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Improving the Stability of An Interconnected Power System Using Genetic Eigenvalue Technique

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Abstract
Improving the power stability of an interconnected Nigerian 330KV 48 bus power system was developed using Genetic Eigenvalue Technique to mitigate the challenges of proper placement of power system stabilizer due to its highly dynamic and nonlinear nature. In order to eliminate load losses, equipment malfunctioning, and other quality issues, unnecessary tripping and cascaded failures in system network, power system stabilizers are installed to improve system stability. The operational and process data of 330KV power system grid network, cable distance meter (CDM-75), Transmission line calculator (AWR version) were sampled at Transmission Company of Nigeria Osogbo, Osun State of Nigeria. The Genetic Eigenvalue technique was used to generate eigenvalues, damping ratios and participation factors for proper placement of PSS (Power System Stabilizers) to mitigate the effect of transmission line and power plant outage contingencies. The PSSs were placed using Genetic Eigenvalue Analysis technique performed better than PSS placed based on conventional Arnoldi eigenvalue technique. The simulation results for base case voltage profile and for the trajectories of the impact of contingencies were plotted on the MATLAB/SUMULINK environment. From the output plots, the percentage of voltage instability suppression time improvement of Genetic technique over Arnoldi is 51.86%. Oscillation suppression at generator 1, is 74%, and that of generator 3 is 79%, and finally at generator 5 is 76.98%. PSS placed on Nigerian 330KV 48 bus plant and transmission line of an interconnected power system case study power system based on genetic analysis suppressed voltage oscillation faster compared to the time it took the PSS based on the conventional Arnoldi eigenvalue analysis technique.
Keywords: Power Stability- Genetic Eigenvalue, ArnoldiEigenvalue, PSS.
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1 Introduction
System stability depends on the existence of both components of torque for each of the synchronous machines. Lack of sufficient synchronizing torque results in a periodic or non-oscillatory instability, whereas lack of damping torque results in oscillatory instability. For convenience in analysis and for gaining useful insight into the nature of stability problems, it is useful to characterize rotor angle stability in terms of the following two subcategories: small disturbance and global problems. However, Small-disturbance (or small-signal) rotor angle stability is concerned with the ability of the power system to maintain synchronism under small disturbances. The disturbances are considered to be sufficiently small that linearization of system equations is permissible for purposes of analysis [10]. Again global problems are caused by interactions among large groups of generators and have widespread effects. They involve oscillations of a group of generators in one area swinging against a group of generators in another area. Such oscillations are called inter-area mode oscillations. Their characteristics are very complex and significantly differ from those of local plant mode oscillations. Load characteristics, in particular, have a major effect on the stability of inter-area modes [9]. However, if power system is perturbed, the equilibrium is upset, resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of a rotating body. If one generator temporarily runs faster than another, the angular position of its rotor relative to that of the slower machine will advance. The resulting angular difference transfers part of the load from the slow machine to the fast machine, depending on the power-angle relationship. This tends to reduce the speed difference and hence the angular separation. The power-angle relationship is highly nonlinear. Beyond a certain limit, an increase in angular separation is accompanied by a decrease in power transfer such that the angular separation is increased further. Instability results if the system cannot absorb the kinetic energy corresponding to these rotor speed differences. For any given situation, the stability of the system depends on whether or not the deviations in angular positions of the rotors result in sufficient restoring torques.

2 Review of the related works
The study of eigenvalue changesdue to the single PSS installation at different units to determine the best PSS installment location was observed [1]. However, this work took a different approach by modeling the effect of PSS installation with an addition of a damping term to the equation of motion. The best PSS placement led to the most damped system.

The methods outlined for PSS placement are sequential and can take into account the presence of PSSs that were already installed [9]. However, sequential placement does not always determine the best multiple PSS placements because placement order can affect the results. These methods require eigenvalue calculations after PSS installation at each generator.

A method was developed that save computation time by computing eigenvalue sensitivities to approximate the post-PSS-installed eigenvalues [9]. A pioneering work on eigenvalue sensitivities applied to power systems was done by They derived the Eigenvalue sensitivities to a power system parameter.

A developed way to calculate the eigenvalue sensitivities [2] to the closure of the open-loop system by installation of an ideal PSS. These sensitivities were computed with matrix residues of the open loop system while (8) used the same idea as [2] but proposed an improved algorithm that could be easily used with a large-scale system.

The study done by [5] on eigenvalue sensitivities were also used by to tune the PSS after installation showed that the eigenvalue sensitivities of an open-loop system due to installation of a static PSS are equal to the open-loop residues. These sensitivities were used to tune the PSS but were not used to determine PSS placement. Similarly to [9] grouped the generators to determine a site of PSS installation. Ostojic, traced the origins of the electromechanical modes to one or a group of generators by looking at their aggregate momentum as shown in [5]. In the studied case, one generator from each group was chosen for PSS installation. However, the number and choice of generators for PSS installation was arbitrary.

The work of [10], by the papers discussed, shows that residues are commonly used to determine PSS installation sites. Another popular method is based on PFs (Participation Factors). A PF is a measure of the relative participation of a state in a mode and a mode in a state. Thus, it shows which machine and particular state greatly affects an eigenvalue of interest. For a given mode to be damped, the machine whose state participates the most in the mode should be installed with a PSS.

The work of [3] minimized the sum of PSS transfer functions weighted by their machine bases to determine PSS placement. The optimization problem was constrained by having to shift the eigenvalues to the stable region and by limits of the PSS parameters. This method both determined PSS placement and computed the PSS parameters. The optimization problem was solved for the shift in the eigenvalues by using a derived equation for eigenvalue sensitivities. This formulation was also used by [4] to determine PSS installation sites.

The work of (7) on optimization problem was also formulated to determine PSS placement. The objective was to minimize the PSS control gains with constraints to move the unstable eigenvalues to the stable region while not changing the stable eigenvalues. This approach assumed that PSSs were installed at every machine. Those with relatively higher gains solved for by the optimization problem were chosen for PSS installation. This method looked at the closed loop system, but minimization of the number of PSSs was not included in the constraints or the cost function. This method put the additional constraint of not moving the stable eigenvalues; a less restrictive constraint would put all the eigenvalues in the stable region. Other approaches to determine the best locations for PSS installations have been investigated

3 Methodology

The Nigerian 330KV, 48-bus system was modeled as the case study power system for the simulation experiment, to validate the stability analysis technique and the proposed power system damping controller. The MATLAB Simulink environment is used for the modeling and development of the case study interconnected power system damping controller and for programming the genetic-eigenvalue stability analyzer. For the testing and evaluation of the solution, different transient disturbances were simulated and injected into the MATLAB model of the case study power grid to investigate the performance of the solution. Simulations are carried out to determine the effect on the power system angle stability, voltage stability and frequency stability of the case study of power system. The stability of the 48-bus case study interconnected power grid is evaluated with the power system damping controller and the stability analyzer on the one hand, and without the damping controller and the hybrid stability analyzer on the other hand. The model of the stability analyzer and the power system damping controller and simulation of case study power system using MATLAB is developed

