Journal of Operation and Automation in Power Engineering

Vol. 8, No. 3, Dec. 2020, Pages: 209-219

http://joape.uma.ac.ir

A Fast Voltage Collapse Detection and Prevention Based on Wide Area Monitoring and Control

M. Mohammadniaei, F. Namdari, M.R. Shakarami*

Department of Electrical Engineering, Lorestan University, Khorramabad, Iran

Abstract- *Voltage stability is one of the most important factors in maintaining reliable operation of power systems. When a disturbance occurs in the power system, it usually causes instabilities and sometimes leads to voltage collapse (VC). To avoid such problems, a novel approach called Vector Analysis (VA) is proposed that exploits a new instability detection index to provide wide area voltage stability for the power systems. The presented index is calculated based on measuring the active and reactive powers that flow through the bus which is connected to the generator bus. Moreover, when the proposed VA approach predicts VC, through disconnecting weak lines and based on network graph, zoning is carried out in the power system. After zoning, damaged and undamaged zones will be differentiated and damaged zones requires load shedding (LS) which is accomplished using ANFIS-TSK (AN-T) intelligent method. The presented approach is applied to the IEEE-39 bus test system. The obtained simulation results demonstrate acceptable performance of the presented approach compared with other suggested methods in terms of speed and accuracy.*

Keyword: Load shedding, Vector analysis, Voltage stability Index, Zoning.

1. INTRODUCTION

Nowadays, reliable and stable operation of the power systems is considered as a significant challenge in various researches. It needs to employ careful attention to the control and protection of subsystems. The occurrence of different faults should not be neglected, because it sometimes leads to irreparable problems. Voltage Collapse (VC) is a critical problem which has been reported as one of the main reasons for wide area blackouts in power systems [1]. So far, many solutions have been proposed to overcome VC.

Indices can be defined to calculate the system voltage stability margin by statically analysis of the voltage stability [2], [3]. P-Q curve [2] as well as Q-V curve [3] can be used to measure the voltage stability margin of the system. However, the issue is a dynamic problem and it is better to evaluate this aspect of stability dynamically because the power system is inherently nonlinear in nature [1]. The weak bus has the fastest rate of change in voltage, and its voltage can be used to measure the short-term voltage stability of the system [4]. In order to determine the weak bus, various methods have been proposed. In [4] authors determine the weak bus by using sophisticated and precise calculations of modal analysis and AC-power flow. However, these calculations are time-consuming and therefore not applicable in cases where VC occurs very quickly [5], [6]. In [5] the voltage instability is assumed as a local problem. Then, an index is proposed to evaluate voltage stability based on the equivalent circuit of one of the generators that supply the most active and reactive power. The modeling of this generator is on the basis of dynamical equations and online measurements of internal voltage and time-varying impedances. But it should be mentioned that the assumptions of the proposed approach are invalid if the voltage instability starts far away from this generator [4]. Furthermore, if the occurrence of a disturbance in the system is too close to the generator, it may lead to a misidentification by the voltage stability index [4]. Therefore, it is more accurate to investigate voltage stability by using wide-area measurements rather than local methods [1], [7]. By using threshold limits in Refs. [6]-[8] indices are presented based on voltage magnitudes in near-end and remote-end of the lines and their derivatives, reactive power and voltage magnitudes of the buses [6], [7] and voltage magnitudes and voltage phase angle of the buses [8], respectively. These methods have an acceptable speed in detecting short-term voltage stability so that if

Received: 29 Apr. 2019
Revised: 18 Nov. 2019
Accepted: 10 Dec. 2019
*Corresponding author:
E-mail: namdari.f@lu.ac.ir (F.Namdari)
Digital object identifier: 10.22098/joape.2019.5992.1452
Research Paper

the index value falls below a threshold during a disturbance, the VC occurs. Although these methods have high detection speeds, the thresholds usually are determined by performing multiple simulations, which are very difficult and practically impossible in a large system. Also, the determination of these limits varies across systems and must be calculated separately for each system [2]-[4]. In Ref. [9], an index is presented to monitor short-term voltage stability without the need for modelling of the system and assuming complete observability of the network. This index uses the finite-time Lyapunov exponent as the criterion of the stability evaluation, which is calculated from the PMU's online voltage measurements. If the maximum exponent of a system is negative, the adjacent paths converge to each other that indicates the system is stable in the terms of voltage stability. If the maximum exponent of a system is positive, the adjacent paths diverge form each other that means the system is unstable in terms of voltage stability. But in systems that are not fully observable or may cause system visibility to be lost during a disturbance, this index is not applicable. Also, VCPrI [10], LCPI [11], and FVSI [12] are indices based on the buses and lines that assesses voltage stability according to the load flow equations and sensitivity of different line parameters. These methods have drawbacks to implement where the Jacobian matrix is singular [9] and in the sensitivity analysis that is completely dependent on the structure of power systems, it involves separate and sometimes complex calculations [7], [8]. In ref. [13], an index based on SVM is presented which is not dependent on the system model and in the case of singularity of the Jacobin matrix, evaluates the voltage stability before and after the occurrence of disturbance by using received data from PMUs. But answers of the proposed method sometimes are trapped in local optimums because of the choosing inappropriate values of the SVM hyperparameters [2], [3], [14]. Hence, in Ref. [14] using the combination of SVM and GA, the problem of appropriate hyperparameter settings is solved and provides a more accurate evaluation of voltage stability of the system. Authors in Ref. [15] present an improved multi-objective method by combining GA and PSO to perform the optimal power flow which resolves the drawbacks of fast convergence in previous studies. But on the other hand, each one of metaheuristic algorithms is defined based on its own conditions and results in different responses to the same problem. In other words, these algorithms may lead to different results with respect to the number of iterations and choosing of the parameters in comparison to other algorithms or even the same algorithm which eventually may not converge to the optimum answer [4],[9].

