International Journal for Innovative Engineering and Management Research
*A Peer Revieved Open Access International Journal*
www.ijiemr.org

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Volume 08, Issue 11, Pages: 253–262.

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# VOLTAGE STABILITY MARGIN (VSM) & MAXIMUM LOADING POINT (MLP) OF A MULTI BUS SYSTEM BEFORE AND AFTER COMPENSATION

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## ABSTRACT

In this to a great extent developing universe of energy framework keeping up voltage dependability is extremely troublesome errand on the grounds that as the span of the power framework organize expands the odds of event of blame additionally increments. In intensely stacked frameworks, voltage dependability farthest point is generally overwhelming and voltage precariousness is typically watched taking after expansive aggravation. In this paper an exertion is made with a specific end goal to keep up the voltage soundness of multi transport framework by controlling the receptive power stream in the framework. Ideal receptive power stream in the system is the key component of voltage dependability of the framework. The repaying gadgets utilized as a part of this paper are STATCOM which is shunt remunerating gadget and DVR which is arrangement remunerating gadget. A NR procedure is utilized to direct the LFS and thus the weakest transport is dictated by the LFS. A relative investigation of arrangement and shunt pay is made. The exhibitions of above repaying gadgets are done on a standard IEEE 14 transport framework. MATLAB/Simulation is utilized to investigate the execution.

## INTRODUCTION

The increase in power demand and limited sources for electric power has resulted in an increasingly complex interconnected system, forced to operate closer to the limits of stability. Voltage instability is mainly associated with reactive power imbalance.

The loadability of a bus in the power system depends on the reactive power support that the bus can receive from the system as the system approaches the voltage collapse point or maximum loading point (MLP). Voltage collapse phenomena in power systems have become one of the important concerns in the power industry over the last two decades, as this has been the major reason for several major blackouts that have occurred throughout the world. Hence, the ability to determine voltage stability before voltage collapse has received a great attention. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse.

‘Voltage stability’ is concerned with the ability of power system to maintain the steady acceptable voltages at all system buses under normal conditions as well as when the system is being subjected to a disturbance. Power system is voltage stable if voltages after a disturbance are close to voltages at normal operating condition. A power system becomes unstable when voltage uncontrollably decreases due to outage of equipment, increment of load, decrement of production. There are two types of voltage stability based on the time frame of simulation: static voltage stability and dynamic voltage stability. Static analysis involves only the solution of algebraic equations and hence is computationally less extensive than dynamic analysis. Static voltage stability is ideal for the bulk of studies in which voltage stability limit for many cases must be determined. ‘Voltage Security’ is basically related to a degree of minimal probability of blackout and equipment damage.

In this work an IEEE standard 14 bus systems is considered and the weakest bus is found out using Newton Raphson Load Flow analysis method and also the weakest bus is compensated by connecting a shunt capacitor to this bus. The after effect on the other buses is also considered. Voltage Stability Margin (VSM) of the weakest bus as well as of the next weakest bus is calculated for checking the security level of these buses. Voltage Stability Margin (VSM) is the measure of the security level of the bus, if the value of VSM is high then the bus is more secured and vice versa. “Contingency Analysis” is an essential part of the security analysis. Contingency arises due to scheduled outage, component switching, or unscheduled outage due to fault. Contingency test is also carried out on the weakest bus of the IEEE standard 14 bus system and it is checked out at which condition the bus is more secured. The investigation reveals that it is possible to identify the weakest load bus in any multi bus system and it is possible to compute the voltage stability margin at that load bus using the developed technique. Compensation is also done by connecting fixed capacitor with the weakest bus.

With the growing demand for electricity, several studies related to the planning and operation of electrical systems has increased its importance to guaranty the system voltage security. In addition to the increased demand, some factors such as the transfer of large amounts of power in the transmission and distribution networks, combined with the economic and environmental requirements conduces the system to operate in stressful conditions. Recent trends towards scale penetration of intermittent renewable energy sources into the grid exacerbate this situation making power systems mucho more vulnerable to stability and security issues.

