599.31
Gombe	74.81	2.08	273.15	379.50	657.78
New Heaven	113.05	3.14	394.76	573.49	994.01
Onitsha	130.51	3.62	476.52	662.06	1147.53
Aalaoji	219.79	6.10	802.50	1114.97	1932.53
Eket	50.50	1.40	184.39	256.18	444.03
Yola	26.29	0.73	95.99	481.57	834.68
Maiduguri	14.70	0.41	53.67	133.37	231.16
Port – Harcourt	286.93	7.96	1,065.64	1,048.56	1,817.44
TOTAL (MW)	**3,603.47**	**100.00**	**13,157.00**	**18,280.00**	**31,684.00**

II. MATERIALS AND METHODS

The work presented the overview analysis of the procedures taken for the conversion of reserved energy resources of coal, natural gas and large hydro potential into its equivalent electric power resource, evaluation of the reserved-based electric power resource, incorporation of the reserved-base electric power resource into existing installed power generating capacity and voltage stability simulation of the reserved-based electric power generating capacity model to enhance the totality of Nigeria power network stability.

Overview Analysis of the Procedures Taken for Conversion of Reserved Resource of Coal, Natural Gas and Large Hydro Potential

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(a) Coal Reserved Resource: Nigeria has a total proven coal energy reserve of 445 million tonnes comprising of sub-bituminous 361 million tonnes (81.05 %), bituminous 21.42 million tonnes (4.81 %) and lignite 63 million tonnes (14.14 %), and a total estimated coal energy reserve of 2,559 million toes comprising of sub-bituminous 1,083 million tonnes (42.32 %), bituminous 1,156 million tonnes (45.17 %) and lignite 320 million tonnes (12.51%).

The proven coal reserves of 445 million tonnes, located in various states Nigeria are expected to contribute a total computed equivalent electrical power value of 1,964 MW to the national grid system at 60% capacity utilization for over 100 years with the highest and lowest values of 757.24 MW and 113.95 MW recorded by Kogi state and Nassarawa state respectively as shown in **Figure 1.**

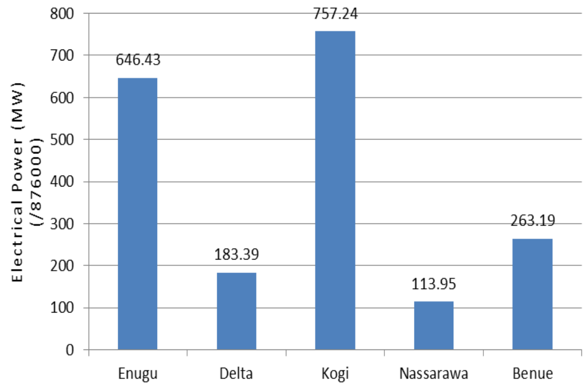

Figure 1 Proven coal reserves in Nigeria and the computed values of electrical energy potentials.

The estimated coal reserves of 2,559 million tonnes occurring in various states of Nigeria are expected to contribute a total computed equivalent electrical power value of 12,082 MW to the national grid system at 60 % capacity utilization for over 100 years with the highest and lowest values of 5,319.97 MW and 87.33 MW coming from Enugu state and Anambara state respectively as shown in **Figure 2.**

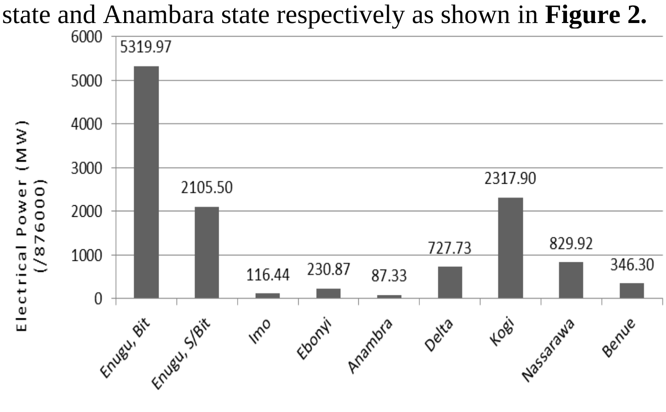

Figure 2 Estimate coal reserves in Nigeria and computed values of electrical energy potentials.

(b) Natural gas energy reserves: Nigeria has a total proven and estimated natural gas reserves of 4 trillion cubic meters (or 142 trillion standard cubic feet) and 5.4 trillion cubic meters (or 189 trillion standard cubic feet) respectively. The proven natural gas reserve would support 29,505 MW equivalent electrical capacity power plants operating at a capacity factor of 60 % for 100 years with River state and Imo or Abia state presenting the maximum and minimum values as shown in **Figure 3**.

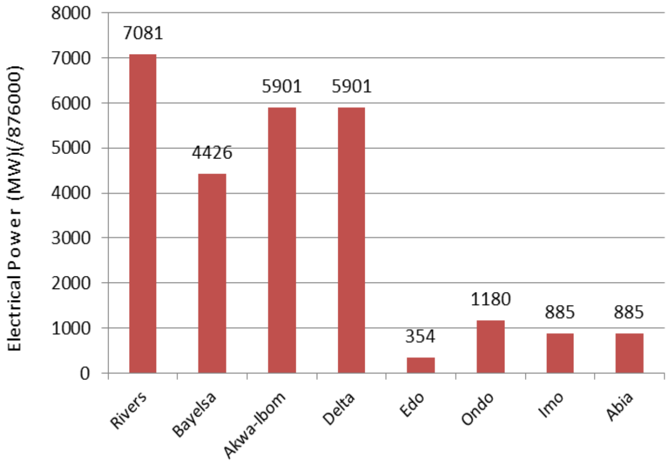

Figure 3 Proven gas reserves in Nigeria and computed values of electrical energy potentials.

The estimated natural gas reserve would contribute a sum total of 39,270 MW equivalent electrical capacity power plants operating at a capacity factor of 60 % for 100 years with the highest and lowest values of 9,425 MW and 1,178 MW coming from River state and Abia state respectively as shown in **Figure 4**.

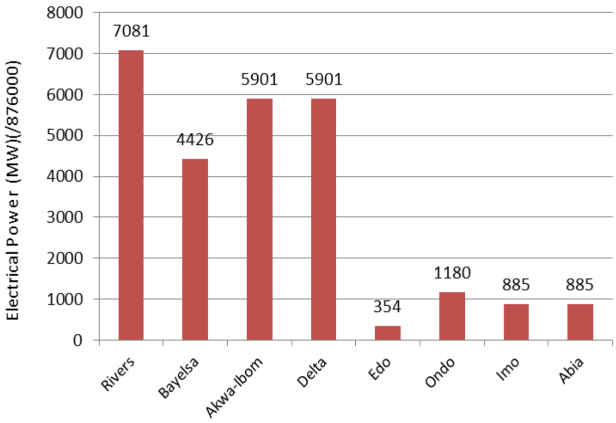

Figure 4 Proven gas reserves in Nigeria and computed values of electrical energy potentials.

(c) Energy Reserves Resources Comparison: A total computed generation capacity value of 43,994.20MW is obtained by comparing the proven fuel reserves of coal, natural gas and large new discovered hydro potentials as shown in **Figure 5**.

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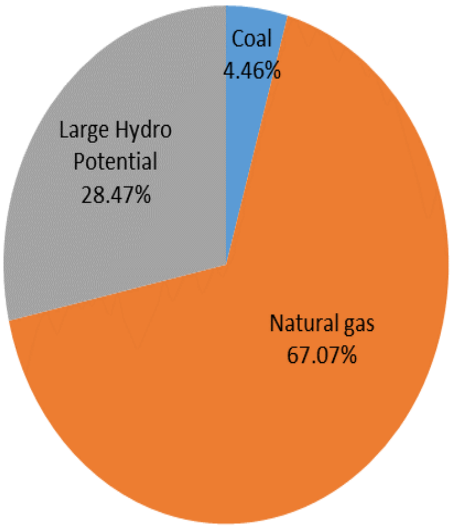

Figure 5 Comparison of electricity generation by proven fuel reserve.

A total computed generation capacity value of 63,876.96 MW is obtained by comparing the estimated fuel reserves of coal (12,081.96 MW), natural gas (39,270 MW) and new large discovered hydro potential (12,525 MW)[13]. The existing and on-going electricity generation by coal (2,340 MW), natural gas (8,404 MW) and hydro (1,938 MW) would contribute a total of 12,682 MW to Nigeria grid system. Both the proven reserve capacity (43,994.20 MW), existing and on-going generation projects (12,682 MW) would offer a grand total of 56,676.20 MW to Nigeria grid system, whereas, the estimated reserve capacity (63,876.96 MW), existing and on-going generation projects (12,682 MW) would as well provide a grand total of 76,558.96 MW to Nigeria grid system.

Evaluation and Deployment of Reserved-Based Electric Power Resource into Nigeria 28-bus Power Network

The overall integrity of the existing Nigeria 28-bus power network in fast increasing population growth is continuously affected by acute shortages of electric power generation and transmission capacities. The existing Nigeria 28-bus power network has as built electrical generation and transmission capacities detail design parameters comprising 12,682 MW and 5,988 Km grid and transmission capacities, 28 buses or nodes, 10 electric power plants, 18 load (PQ) buses, 16 equal numbers of single and double lines and 4 loops as shown in **Figure 6**. The existing Nigeria 28-bus power network is reinforced and strengthened with additional 41 reserved electric power plants operating at 33,525 MW capacity, 5,723 Km new transmission capacities, 17 new load (PQ) buses, 58 new buses, 3 new loops, 18 new single lines and 42 new double lines as shown in **Figure 7**.

The technical integrity of Nigeria power availability and evacuation capacities are restored by redesigning and redeveloping the 28-bus power network by deploying a grand total of 76,302.96 MW from the summation of the reserved estimated energy resources of coal(12,559x10^{10} tones or 12,081.96 MW), natural gas (5.32 trillion cubic meters or 189x10^{12} cubic feet or 39,270 MW, new discovered large hydro potentials(12,525 MW) and existing installed capacity(12,682MW) into the 28-bus test Nigeria power network to form improve and modernized reserved 86-bus electric power network.