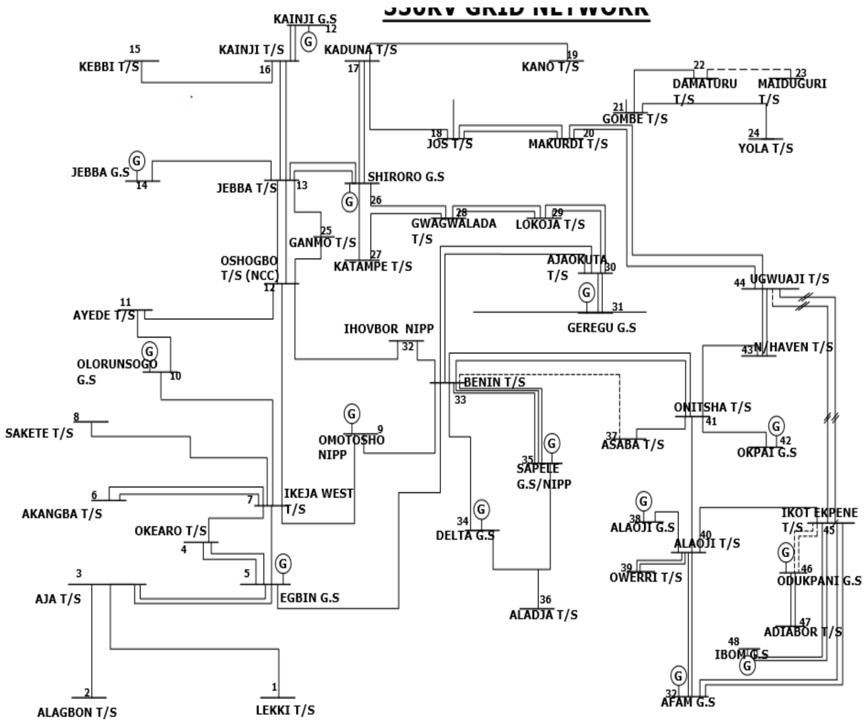


Figure 1: Line Diagram of Nigerian 330KV 48-Bus

The Nigerian 330KV, 48-bus was modeled using MATLAB Simulink tool box. This shows 48-bus for further simulations on the network as shown on fig 1. System data for the existing 48-bus Nigeria 330kV power networks obtained from Power Transmission Company of Nigeria (TCN), were used as input data which provided the values of series impedances, admittances of the transmission lines, transformer ratings and impedances required for the power/load flow study. These parameters were modeled and simulated in MATLAB/SIMULINK power system analysis using Newton-Raphson power flow algorithm.

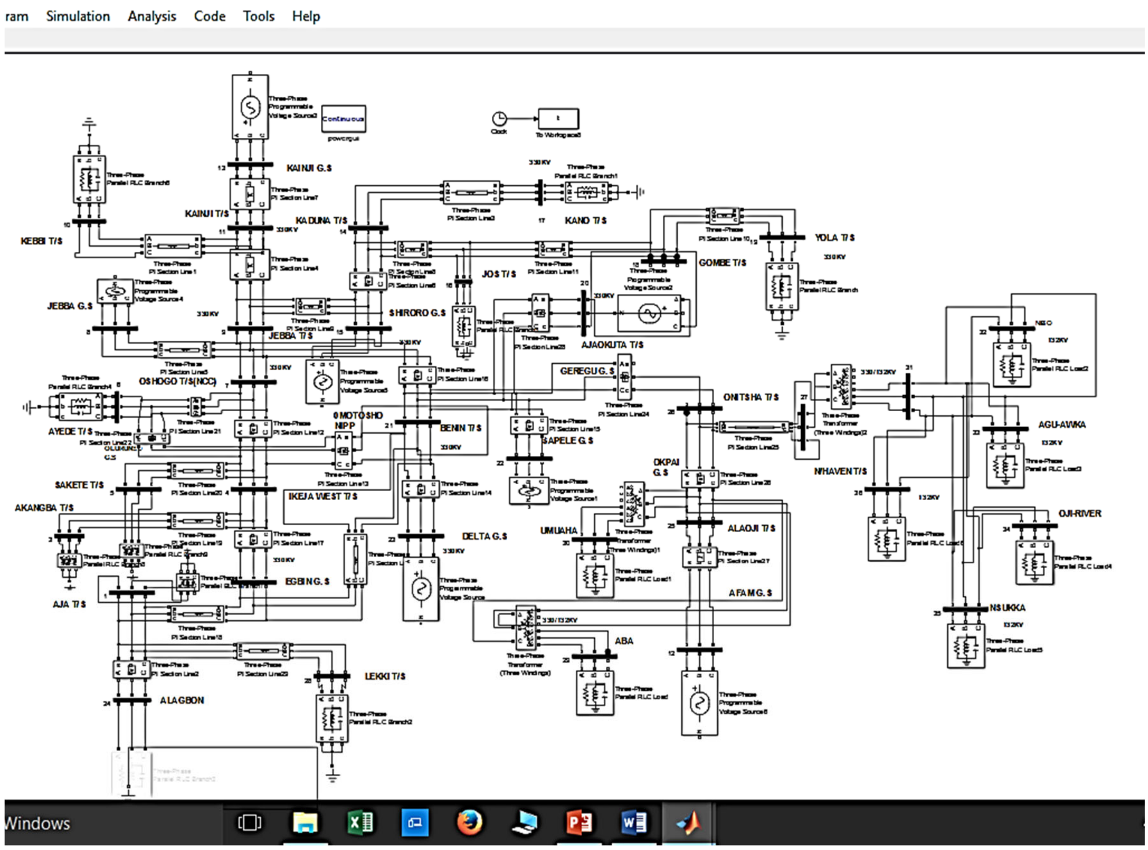


Figure 2: The Simulink model of Nigerian 330KV, 48-bus

The Simulink model of Nigerian 330KV, 48-bus interconnected system was developed for load flow studies, to see the base case voltage profile of the network and for further simulations on the implementation of genetic eigenvalue algorithm

Mathematical Model of Power Flow and Eigenvalue Analysis

Power system matrices are required for the stability analyses of genetic eigenvalue analysis program, hence the mathematical model were derived as shown

$$I = YV = \frac{S*}{V*} \quad (1)$$

Where

I = Modal current injection matrix
Y = System modal admittance
V = Unknown complex mode voltage vector
S = Apparent power modal injection vector representing specified load and generation of nodes.

Where

$$S = P + JQ \quad (2)$$

The using Newton-Raphson method from (3), the equation for node K (bus K) is written as:

$$I_K \sum_{m=1}^{n} Y_{KM} V_m \quad (3)$$

$$P_K + JQ_k = V_K I_K = V_K \sum_{m=1}^{n} Y_{KM} V_m \quad (4)$$

Where

M = 1, 2 ………. n
n = number of buses
V_k is the voltage of the K bus

Y_{KM} is the element of the admittance bus equating the real and imaginary parts

$$P_K = K_e \left(V_K \left(\sum_{m=1}^{n} Y^*_{KM} V^*_K \right) \right) \quad (5)$$

$$Q_K = I_M \left(V_K \left(\sum_{m=1}^{n} Y^*_{KM} V^*_K \right) \right) \quad (6)$$

Where

P_K is the real power

Q_K is the reactive power with the following notation:

$$V_K = |V_K| e^{jq_k}, V_M = |V_m| e^{jq_m}, Y_{KM^2} |Y_{KM}| e^{jt} \quad (7)$$

Where

$|V_K|$ is the magnitude of the voltage

δ_k is the angle of the voltage

δ_{km} is the load angle

Substituting for V_k, V_m, and Y_{km} in equation (8)

$$P_K + JQ_K = |V_K| e^{jd_k} \sum_{m=1}^{n} |V_k| |Y_{KM}| e^{jq_{km}} \quad (9)$$

$$P_K + JQ_K = |V_K| \sum_{m=1}^{n} |V_k| |Y_{KM}| e^{j(\delta_k - \delta_m = \delta_{km})} \quad (10)$$

Or

$$P_K + JQ_K = |V_K| \sum_{m=1}^{n} |V_k||Y_{KM}| < (\delta_k - \delta_k - \delta_{km}) \quad (11)$$