After predicting and detecting VC by stability indices, control and protection devices aim to stabilize it and prevent VC. The last solution under these situations is load shedding (LS). Several methods have been proposed to LS, the main purpose of which is to stabilize the power system with the least LS. In Ref. [16] optimal LS using the Support Vector Machine (SVM) method is presented. In this technique, the reactive power pre- and past the disturbance of each system is measured and assumed as SVM test and training data. Then, by calculating their difference, the rate of reactive power reduction is measured during the disturbance. After that as much as this reduced power, loads would be removed from the system. Ref. [17] introduces a step-by-step approach to LS. In this method, in the area of the system where the collapse begins, the LS index first compares the sensitivity changes of the lines connected to the load buses during the disturbance to its preceding amount. As such, the lost reactive power would be calculated. Then, according to this method, the reactive power of the system is separated from the buses of that area by percentages and in different steps. This method is very fast and, in the instability, beginning area, it quickly avoids VC and prevents rapid voltage changes in other areas. But in a real system, the LS cannot be considered as a percentage of load outage related to each bus and, if necessary, the load of the intended bus should be completely removed. Therefore, this method cannot be considered practical [18], [19].

In the present study, the voltage stability index is calculated based on the amount of the active and reactive powers which are injected/absorbed to/from the bus connected to the generator bus. The proposed index evaluates the voltage stability dynamically, wide-area and without the need for complex calculations. It also does not face the problem of the singularity of the Jacobean matrix and accurate training and only has a general optimal response. Without complete system observability, this index evaluates the voltage condition independent of the model and structure of the system. After predicting the VC by the index, by implementing a new method, weak lines are identified and cut off and the system is zoned. Under these conditions, the stress applied to the system is reduced and LS is only carried out in areas of the system that do not have proper voltage profiles which cause the normal operation of other areas during a disturbance. Additionally, in this paper, a smart load elimination based on ANFIS and TSK network combination is introduced which results in an increase in the accuracy of the load removal index compared to indices of other neural networks such as SVM. In this method, the LS of each bus is complete, meaning that the load is not eliminated as a percentage. The remainder of this contribution is as follows: In section 2, the relationship between the active and reactive power of the power system during a disturbance is introduced and analysed, and its relation to voltage stability is investigated. Voltage stability index, weak line identification method, and LS index are explained in section 3. Simulations of the standard IEEE 39-bus system and how the stability index is evaluated are introduced in section 4. Finally, in section 5, simulation results and discussions of the presented study along with conclusions are reported.

2. BACKGROUND

2.1. Relationship Between Active and Reactive Powers for Voltage Stability

From Fig. 1, the produced generator reactive power is equal to the sum of reactive load and losses (without active losses for lines R=0) [20].

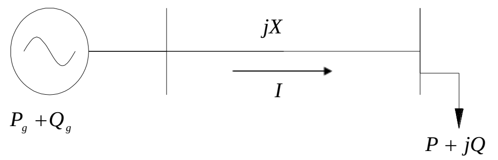


Fig. 1. Generator connected to load bus

$$Q_g = Q + XI^2 \quad (1)$$

The line current I is related to the generator apparent power S_g as below:

$$I = \frac{S_g}{E} = \frac{\sqrt{P_g^2 + Q_g^2}}{E} \quad (2)$$

By substituting I at the Eq. (1), new equations are as follow:

$$Q_g = Q + \frac{X}{E^2}\left(P_g^2 + Q_g^2\right) \quad (3)$$

Or

$$Q_g^2 - \frac{E^2}{X}Q_g + \frac{E^2}{X}Q + P_g^2 = 0 \quad (4)$$

Solving Eq. (4) respect to Q_g gives:

$$Q_g = \frac{E^2}{2X} + \sqrt{\left(\frac{E^2}{2X}\right)^2 - \frac{QE^2}{X} - P_g^2} \quad (5)$$

If Eq. (5) is simplified, the maximum ratio of generator active and reactive power with respect to each other will be as below:

$$Q_g = \frac{E^2}{X} - E\sqrt{\frac{Q}{X}} - P_g \quad (6)$$

In which, P_g, Q_g, E and X are active and reactive powers, generator voltage, and the reactance of line connected to bus, respectively. Also, it is told that voltage instability during disturbances is due to reduction in the maximum deliverable power [1]-[4]. According to Eq. (6), if active power is equal to reactive power, the maximum power will be delivered to load. On the other hand, power systems have nonlinear structures and active and reactive powers change at any time instance. For example, in Fig. 2, P, Q are the parameters which have been measured. Note that these parameters are equal to their previous values from t_0 until t_1, which means the system is stable at the end of this interval. When we consider a disturbance at t_1. From t_1 to t_2, external controlling is not required regarding the activities of under voltage relays, power system stabilizers (PSS) and other processes to prevent VC. The previous condition is true for t_2 to t_3 and voltage, so the probability of voltage instability is high. If P and Q variables reach t_3, voltage instability will have the maximum probability. From t_3 to t_4, external controlling no action is necessary because of the activities of under voltage relays, Power System Stabilizers (PSS) and other protection devices.