The improved and modernized 86-bus reserved-based electric power network is characterized with the sound electrical generation and transmission capacities detailed design parameters comprising 86buses or nodes, 46,207 MW and 11,711 Km grid and transmission capacities,35 load (PQ) buses,7 loops, 34 single lines and 58 double lines as shown in **Figure 7**.

The process of modernization of the present Nigeria 28-bus power network with reserved energy sources would productively bring increase in industrial goods, agricultural products and quality life improvement of ever growing Nigeria population, which measure the annual per capita energy consumption from the energy availability and supply. Several numbers of coal-fired generating plants from the reserved energy sources are added into the present Nigeria 28-bus power network by looking at design technical features of new improved coal technology such as calorific value, weatherability, sulphur content, ash content, particle size, grindability index and caking quality.

High firing temperatures, advanced cooling systems, advanced materials to withstand higher temperatures and more efficient compressors with transonic blades are design technical considerations for deploying natural gas from reserved energy sources for modernisation and improvement of 28-bus power network.

Energy generation cost, capital cost of generators, capital cost of erecting and maintaining the transmission lines, and annual energy loss in transformation and transmission of electric power are considered for adding new hydro power generating plant from the reserved energy sources into 28-bus power network.

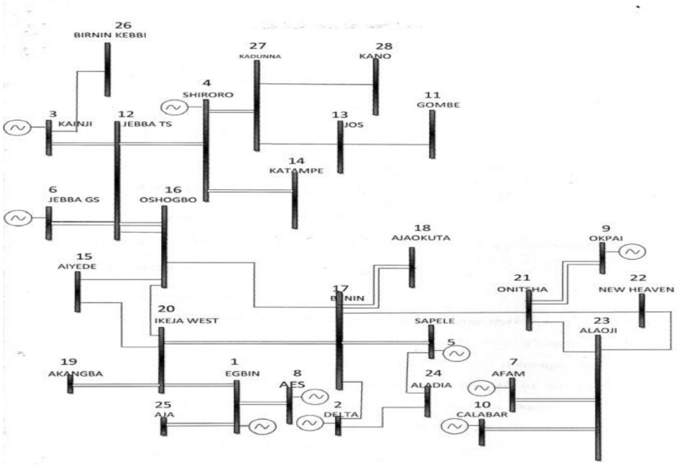

Figure 6 The existing 28 bus 330KV Nigerian transmission grid [13].

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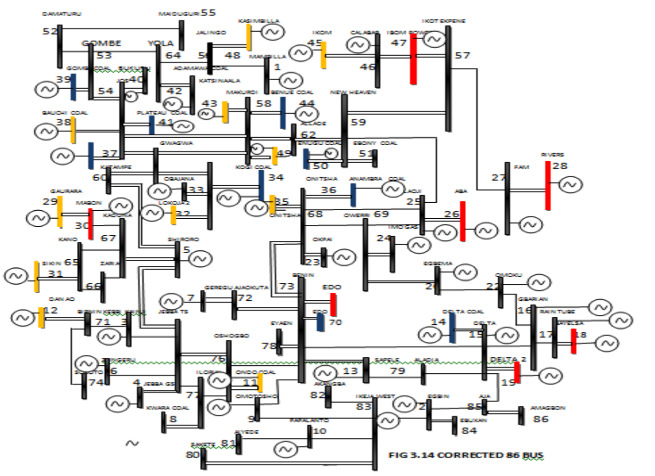

Figure 7 The improved and modernised 86-bus electric power network with the reserved energy resources [13].

The Continuation Power-Flow Analysis

The continuation methods are developed, formulated and implemented in assessing the voltage stability analysis of the improved and modernised reserved 86-bus electric power network in order to justify its viability and utilization in Nigeria power industry.

The Jacobian matrix of the conventional power-flow algorithms becomes singular at the voltage limit. These conventional power-flow algorithms are prone to convergence problems at operating conditions near the stability limit. The continuation power-flow analysis overcomes this problem by reformulating the power-flow equations so that they remain well-conditioned at all possible loading conditions. This allows the solution of the power-flow problem for stable (upper) and unstable (lower) portions (equilibrium points) of the P-V curves.

The continuation power-flow method uses a locally-parameterized continuation method for solving nonlinear algebraic equations known as path-following methods [14 - 17].

The continuation power-flow analysis uses an iterative process involving predictor and corrector steps. From a known initial solution, a tangent predictor is used to estimate the solution path for a specified pattern of load increase. The corrector step then determines the exact solution path using a conventional power-flow analysis with the system load assumed to be fixed. The voltages for a further increase in load are then predicted based on a new tangent predictor. If the new estimated load is now beyond the maximum load on the exact solution path, a corrector step with loads fixed would not converge; therefore, a corrector step with a fixed voltage at the monitored bus is applied to find the exact solution. As the voltage stability limit is reached, to determine the exact maximum load, the size of load increase is reduced gradually during the successive predictor steps.

Mathematical formulation of a continuation algorithm:

Power flow equations can be represented as

$$P_s = P(\theta, V) \qquad (1a)$$
$$Q_s = Q(\theta, V) \qquad (1b)$$

Where P_s, Q_s are specified active and reactive powers of buses, θ and V are bus voltage angles and magnitudes respectively.

Equation (1) can be expressed as,

$$F(\theta, V) = PQ_{spc} = [P_s, Q_s]^T$$

The reformulated power-flow equations, with provision for increasing generation as the load is increased, is expressed as,

$$F(\theta, V) = \lambda PQ_{spc} = \lambda[P_s, Q_s]^T \quad \text{or}$$
$$F(\theta, V) - \lambda[P_s, Q_s]^T = 0 \qquad (3)$$

where λ is the loading parameter. Equation (3) is set of nonlinear equations, which are solved by specifying a value of λ such that $0 \leq \lambda \leq \lambda_{critical}$. Where $\lambda = 0$ *represents the base load codition, and* $\lambda = \lambda_{critical}$ represents the critical load.

Equation (3) is rearranged as,

$$F(\theta, V, \lambda) = 0.0 \leq \lambda \leq \lambda_{critical} \qquad (4)$$

The computational procedures involved in continuation power-flow methods consist of predictor and corrector steps, as explained as follows:

Predictor Step: In the predictor step, a linear approximation is used to estimate the next solution for a change in one of the state variables (i.e., θ, V, or λ). Taking the partial derivatives of both sides of equation (4), with respect to the state variables (i.e., θ, V, or λ) corresponding to the initial solution, will result in the following set of linear equations:

Hence, $$\Delta F = \frac{\partial F}{\partial \theta}\Delta\theta + \frac{\partial F}{\partial v}\Delta V + \frac{\partial F}{\partial \lambda}\Delta\lambda \qquad (5a)$$

Or, $$dF = \frac{\partial F}{\partial \theta}d\theta + \frac{\partial F}{\partial v}dV + \frac{\partial F}{\partial \lambda}d\lambda = 0 \qquad (5b)$$

Or, $$d[F(\theta, V, \lambda)] = F_\theta\, d\theta + F_V\, dV + F_\lambda\, d\lambda = 0 \qquad (5c)$$

Now, $$\Delta F = F(\theta_0, V_0, \lambda_0) - F(\theta, V, \lambda) = -F(\theta, V, \lambda) \qquad (6)$$

where $(\theta_0, V_0, \lambda_0)$ is the solution of equation (4).

Using the above in equation (5) and writing in matrix form, gives

$$\left[\frac{\partial F}{\partial \theta}\frac{\partial F}{\partial v}\frac{\partial F}{\partial \lambda}\right]\begin{bmatrix}\Delta\theta\\ \Delta V\\ \Delta\lambda\end{bmatrix} = [-F(\theta, V, \lambda)] \qquad (7a)$$

Or, $$\left[\frac{\partial F}{\partial \theta}\frac{\partial F}{\partial v}\frac{\partial F}{\partial \lambda}\right]\begin{bmatrix}d\theta\\ dV\\ d\lambda\end{bmatrix} = [-F(\theta, V, \lambda)] \qquad (7b)$$

Or, $$[F_\theta F_V F_\lambda]\begin{bmatrix}d\theta\\ dV\\ d\lambda\end{bmatrix} = [-F(\theta, V, \lambda)] \qquad (7c)$$

This can be written as,

$$J.[\Delta\theta \Delta V \Delta\lambda]^T = [-F(\theta, V, \lambda)]$$

Or, $$[\Delta\theta \Delta V \Delta\lambda]^T = J^{-1}.[-F(\theta, V, \lambda)] \qquad (8a)$$

Or, $J.[d\theta dV d\lambda]^T = [-F(\theta, V, \lambda)]$
Or, $[d\theta dV d\lambda]^T = J^{-1}.[-F(\theta, V, \lambda)]$
(8b)

Where:
J is the Jacobian matrix.
$[\Delta\theta\Delta V\Delta\lambda]^T or [d\theta dV d\lambda]^T$ is the tangent vector being sought.
$[F_\theta F_V F_\lambda]$ is the partial derivative of F with respect to θ, V, λ.