Or

$$+JQ_K = |V_K| \sum_{m=1}^{n} |V_k||Y_{KM}| (\cos(\delta_k - \delta_m - Q_{km}) + J\sin(\delta_k - \delta_m - Q_{km})) \quad (12)$$

Separating the real and imaginary parts of above equations to get real and reactive power

$$P_K = |V_K| \sum_{m=1}^{n} |V_k||Y_{KM}| \cos(\delta_k - \delta_m - Q_{km}) \quad (13)$$

$$Q_K = |V_K| \sum_{m=1}^{n} |V_k||Y_{KM}| \sin(\delta_k - \delta_m - Q_{km}) \quad (14)$$

The mismatch power at bus K is given by:

$$\Delta P_K = P_K^{sch} - P_K \quad (15)$$

$$\Delta Q_K = Q_K^{sch} - Q_K \quad (16)$$

The P_K and Q_K are calculated from equations (3.13) and (3.14)

The Newton – Raphson method solves the partitioned matrix equation:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J \begin{bmatrix} \Delta Q \\ \Delta V \end{bmatrix} \quad (17)$$

Where

ΔP and ΔQ = mismatch active and reactive power vectors

ΔV and ΔQ = unknown voltage magnitude and angle correction vectors

J = Jacobean matrix of partial derivative terms

The eigenvalues associated with a mode of voltage and reactive power variation can provide a relative measure of proximity to voltage instability. Then, the participation factor can be used to find out the weak nodes or buses in the system.

Equation (3.15) can be written as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} \Delta Q \\ \Delta V \end{bmatrix} \quad (18)$$

By letting $\Delta P = O$ in Equation (3.18)

$$\Delta P = O = J_{11}\Delta\theta + J_{12}\Delta V \quad (19)$$

Where

$$\Delta\theta = -J_{11}^{-1} J_{12}\Delta V \quad (20)$$

$$\Delta\theta = -J_{21} \Delta\theta + J_{22}\Delta V \quad (21)$$

Subtracting equation (17) in equation (21)

$$\Delta\theta = -J_R \Delta V \quad (22)$$

Where

$$J_R = [J_{22} - J_{21}J_{11}^{-1}J_{12}]$$

J_R is the reduced jacobian matrix of the system

Equation (13) can be written as

$$\Delta V = J_R^{-1} \Delta Q \tag{23}$$

The matrix J_R represents the linearized relationship between the incremental changes in bus voltage (ΔV) and bus reactive power injection (ΔQ). It is well known that the system voltage is affected by both real and reactive power variations. In order to focus the study of the reactive demand and supply problem of the system as well as minimize computations effort by reducing dimension of the computation effort by reducing dimensions of the Jacobean Matrix J the real power $(\Delta P = O)$ and angle part from the system his equation (3.13) are eliminated..

The eigenvalues and Eigen-vectors of the reduced order Jacobean matrix (J_R) are used for the power system stability characterized analysis. Instability can be detected by identifying modes of the eigenvalues matrix (J_R). The magnitude of the eigenvalues provides a relative measure of proximity to instability. The eigenvectors on the other hand present information related to the mechanism of loss of voltage stability.

Modal analysis of (J_R) results in the following

$$(J_R) = \tau \phi \xi_{eigl} \tag{24}$$

Notation used in the flow chart:

$A = (J_R)$ is the system matrix, based on the model of the power system
H is matrix having orthonormal columns
V is matrix having orthonormal columns (can also be an invariant sup space of matrix A)
x, f are the Ritz vectors
λ is the eigenvalues
σ is a shift
I is the identity matrix
ξ_{eigl} = left eigenvector matrix of (J_R)
X = diagonal eigenvalue matrix of (J_R)

Equation (3.22) can be written as:

$$J_R^{-1} = \phi \xi_{eigl} \tag{25}$$

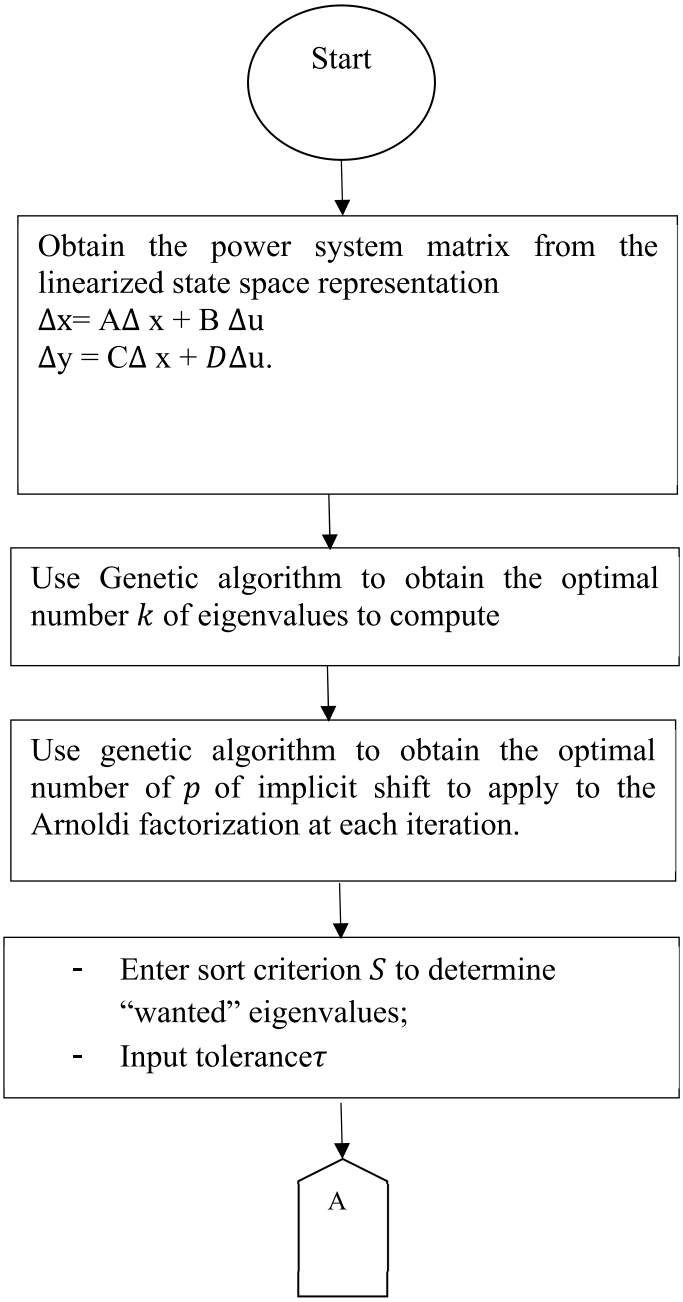
The appropriate definition and determination as to which modes or buses participates in the selected mode become very important. The participation factor is computed to identify the weakest nodes or lead buses that are making significant contribution to the selected modes.

The participation factor is given by

$$X_i = \frac{\sum \phi_i \xi_{ei\lambda l}}{\lambda_i} \Delta Q \tag{26}$$

Where λ_i is the i^{th} eigenvalue, ϕ_i is the column right eigenvector and is the i^{th} column right eigenvector and $\xi_{ei\lambda l}$ is the i^{th} row left eigenvector of matrix (J_R)

Each eigenvalue and corresponding right and left eigenvectors ϕ_i and $\xi_{ei\lambda l}$, defines the i^{th} modes of the system.