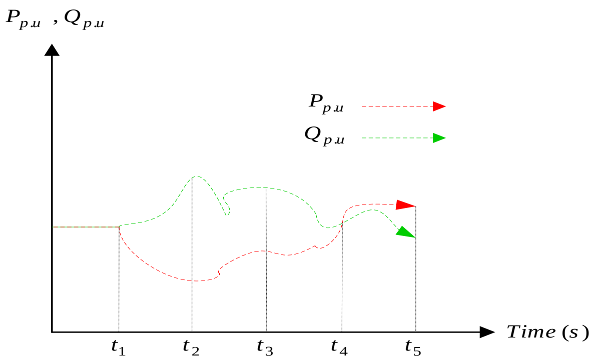


Fig. 2. Vector analysis method

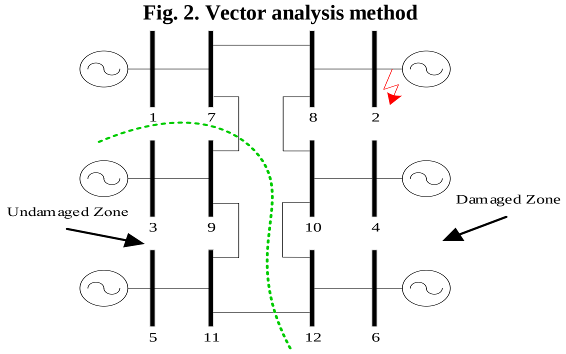


Fig. 3. Zoning in the power system

At t_4, the system no longer has enough ability for prevention of VC. Therefore, the external corrective controlling actions are needed; otherwise, the VC in the system will occur at t_5.

2.2. Zoning

There are many advantages in zoning for VC prevention. If the weak lines get disconnected from the network under the stressed conditions, there will not be damages during over or under voltage cases. Furthermore, undamaged zones will work without any problem and any influence from damaged ones [21]. Another advantage of zoning is when LS is needed. Because the emergency LS will be required only in the damaged zones. Furthermore, disconnecting of weak lines resulting in VC under normal condition acts as a common transient event. Therefore, VC may encounter no threat. For example, Fig. 3, illustrates a power system with 12 buses on which a hypothetical disorder is imposed, moving the power system toward VC. In this state by disconnecting weak lines of 7-9 and 11-12, the power system will be divided into two damaged and undamaged zones. After zoning each controlling action such as LS is only performed in the damaged zone and undamaged zone needs no additional controlling action so there will be voltage stability.

3. PROPOSED METHOD

3.1. Vector Analysis (VA) for voltage stability

In this paper, voltage stability is studied using a new method called vector analysis which is based on the system parameter online measurements. Such analysis will result in better investigations of different system conditions. Based on vector analysis, stability index is divided into two parts:

A. Internal Part (IP): This part of the index is related to all events which are happening behind the bus connecting the generator bus in Fig. 4.

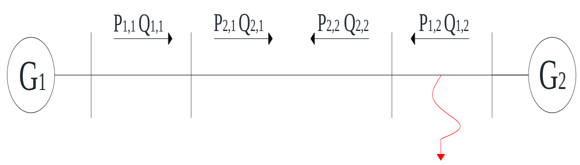


Fig. 4. IP detection

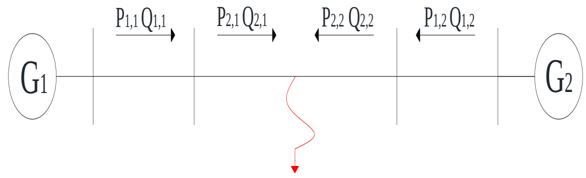


Fig. 5. EP detection

Therefore, disturbance calculations are investigated as follows:

$$\begin{aligned} &P_{1,1}(t)-P_{2,1}(t)=P_1(t)\\ &Q_{1,1}(t)-Q_{2,1}(t)=Q_1(t)\end{aligned} \quad (7)$$

$$\frac{P_1(t)}{P_{ref}}=P(t),\ \frac{Q_1(t)}{Q_{ref}}=Q(t) \quad (8)$$

Where, P_{ref}, Q_{ref} are internal active and reactive powers before the event.

B. External part (EP): based on Fig. 5, all events connected to the bus after the generator bus are calculated using external part of the index. Index calculation, under this condition, is investigated as follows:

$$\begin{cases}\begin{cases}P_{1,1}(t)-P_{2,1}(t)=P_1(t)\\ Q_{1,1}(t)-Q_{2,1}(t)=Q_1(t)\end{cases}\\ \begin{cases}P_{1,2}(t)-P_{2,2}(t)=P_2(t)\\ Q_{1,2}(t)-Q_{2,2}(t)=Q_2(t)\end{cases}\end{cases} \quad (9)$$

Note:

1- The buses connected to the generator buses that are not fed by active and reactive powers under normal condition (Slack Bus), cannot assess voltage stability.

2- Outage for the generators, which are connected to the power system from both sides, is identified using external part.

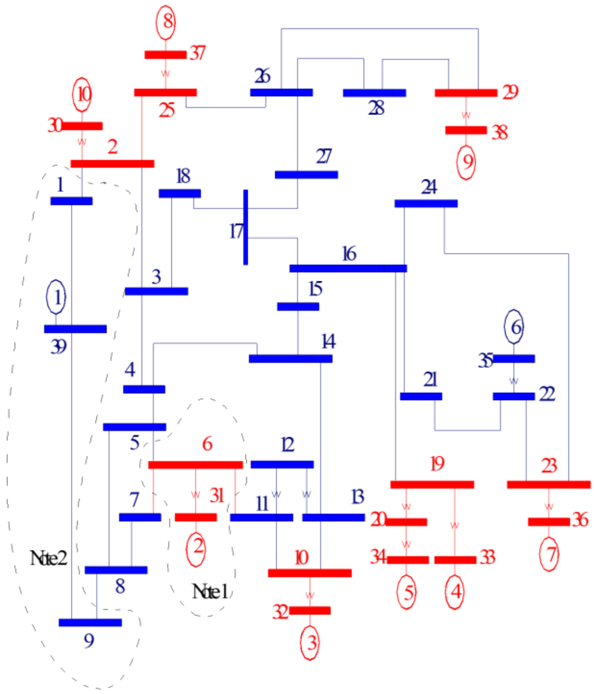


Fig. 6. Voltage Stability assessment using VA index in IEEE 39 bus test system

3.2. VA in IEEE 39 Bus

In Fig. 6, an IEEE 39 bus system has been represented. In general, evaluating of voltage stability in red part of the power system done with the internal part of VA index and the blue part of the power system is evaluated by the external part of the VA index. Moreover, in order to apply Eqns. (8)-(9), measuring active and reactive powers of buses no. 2, 10, 19, 20, 22, 23, 25, 29 is carried out on time.