Near the point of voltage collapse, the Jacobian matrix, J approaches singularity; hence it is difficult to calculate J^{-1} near the collapse point. To overcome this problem, one more equation is added, assuming one of the variables as fixed. This problem is solved by setting one of the components of tangent vector, say dλ as ±1, depending on who the solution curve changes. When the tangent vector, dλ is equal to +1, the solution curve increases and when dλ is equal to -1, the solution curve decreases. This fixed variable is called the continuation variable. Assuming that the i^{th} variable is the continuation variable, one can write,

$$[e_i][\Delta\theta\Delta V\Delta\lambda]^T = 0$$
(9a)

Or, $[e_i][d\theta dV d\lambda]^T = 0$
(9b)

$where [e_i]$ is the vector having i^{th} element as one and all other elements as zero.
Rewriting equation (11), gives

$$\begin{bmatrix} J \\ e_i \end{bmatrix} [\Delta\theta\Delta V\Delta\lambda]^T = \begin{bmatrix} -F(\theta, V, \lambda) \\ 0 \end{bmatrix}$$
(10a)

$$\begin{bmatrix} J \\ e_i \end{bmatrix} [d\theta dV d\lambda]^T = \begin{bmatrix} -F(\theta, V, \lambda) \\ 0 \end{bmatrix}$$
(10b)

The difference vector $[\Delta\theta\Delta V\Delta\lambda]^T or [d\theta dV d\lambda]^T$ is found from equation (10) and added with the initial assumption of vector ($(\theta_0\ V_0\ \lambda_0)$ to get the predictor. That is, the predicted value is computed by:

$$\begin{bmatrix} \theta \\ V \\ \lambda \end{bmatrix}^{predicted} = \begin{bmatrix} \theta_0 \\ V_0 \\ \lambda_0 \end{bmatrix} + h \begin{bmatrix} \Delta\theta \\ \Delta V \\ \Delta\lambda \end{bmatrix}^T$$
(11a)

Or, $\begin{bmatrix} \theta_0 \\ V_0 \\ \lambda_0 \end{bmatrix} + h \begin{bmatrix} d\theta \\ dV \\ d\lambda \end{bmatrix}^T$
(11b)

Where h is a scalar quantity representing the step size. In this study, the step size, h is assigned a constant value of 0.001. Hence, the procedures involved in predictor step are summarized as follows: specifying the step size h; finding the partial derivatives of F(θ, V, λ) with respect to θ, V and λ respectively; using the step size h and partial derivatives to find the next point or predicted value (θ, V, λ).
Corrector step:In the corrector step, the original set of equations of F(θ, V, λ) =$0 \leq \lambda \leq \lambda_{critical}$ is augmented by one equation that specifies the state variable selected as the continuation parameter. Thus, the new set of equation is

$$X_i = \mu^{predicted} or X_i - \mu^{predicted} = 0$$
(12)

$where \mu$ is the assumed fixed/predicted value of the continuation variable, and X_i is the state variable chosen as continuation parameter.
Thus, the system equations become,

F(θ, V, λ) = 0 and, $X_i - \mu^{predicted} = 0$
(13a)

$or, F(X, \lambda) = 0\ and, X_i - \mu^{predicted} = 0$
(13b)

Or, $\begin{bmatrix} F(X, \lambda) \\ X_i - \mu \end{bmatrix} = 0$
(13c)

In the above, X_i is the state variable selected as the continuation parameter andμ is the assumed fixed/predicted value of the continuation variable(X_i). This set of equations can be solved using a slightly modified Newton-Raphson power-flow method. The introduction of the additional equation specifying X_i makes the Jacobian non-singular at critical point and allows the computation of power flow solutions even beyond the critical point, i.e., in the lower portion of the P-V curve.
The tangent component of $\lambda(\ i.e., d\lambda)\ is$ positive for the upper portion of P-V curve, is zero at the critical point, and is negative beyond the critical point. Thus, the sign of the tangent component of $\lambda\ (\ i.e., d\lambda)$will indicate whether or not the critical point has been reached. If the continuation parameter is the load increase, the corrector will be a vertical line on the P-V plane. If, on the other hand, a voltage magnitude is the continuation parameter, the corrector will be a horizontal line on the plane.
Continuation power-flow allows the load voltage to be computed even when the power flow Jacobian matrix is singular. The complete P – V curve, including the critical (knee) point and the lower part of the curve, can be drawn using continuation power-flow. The complete P –V curves of the network are drawn using the MATLAB SIMULINK Power System Analysis Toolbox (PSAT) that uses continuation power flow.
Selecting the continuation parameter: The best method of selecting the correct continuation parameter at each step is to select the state variable with the largest tangent vector component. The selected state variable must have the evidence of producing the maximum rate of change near a given solution.

Application of Continuation Power-Flow Method to Investigate the Voltage Stability of Modernised reserved 86-Bus Electric Power Network

The improved and modernised Nigeria reserved 330 KV transmission grid has 86 nodes, 51 generators, 35 load (PQ) buses, 67 transformers, 42,207 MW and 11,711Km grid and transmission capacities, 34 and 58 numbers of single and double lines and 7 numbers of loops as shown in **Figure 7**.

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The total loads on the modernised power network are 4,795.02 MW and 3,596.25 Mvar respectively. The buses are numbered so that bus no.1 becomes slack bus whereas, buses no.2 to 51 and buses 52 to 86 are PV and PQ (load) buses respectively. The designed MATLAB SIMULINK model for investigating voltage stability of improved and modernised Nigeria reserved 330kV 86-bus electric power network via continuation power flow method is shown in figure 8. The new electric power network is designed using electrical blocks contained in the SIMULINK library. The main components of electrical power system: generators, transformers, transmissions lines and loads blocks are used as the interface between the two buses as shown in **Figure 8**.

The results obtained if favourable would prove its viability and utilization in Nigeria power industry. The input data for power/load flow analysis and CPF method is presented in **Table 2**. The continuation power flow method uses the conventional Newton – Raphson method at the base case where $\lambda=\lambda_0=0$ to compute the base power load data. Continuation power flow process is applied to 86 bus network system with reserved energy resources. Jacobian of the first load flow (Newton – Raphson) is used in the predictor step to predict state variables for the next loading factor (LF or λ). At the next loading factor (LF) and predicted state variables, the corrected state variables can be found in the corrector step. When the load flow solution is diverged, parametization step is activated at the last converged loading factor (LF). The complete system data is introduced in MATLAB code along with the generation and load profiles. The continuation power flow is run until the critical point is reached, that is when the maximum loading point/collapse point reaches, the continuation power flow will stop.

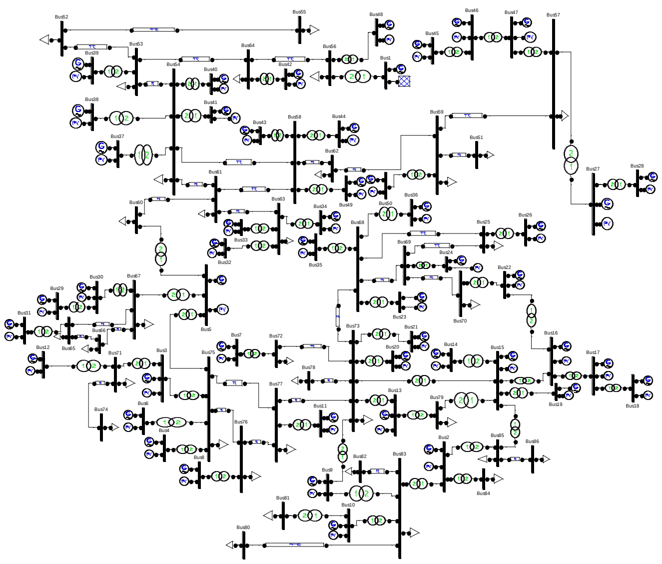

Fig 8: Designed MATLAB/SIMULINK circuit model for investigating voltage stability of improved and modernised reserved 330kV 86-bus electric power network via continuation power flow method.

III. RESULTS AND DISCUSSION

The continuation power-flow result of the improved and modernised reserved 86 bus electric power network under normal operating conditions is shown in table 3 and the corresponding voltage violation result, P – V curve and voltage profiles of the system are presented in figures 9 to 10 respectively.

Under normal operating conditions, the weakest bus is bus52 (Damaturu TS bus) with voltage profiles of 0.7946 pu (262.22 KV). Other weak buses include bus51 (Eboyi PS) and bus48 (Kasimbila hydro PS) with voltage profiles of 0.8323 pu (274.66 KV) and 0.8386pu (274.84 KV) as shown in **Table 3** and **Figure 9** respectively.

Table 3 shows individual bus voltages, bus phase angles, and total maximum active power load and total reactive power load of the modernised reserved 86-bus electric power network computed under normal operating conditions as 15.983 pu (4,795.02 MW) and 11.9875 pu (3,596.25 Mvar) respectively.

Figure 9(a) shows variation of bus voltage with increasing load factor, λ on the modernised reserved 86-bus electric power network under normal operating conditions. From the P – V curve of **Figure 9(a),** maximum loadability point/ collapse point, λ of the bus system is 1.1753 pu (352.59 MW). It means that the maximum power expected for the modernised reserved 86-bus electric power network to be loaded under base load point/normal operating conditions is 1.1753 pu (352.59 MW). The base load point is taken as 1pu = 300 MW = 300 Mvar. After that, the whole system might collapse at any time. At collapse point, only slack generator supplies the reactive power. Majority of the critical bus voltages of the modernised network fall within the acceptable voltage profiles range or voltage stability indices of ±5 % tolerance of the rated value, that is, 0.95 pu (313.5 KV) to 1.05 pu (346.5 KV) as shown in **Table 3** and **Figure 9** respectively. It means that the modernised reserved 86-bus electric power network is a stable network due to availability of adequate power generation and transmission capacities.

The simulations of a large disturbance, a 3-phase fault at all generator buses and all lines are performed on the modernised reserved 86-bus electric power network using continuation power-flow method. The continuation power-flow results after the 3-phase faults simulations of generator bus 2 and line 2 - 83 of the modernised reserved 86-bus electric power network are shown in **Tables 4 To 7**, respectively and the corresponding voltage violation results, P – V curves and voltage profiles of the system are shown in **figure 10 (a) and (b)** , respectively.

When a 3-phase fault occurred at generator bus 2, the continuation power-flow result, power-voltage (P – V) graph and voltage profiles are shown in **Table 4** and **Figures 10** respectively. The maximum loading point (λ) / collapse point increases from 1.1753 pu (352.59 MW) to 1.2166 pu (364.98 MW), indicating an improvement in the system voltage stability index/margin. Also, the overall/ total maximum active power load ($\sum P_{load}$) increases from 15.9834 pu (14,795.02 MW) to 16.5462 pu (4,963.86 MW), thus indicating an improvement in the voltage stability margin for the system. Voltage stability results analysis of the modernised reserved 86-bus electric power network after3-phase fault at different generator buses are summarised in **Table 5**.