This variability in generation, in addition to the existent load variability requires faster and efficient algorithms for monitoring of the power system. Voltage stability and security monitoring with continuation power flow (CPF) and methods based on the CPF are being incorporated in energy control centers. These methods allow the P-V curve drawing and the computation of the system's maximum loading point (MLP). This is important for the knowledge of voltage stability margin and modal analysis studies; this point provides information for determining effective measures for strengthening the system, since the MLP defines the boundary between regions of stable and unstable operation. The voltage stability has been considered a static phenomenon, due to slow variation of voltage over a long period until it reaches to the MLP and then it decreases rapidly to the voltage collapse. Static voltage stability can be analyzed by using saddle-node bifurcation theory.

As the need of deregulation for overall electric utility enterprises, utility transmission frameworks are moving toward their points of confinement. This makes the requirement for solid power more prominent than any time in recent memory. In deregulation condition, the requirement for new power stream controllers to upgrade transmission line ability will increment. Primarily, these new controllers ought to have the capacity to control voltage level and increment control stream ability of transmission line to their protected stacking with no lessening of framework steadiness and security edges. THE expansion in power request and constrained hotspots for electric power has brought about an inexorably complex interconnected framework, compelled to work nearer to the furthest reaches of security. Voltage insecurity is fundamentally connected with responsive power awkwardness. The loadability of a transport in the power framework relies on upon the receptive power bolster that the transport can get from the framework as the framework approaches the voltage crumple point.

Investigation of responsive power affectability as a record for discovering the weakest transport. The method for discovering Voltage Stability Margin is likewise proposed. At long last, a technique to repay the receptive energy of the weakest transport to enhance its dependability is likewise proposed. Possibility test is likewise done to learn at which condition the framework is more secured. These strategies are tried on the IEEE-14 transport framework and results are given to demonstrate the viability of the proposed technique. A use of ideal receptive power stream answers for summons the responsive power infusion of STATCOM. Commonly, a responsive power compensator, for example, STATCOM can be controlled by different means. The ideal power stream arrangement is extremely valuable.

It is a streamlining agent in which a specific target is limited while meeting all framework requirements. Arrangements of ideal receptive power streams are utilized to set as the reference to the STATCOM's controller. Be that as it may, arrangement pay system is not proposed, additionally they have said with respect to shunt pay as it were. To exhibit this control procedure, 24-hour ideal power stream arrangements of a basic three-transport test framework was utilized for test. The outcome demonstrated that responsive power pay by utilizing the ideal receptive power stream arrangement can prompt the base power misfortune operation of the whole influence framework and the framework voltage profile is level and smooth. An exertion is made to evaluate nearby and worldwide voltage security of multi-transport control framework in nearness of STATCOM and SVC.

## LITERATURE

**Hazarika D., Talukdar B.K., Das R (2013)** This paper presents new analytical expressions to efficiently capture the optimal power factor of each Distributed Generation (DG) unit for reducing energy losses and enhancing voltage stability over a given planning horizon. These expressions are based on the derivation of a multi-objective index (*IMO*), which is formulated as a combination of active and reactive power loss indices. The decision for the optimal location, size and number of DG units is then obtained through a benefit–cost analysis. Here, the total benefit includes energy sales and additional benefits, namely energy loss reduction, network upgrade deferral and emission reduction. The total cost is a sum of capital, operation and maintenance costs. The methodology was applied to a 69-bus industrial distribution system. The results showed that the additional benefits are imperative. Inclusion of these in the analysis would yield faster DG investment recovery.

**Vu K., Begovic M.M., Novosel D., Saha M.M (2013)** Congestion management is a vital part of power system operations in recent deregulated electricity markets. However, after relieving congestion, power systems may be operated with a reduced voltage or transient stability margin because of hitting security limits or increasing the contribution of risky participants. Therefore, power system stability margins should be considered within the congestion management framework. The multi-objective congestion management provides not only more security but also more flexibility than single-objective methods. In this paper, a multi-objective congestion management framework is presented while simultaneously optimizing the competing objective functions of congestion management cost, voltage security, and dynamic security. The proposed multi-objective framework, called modified augmented ε-constraint method, is based on the augmented ε-constraint technique hybridized by the weighting method. The proposed framework generates candidate solutions for the multi-objective problem including only efficient Pareto surface enhancing the competitiveness and economic effectiveness of the power market. Besides, the relative importance of the objective functions is explicitly modeled in the proposed framework. Results of testing the proposed multi-objective congestion management method on the New-England test system are presented and compared with those of the previous single objective and multi-objective techniques in detail. These comparisons confirm the efficiency of the developed method.