Start
Obtain the power system matrix from the linearized state space representation
Δx= AΔ x + B Δu
Δy = CΔ x + DΔu.
Use Genetic algorithm to obtain the optimal number k of eigenvalues to compute
Use genetic algorithm to obtain the optimal number of p of implicit shift to apply to the Arnoldi factorization at each iteration.
- Enter sort criterion S to determine "wanted" eigenvalues;
- Input toleranceτ
A

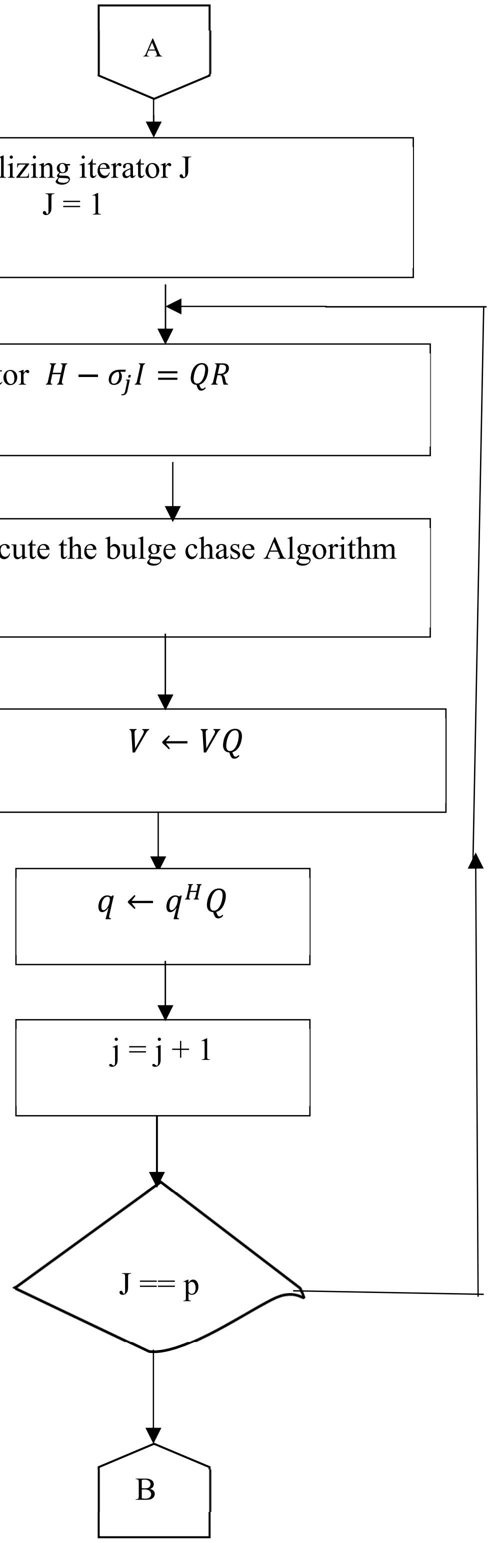


Fig 3: Flow Chart for Genetic Eigenvalue programming

The flow chart for the implementation of the Genetic eigenvalue algorithm programming was developed as shown in fig 3 contains an arranged parameters for simulation and generation of eigenvalues, and computation of participation factors and damping ratios of the Nigerian 330KV 48-Bus network from the network Simulink of figure 3. The genetic eigenvalue stability analysis program, the eigenvalues of the network are extracted, participation factors and damping ratios of the generators were equally computed by the program hence the stabilizers are placed on the generators based on their participation factors and damping ratios as computed from their eigenvalues.

4. Simulations

The base data for this paper are system parameters of Nigerian 330KV 48-bus system from Transmission Company of Nigeria. There are 14 synchronous generators in the system. The base voltage is 330KVA and 100MVA. The generator, line and bus parameters used for simulation and computations are listed in table 1.

Table 1: The Generator Parameters

S/No	Generator Station	Generation	Rated Voltage	Voltage P.U
1	Kainji	292Mw	332KV	1.0060
2	Jebba	404Mw	312KV	0.9455
3	Shiroro	450Mw	320KV	0.9697
4	Egbini	611Mw	335KV	1.0151
5	Sapele	68Mw	332KV	1.0060
6	Delta	470Mw	318KV	0.9636
7	Geregu	144Mw	319KV	0.9677
8	Omotosho	187.5Mw	305KV	0.9242
9	Olominsogo gas	163.6Mw	300KV	0.9090
10	Geregu NIPP	150Mw	331KV	1.0030
11	Sapele NIPP	113.1Mw	320KV	0.9692
12	Olorunsogo NIPP	130.9Mw	316KV	09576
13	Omotosho NIPP	228Mw	347KV	1.05151
14	Okapia	363Mw	331KV	1.0030

Bus Parameter

System Details **Type:**
MVA Base = 100MVA 1 = Load Bus
System frequency = 50Hz
2 = Generator Bus (pv)
Bus Nominal Voltage = 330KV 3 = System Wiring Bus
Bus Maximum Voltage = 330.5kv

Table 2: Bus Parameters

Bus No	Type	Max-Vm-Pu	Min-Vm-Pu	Area	Zone	In-Service	Vn-KV
1	2	1.05	0.95	1	1	True	330KV
2	2	1.05	0.95	1	1	True	330KV
3	2	1.05	0.95	1	1	True	330KV
4	2	1.05	0.95	1	1	True	330KV
5	2	1.05	0.95	1	1	True	330KV
6	2	1.05	0.95	1	1	True	330KV
7	2	1.05	0.95	1	1	True	330KV
8	2	1.05	0.95	1	1	True	330KV
9	2	1.05	0.95	1	1	True	330KV
10	2	1.05	0.95	1	1	True	330KV
11	2	1.05	0.95	1	1	True	330KV
12	2	1.05	0.95	1	1	True	330KV
13	2	1.05	0.95	1	1	True	330KV
14	2	1.05	0.95	1	1	True	330KV
15	2	1.05	0.95	1	1	True	330KV
16	2	1.05	0.95	1	1	True	330KV
17	2	1.05	0.95	1	1	True	330KV
18	2	1.05	0.95	1	1	True	330KV
19	2	1.05	0.95	1	1	True	330KV
20	2	1.05	0.95	1	1	True	330KV
21	2	1.05	0.95	1	1	True	330KV
22	2	1.05	0.95	1	1	True	330KV
23	2	1.05	0.95	1	1	True	330KV
24	2	1.05	0.95	1	1	True	330KV

Bus No	Type	Max-Vm-Pu	Min-Vm-Pu	Area	Zone	In-Service	Vn-KV
25	2	1.05	0.95	1	1	True	330KV
26	2	1.05	0.95	1	1	True	330KV
27	2	1.05	0.95	1	1	True	330KV
28	2	1.05	0.95	1	1	True	330KV
29	2	1.05	0.95	1	1	True	330KV
30	2	1.05	0.95	1	1	True	330KV
31	2	1.05	0.95	1	1	True	330KV
32	2	1.05	0.95	1	1	True	330KV
33	2	1.05	0.95	1	1	True	330KV
34	2	1.05	0.95	1	1	True	330KV
35	2	1.05	0.95	1	1	True	330KV
36	2	1.05	0.95	1	1	True	330KV
37	2	1.05	0.95	1	1	True	330KV
38	2	1.05	0.95	1	1	True	330KV
39	2	1.05	0.95	1	1	True	330KV
40	2	1.05	0.95	1	1	True	330KV
41	2	1.05	0.95	1	1	True	330KV
42	2	1.05	0.95	1	1	True	330KV
43	2	1.05	0.95	1	1	True	330KV
44	2	1.05	0.95	1	1	True	330KV
45	2	1.05	0.95	1	1	True	330KV
46	2	1.05	0.95	1	1	True	330KV
47	2	1.05	0.95	1	1	True	330KV
48	2	1.05	0.95	1	1	True	330 KV