When a 3-phase fault occurred at line 2 – 83, the continuation power flow result is presented in table 6 and the voltage violation result, corresponding P – V graph and

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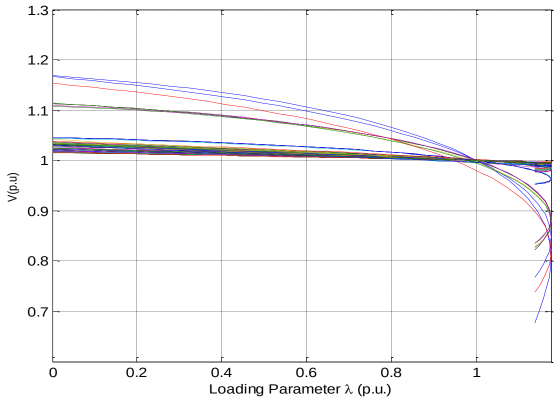
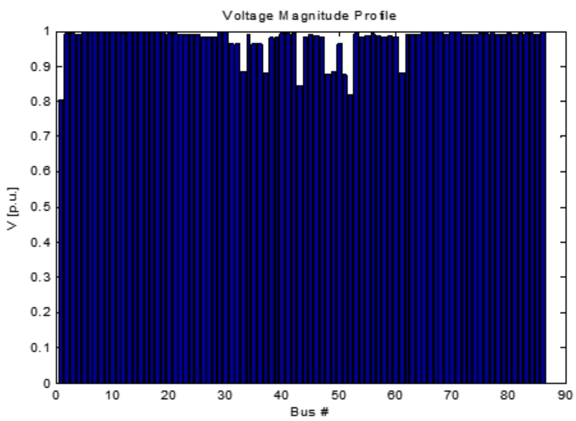
voltage profiles are shown in **Figures 11 (a) and (b)** respectively. The maximum loadability point recorded for a 3-phase fault occurred at line 2-83 is 1.1753 pu (352.59 MW). Voltage stability results analysis of the modernised reserved 86-bus electric power network after 3-phase fault at different transmission lines are summarised in **Table 7**.

These continuation power-flow results of the modernised reserved 86-bus electric power network recorded under normal operating conditions and after 3-phase faults at all generator buses and all lines indicated better voltage profile, better power quality, huge generation capacity and adequate power evacuation corridor.

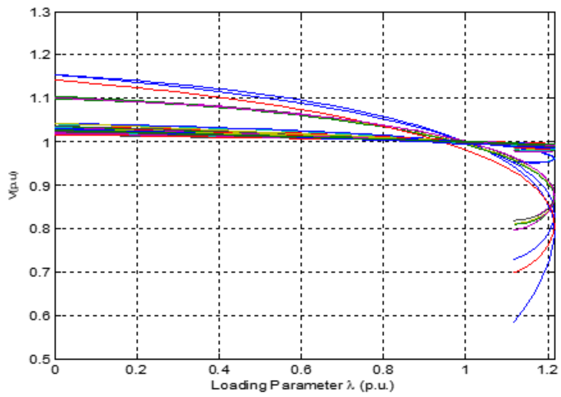


(a)

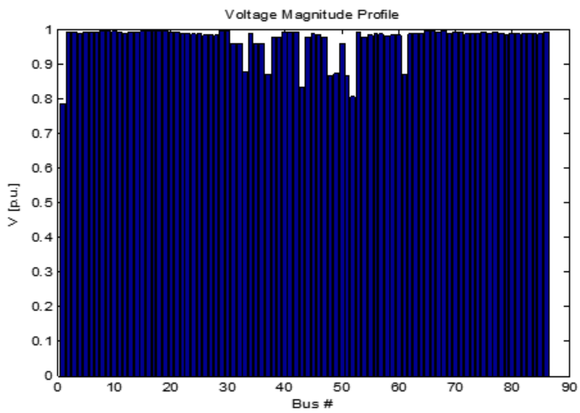


(b)

Figure 9 Represents (a) P – V curve of the modernised 86 bus network under normal operating conditions, (b) Voltage profiles of the modernised 86 bus network under normal operating conditions

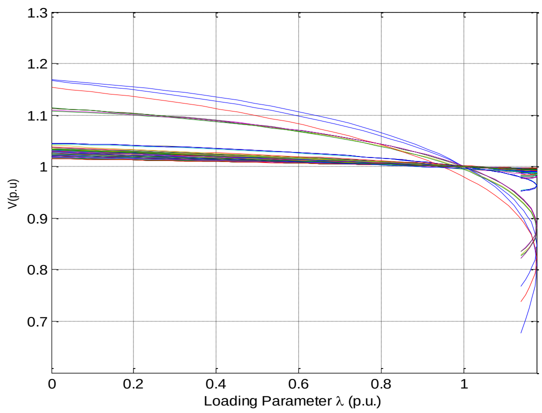


(a)

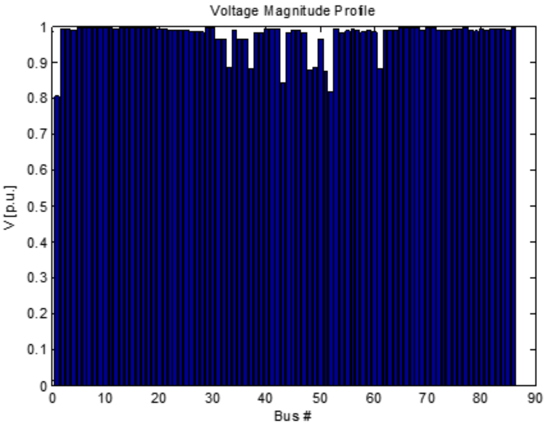


(b)

Figure 10 Represents (a) P – V curve of the modernised 86 bus network after 3-phase fault at generator bus 2, (b) Voltage profiles of the modernised 86 bus network after 3-phase fault at generator bus 2



(a)



(b)

Figure 11 Represents (a) P – V curve of the modernised 86 bus network after 3-phase fault at line 2-83, (b) Voltage profiles of the modernised 86 bus network after 3-phase fault at line 2-83

After a 3-phase fault at generator bus 2, the weakest bus is bus 52 (Damaturu TS bus) with voltage profiles of 0.8051 pu (265.68 KV). Other weak buses include bus43 (Kastina Ala1 hydro PS bus) and bus48 (Kasimbila hydro PS bus) with voltage profiles of 0.83067 pu (274.12 KV) and 0.86809 pu (286.47 KV) as shown in table 4 and **Figure 11 (a) and (b)** respectively.

The modernised reserved 86-bus electric power network recorded low and high voltage violations ranges of ±5 % tolerance of rated 1pu (330 KV), that is, 0.95pu (313.5 KV) to 1.05pu (346.5 KV) at different lines loss as follows: a total number of 8 voltage violations at the base case and on 48-56 line; 9 voltage violations on 25 lines and 10 voltage violations on 31 lines, as summarized in **Table 7**.

Tables 2 to 7 containing both Bus Data and Line Data of the networks used as input for the Simulation can be seen in the Appendix.

IV CONCLUSIONS

The improved and modernised Nigeria reserved 86-bus electric power network solved the voltage instability problems by providing adequate and sufficient generation and transmission line capacities. The voltage stability investigation results of the modernised reserved330 kV 86-bus electric power network recorded under normal operating conditions and after 3-phase faults showed that majority of bus voltage profiles and line loadability limits of this network met the acceptable range of ±5 % tolerance of rated value due to sufficient power generation and transmission capacities of 42,207 MW and 11,711 Km. This network accepts more loading and still retains its voltage stability limit to a very large extend. Majority of bus voltages of the modernised reserved 86-bus electric power network recorded a total number of 9 low and high voltage violations of ±5 % tolerance of rated 1pu (330KV), that is, 0.95pu (313.5 KV) to 1.05 pu (346.5 KV) at different generators loss contingencies. Whereas, a total number of 8 voltage violations at the base case and on 48-56 line, 9 voltage violations on 25 lines and 10 voltage violations on 31 lines are recorded at different lines loss by the same power network. The improved and modernised Nigeria reserved 86-bus electric power network presented an appreciable reduction in transmission line congestion, maintaining grid voltage stability and effective interconnectivity due to sufficient transmission and generation capacities.

REFERENCES

[1] A Iwayemi, Nigeria Dual Energy Problems: Policy Issues and Challenges, *International Association for Energy Economics*, 2010.

[2] DJ Obadote. Energy Crisis in Nigeria: Technical Issues and Solutions, Power Sector Prayer Conference, June 25-27, 2009.

[3] Nigeria Vision 2020 Program, "Analysis for Power Generation capacity required to support 20; 2020 Economic vision", Report of the Energy Sector National Technical working Group.

[4] AS Sambo, B Garba, IH Zarma and MM Gaji. Electricity Generation and the Present Challenges in the Nigerian Power Sector, Energy Commission of Nigeria, Abuja, Nigeria, 2011.

[5] AS Sambo. Paper presented at the "National Workshop on the Participation of State Government in The Power Sector: Matching Supply with Demand.

[6] Energy Profile of Nigeria, Available at: http://www.eoearth.org/article/energy profile of Nigeria published October 11, 2009.

[7] AO Cole. Restructuring the Electric Power Utility Industry in Nigeria, *Proc:, 20th National Conference of the Nigerian Society of Engineers (Electrical Division)*, pp. 1-6 October 6-7, 2004..

[8] MMSD Coal Exploration and Power Generating Opportunities in Nigeria, the Ministry of Mines and Steel Development, Nigeria, 2010. , Available at: http://mmsd.gov.ng/downloads/coal.pdf.

[9] United State Development of Energy, Coal Our Most Abundant Fuel, 2011.

[10] CR Werner and VBA John. locally Parameterized Continuation Process, *ACM Trans. On Mathematical Software*, Vol. 9, no 2, PP. 215-235, 1983.

[11] MZ Laton, I Musirin, and TK Abdul Rahman. Voltage Stability Assessment Via Continuation Power Flow Method, International *Journal of Electrical and Electronic Systems Research*, Vol. 1, PP 71-78, June 2008.

[12] HA Al-Awami. Power Flow Control to Determine Voltage Stability Limit by using the Continuation Method, EE 550, 062 Term Paper, Dept. Of Electrical Engineering, KFUPM, 2012.

[13] IO Akwukwaegbu, ENC Okafor, FI Izuegbunam and MC Ndinechi. Evaluation of the Reserved Energy Resource for Nigeria Power Generation and Transmission Capacities Improvement, *International Journal of Research in Engineering and Technology*, vol.5, Issue 5, pp.136-145, 2016.

[14] P Kundur. Power System Stability and Control, McGraw-Hill, pp.1012-1024, 1994.

[15] R Seydel. From Equilibrium to Chaos, Elsevier, New York, 1988.