**Smon I., Verbic G., Gubina F (2006)** Congestion in a power network is turned up due to system operating limits. To relieve congestion in a deregulated power market, the system operator pays to market participants, GENCOs and DISCOs, to alter their active powers considering their bids. After performing congestion management, the network may be operated with a low security level because of hitting some flows their upper limit and some voltages their lower limit. In this paper, a novel congestion management method based on the voltage stability margin sensitivities is introduced. Using the proposed method, the system operator so alleviates the congestion that the network can more retain its security. The proposed method not only makes the system more secure after congestion management than other methods already presented for this purpose but also its cost of providing security is lower than the earlier methods. Test results of the proposed method along with the earlier ones on the New-England test system elaborate the efficiency of the proposed method from the viewpoint of providing a better voltage stability margin and voltage profile as well as a lower security cost.

**Wang Y., Li W., Lu J (2009)** Transmission congestion management plays a key role in deregulated energy markets. To correctly model and solve this problem, power system voltage and transient stability limits should be considered to avoid obtaining a vulnerable power system with low stability margins. Congestion management is modeled as a multi-objective optimization problem in this paper. The proposed scheme includes the cost of congestion management, voltage stability margin and transient stability margin as its multiple competing objectives. Moreover, a new effective Multi-objective Mathematical Programming (MMP) solution approach based on normalized normal constraint (NNC) method is presented to solve the multi-objective optimization problem of the congestion management, which can generate a well-distributed and efficient Pareto frontier. The proposed congestion management model and MMP solution approach are implemented on the New-England's test system and the obtained results are compared with the results of several other congestion management methods. These comparisons verify the superiority of the proposed approach.

## METHODOLOGY

The computational procedure of the VSC-OPF problem is presented in the flowchart of Figure 2. The optimization algorithm of this study is a hybrid DA-PSO optimization algorithm. This hybrid algorithm was proposed.

### Dragonfly Algorithm (DA)

The dragonfly algorithm is a metaheuristic algorithm. It was inspired by the static and dynamic swarming behaviors of dragonflies in nature. The goals of swarming are hunting (static swarm) and migration (dynamic swarm). In the hunting, dragonflies move in larger swarms and along one direction, which is appropriated in the exploitation phase. In the dynamic swarm, when roaming over long distances and different areas, many dragonflies will swarm which is suitable in the exploration phase.

$$S_i = -\sum_{j=1}^{N} X - X_j,$$

where $S_i$ is the separation of the ith individual. N is the number of neighboring individuals. X is the position of the current individual. $X_j$ is the position of neighboring individual.

(ii)Alignment: it represents the velocity matching of individuals to the velocity of others in the neighborhood. It is able to compute by the following equation:

$$A_i = \frac{\sum_{j=1}^{N} V_j}{N},$$

where $A_i$ is the alignment of the individual and $V_j$ is the velocity of the neighboring individual.

(iii)Cohesion: it is the proclivity of individuals to the center of mass of the neighborhood. It can be calculated by the following equation:

$$C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X,$$

where $C_i$ is the cohesion of the individual.

(iv)Attraction to a food source: it should be the main objective of any swarm to survive. And it is computed by the following equation:

$$F_i = X^{+} - X,$$

where $F_i$ is the food source of the ith individual and $X^{+}$ is the position of the food source.

(v)Distraction of an enemy: it is another survival objective of the swarm, which is formulated in the following equation:

$$E_i = X^{-} - X,$$

where $E_i$ is the position of enemy of the individual and $X^{-}$ is the position of the enemy source.