Table 3: Load Flow Result for the Plot of the Profile of the Base Case Power System

BUS	Voltage(p.u)	Angle(rad)	P gen(p.u)	Q gen(p.u)	P load(p.u)
1	0.9604	-0.03153	4.86E-14	1.4E-12	1.89
2	0.9668	-0.02274	2.4	1.251088	0
3	0.9026	-0.01048	1.15E-13	4.33E-13	4.5
4	0.9702	-0.0254	1.55E-15	-9.4E-15	1.95
5	0.8436	0.087284	3.213	0.004826	0
6	0.7858	-0.00543	-1.1E-13	-5.6E-13	9.18
7	0.9754	0.085714	0.8	0.583475	0
8	0.9118	-0.03631	4.09E-14	9.21E-13	1.545
9	0.9546	-0.08476	2.16	9.594193	1.545
10	0.7598	-0.10347	-1E-14	-1.7E-13	0
11	0.7003	-0.0065	8.08E-14	-1.2E-13	2.424
12	0.9176	0.08684	1.928	0.753387	0
13	0.9731	0.085158	2.71E-13	1.98E-13	2.292
14	0.8760	-0.07592	1.2	-1.84677	0
15	0.9055	0.085664	-7.3E-14	-6.3E-14	0
16	0.7962	-0.13836	-1.3E-13	-1E-13	1.146
17	0.8338	-0.03392	-3E-13	-2.2E-13	1.53
18	0.9569	-0.13756	-3.2E-14	-2.4E-14	0
19	0.9506	-0.03113	1.76	5.189297	1.89
20	0.7517	-0.07522	2.35E-13	9.63E-14	0
21	0.7540	0.085614	-2.9E-13	1.91E-13	2.292
22	0.9535	-0.00585	-9.4E-14	1.06E-12	2.7
23	0.7257	-0.02394	-4.5E-13	-4.6E-14	0
24	0.9691	-0.02655	-4.6E-14	-3.2E-13	1.146
25	0.8899	-0.00946	-1.3E-13	-6.3E-13	3.6
26	0.9436	-0.02736	1.125	0.236856	0
27	0.9621	0.083392	-2.2E-13	-1.3E-13	0
28	0.8587	-0.06639	9.88E-16	2.81E-14	0
29	0.7720	-0.10593	7.99E-15	7.53E-14	1.275
30	0.9754	-0.0242	-2.4E-14	-1.7E-13	1.95
31	0.7431	-0.02572	-1E-14	-1.7E-13	0.73725
32	0.7991	-0.02977	-2.7E-15	-3.1E-14	1.617
33	0.9032	-0.11249	7.24E-15	-2.9E-14	0
34	0.8465	-0.02361	7.82E-13	5.08E-13	1.2471
35	0.9529	-0.13943	-4.3E-14	-3E-14	0.615
36	0.9801	-0.02648	2.4	0.104634	0
37	0.9529	0	46.0197	9.032308	0
38	0.9853	-0.14123	-1.9E-14	2.61E-14	0.573
39	0.9639	-0.03703	-5.1E-15	-1.2E-14	1.545
40	0.9766	-0.02195	2.4	-0.33846	0
41	0.9303	-0.13818	4.2E-14	1.86E-13	1.548
42	0.9673	-0.04831	-6E-15	1.44E-14	1.8609
43	0.9147	-0.14204	1.104	1.672078	0
44	0.9598	-0.03259	1.42E-14	8.36E-14	0.91725
45	0.8477	-0.01242	4.56	0.542995	0.6225
46	0.9587	-0.01106	-6.5E-14	3.14E-13	6.29
47	0.8205	-0.53696	3.29E-13	3.79E-14	1.65
48	0.9014	-0.02617	4.416	0.667066	0.765

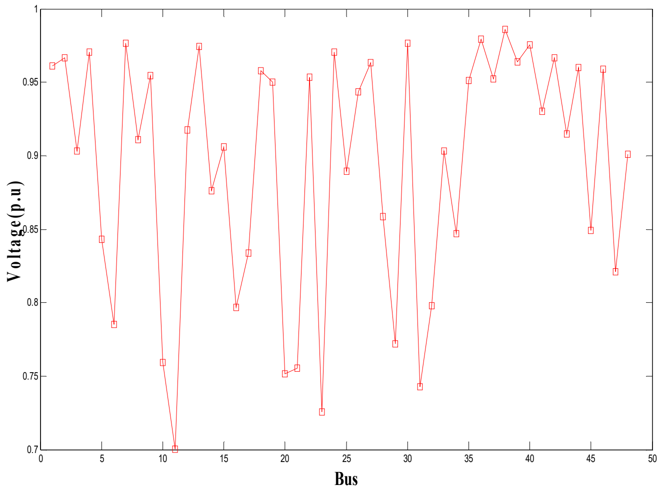


Fig. 4: Voltage Profile of the Base Case of Nigerian 330KV Power System

From the load flow result, it can be seen that 27 buses are below the 5% voltage drop limit. This shows substantial weakness in the power system under investigation which might lead to instability.. However, this does not give much information regarding the distribution of instabilities in the system. Hence further simulations were carried out using the hybrid of Genetic and Arnoldi Eigenvalue analysis technique to find the eigenvalues, the damping ratios and the participation factors in the power system for proper placement of Power System Stabilizers Result of Pflw solution on outage of transmission line without stabilizer

Table 4: Eigenvalue and Damping Ratio of the case Study Power System Buses during the Outage of the Transmission Line between Bus 31 and 29.

S/No.	Bus No.	Eigen value(λ)	Damping Ratio(ς)
1	1	0.1123±j7.0876	1.0675
2	2	0.0448±j4.0309	-0.0110
3	3	0.5526±j7.3025	0.02437
4	4	0.0547±j3.2853	0.0135
5	5	0.0413±j3.3227	-0.0124
6	6	-0.5248±j3.8483	0.1035
7	7	0.0014±j2.5144	-0.0057
8	8	0.1912±j5.808	-0.0332
9	9	0.1953±j5.716	-0.0348
10	10	0.088±j4.002	-0.022
11	11	0.4302±j3.6798	-0.4067
12	12	0.0281±j2.0154	-0.0013
13	13	-0.1212±j3.7982	-0.0324
14	14	0.0953±j3.3835	-0.0256
15	15	0.0883±j4.0012	-0.0225
16	16	0.0335±j6.852	-0.005
17	17	0.0658±j3.7896	-0.0017
18	18	0.2012±j4.3186	-0.3107
19	19	0.4029±j3.1139	-0.0108
20	20	0.0079±j2.0146	-0.2889
21	21	-0.1176±j3.1134	-0.4011
22	22	0.2021±j2.0343	-0.0003
23	23	0.3964±j4.1342	-0.2987
24	24	0.0788±j3.4342	-0.3421
25	25	0.1865±j4.0072	-0.0482
26	26	0.2108±3.3319	-0.0569
27	27	0.0984±j2.7934	-0.1867
28	28	0.3012±j4.4310	-0.3065
29	29	0.0567±j4.0173	-0.0768
30	30	0.1684±j3.1605	-0.1347
31	31	0.2123±j5.0876	0.3675