3.3. LS

Wide area blackout is a concerning problem in many modern power systems. On the other hand, in recent years due to financial problems and environmental issues, designers and operators have focused on the development of the power systems with less redundancy and operation on state stability. Therefore, the LS has been one of the most effective options, especially in the final stages as the last resort for the power systems in the case of VC [1], [20]. On the other hand, the LS amount should be proportional with to system conditions and it cannot be out of a justifiable mechanism. Therefore, there is a limit for each power system called as maximum overload which is computed using the equation below:

$$L = \frac{Total\ load\ - Total\ Generation}{Total\ Generation} \times 100\% \tag{10}$$

In which L is the maximum tolerable overload in each zone. From the above equation, 33% removal of produced power will result in the 50% overloading in the power system. While the L value is arbitrary, values more than 50% for L is not suitable and LS in the small events will occur [19], [22]-[23]. Furthermore, the intelligence systems like neural and fuzzy networks are well known as general approximations that are capable to estimate each nonlinear function due to the existence of enough neurons in the mid layer and correct fuzzy rules [24], [25]. Recent studies on the neural and fuzzy networks have shown that the composition of these two networks is more effective in detection of nonlinear algorithms. Since the power systems have nonlinear dynamics, the neural-fuzzy structure might solve the problem in LS. The LS continues unless following equation is observed.

$$Q_i \simeq X_i Q_i^{new} \qquad i = 1, 2, ..., N \tag{11}$$

Where Q_i and Q_i^{new} are mean reactive power of each bus before and after event respectively. At first, reactive power demand is measured at the instantaneous of disturbance detection, and then the Q_i values are stored for each bus in the Eq. (11). Because the detected fault may have resulted from some transient conditions, voltage stability will be performed after a certain time (5.2 second after fault detection). If LS is required according to the vector index, new measurements of reactive power are used as Q_i^{new} values in equation Eq. (11). Using these reactive power values, each of load buses is trained through the intelligent ANFIS-TSK (AN-T) method. After training, reactive power changes are assessed and then prioritized at load buses. In other words, if there is a big difference between the learned and measured reactive power, LS priority will be higher. Furthermore, X_i is responsible for network training using AN-T method and is limited to $0 < X_i \le L$. After correctness, the below relationship should be confirmed for each network bus:

$$0.8_{p.u} \le V_i^{new} \le 1.2_{p.u} \qquad i = 1, 2, ..., N \tag{12}$$

In which V_i^{new} is the bus voltage after LS.

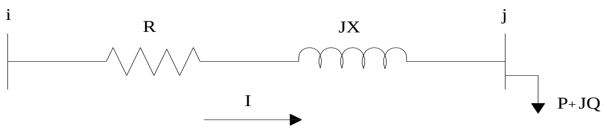


Fig. 7. Show line connected to load bus

3.4. Weak Bus Detection

Fig .7 shows the load $P + jQ$ connected to end of the line between buses i and j line impedance is $R + jX$ and the current is computed as:

$$I = \frac{P - jQ}{V_j} \tag{13}$$

Also, the beginning bus voltage is:

$$V_i = V_j + I\left(R + jX\right) \tag{14}$$

By substituting I in the previous equation,

$$V_i = V_j + \left(\frac{PX\ -QR}{|V_j|}\right)(R + jX) \\ \Rightarrow V_i = V_j + \left(\frac{PX + QR}{|V_j|}\right) + j\left(\frac{PX - QR}{|V_j|}\right) \tag{15}$$

Let $\measuredangle \theta V_i \simeq \measuredangle \theta V_j$

$$PQ = QR \tag{16}$$

Therefore:

$$\frac{PX + QR}{|V_j|} = |V_i| - |V_j| \tag{17}$$

Finally, ΔV is the voltage drop for each line as bellow:

$$\Delta V = \frac{|V_i| - |V_j|}{|V_j|} \quad (18)$$

Accordingly, voltage drop for each line is achieved via below steps:

1- The beginning and end bus voltages are measured:

$$V_i^k = [1, 2, ..., n]$$
$$V_j^k = [1, 2, ..., n] \quad (19)$$

In which k is the line number ($k = [1,2, \dots, n]$) and n is the total number of buses.

2- Voltage drop value for each line:

$$\Delta V^k = \frac{|V_i^k| - |V_j^k|}{|V_j^k|} \quad (20)$$

3- considering indexes with their rates make them faster and more accurate:

$$\dot{\Delta V}^k = \frac{d}{dt} \Delta V^k \quad (21)$$

4- Finally, the voltage drop for each line is computed as:

$$Line\ Information^k = \Delta V^k + \dot{\Delta V}^k \quad (22)$$

4. SIMULATION RESULTS

4.1. System Under Study

The 39 bus NE system has 10 generators and 29 load buses with a nominal frequency of 60 Hz. Voltage and frequency dependent static load models are considered at all the buses except at buses 3 and 18, where the dynamic load model was considered [26].

4.2. Scenario One

Following the disturbance occurrence, the G4 se is separated in 1s. According to Fig. 6, this outage is considered as an internal disturbance. In this case, the evaluation of voltage stability does not require a system modelling, and the IP will be determined without the complex calculation. Fig. 8, shows the voltage collapse detection using IP during the disturbance. VC is predicted in all buses, and the IP has an optimal global response.