The movement of artificial dragonflies and updation of their positions are simulated by considering the step vector (ΔX) and position vector (X). The step vector demonstrates the direction of the movement of the artificial dragonflies, which is formulated in the following equation:

where $\Delta X^{t+1}$ is the step vector at iteration $t + 1$. $\Delta X^{t}$ is the step vector at iteration t; s, a, c, f, and e are the separation weight, alignment weight, cohesion weight, food factor, and enemy factor, respectively. $\omega^{t}$ is the inertia weight factor at iteration t and is calculated by the following equation:

where $\omega_{max}$ and $\omega_{min}$ are set to 0.9 and 0.4, respectively; Iter is the iteration; and $Iter_{max}$ is the maximum iteration.

$$\Delta X^{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + \omega^{t} \Delta X^{t}$$

The position of the artificial dragonflies is able to be updated by the following equation:

where $X^{t+1}$ is the position at iteration $t + 1$ and $X^{t}$ is the position at iteration t.

$$\omega^t = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{\text{Iter}_{\max}} \times \text{Iter},$$

In case the search space is not able to find a neighboring solution, stochastic behavior need to be improved by the moving of the artificial dragonflies around the search space with the application of random walk (Lévy flight). For this case, the position of the dragonflies can be calculated as follows:

$$X^{t+1} = X^t + \Delta X^{t+1},$$

where Lévy is the Lévy flight which is computed by the following equation and d is the dimension of the position vectors:

$$\text{Levy}(d) = 0.01 \times \frac{r_1 \times \sigma}{|r_2|^{1/\beta}},$$

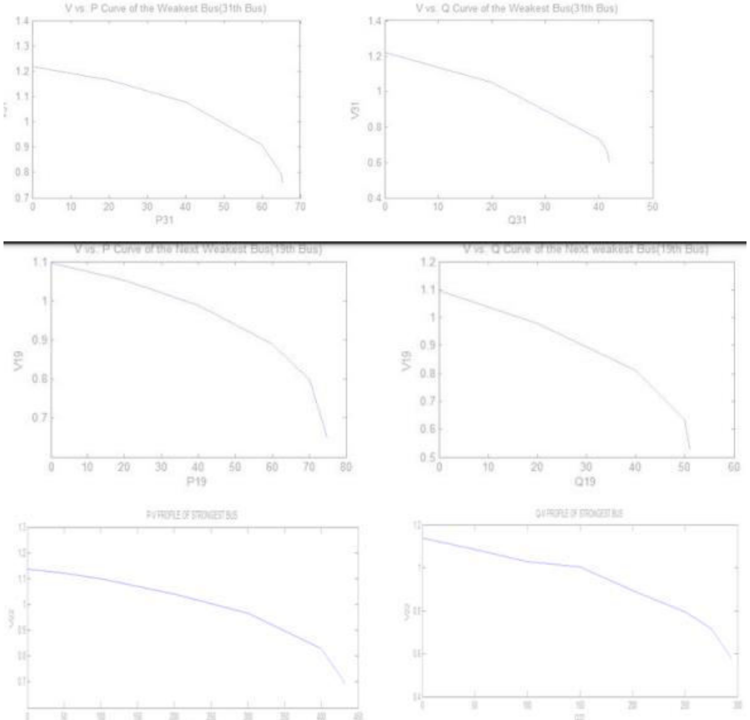
where $r_1$ and $r_2$ are the two uniform random values in a range of [0,1]. σ is calculated by the following equation:

$$\sigma = \left( \frac{\tau(1+\beta) \times \sin(\pi\beta/2)}{\tau(1+\beta/2) \times \beta \times 2^{(\beta-1/2)}} \right)^{1/\beta},$$

**RESULTS**

The IEEE-57 bus system is shown in figure.
There are three type of buses
1 - Slack Bus
2 - PV Bus
3 - PQ Bus

The minimum value of (∂qi/∂vi) corresponds to the weakest bus and the maximum value corresponds to the strongest bus. Hence for this system 31st bus is the weakest, 19th is the next weakest and 22nd is the strongest bus. The P-V and Q-V profile of the weakest, next weakest and strongest bus are shown in the figure below,



The Maximum Watt Margin (MWM) as obtained from the analysis for the weakest, next weakest and strongest bus.