[16] Rheinboldt, W. C., Numerical Analysis of Parameterized Nonlinear Equations, John Wiley and Sons, New York, 1986.

[17] IO Akwukwaegbu, ENC Okafor, FI Izuegbunam and MC Ndinechi. Voltage Stability Assessment of 330kV Nigeria Power System Using Continuation Power-flow Techniques, *International Journal of Engineering Research and Management*, vol. 3, Issue 6, pp. 222-233.

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APPENDIX

Table 2 The modernised Nigerian reserved 330kV 86-bus transmission grid line data on a base of 100MVA.

S/N	Lines Between buses		Bus No.		Length H(KM)	Circuit Type	Line Impendence (PU)			Tap Ratio
	From	To	from	To			R(PU)	X(PU)	B/2(PU)	
1	Mambilla	Jalingo	1	56	80	DC	0.0048	0.00373	0.99624	1
2	Egbin	Ikeja West	2	83	62	DC	0.0004	0.0029	0.771	1
3	Egbin	Eruka	2	84	42	SC	0.0004	0.00304	0.171	1
4	Egbin	Aja	2	85	16	DC	0.0007	0.0057	0.3855	1
5	Kainji	Birnin Kebbi	3	71	310	SC	0.004151	0.03041	1.8135	1
6	Kainji	Jebba TS	3	75	81	DC	0.000097	0.0082	0.924	1
7	Jebba GS	Jebba TS	4	75	8	DC	0.0001	0.0004	0.096	1
8	Shiroro	Katampe	5	60	144	DC	0.0009	0.0067	1.7933	1
9	Shiroro	Jebba TS	5	75	244	DC	0.0022	0.0234	1.3904	1
10	Shiroro	Kaduna	5	67	96	SC/SC	0.0011	0.0097	0.546	1
11	Zungeru	Jebba TS	6	75	90	DC	0.0054	0.0042	1.12077	1
12	Geregu	Ajaokuta	7	72	5	DC	0.00001	0.0005	0.057	1
13	Kwara Coal	Ilorin	8	76	30	DC	0.0018	0.0014	0.37359	1
14	Omotosho	Benin	9	73	120	SC	0.0014	0.0122	0.6841	1
15	Omotosho	Ikeja West	9	83	160	SC	0.0019	0.0162	0.9122	1
16	Papalanto	Aiyede	10	81	60	SC	0.0007	0.0061	0.3421	1
17	Papalanto	Ikeja West	10	83	30	SC	0.0004	0.003	0.171	1
18	Ondo Coal	Oshogbo	11	77	50	DC	0.003	0.002334	0.62265	1
19	Danko	Birnin Kebbi	12	71	18	DC	0.00108	0.00084	0.224154	1
20	Sapele	Benin	13	73	50	DC	0.0002	0.0015	0.936	1
21	Sapele	Aladja	13	79	63	SC	0.0008	0.0063	0.3585	1
22	Delta Coal	Delta PS	14	15	18	DC	0.00108	0.00084	0.224154	1
23	Delta PS	Gbarian	15	16	50	DC	0.003	0.002334	0.62265	1
24	Delta PS	Delta (gas)	15	19	18	DC	0.00108	0.00084	0.224154	1
25	Delta PS	Benin	15	73	107	SC	0.0008	0.0063	0.3585	1
26	Delta PS	Aladja	15	79	32	SC	0.0008	0.0063	0.3585	1
27	Delta PS	Aja	15	85	275	SC	0.0036	0.0269	1.6089	1
28	Gbarian	Rain/Ube	16	17	18	DC	0.00108	0.0084	0.224154	1
29	Gbarian	Omoku	16	22	60	DC	0.0036	0.0028	0.74718	1
30	Rain/Ube	Bayelsa (gas)	17	18	14	DC	0.00084	0.000653	0.17434	1
31	Egbema (gas)	Benin	20	73	18	DC	0.00108	0.00084	0.224154	1
32	Edo (gas)	Benin	21	73	18	DC	0.00108	0.00084	0.224154	1
33	Omoku	Edo	22	20	30	DC	0.0018	0.0014	0.37359	1
34	Okpai	Onitsha	23	68	80	DC	0.0002	0.0014	0.3736	1
35	Imo (gas)	Owerri	24	69	18	DC	0.0015	0.0012	0.312	1
36	Alaoji (hydro)	Aba	25	26	8	DC	0.0001	0.0004	0.096	1
37	Alaoji (hydro)	Onitsha	25	68	138	DC	0.00792	0.00616	1.6434	1
38	Alaoji (hydro)	Owerri	25	69	69	DC	0.0163	0.014	0.786	1
39	Afam (I – V) gas	Rivers (gas)	27	28	18	DC	0.0004	0.0028	0.7472	1
40	Afam (I – V) gas	Ikot Ekpene	27	57	90	DC	0.0054	0.0042	1.12077	1
41	Guarara (hydro)	Mabon (gas)	29	30	30	DC	0.0054	0.0042	1.1208	1
42	Mabon (gas)	Kaduna	30	67	18	DC	0.00108	0.00084	0.224154	1
43	Sarkin (hydro)	Kano	31	65	18	DC	0.00108	0.00084	0.224154	1

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44	Lokoja (hydro)	Lokoja	32	63	20	DC	0.0012	0.000933	0.24906	1
45	Obajana (hydro)	Lokoja	33	63	23	DC	0.00138	0.001073	0.286419	1
46	Kogi (coal)	Lokoja	34	63	18	DC	0.00108	0.00084	0.224154	1
47	Onitsha$_2$ (hydro)	Onitsha	35	68	10	DC	0.0006	0.000467	0.012453	1
48	Anambra (coal)	Onitsha	36	68	18	DC	0.00108	0.00084	0.224154	1
49	Plateau (hydro)	Jos	37	54	25	DC	0.0015	0.001167	0.311351	1
50	Bauchi (coal)	Jos	38	54	150	DC	0.009	0.007	1.86795	1
51	Gombe (coal)	Gombe	39	53	18	DC	0.00108	0.00084	0.224154	1
51	Bukuru (coal)	Jos	40	54	10	DC	0.0006	0.000467	0.012453	1
53	Plateau (coal)	Jos	41	54	18	DC	0.00108	0.00084	0.224154	1
54	Adamawa (coal)	Yola	42	64	18	DC	0.00108	0.00084	0.224154	1
55	Katsina Ala (hydro)	Makurdi	43	58	98	DC	0.00588	0.004574	1.220394	1
56	Benue (coal)	Makurdi	44	58	18	DC	0.00108	0.00084	0.224154	1
57	Ikom (hydro)	Calabar	45	46	25	DC	0.0015	0.001167	0.311351	1
58	Ibom (gas)	Ikot Ekpene	46	57	18	DC	0.00108	0.00084	0.224154	1
59	Kasimbela (hydro)	Jalingo	47	56	18	DC	0.00108	0.00084	0.224154	1
60	Katsina Ala$_2$ (hydro)	Makurdi	49	58	100	DC	0.006	0.004667	1.2453	1
61	Enugu (coal)	New Heaven	50	59	18	DC	0.00108	0.00084	0.224154	1
62	Ebonyi (coal)	New Heaven	51	59	70	DC	0.0042	0.003267	0.87171	1
63	Damturu (coal)	Gombe	51	53	30	DC	0.0018	0.0014	0.37359	1
64	Dmaturu (coal)	Maiduguri	51	55	308	SC	0.0002	0.0029	0.1649	1
65	Gombe TS	Jos	53	54	265	SC	0.004	0.0302	1.8018	1
66	Jos	Gwagwa	54	61	180	SC	0.0032	0.027	1.515	1
67	Jos	Makurdi	54	58	230	DC	0.0013	0.0099	2.3517	1
68	Jalingo	Kasimbila (hydro)	56	48	150	DC	0.0017	0.0126	3.0069	1
69	Jalingo	Yola	56	64	132	SC	0.00792	0.00616	1.6434	1
70	Ikot Ekpene	New Heaven	57	59	143	DC	0.0016	0.0134	0.7515	1
71	Makurdi	Gwagwa	58	61	201	DC	0.0005	0.0033	3.5618	1
72	Makurdi	Aliade	58	62	50	DC	0.0014	0.0107	2.8644	1
73	New Heaven	Aliade	59	62	150	DC	0.0003	0.0023	0.6227	1
74	Katampe	Gwagwa	60	61	30	DC	0.0009	0.007	1.8681	1
75	Gwagwa	Lokoja	61	63	140	DC	0.0018	0.0014	0.3736	1
76	Kano	Zaria	65	66	147	SC	0.0008	0.0065	1.7435	1
77	Kano	Kaduna	65	67	81	SC	0.000097	0.0082	0.924	1
78	Zaria	Kaduna	66	67	81	SC	0.000097	0.0082	0.924	1
79	Onitsha	Owerri	68	69	137	DC	0.0019	0.0144	0.8307	1
80	Onitsha	Benin	68	73	137	SC	0.0008	0.0064	1.7062	1
81	Owerri	Egbema (gas)	69	20	30	DC	0.0016	0.0139	0.781	1
82	Birnin Kebbi	Sokoto	71	74	142	SC	0.0002	0.0014	0.3736	1
83	Ajaokuta	Benin	72	73	195	SC/SC	0.0019	0.0139	0.8307	1
84	Benin	Oshogbo	73	77	251	SC	0.0023	0.0198	0.748	1
85	Benin	Eyaen	73	78	5	DC	0.0003	0.0254	1.431	1
86	Jebba TS	Ilorin	75	76	84	SC	0.0001	0.0002	0.0623	1
87	Jebba TS	Oshogbo	75	77	157	SC/SC	0.0011	0.0083	0.4914	1
88	Ilorin	Oshogbo	76	77	90	SC	0.0019	0.00159	0.8955	1
89	Sakete	Ikeja West	80	83	70	SC	0.0012	0.0088	0.5165	1
90	Akangba	Ikeja West	82	83	18	SC/SC	0.00084	0.00709	0.3991	1
91	Aja	Alagbon	85	86	26	DC	0.0007	0.0057	0.3855	1

Table 3 Continuation power flow result of the modernised reserved 86-bus electric power network under normal operating conditions.