Table 1. IP detection after G4 outage

Bus Number	Time (s)	Detection Priority
10	5.6	6
20	0.85	4
22	0.4	1
23	0.55	3
25	1	5
29	0.5	2
2	5.85	7

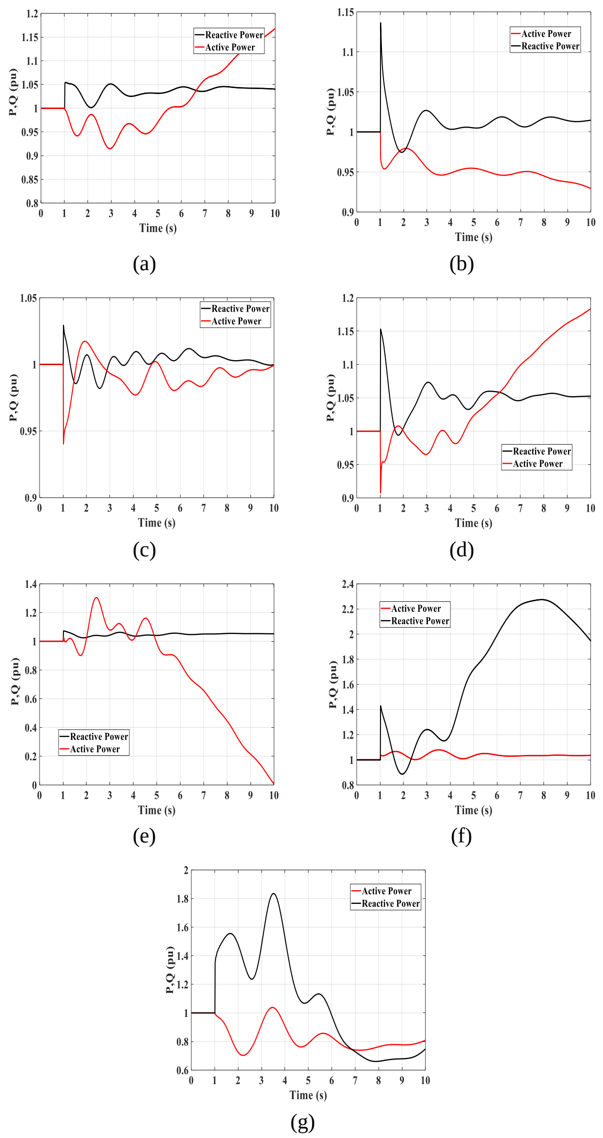


Fig.8. IP index after G4 outage: (a) bus10, (b) bus20, (c) bus22, (d) bus23, (e) bus25, (f) bus 29, (g) bus2

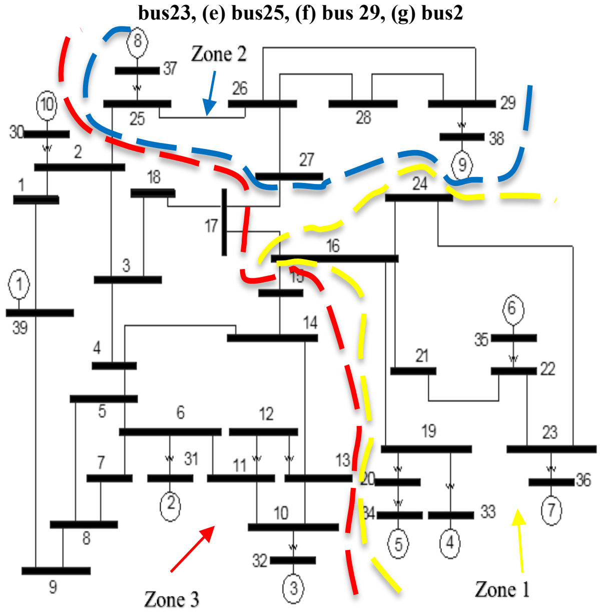


Fig. 9. Zoning diagram of the IEEE 39 bus system after G4 outage

Table. 2: VC detection between IP and other methods G4 outage

Method	Time (s)
Ref [2]	1.5
Ref [3]	1.6
Ref [4]	2.25
Ref [7]	0.8
Ref [12]	0.9
Ref [26]	1.65
IP	0.4

Table 1 shows the time and priority of voltage collapse detection by each bus. VC detection in bus 22 is faster than other the buses. In addition, the speed of VC detection predicted in the 29 and 23 buses is highly considerable.

Therefore, when bus 22 has not been observable, the voltage collapse would be prediction using other buses with an acceptable speed. While, these buses are in separate areas, the voltage instability spreads rapidly in the system and the precise instability beginning is unclear. So, wide area index has higher reliability compared with the local index [4, 7, 26]. Table 2 shows the VC time detection using IP and other methods. According to [26] (time interval that mentioned in [26]), zoning is performed at t=6.2s in the power system. Therefore, the weak lines including 15-16, 16-17, 17-27, and 2-25, are disconnected and the power system is divided into three zones that shown in Fig. 9.