A standard IEEE 14 bus system is as sg

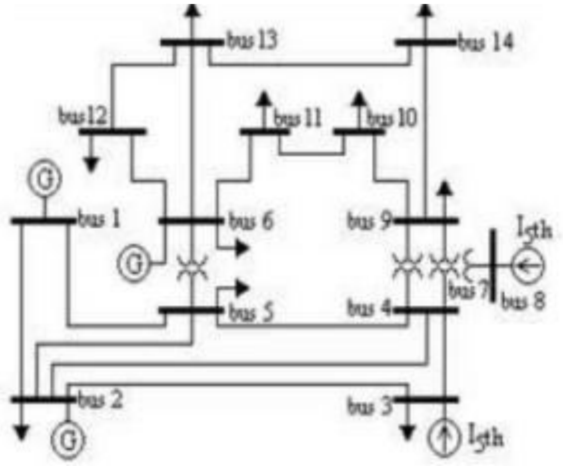
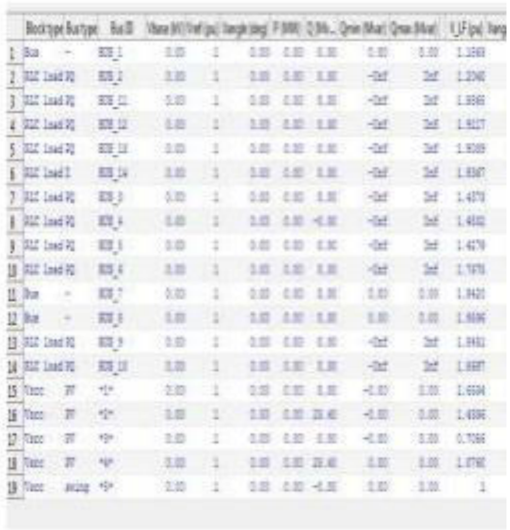