S/No.	Bus No.	Eigen value(λ)	Damping Ratio(ς)
32	32	0.0478±j3.0309	-0.2110
33	33	0.5426±j7.3025	0.02137
34	34	0.0647±j3.2253	0.0135
35	35	0.0713±j3.3427	-0.0424
36	36	-0.7248±j2.8783	0.1135
37	37	0.0014±j2.5144	-0.0057
38	38	0.1912±j5.808	-0.0332
39	39	-0.1953±j5.716	-0.0348
40	40	0.088±j4.002	-0.022
41	41	0.4302±j3.6798	-0.3107
42	42	0.0271±j2.0154	-0.0313
43	43	-0.1212±j3.7982	-0.0324
44	44	0.0753±j3.3835	-0.0256
45	45	0.0853±j4.1012	-0.0227
46	46	0.0335±j6.852	-0.0015
47	47	0.0658±j3.7896	-0.0016
48	48	0.3012±j5.3186	-0.3089

Table 5: Result of Power Flow Solution of the Case Study Power System Buses During the Outage of Transmission Line between Bus 31 and 29

Bus#	Voltage magnitude (P.u)	Voltage angle(rad)	P(P.u)	Q(P.u)
1	0.7326	-0.7817	-0.5913	-0.1086
2	0.6979	-0.5016	-0.5344	-0.1122
3	0.9328	-0.6943	-0.7676	-0.2697
4	0.4513	-0.7625	-0.5347	-0.0498
5	1.1056	-0.9227	-0.4264	-0.5617
6	0.3696	-0.3348	-0.4128	-0.9834
7	0.4934	-0.5812	-0.4576	-0.1307
8	0.7579	-0.3521	-0.5504	-0.1809
9	1.2041	-0.4817	-0.5413	-0.1086
10	0.9873	-0.4016	-0.5644	-0.1122
11	0.3934	-0.6243	-0.7646	-0.2607
12	1.0034	-0.4625	-0.5347	-0.0998
13	0.4676	-0.4227	-0.4264	-0.1017
14	0.3696	-0.3998	-0.4128	-0.1034
15	0.4986	-0.5012	-0.4576	-0.1507
16	0.7579	-0.4521	-0.5504	-0.1809
17	0.6506	-0.4332	-0.4869	-0.1264
18	0.6347	-0.3865	-0.4337	-0.1413
19	0.9717	-0.4386	-0.5812	-0.1118
20	0.9681	-0.3318	-0.5795	-0.0819
21	0.8576	-0.4626	-0.4932	-0.1338
22	0.6792	-0.3982	-0.5216	-0.2013
23	0.4647	-0.5984	-0.6937	-0.2446
24	0.3120	-0.3202	-0.4827	-0.1579
25	0.4795	-0.4529	-0.4243	-0.1834
26	1.1052	-0.4467	-0.5006	-0.1134
27	0.5613	-0.3846	-0.5138	-0.2007
28	0.8819	-0.4822	-0.5623	-0.1613
29	0.4982	-0.4116	-0.4985	-0.1517
30	0.6813	-0.3976	-0.5963	-0.1549
31	0.9326	-0.7817	-0.5913	-0.1086
32	1.0120	-0.5016	-0.5344	-0.1122

Bus#	Voltage magnitude (P.u)	Voltage angle(rad)	P(P.u)	Q(P.u)
33	0.9328	-0.6943	-0.7676	-0.2697
34	1.0123	-0.7625	-0.5347	-0.0498
35	1.0234	-0.9227	-0.4264	-0.5617
36	0.7696	-0.3348	-0.4128	-0.9834
37	0.8934	-0.5812	-0.4576	-0.1307
38	1.0325	-0.3521	-0.5504	-0.1809
39	0.5326	-0.4817	-0.5413	-0.1086
40	0.9579	-0.4016	-0.5644	-0.1122
41	0.3248	-0.6243	-0.7646	-0.2607
42	1.0045	-0.4625	-0.5347	-0.0998
43	0.8676	-0.4227	-0.4264	-0.1017
44	0.4696	-0.3998	-0.4128	-0.1034
45	0.8934	-0.5012	-0.4576	-0.1507
46	1.2067	-0.4521	-0.5504	-0.1809
47	0.9506	-0.4332	-0.4869	-0.1264
48	1.0453	-0.3865	-0.4337	-0.1413

The 330KV Simulink network was simulated without PSS for transmission line and power plant. The circuit breaker in the Simulink library was made to open and reclose the circuit of bus 31 and 29 in 1second after five cycles and Genetic Eigenvalue computation program was run during the simulation to compute the system eigenvalue, damping ratio and participation factor.The power flow program was activated to carry out power flow solution of the power system.The comparative analysis of the impact of contingencies on network without PSS as shown in table **4,** all the real part of eigenvalues lie on the right half s-plane (all positive) – system unstable, damping ratios of eigenvalues are very small, bus 11 is most negative and most of the buses are below 5% and 0.2 damping threshold. Table **5**shows that there is serious voltage degradation at the buses of the power system. The voltages in most of the buses are degraded. The exciters on the generators alone cannot stabilize the oscillation.

Table 6: Eigen values and damping ratios of the case study power system buses for the outage of generator 4.

S/No.	Bus No.	Eigen value(λ)	Damping Ratio(ς)
1	1	0.4806±j8.1476	-0.7627
2	2	0.46302±j6.7734	-0.37414
3	3	0.4564±j5.3247	-0.3867
4	4	0.3206±j8.1476	-0.3627
5	5	0.4465±j 4.8942	-0.4019
6	6	0.4947±j 4.4366	-0.39434
7	7	0.5367±j 4.3008	-0.3762
8	8	0.4823±j5.1163	-0.4918
9	9	0.6975±j63465	-0.5328
10	10	0.6732±j 6.2248	-0.5562
11	11	0.7806±j8.1476	-0.7627
12	12	0.7453±j7.9969	-0.6834
13	13	0.7113±j6.9937	-0.7234
14	14	0.7734±j7.93644	-0.7274
15	15	0.6973±j6.9347	-0.6348
16	16	0.7389±j6.3021	-0.6849
17	17	0.7546±j7.3489	-0.6805
18	18	0.6874±j6.6534	-0.5964
19	19	0.5686±j7.7347	-0.5004
20	20	0.6896±j6.7347	-0.4908
21	21	0.7834±j8.2236	-0.6618
22	22	0.7263±j7.7993	-0.6536
23	23	0.7658±j8.8463	-0.6889
24	24	0.6835±j8.0013	-0.5876
25	25	0.5342±j6.1136	-0.4546
26	26	0.6423±j5.8376	-0.4987

S/No.	Bus No.	Eigen value(λ)	Damping Ratio(ς)
27	27	0.7102±j6.3476	-0.6482
28	28	0.6659±j5.3426	-0.5586
29	29	0.7508±j6.3246	-0.6863
30	30	0.7302±j7.0034	-0.6537
31	31	0.4706±j8.1476	-0.5627
32	32	0.36302±j6.7734	-0.37414
33	33	0.4564±j5.3247	-0.3867
34	34	0.3206±j8.1476	-0.1627
35	35	0.4465±j 4.8942	-0.4019
36	36	0.6947±j 4.4366	-0.39434
37	37	0.5367±j 4.3008	-0.3762
38	38	0.4823±j5.1163	-0.6918
39	39	0.3975±j63465	-0.5328
40	40	0.6732±j 6.2248	-0.5562
41	41	0.7806±j8.1476	-0.7627
42	42	0.6353±j7.9969	-0.6834
43	43	0.6813±j6.9937	-0.7634
44	44	0.2434±j7.93644	-0.2274
45	45	0.5973±j6.9347	-0.6348
46	46	0.8389±j6.3021	-0.4849
47	47	0.2946±j7.3489	-0.9805
48	48	0.5174±j6.6534	-0.2964

Table 7: Result of Power flow Solution of Case Study Power System for The Outage of Generator 4 without Stabilizer