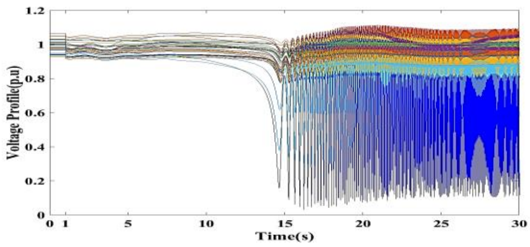


Fig. 10. Voltage profile of generators for outage at bus 33

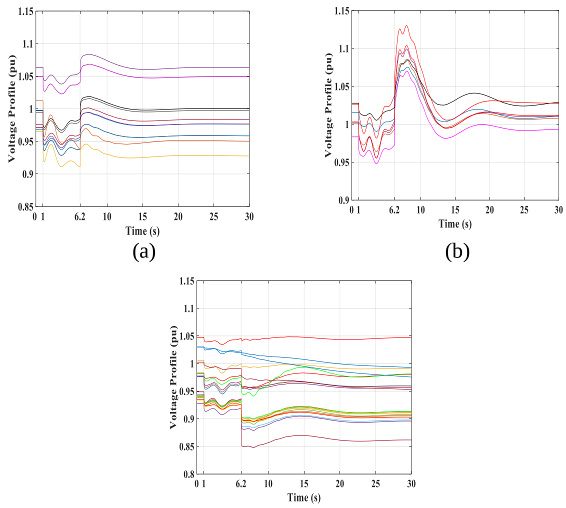


Fig. 11. Voltage profile after zoning: (a) Zone1, (b) Zone2, (c) Zone3

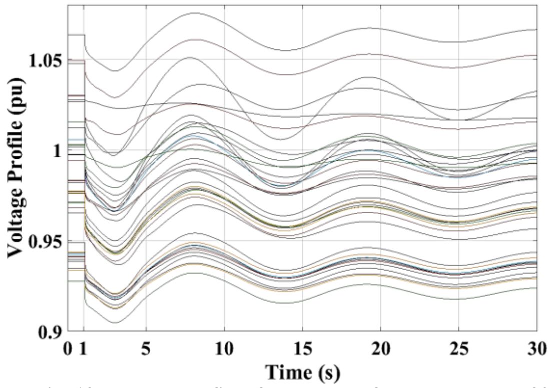


Fig. 12. Voltage profile of generators for outage at bus 30

After the zoning, VC is not prediction in any zone. Since, the identification of weak lines leads to a reduction in the produced stress level for the system will considering voltage profile in these three zones, LS or other controlling methods would not be required. However, in Refs. [2] - [15] without zoning, we need LS to achieve voltage stability in the power system. Fig. 10 illustrates the voltage profile effect of G4 outage without zoning. Therefore, the voltage collapse is correctly predicted by the IP. Fig. 11 shows the voltage profiles of each area, after zoning and without LS.

4.3. Scenario Two

This part displays G10 as a phenomenon that only causes a simple stress in system and does not make VC in Fig. 12. Also, proper application of the proposed index is quite evident from Fig. 13.

According to the IP measurements coming from the buses connected to the generator bus, it does not warn voltage collapse which is a correct detection. As a result, zoning is not required. In addition, if another disturbance in the system occurs, voltage collapse will really be evaluated. So that, the effect of the generator outage at bus number 30 will be considered in the measurement-based index and both its IP and EP of index act carefully. This is beneficial in preventing the blackouts which usually happen due to simultaneous disturbances or sequential stresses with short time intervals.

4.4. Scenario Three

G1 is separated in t=1s. According to Fig. 6, EP index is used to evaluate voltage stability. Fig. 14, is obtained using EP index calculations for each bus. According to EP index, the power system will face a voltage collapse. Table 3 shows the detection time and priority of voltage collapse prediction in each bus. Although bus 29 is not located in the G1 outage area, but VC collapse is predicted at 20ms after the disturbance.

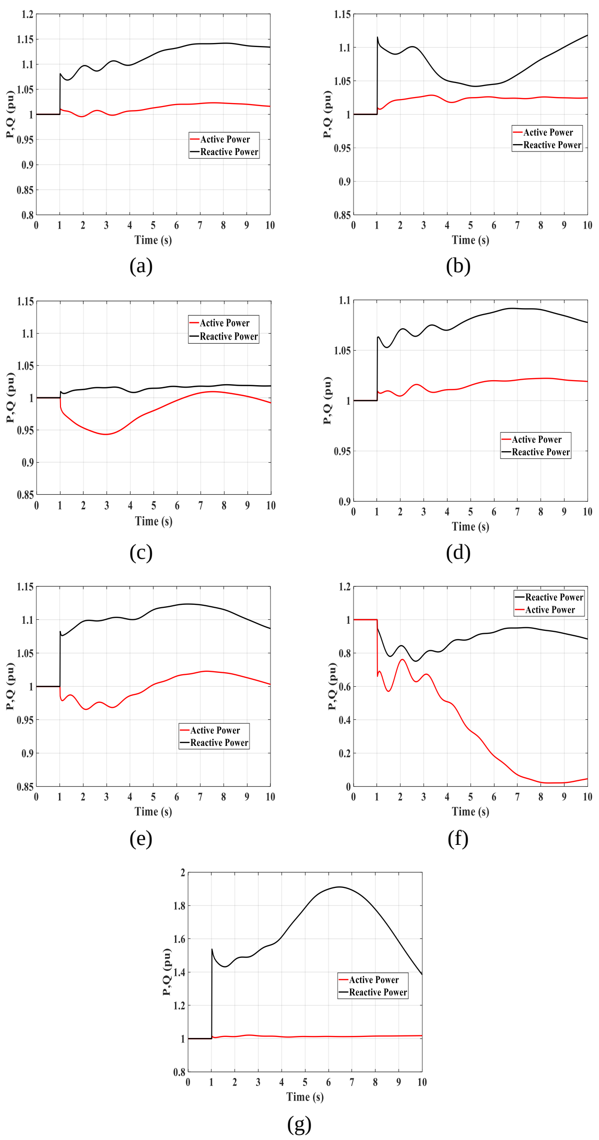


Fig. 13. EP index after G10 outage: (a) bus10, (b) bus20, (c) bus22, (d) bus23, (e) bus25, (f) bus 29, (g) bus2

Table 3. EP detection after G4 outage

Bus Number	Time (s)	Detection Priority
10	0.8	6
19	0.025	2
20	4.3	8
22	0.07	4
23	0.15	5
25	0.03	3
29	0.020	1
2	3.4	7

Table 4. Voltage collapse detection between EP and other methods

Method	Time (s)
Ref [2]	1.5
Ref [3]	1.6
Ref [4]	1.5
Ref [7]	0.5
Ref [9]	1.65
Ref [12]	0.9
Ref [26]	0.56
EP	0.02