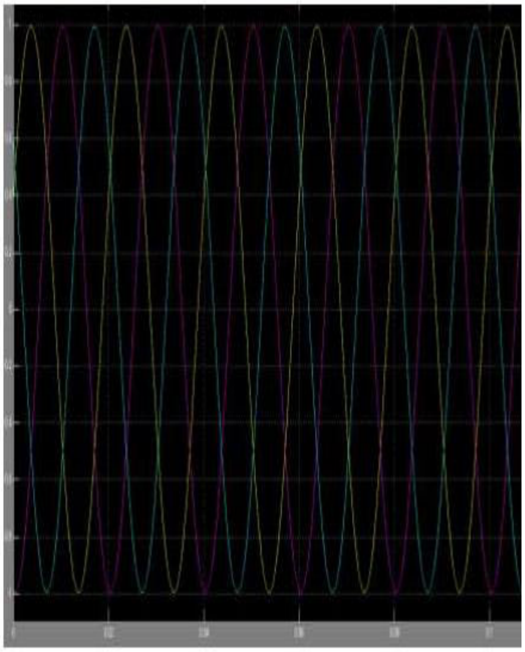
**Figure IEEE standard 14 bus system**

1. Load flow results before fault

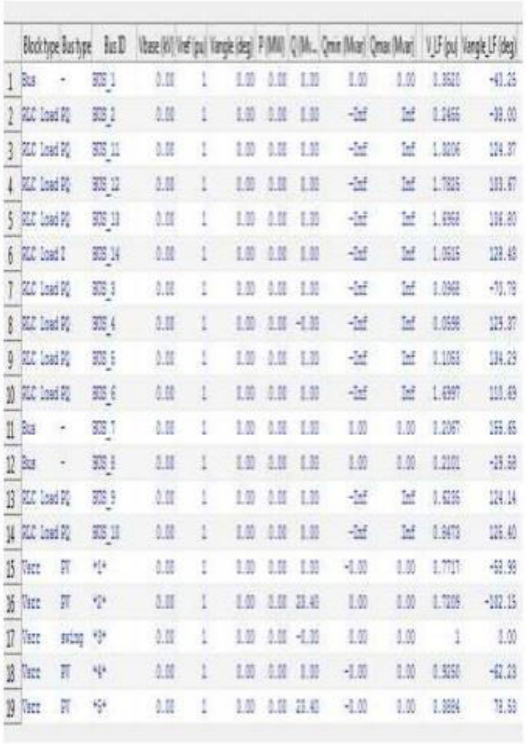


| | Block type | Bus type | Bus ID | Vbase (kV) | Vref (pu) | Vangle (deg) | P (MW) | Q (Mv... | Qmin (Mvar) | Qmax (Mvar) | V_LF (pu) | Vang |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bus | - | BUS_1 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.1369 | |
| 2 | RLC Load PQ | | BUS_2 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.2340 | |
| 3 | RLC Load PQ | | BUS_11 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.3366 | |
| 4 | RLC Load PQ | | BUS_12 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.9117 | |
| 5 | RLC Load PQ | | BUS_13 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.9309 | |
| 6 | RLC Load Z | | BUS_14 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.8347 | |
| 7 | RLC Load PQ | | BUS_3 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.4378 | |
| 8 | RLC Load PQ | | BUS_4 | 0.00 | 1 | 0.00 | 0.00 | -0.30 | -Inf | Inf | 1.4102 | |
| 9 | RLC Load PQ | | BUS_5 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.4179 | |
| 10 | RLC Load PQ | | BUS_6 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.7978 | |
| 11 | Bus | - | BUS_7 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.9421 | |
| 12 | Bus | - | BUS_8 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.9696 | |
| 13 | RLC Load PQ | | BUS_9 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.9461 | |
| 14 | RLC Load PQ | | BUS_10 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.8687 | |
| 15 | Vsrc | PV | *1* | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -0.00 | 0.00 | 1.6584 | |
| 16 | Vsrc | PV | *2* | 0.00 | 1 | 0.00 | 0.00 | 23.40 | -0.00 | 0.00 | 1.4596 | |
| 17 | Vsrc | PV | *3* | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -0.00 | 0.00 | 0.7066 | |
| 18 | Vsrc | PV | *4* | 0.00 | 1 | 0.00 | 0.00 | 23.40 | 0.00 | 0.00 | 1.0790 | |
| 19 | Vsrc | swing | *5* | 0.00 | 1 | 0.00 | 0.00 | -0.30 | 0.00 | 0.00 | 1 | |