Bus#	Voltage magnitude (P.u)	Voltage angle (rad)	P(P.u)	Q(P.u)
1	0.5427	-0.7423	-0.8347	-0.1579
2	0.4012	-0.5276	-0.9809	-0.1834
3	0.5867	-0.9043	-0.7643	-0.1134
4	0.4216	-0.5646	-0.6217	-0.2007
5	1.002	-0.5267	-0.5784	-0.1613
6	0.7017	-0.4896	-0.5629	-0.1517
7	0.1987	-0.6876	-0.6243	-0.1549
8	0.1996	-0.6248	-0.6543	-0.1086
9	1.0231	-0.6423	-0.6347	-0.1122
10	1.0012	-0.5836	-0.9809	-0.2697
11	0.2342	-0.8643	-0.7643	-0.0498
12	0.9978	-0.5646	-0.6217	-0.5617
13	0.2213	-0.5967	-0.5784	-0.9834
14	0.3017	-0.4896	-0.5629	-0.1307
15	0.3987	-0.6876	-0.6243	-0.1809
16	0.7996	-0.6248	-0.6543	-0.1086
17	0.2003	-0.6024	-0.5567	-0.1122
18	0.6876	-0.4567	-0.5243	-0.2607
19	0.9226	-0.6132	-0.6617	-0.0998
20	0.3672	-0.4342	-0.6834	-0.1017
21	0.3214	-0.6182	-0.6324	-0.1034
22	0.7186	-0.4644	-0.6685	-0.1507
23	0.3987	-0.8835	-0.7408	-0.1809
24	0.4236	-0.4263	-0.6847	-0.1264
25	0.8106	-0.6124	-0.5246	-0.1413
26	0.3242	-0.6245	-0.6534	-0.1086
27	0.3743	-0.4168	-0.5965	-0.1122
28	0.5206	-0.6428	-0.6703	-0.2697
29	0.2459	-0.5986	-0.6136	-0.0498

Bus#	Voltage magnitude (P.u)	Voltage angle (rad)	P(P.u)	Q(P.u)
30	0.3842	-0.4857	-0.6889	-0.5617
31	0.5427	-0.7423	-0.8347	-0.9834
32	0.2012	-0.5276	-0.9809	-0.1307
33	0.1867	-0.9043	-0.7643	-0.1809
34	1.0342	-0.5246	-0.6217	-0.1086
35	1.1056	-0.5267	-0.5784	-0.1122
36	0.7017	-0.4896	-0.5629	-0.2607
37	0.1987	-0.6976	-0.6243	-0.0998
38	1.1996	-0.6248	-0.6543	-0.1017
39	0.3427	-0.6123	-0.6347	-0.1034
40	0.2012	-0.5436	-0.9809	-0.1507
41	0.1867	-0.8643	-0.7643	-0.1809
42	1.0342	-0.5646	-0.6217	-0.1264
43	0.4213	-0.5967	-0.5784	-0.1413
44	0.3017	-0.4896	-0.5629	-0.1118
45	0.2987	-0.6876	-0.6243	-0.0819
46	1.1906	-0.6248	-0.6543	-0.1338
47	0.2003	-0.6024	-0.5567	-0.2013
48	0.2876	-0.4567	-0.5243	-0.2446

Table 7 gives the output of the power flow solution carried out by ***P-flow*** using the generator outage disturbance data.

The result in this table shows that Voltage magnitude indicates serious degradation in the bus voltage. The degradation in table 7 is higher than that of 5 showing more voltage degradation severity

From table 6 the transmission line outage contingency, the voltage of bus 11 stood at 0.3934 p.u, that of bus 15 stood at 0.4986p.u and that of bus 23 stood at 0.4647

From table 7, for power plant outage, the voltage of bus 11 stood at 0.2342p.u that of bus 15 stood at 0.3987p.u while that of bus 23 stood at 0.3987p.u. The real parts of the eigenvalue in table 5 are very much positive than the real parts of the eigenvalues in table 4.

The voltage trajectories of the power system case study buses were compared from without PSS, and with PSS using Genetic and Arnoldi stability analysis technique as shown in figures 5-13

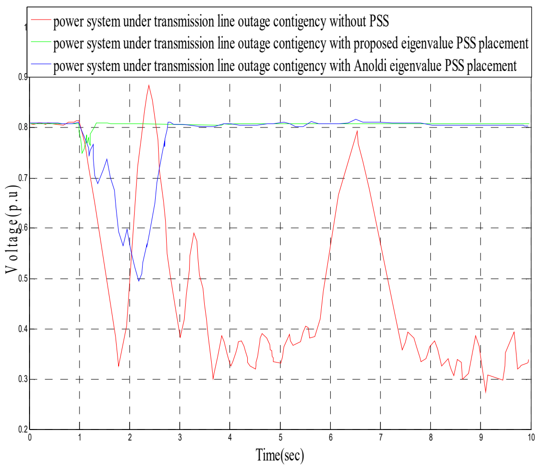


Figure: 5. Comparison of Voltage Trajectory at Bus 11 during Transmission Line Outage Contingency

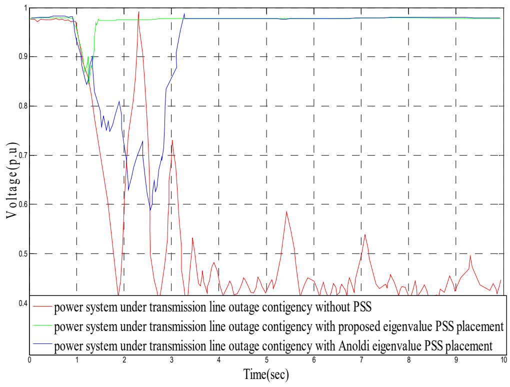


Figure 6. Comparison of Voltage Trajectory at Bus 15 during Transmission Line Outage Contingency

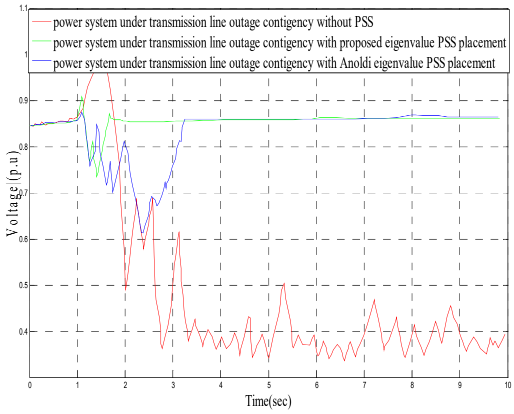


Figure 7:Comparison of Voltage Trajectory at Bus 23 duringTransmission Line Outage

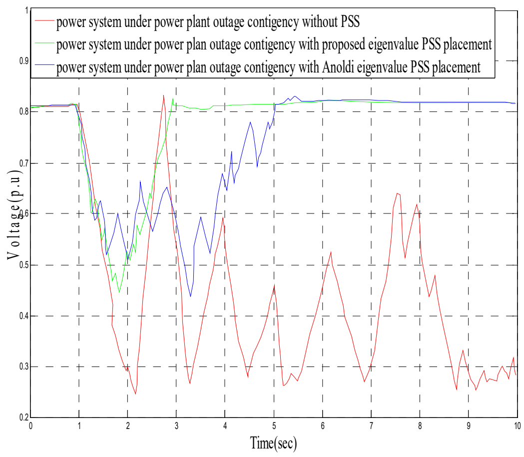


Figure. 8: Comparison of Voltage Trajectory at Bus 11 during Power Plant Outage Contingency