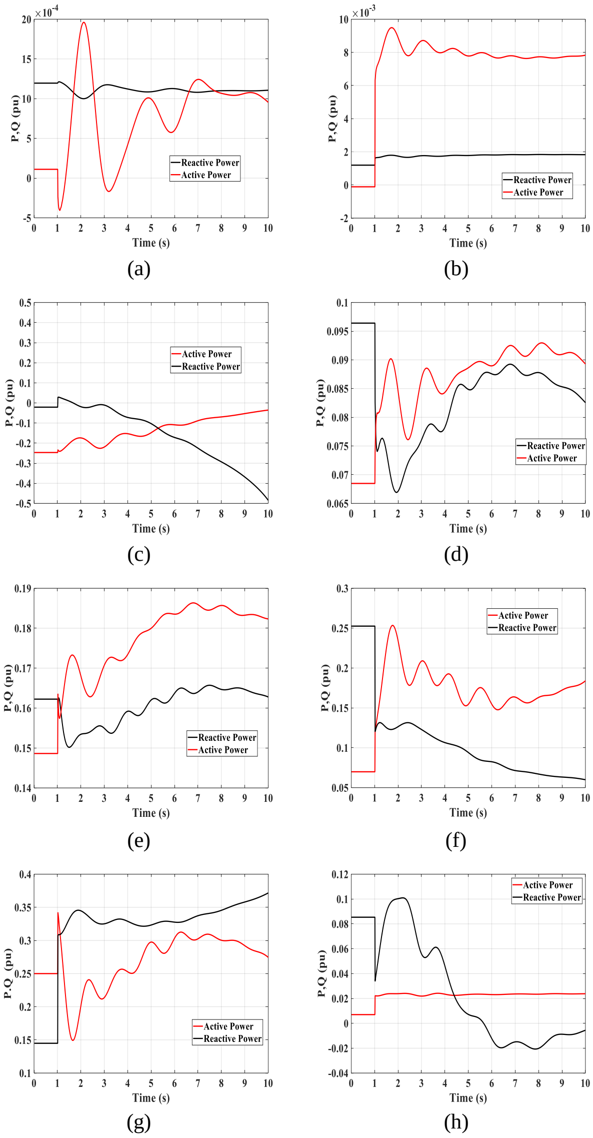


Fig. 14. VA index after G1 outage: (a) bus10, (b) bus 19, (c) bus20, (d) bus22, (e) bus23, (f) bus25, (g) bus29 (h) bus2

Priorities 2, 3, and 4 have a high speed in predicting VC. Table 4 compares the VC prediction time using EP index with other methods. According to [26], 5.2sec after disturbance occurrence, zoning is carried out at t= 6.2 s. In Fig. 15, the system is divided into three zones by disconnecting weak lines 5-6, 7-8, 13-14, 14-15, 17-18, 25-26. The EP index predicts that the voltage profile the first and second zones are stable, and in the third zone VC is occurred. Table 5 shows the VC detection time in the third zone. Fig. 16 shows the voltage profiles of the third zone, before disturbance and after the zoning. So, LS is only performed in the third zone and no problem in the other zones. In order to prevent unnecessary LS, the L index is calculated. Table 6 illustrates the amount and priority of the third zone's load shedding which has been delivered using SVM and AN-T method.

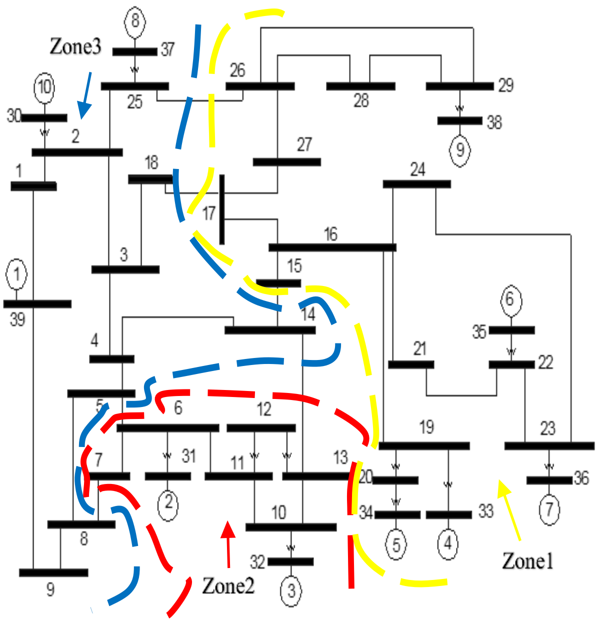


Fig. 15. Zoning diagram of the IEEE 39 bus system after G10 outage

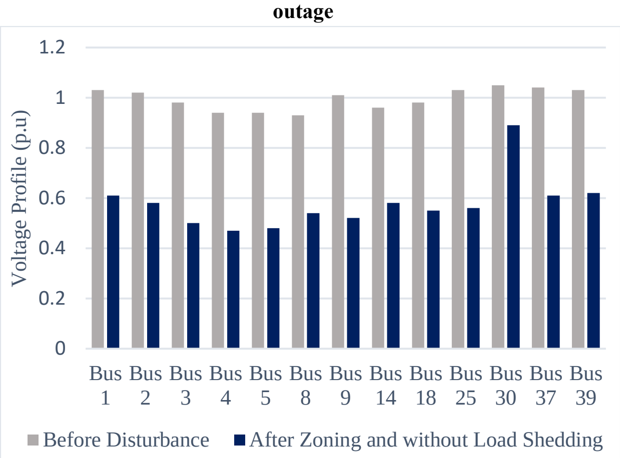
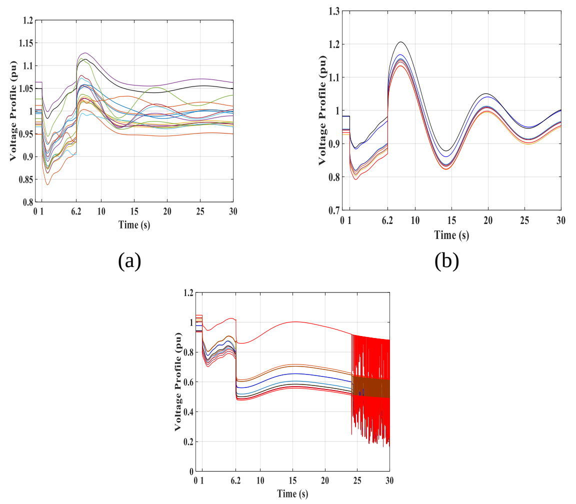