Bus No	V [pu]	phase [rad]	P gen [pu]	Q gen [pu]	P load [pu]	Q load [pu]
Bus1	0.89653	0	-12.4627	3.359	0	0
Bus2	1.0012	0.99459	1.153	1.6714	0	0
Bus3	1.0011	0.98753	1.1529	-2.9634	0	0
Bus4	1.0015	0.97031	1.153	1.2907	0	0
Bus5	1.0009	1.0022	1.153	0.12667	0	0

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Bus6	1.0009	1.0043	1.1529	-1.6757	0	0
Bus7	1.0009	1.004	1.1526	9.09	0	0
Bus8	1.0008	1.0071	1.1529	-1.4166	0	0
Bus9	1.0008	1.0077	1.1529	-1.9497	0	0
Bus10	1.0008	1.0079	1.1529	-1.3942	0	0
Bus11	1.0009	1.0043	1.1529	-1.6757	0	0
Bus12	1.0012	0.99479	1.1529	2.99	0	0
Bus13	1.0009	1.0022	1.1529	-2.0713	0	0
Bus14	1.0009	1.0022	1.1529	-2.0713	0	0
Bus15	1.0008	1.008	1.1529	-0.9887	0	0
Bus16	1.0007	1.0175	1.153	-0.19376	0	0
Bus17	1.0006	1.0183	1.1529	-1.6837	0	0
Bus18	1.0007	1.0174	0	0	1.1564	0.86732
Bus19	1.0007	1.0175	1.1529	-0.93657	0	0
Bus20	0.99761	0.96593	1.1529	-1.6801	0	0
Bus21	0.99765	0.96629	1.153	-0.19555	0	0
Bus22	0.99753	0.95597	1.1529	-1.5857	0	0
Bus23	1.0009	0.97423	1.153	0.1196	0	0
Bus24	0.99759	0.95452	1.153	0.73989	0	0
Bus25	0.99949	0.95132	1.1529	-1.3686	0	0
Bus26	0.98469	0.91792	1.1529	-1.1618	0	0
Bus27	0.98469	0.91797	1.1529	-1.1786	0	0
Bus28	0.98468	0.91789	1.1529	-1.1501	0	0
Bus29	1.0007	1.0175	1.1529	-1.4705	0	0
Bus30	1.0007	1.0176	1.1529	-1.6758	0	0
Bus31	0.94361	0.83243	1.1529	-0.36053	0	0
Bus32	0.94458	0.83448	1.1529	-1.436	0	0
Bus33	0.83664	0.46964	1.1532	4.5109	0	0
Bus34	1.0014	0.97424	1.1529	4.685	0	0
Bus35	0.94349	0.8322	1.153	1.4546	0	0
Bus36	0.94354	0.83231	1.153	0.11555	0	0
Bus37	0.97961	0.90231	1.1529	-1.8999	0	0
Bus38	0.8500	0.40231	1.1518	-10.8459	0	0
Bus39	0.97943	0.90104	1.1529	-3.431	0	0
Bus40	0.99776	0.9661	1.1529	-1.525	0	0
Bus41	0.99778	0.9657	1.153	1.208	0	0
Bus42	0.9977	0.9639	1.1529	1.8863	0	0
Bus43	0.85063	0.27351	1.1533	14.1567	0	0
Bus44	0.97962	0.90234	1.1529	-1.8863	0	0
Bus45	0.99675	0.95421	1.1529	-0.35171	0	0
Bus46	0.99477	0.9224	1.1529	-1.5871	0	0
Bus47	0.99452	0.92018	0	0	1.1564	0.86732
Bus48	0.83286	0.46937	0	0	1.1564	0.86732
Bus49	0.83424	0.47007	0	0	1.1564	0.86732
Bus50	0.94281	0.83223	0	0	1.1564	0.86732
Bus51	0.83231	0.46725	0	0	1.1564	0.86732
Bus52	0.7946	0.27454	0	0	1.1564	0.86732
Bus53	1.0004	0.96379	0	0	1.1564	0.86732
Bus54	1.0023	0.90053	0	0	0	0
Bus55	1.0019	0.92211	0	0	1.1564	0.86732
Bus56	1.0014	0.97541	1.1529	-1.1041	0	0

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Bus57	1.0018	0.94757	0	0	1.1564	0.86732
Bus58	0.98225	0.91065	0	0	1.1564	0.86732
Bus59	0.99479	0.91655	0	0	1.1564	0.86732
Bus60	0.98461	0.91766	0	0	1.1564	0.86732
Bus61	0.85094	0.40094	0	0	1.1564	0.86732
Bus62	0.99957	0.95106	0	0	1.1564	0.86732
Bus63	1.003	0.9495	0	0	1.1564	0.86732
Bus64	0.99748	0.95422	0	0	1.1564	0.86732
Bus65	1.0007	1.0173	0	0	0	0
Bus66	1.0007	1.0178	0	0	0	0
Bus67	1.001	1.0019	1.153	0.24436	0	0
Bus68	1.0007	1.0081	0	0	1.1564	0.86732
Bus69	1.0012	0.97037	0	0	1.1564	0.86732
Bus70	1.001	1.0019	0	0	1.1564	0.86732
Bus71	1.001	1.0019	0	0	1.1564	0.86732
Bus72	1.0005	0.96937	0	0	1.1564	0.86732
Bus73	1.0012	0.97424	0	0	1.1564	0.86732
Bus74	0.99981	0.97511	0	0	1.1564	0.86732
Bus75	1.0015	0.98629	0	0	1.1564	0.86732
Bus76	1.002	0.98194	0	0	1.1564	0.86732
Bus77	1.0006	1.0028	0	0	1.1564	0.86732
Bus78	1.0014	0.97504	1.153	1.2332	0	0
Bus79	0.99719	0.98821	0	0	1.1564	0.86732
Bus80	1.0005	0.99389	0	0	1.1564	0.86732
Bus81	0.99759	0.98945	0	0	1.1564	0.86732
Bus82	1.0009	0.99462	0	0	1.1564	0.86732
Bus83	1.0009	0.99446	0	0	1.1564	0.86732
Bus84	1.0004	0.9953	0	0	1.1564	0.86732
Bus85	0.99761	0.99117	0	0	1.1564	0.86732
Bus86	1.001	0.99964	1.153	-0.04158	0	0
Total			**18.1499**	**6.983**	**15.9834**	**11.9875**

Table 4 Continuation power-flow result of modernised reserved 86-bus electric power network after 3-phase fault at generator bus 2.

Bus No	**V [pu]**	**phase [rad]**	**P gen [pu]**	**Q gen [pu]**	**P load [pu]**	**Q load [pu]**
Bus1	0.78648	0	-5.1715	1.5681	0	0
Bus2	0.9916	1.6498	0.50621	1.4049	0	0
Bus3	0.99187	1.6438	0.50624	-0.77326	0	0
Bus4	0.98931	1.6248	0.50612	0.54199	0	0
Bus5	0.99357	1.6615	0.50613	0.1309	0	0
Bus6	0.99381	1.664	0.50618	-0.4892	0	0
Bus7	0.99375	1.6637	0.50689	3.2377	0	0
Bus8	0.99432	1.6671	0.50617	-0.40957	0	0
Bus9	0.99443	1.6677	0.50619	-0.5875	0	0
Bus10	0.99447	1.6679	0.50617	-0.40385	0	0
Bus11	0.99381	1.664	0.50618	-0.4892	0	0
Bus12	0.98997	1.65	0	0	0	0
Bus13	0.99359	1.6614	0.50619	-0.5796	0	0

Bus14	0.99359	1.6614	0.50619	-0.5796	0	0
Bus15	0.99448	1.6681	0.50615	-0.27448	0	0
Bus16	0.99539	1.6816	0.50613	-0.01669	0	0
Bus17	0.99551	1.6822	0.50617	-0.51181	0	0
Bus18	0.99539	1.6819	0	0	0.48665	0.36499
Bus19	0.99537	1.682	0.50615	-0.2625	0	0
Bus20	0.99266	1.6214	0.50618	-0.47863	0	0
Bus21	0.99274	1.6219	0.50613	0.01159	0	0
Bus22	0.9883	1.6054	0.50619	-0.39523	0	0
Bus23	0.98971	1.6295	0.50613	0.1441	0	0
Bus24	0.98795	1.604	0.50611	0.37412	0	0
Bus25	0.9878	1.6003	0.50618	-0.31726	0	0
Bus26	0.98267	1.5525	0.50617	-0.1996	0	0
Bus27	0.98269	1.5525	0.50618	-0.20439	0	0
Bus28	0.98266	1.5525	0.50617	-0.19634	0	0
Bus29	0.99539	1.6815	0.50617	-0.44032	0	0
Bus30	0.99542	1.6817	0.50617	-0.50871	0	0
Bus31	0.95989	1.4378	0.50611	0.27437	0	0
Bus32	0.96094	1.4391	0.50621	-0.05359	0	0
Bus33	0.87497	0.85828	0	0.50459	2.3524	0
Bus34	0.98956	1.6294	0.50621	1.5104	0	0
Bus35	0.95983	1.4377	0.50607	0.41098	0	0
Bus36	0.95977	1.4376	0.50597	0.80995	0	0
Bus37	0.87026	0.74092	0.50933	-1.7527	0	0
Bus38	0	0.9791	1.534	0.50623	-0.39972	0
Bus39	0.97866	1.5329	0.50639	-0.91253	0	0
Bus40	0.99272	1.6221	0.50617	-0.42794	0	0
Bus41	0.99264	1.6217	0.50613	0.47706	0	0
Bus42	0.99226	1.6193	0.50613	0.70537	0	0
Bus43	0.83067	0.56773	0.50188	5.1216	0	0
Bus44	0.97911	1.5341	0.50623	-0.39531	0	0
Bus45	0	0.9874	1.6036	0.50614	0.00471	0
Bus46	0.98379	1.5637	0.5062	-0.34485	0	0
Bus47	0.97847	1.5614	0	0	0.48665	0.36499
Bus48	0.86809	0.85846	0	0	0.48665	0.36499
Bus49	0.87407	0.85921	0	0	0.48665	0.36499
Bus50	0.95953	1.4377	0	0	0.48665	0.36499
Bus51	0.86562	0.85489	0	0	0.48665	0.36499
Bus52	0.36499	0.8051	0.56889	0	0	0.48665
Bus53	0.99152	1.6192	0	0	0.48665	0.36499
Bus54	0.97872	1.5325	0	0	0	0
Bus55	0.36499	0.9837	1.5634	0	0	0.48665
Bus56	0.98987	1.6306	0.50616	0	-0.2681	0
Bus57	0.36499	0.9864	1.5949	0	0	0.48665
Bus58	0.98126	1.546	0	0	0.48665	0.36499
Bus59	0.98435	1.5558	0	0	0.48665	0.36499
Bus60	0.98253	0.36499	1.5522	0	0	0.48665
Bus61	0.87057	0.36499	0.48665	0.73992	0	0
Bus62	0.36499	0.48665	0	0.9877	1.6	0
Bus63	0.98844	0	1.598	0	0.48665	0.36499
Bus64	0.98759	0.36499	1.6037	0	0	0.48665