2. Voltage at bus num 7 before fault

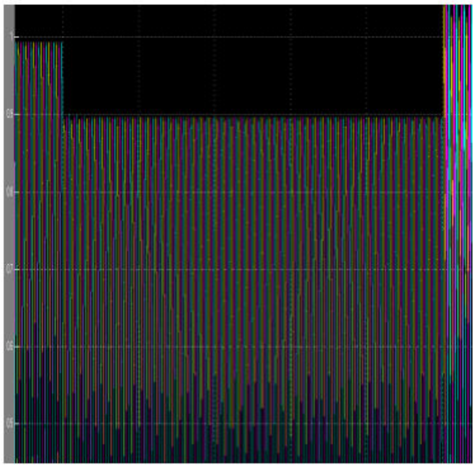


3. Load flow results after fault

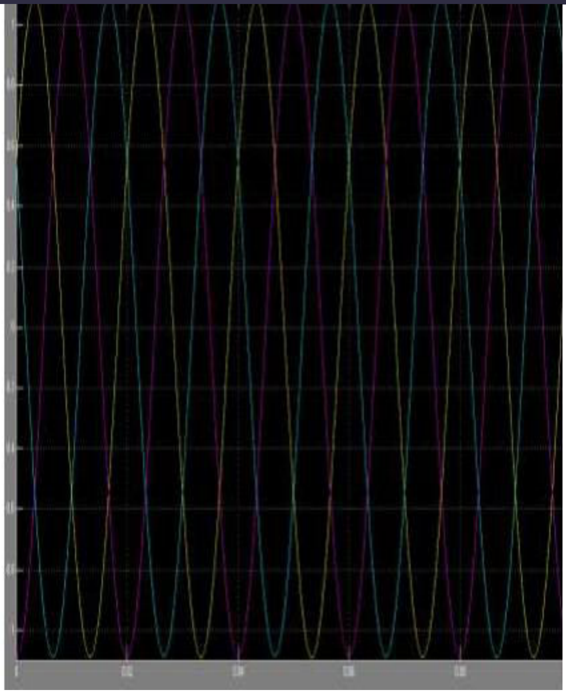


| | Block type | Bus type | Bus ID | Vbase (kV) | Vref (pu) | Vangle (deg) | P (MW) | Q (Mv... | Qmin (Mvar) | Qmax (Mvar) | V_LF (pu) | Vangle_LF (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bus | - | BUS_1 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.3620 | -43.25 |
| 2 | RLC Load PQ | | BUS_2 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 0.2455 | -38.00 |
| 3 | RLC Load PQ | | BUS_11 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.3206 | 124.37 |
| 4 | RLC Load PQ | | BUS_12 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.7825 | 103.67 |
| 5 | RLC Load PQ | | BUS_13 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.6968 | 106.80 |
| 6 | RLC Load Z | | BUS_14 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.0515 | 128.43 |
| 7 | RLC Load PQ | | BUS_3 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 0.0968 | -70.78 |
| 8 | RLC Load PQ | | BUS_4 | 0.00 | 1 | 0.00 | 0.00 | -0.30 | -Inf | Inf | 0.0598 | 123.37 |
| 9 | RLC Load PQ | | BUS_5 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 0.1063 | 134.29 |
| 10 | RLC Load PQ | | BUS_6 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 1.4997 | 110.49 |
| 11 | Bus | - | BUS_7 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.2067 | 155.65 |
| 12 | Bus | - | BUS_8 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.2101 | -25.58 |
| 13 | RLC Load PQ | | BUS_9 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 0.6235 | 124.14 |
| 14 | RLC Load PQ | | BUS_10 | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -Inf | Inf | 0.9473 | 126.40 |
| 15 | Vsrc | PV | *1* | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -1.00 | 0.00 | 0.7717 | -58.98 |
| 16 | Vsrc | PV | *2* | 0.00 | 1 | 0.00 | 0.00 | 23.40 | 0.00 | 0.00 | 0.7205 | -102.15 |
| 17 | Vsrc | swing | *3* | 0.00 | 1 | 0.00 | 0.00 | -0.30 | 0.00 | 0.00 | 1 | 0.00 |
| 18 | Vsrc | PV | *4* | 0.00 | 1 | 0.00 | 0.00 | 0.00 | -1.00 | 0.00 | 0.9350 | -62.23 |
| 19 | Vsrc | PV | *5* | 0.00 | 1 | 0.00 | 0.00 | 23.40 | -1.00 | 0.00 | 0.8884 | 78.53 |

4. voltage at bus number 7 after fault



5. Voltage at bus number 7 after connecting DVR



## CONCLUSION

This paper focus in a voltage stability analysis using the continuation power flow and tangent vector techniques. This methodology is considering a computational simulation tool to aid in operating, planning and investment decisions in power systems. The injection of active power and compensation of reactive power in the system was studied using different allocations for the same apparent power. As conclusion about this analysis, the best criteria to include distributed generation in the system is selecting more than one injection point in different areas of the system and divide the total apparent power in these connection points. With this procedure, improvements in the stability of the system can be guaranteed.

Finally, the simulation time for this system using parallel programation techniques corresponds to 2.66 milliseconds. Voltage stability is improved by using both D-STATCOM and DVR. This system has improved reliability and power quality. The simulation results are in line with predictions. The scope of present work is the modelling and simulation of eight bus system and compared. This concept can be extended to 64 bus system. The future work consists in improving this time, including a Graphic Processing Unit in the methodology to process the information in large transmission and distribution systems.

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