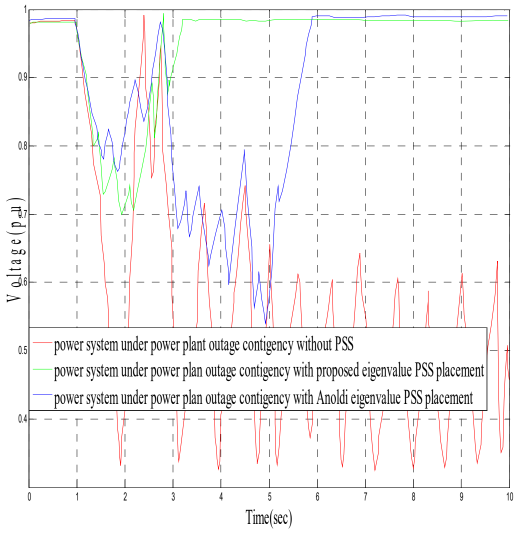


Figure 9: Comparison of Voltage Trajectory at Bus 15 during Power Plant Outage Contingency

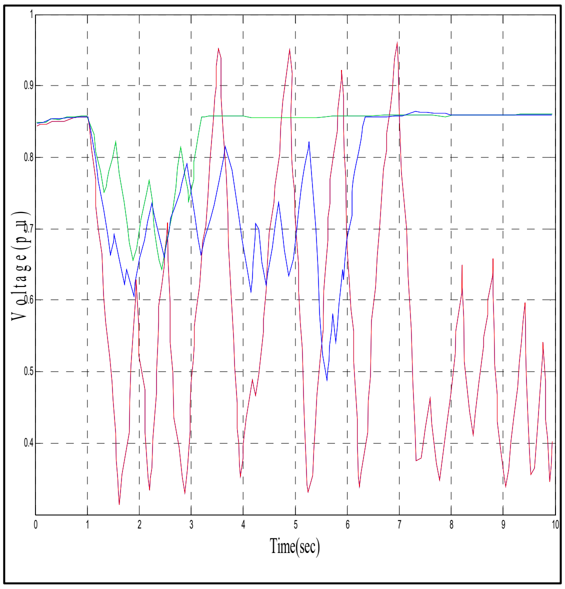
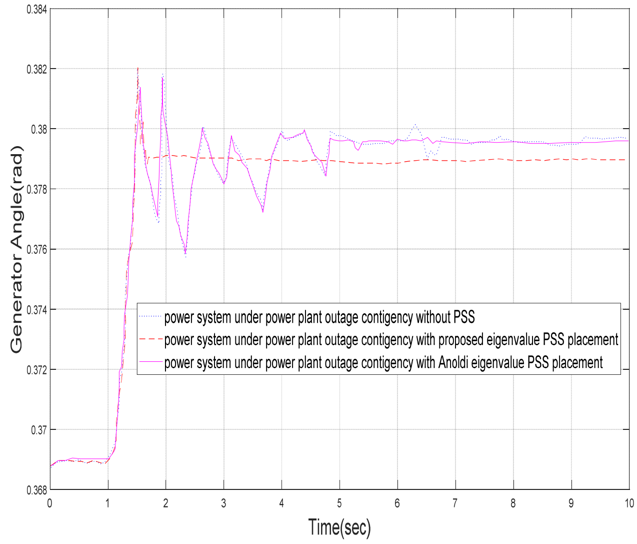


Figure 10: Comparison of Voltage Trajectory at Bus 23 during Power Plant Outage Contingency



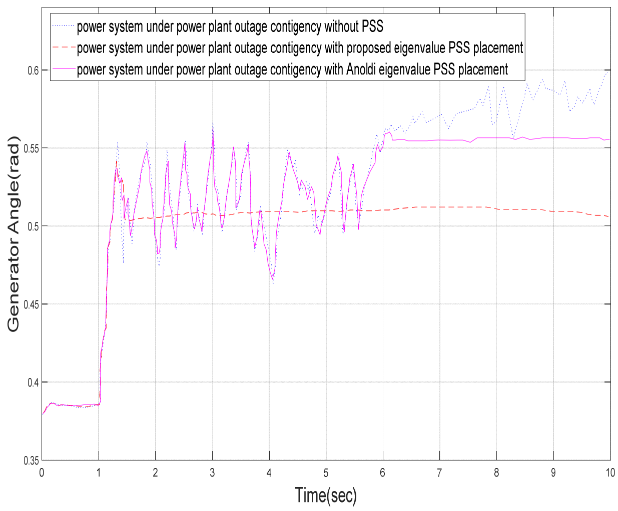


Figure 12: Comparison of generator 3 angle trajectory during power plant outage contingency

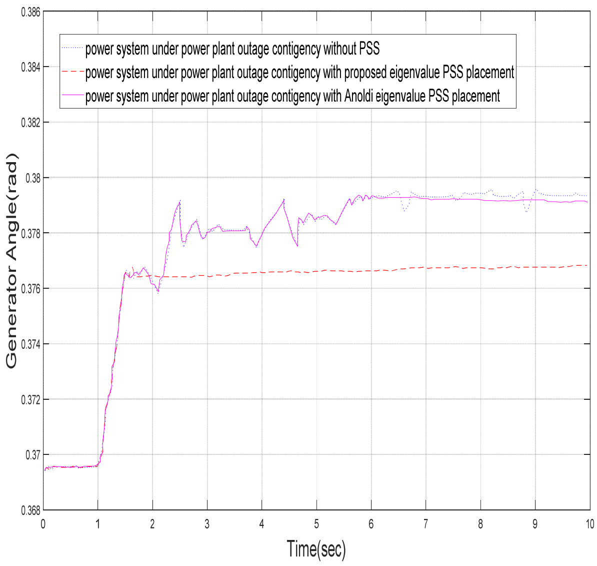


Figure 13: Comparison of generator 5 angle trajectory during power plant outage contingency

Confirmatory Evaluation of Power System Stabilization on an Interconnected Power System

Figures 5 - 13showed comparative output trajectory of simulations with and without stabilizers installed under transmission line outage contingency and power plant outage contingencies using Genetic Eigenvalue stability technique and conventional Arnoldi Eigenvalue stability technique for placement of power system stabilizers at buses 11, 15and 23 for damping out oscillations

- **At Bus 11**,Genetic technique of placing PSS damped out voltage oscillations in 1.3458 secs Arnoldi technique of placing PSS damped out voltage oscillations in 2.772 secs
- **At Bus 15**,Genetic technique of placing PSS damped out voltage oscillations in 1.446 secs Arnoldi technique of placing PSS damped out voltage oscillations in 2.3.2712 secs
- **At Bus 23**Genetic technique of placing PSS damped out voltage oscillations in **1.6784secs.**Arnoldi technique of placing PSS damped out voltage oscillations in **3.2409 secs.** % of voltage instability suppression time improvement of Genetic Eigenvalue technique Arnoldi = 51.86%
- **At generator 1**, % load angle suppression time improvement for power plant outage contingency of Genetic Eigenvalue technique over Arnoldi =74%
- **At generator 3**, % load angle suppression time improvement for power plant outage contingency of Genetic Eigenvalue technique over Arnoldi = 79%
- **At generator 5**, % load angle suppression time improvement for power plant outage contingency of Genetic Eigenvalue technique over Arnoldi = 76.98%

5.0 conclusion

At this stage it is important to show the gain of power system stability of 330KV bus transmission line Grid network as well as the milestones achieved in this research. Apart from the over re-occurring benefit of improvement in Transmission Company of Nigeria and cost effectiveness, this work has led to the appreciation of somewhat power system Genetic Eigenvalue technique. The technique is unique and has proved quite handy in solving problems from load loss, equipment malfunctioning and unnecessary tripping arising from system contingencies in power plant and transmission lines. Having tested this technique personally, it is clear that the contingencies in power plant and transmission lines in National grid can be reduced drastically.

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