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Bus65	0.99537	0	1.6814	0	0	0
Bus66	0.99547	0	1.6818	0	0	0
Bus67	0.99342	0	1.6617	0	0.50613	0.1518
Bus68	0.99439	0.36499	1.6682	0.48665	0	0
Bus69	0.98899	0.36499	1.6248	0.48665	0	0
Bus70	0.36499	0.48665	0.9934	0	1.6617	0
Bus71	0.99356	0.36499	1.6611	0	0	0.48665
Bus72	0.98801	0.36499	1.6235	0	0	0.48665
Bus73	0.98934	1.6294	0	0	0.48665	0.36499
Bus74	0.98925	1.6305	0	0	0.48665	0.36499
Bus75	0.99195	1.6427	0	0	0.48665	0.36499
Bus76	0.98954	1.636	0	0	0.48665	0.36499
Bus77	0.99322	1.6621	0	0	0.48665	0.36499
Bus78	0.98975	1.6305	0.50612	0.42647	0	0
Bus79	0.98512	1.6417	0	0	0.48665	0.36499
Bus80	0.99076	1.6489	0	0	0.48665	0.36499
Bus81	0.98591	1.6432	0	0	0.48665	0.36499
Bus82	0.99058	1.6499	0	0	0.48665	0.36499
Bus83	0.98955	1.6495	0	0	0.48665	0.36499
Bus84	0.98957	1.651	0	0	0.48665	0.36499
Bus85	0.98572	1.6457	0	0	0.48665	0.36499
Bus86	0.99287	1.6574	0.50613	0.20764	0	0
Total			**18.6163**	**7.1937**	**16.5462**	**12.4097**

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Table 5 summary of voltage stability results analysis of the modernised reserved 86-bus electric power network after3-phase fault at different generator buses.

Loss of Generator	Maximum loading factor/ Collapse Pt λ (pu)	Total generation		Total load		Total losses		Voltage Violations
		Real power Ptotal (pu)	Reactive power Qtotal (pu)	Real load power Ptotal (pu)	Reactive load power Qtotal (pu)	Real power loss Ploss (pu)	Reactive power loss Qloss (pu)	
2	1.2166	18.6163	7.1937	16.5462	12.4097	2.0701	-5.216	9
3	1.2176	18.6417	7.2024	16.5599	12.42	2.0817	-5.2176	9
4	1.2175	18.6397	7.1995	16.5584	12.4188	2.0813	-5.2192	9
5	1.2177	18.642	7.2131	16.5604	12.4203	2.0816	-5.2072	9
6	1.2176	18.6403	7.2002	16.5591	12.4193	2.0812	-5.2192	9
7	1.2166	18.6151	7.1892	16.5455	12.4091	2.0696	-5.2199	9
8	1.2176	18.6395	7.2004	16.5586	12.419	2.0809	-5.2186	9
9	1.2166	18.6143	7.1821	16.5452	12.4089	2.0691	-5.2268	9
10	1.2166	18.6161	7.1923	16.5461	12.4096	2.07	-5.2173	9
11	1.2166	18.6163	7.1822	16.5452	12.4089	2.0711	-5.2267	9
12	1.2177	18.6437	7.2163	16.5609	12.4207	2.0828	-5.2044	9
13	1.2165	18.6133	7.1773	16.5447	12.4086	2.0686	-5.2313	9
14	1.2165	18.6126	7.1751	16.5443	12.4082	2.0683	-5.2331	9
15	1.2163	18.6091	7.1719	16.5417	12.4062	2.0675	-5.2344	9
16	1.2162	18.606	7.1701	16.5401	12.4051	2.0659	-5.235	9
17	1.2161	18.6048	7.1692	16.5393	12.4045	2.0654	-5.2353	9
18	1.2161	18.6045	7.169	16.5392	12.4044	2.0653	-5.2354	9
19	1.2165	18.6126	7.1751	16.5443	12.4082	2.0683	-5.2331	9
20	1.2165	18.6133	7.1771	16.5448	12.4086	2.0685	-5.2315	9
21	1.2165	18.6133	7.1771	16.5448	12.4086	2.0685	-5.2315	9
22	1.2162	18.6051	7.1698	16.5396	12.4047	2.0655	-5.235	9
23	1.2163	18.6086	7.1636	16.5419	12.4065	2.0667	-5.2428	9
24	1.2163	18.6081	7.1625	16.5416	12.4062	2.0665	-5.2437	9
26	1.2166	18.615	7.1731	16.5459	12.4094	2.0691	-5.2364	9
27	1.2175	18.636	7.1787	16.5581	12.4186	2.0778	-5.2399	9
28	1.2175	18.636	7.1785	16.5582	12.4186	2.0778	-5.2401	9
29	1.2176	18.6399	7.2121	16.559	12.4193	2.0809	-5.2071	9
30	1.2176	18.641	7.2138	16.5597	12.4198	2.0813	-5.206	9
31	1.2178	18.6405	7.2199	16.5623	12.4217	2.0829	-5.2019	9
32	1.2171	18.6319	7.2199	16.5519	12.4139	2.08	-5.1941	9
33	1.2171	18.6319	7.2198	16.5519	12.4139	2.08	-5.1941	9
34	1.2171	18.6319	7.2199	16.5519	12.4139	2.08	-5.1941	9
35	1.2163	18.6088	7.1637	16.5421	12.4066	2.0667	-5.2428	9
36	1.2163	18.6085	7.1635	16.5419	12.4064	2.0666	-5.2429	9
37	1.2137	18.5941	7.2358	16.5066	12.3799	2.0875	-5.1441	9
38	1.2137	18.5932	7.2333	16.5064	12.3798	2.0868	-5.1465	9
39	1.1374	17.4973	5.7411	15.4685	11.6014	2.0288	-5.8603	9
40	1.2137	18.5936	7.2358	16.5059	12.3794	2.0877	-5.1436	9
41	1.2137	18.594	7.2359	16.5064	12.3798	2.0876	-5.1439	9
42	1.1341	17.216	5.2227	15.424	11.568	1.7919	-6.3454	9
43	1.2172	18.6367	7.2329	16.5537	12.4153	2.0829	-5.1824	9
44	1.2177	18.6455	7.2385	16.5604	12.4203	2.0851	-5.1818	9
45	1.2177	18.6392	7.1799	16.5603	12.4202	2.0789	-5.2403	9
46	1.2177	18.6394	7.1801	16.5604	12.4203	2.079	-5.2402	9
47	1.2176	18.6377	7.1805	16.5591	12.4193	2.0786	-5.2388	9
48	1.0978	16.6323	4.1426	14.9299	11.1974	1.7024	-7.0548	9
49	1.2172	18.6336	7.2329	16.4153	12.4153	2.0829	-5.1824	9
50	1.2177	18.6441	7.215	16.5612	12.4209	2.0829	-5.2059	9

Table 6 Continuation power-flow result of modernised reserved 86-bus electric power network after 3-phase fault at line 2 – 83.

Bus No	V [pu]	phase [rad]	P gen [pu]	Q gen [pu]	P load [pu]	Q load [pu]
Bus1	0.80498	0	-5.286	1.6361	0	0
Bus2	0.99349	1.666	0.48827	0.85559	0	0
Bus3	0.99324	1.6573	0.48837	-0.90576	0	0
Bus4	0.99086	1.6363	0.48825	0.52821	0	0

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Bus5	0.99501	1.6775	0.48826	0.09744	0	0
Bus6	0.99526	1.6806	0.4883	-0.50361	0	0
Bus7	0.99522	1.6802	0.48883	3.0601	0	0
Bus8	0.99567	1.6836	0.48829	-0.42276	0	0
Bus9	0.99576	1.6842	0.48831	-0.60077	0	0
Bus10	0.99579	1.6844	0.48829	-0.41681	0	0
Bus11	0.99526	1.6806	0.4883	-0.50361	0	0
Bus12	0.9941	1.6721	0.48827	0.78146	0	0
Bus13	0.99502	1.6774	0.48832	-0.63039	0	0
Bus14	0.99502	1.6774	0.48832	-0.63039	0	0
Bus15	0.9958	1.6845	0.48828	-0.2764	0	0
Bus16	0.99643	1.697	0.48826	-0.02611	0	0
Bus17	0.99655	1.6978	0.4883	-0.52332	0	0
Bus18	0.99645	1.6973	0	0.4701	0.35257	0
Bus19	0.99643	1.6974	0.48828	-0.27273	0	0
Bus20	0.99355	1.6197	0.48831	-0.48709	0	0
Bus21	0.99362	1.6201	0.48826	0.00362	0	0
Bus22	0.98971	1.6142	0.48831	-0.409	0	0
Bus23	0.99112	1.6409	0.48826	0.13819	0	0
Bus24	0.98941	1.6128	0.48825	0.36088	0	0
Bus25	0.98938	1.6091	0.4883	-0.33275	0	0
Bus26	0.98423	1.5557	0.4883	-0.20937	0	0
Bus27	0.98424	1.5557	0.4883	-0.21508	0	0
Bus28	0.98422	1.5556	0.4883	-0.20547	0	0
Bus29	0.99643	1.6969	0.48829	-0.44982	0	0
Bus30	0.99645	1.6971	0.4883	-0.51841	0	0
Bus31	0.96298	1.4368	0.48823	0.27804	0	0
Bus32	0.96392	1.4381	0.48833	-0.0765	0	0
Bus33	0.88491	0.85253	0.48678	2.4383	0	0
Bus34	0.99097	1.6408	0.48835	1.6464	0	0
Bus35	0.96287	1.4366	0.48811	0.86005	0	0
Bus36	0.96292	1.4367	0.48819	0.43104	0	0
Bus37	0.88063	0.73472	0.49136	-2.0047	0	0
Bus38	0.98092	1.5357	0.48835	-0.41362	0	0
Bus45	0.98889	1.6123	0.48827	0.00693	0	0
Bus39	0.98054	1.5346	0.48848	-0.90873	0	0
Bus40	0.99361	1.6203	0.4883	-0.43637	0	0
Bus41	0.99354	1.6199	0.48826	0.46924	0	0
Bus42	0.99321	1.6176	0.48826	0.6973	0	0
Bus43	0.84473	0.55649	0.48416	5.3797	0	0
Bus44	0.98093	1.5357	0.48835	-0.40928	0	0
Bus46	0.98564	1.5641	0.48832	-0.36281	0	0
Bus47	0.98057	1.5618	0	0	0.4701	0.35257
Bus48	0.87832	0.85274	0	0	0.4701	0.35257
Bus49	0.884	0.85348	0	0	0.4701	0.35257
Bus50	0.96262	1.4367	0	0	0.4701	0.35257
Bus51	0.87598	0.84936	0	0	0.4701	0.35257
Bus52	0.81835	0.55793	0	0	0.4701	0.35257
Bus53	0.9925	1.6175	0	0	0.4701	0.35257
Bus54	0.9806	1.5341	0	0	0	0

Bus55	0.98556	1.5638	0	0	0.4701	0.35257
Bus56	0.99124	1.642	0.48829	-0.26726	0	0
Bus57	0.98791	1.6029	0	0	0.4701	0.35257
Bus58	0.98302	1.5492	0	0	0.4701	0.35257
Bus59	0.98629	1.5565	0	0	0.4701	0.35257
Bus60	0.9841	1.5554	0	0	0.4701	0.35257
Bus61	0.88102	0.73363	0	0	0.4701	0.35257
Bus62	0.98929	1.6088	0	0	0.4701	0.35257
Bus63	0.99011	1.6069	0	0	0.4701	0.35257
Bus64	0.98907	1.6125	0	0	0.4701	0.35257
Bus65	0.99641	1.6967	0	0	0	0
Bus66	0.99652	1.6973	0	0	0	0
Bus67	0.99485	1.6776	0.48826	0.13815	0	0
Bus68	0.9957	1.6846	0	0	0.4701	0.35257
Bus69	0.99054	1.6363	0	0	0.4701	0.35257
Bus70	0.99483	1.6775	0	0	0.4701	0.35257
Bus71	0.99501	1.677	0	0	0.4701	0.35257
Bus72	0.98961	1.6351	0	0	0.4701	0.35257
Bus73	0.99074	1.6408	0	0	0.4701	0.35257
Bus74	0.99063	1.642	0	0	0.4701	0.35257
Bus75	0.99344	1.656	0	0	0.4701	0.35257
Bus76	0.99184	1.6528	0	0	0.4701	0.35257
Bus77	0.99469	1.6784	0	0	0.4701	0.35257
Bus78	0.99115	1.6419	0.48825	0.50538	0	0
Bus79	0.98783	1.6581	0	0	0.4701	0.35257
Bus80	0.99268	1.6651	0	0	0.4701	0.35257
Bus81	0.98855	1.6596	0	0	0.4701	0.35257
Bus82	0.99299	1.666	0	0	0.4701	0.35257
Bus83	0.99369	1.6717	0	0	0.4701	0.35257
Bus84	0.9933	1.6722	0	0	0.4701	0.35257
Bus85	0.98965	1.6671	0	0	0.4701	0.35257
Bus86	0.99447	1.6734	0.48826	0.09154	0	0
Total			**18.1499**	**6.9847**	**15.9834**	**11.9875**

Table 7 Summary of voltage stability results analysis of the modernised reserved 86-bus electric power network after3-phase fault at different transmission lines.

Loss of LINES	Maximum loading factor/ Collapse Pt λ (pu)	Total generation		Total load		Total losses		Voltage Violations
		Real power Ptotal (pu)	Reactive power Qtotal (pu)	Real load power Ptotal (pu)	Reactive load power Qtotal (pu)	Real power loss Ploss (pu)	Reactive power loss Qloss (pu)	
Base case/ normal	1.1753	18.1499	6.983	15.9834	11.9875	2.1665	-5.0045	8
2-83	1.1753	18.1499	6.9847	15.9834	11.9875	2.1665	-5.0028	9
2-85	1.1753	18.1505	6.9885	15.9837	11.9877	2.1665	-4.9993	9
4-75	1.2174	18.6438	7.2436	15.9837	11.98	2.0867	-5.1743	10
6-75	1.2175	18.6444	7.2442	16.5579	12.4184	2.0865	-5.1742	10
7-72	1.2165	18.6192	7.234	16.5442	12.4081	2.075	-5.1741	10
8-76	1.2175	18.6437	7.2445	16.5574	12.4181	2.0862	-5.1736	10

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9-73	1.1754	18.149	6.9602	15.9853	11.989	2.1637	-5.0288	9
9-83	1.1758	18.1538	6.9839	15.9876	11.9907	2.1662	-5.0068	9
11-77	1.2165	18.6205	7.2269	16.544	12.408	2.0765	-5.1811	10
12-71	1.2176	18.6478	7.2598	16.5597	12.4198	2.0881	-5.16	10
13-73	1.1753	18.1499	6.9846	15.9834	11.9876	2.1665	-5.003	9
13-79	1.1753	18.1498	6.9831	15.9834	11.9875	2.1665	-5.004	9
14-15	1.2164	18.6168	7.2207	16.5429	12.4072	2.0739	-5.1865	10
15-16	1.1768	18.2256	7.468	15.9985	11.9985	2.2271	-4.5308	9
15-19	1.2164	18.6168	7.2207	16.5429	12.4072	2.0739	-5.1865	10
15-73	1.1753	18.1496	6.9862	15.9833	11.9875	2.1663	-5.0013	9
15-79	1.1753	18.15	6.9852	15.9834	11.9875	2.1666	-5.0023	9
15-85	1.1755	18.1514	6.9829	15.9863	11.9897	2.1651	-5.0069	9
16-22	1.1751	18.1456	6.9838	15.9811	11.9858	2.1645	-5.002	9
17-18	1.216	18.6087	7.2146	16.5378	12.4034	2.0709	-5.1888	10
20-73	1.2164	18.6175	7.2226	16.5434	12.4076	2.0741	-5.185	10
21-73	1.2164	18.6175	7.2226	16.5434	12.4076	2.0741	-5.185	10
22-70	1.1753	18.1484	6.9526	15.9842	11.9881	2.1623	-5.0355	9
23-68	1.2162	18.6128	7.2098	16.5405	12.4054	2.0723	-5.1956	10
24-69	1.2162	18.6122	7.2086	16.5402	12.4051	2.0721	-5.1966	10
25-26	1.2165	18.6192	7.2192	16.5444	12.4083	2.0747	-5.1891	10
25-68	1.1752	18.1497	7.7989	15.9832	11.9874	2.1665	-4.1885	9
25-69	1.1753	18.1497	7.3733	15.9832	11.9874	2.1665	-4.6141	9
27-28	1.2175	18.6404	7.2207	16.5574	12.4181	2.083	-5.1973	10
29-30	1.2175	18.6441	7.2549	16.558	12.4185	2.0861	-5.1636	10
31-65	1.2178	18.6493	7.2621	16.5613	12.421	2.088	-5.1589	10
32-63	1.217	18.6363	7.26	16.5514	12.4135	2.0849	-5.1535	10
33-63	1.217	18.6362	7.26	16.5513	12.4135	2.0849	-5.1535	10
34-63	1.217	18.6363	7.26	16.5514	12.4135	2.0849	-5.1535	10
35-68	1.2162	18.613	7.2099	16.5407	12.4055	2.0723	-5.1956	10
36-68	1.2162	18.6126	7.2097	16.5404	12.4053	2.0722	-5.1956	10
37-54	1.2137	18.5983	7.2713	16.5064	12.3798	2.0919	-5.1086	10
38-54	1.2137	18.5975	7.2687	16.5063	12.3797	2.0911	-5.111	10
39-53	1.1374	17.4991	5.7542	15.4683	11.6012	2.0308	-5.847	9
40-54	1.2137	18.5979	7.2712	16.5058	12.3793	2.0921	-5.1081	10
41-54	1.2137	18.5983	7.2713	16.5063	12.3797	2.092	-5.1084	10
42-64	1.1341	17.2173	5.2325	15.424	11.568	1.7934	-6.3355	9
43-58	1.2172	18.641	7.2725	16.5533	12.415	2.0877	-5.1425	10
44-58	1.2176	18.6499	7.2781	16.56	12.42	2.0899	-5.1419	10
45-46	1.2176	18.6436	7.2222	16.5595	12.4197	2.0841	-5.1975	10
48-56	1..0978	16.6336	4.1521	14.9296	11.1972	1.704	-7.0451	8
49-58	1.2172	18.641	7.2724	16.5533	12.4149	2.0877	-5.1425	10
50-59	1.2177	18.6484	7.2554	16.5606	12.4205	2.0878	-5.1651	10
54-58	1.1619	18.1604	9.7075	15.8016	11.8512	2.3587	-2.1437	9
54-61	1.1726	18.1569	7.9748	15.9475	11.9607	2.2094	-3.9859	9
58-61	1.1733	18.1769	9.2275	15.957	11.9677	2.2199	-2.7403	9
65-66	1.1752	18.1457	7.8062	15.9833	11.9875	2.1625	-4.1812	9
65-67	1.1753	18.1454	7.3516	15.9835	11.9876	2.1619	-4.636	9
66-67	1.1753	18.1468	7.185	15.9842	11.9882	2.1626	-4.8032	9
68-69	1.1753	18.1502	7.2177	15.9836	11.977	2.1667	-4.77	9
68-73	1.1783	18.2535	7.2667	16.0148	12.0111	2.2386	-3.7444	9
69-70	1.1751	18.1461	7.3749	15.9811	11.9858	2.15	-4.6109	9