Fig 16. Voltage profile in zone 3: Before disturbance; After zoning and without load shedding



(a) (b)

(c)

Fig. 17. Voltage profile after zoning and without LS: (a) Zone1, (b) Zone2, (c) Zone3

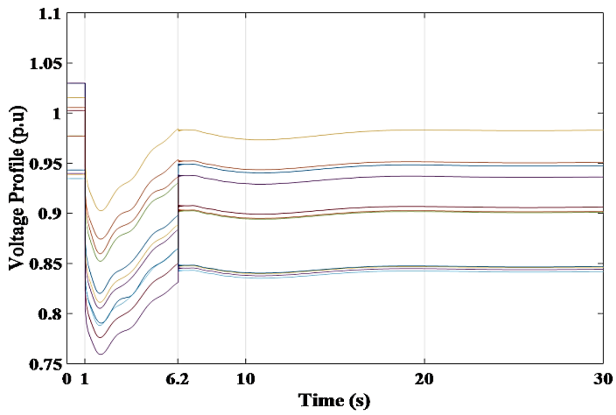


Fig. 18. Voltage profile with LS in zone 3

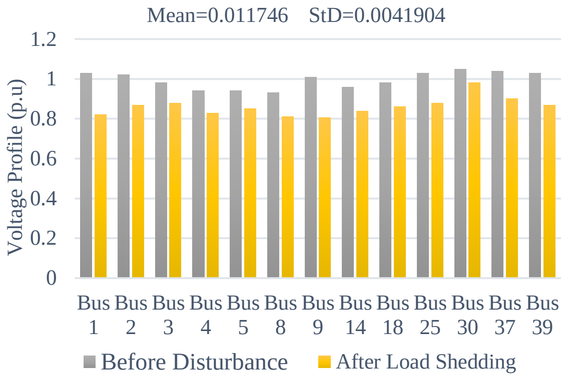


Fig. 19. Voltage Profile in zone 3: Before disturbance; After zoning and with LS

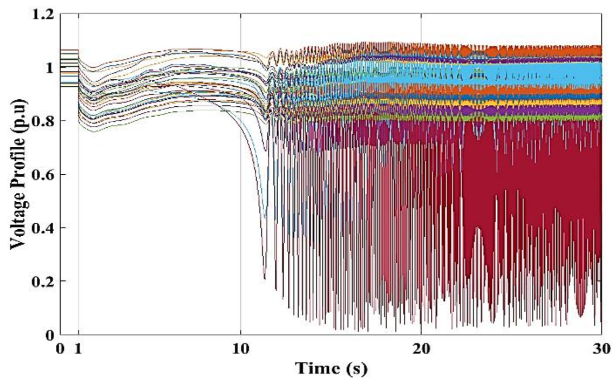


Fig. 20. Voltage profile of generators for outage at bus 39

Table 5. Voltage collapse detection after zoning in zone 3

BUS Number	Time (s)	Detection Priority
25	0.8	2
2	0.09	1

Table 6. LS in zone3 (L=21.19%)

Load Bus	$\frac{Load_{bus}}{Load_{total}} \times 100$	LS Ability	AN-T Method		ANFIS Method		SVM Method	
			Priority	LS	Priority	LS	Priority	LS
4	21.27	Yes	2	No	1	Yes	1	Yes
8	22.21	Yes	1	Yes	2	Yes	2	Yes
25	9.53	Yes	3	No	3	No	3	No
39	46.978	No	-	No	-	No	-	No

According to the table, in AN-T method, voltage stability is assured through load shedding of bus 8. On the other hand, SVM method to sustain voltage stability is conducted by load shedding of bus 4 and bus 8, respectively. The result showed that load shedding in AN-T method was much less due to better training of this method in the priority load shedding. Therefore, the existing difference between these methods is placed on their different ways of training. As in SVM method unlike AN-T, network training at difficulty with small row or column [20]. Additionally, it should be taken into consideration that each training and input data applied in Eq. (11) has been an $n \times 1$ matrix of reactive powers of each load bus in two different times which *n* is the total loading number of the zone. Fig. 17 shows the third zones voltage profiles before disturbance and after LS. The voltage profile is in an acceptable range. Fig. 18 illustrated the third zone voltage profile without LS. Fig. 19 shows the third zone voltage profile by LS.

Where:

Mean: the difference means between target and output in the AN-T method. STD: the standard deviation of the difference between target and output.

Where:

Output: is a train reactive power in the zone 3 according to Eq. 11, Target: pre-disturbance reactive power of the third zone buses. According to mean, network training is done correctly. Fig. 20 illustrates the voltage profile effect of G1 outage without zoning.

5. CONCLUSION

In present study new index for identification of voltage collapse time was investigated. The basic point for the application of this index is the measurement of active and reactive powers of buses connected to generator bus. One of advantages of this index is its high precision, independent on time-consuming and complicated calculation it has very high precision. Another advantage of this index is its high speed which analyses the power system online. Additionally, LS in today's power systems has commonly been applied. Therefore, in this paper, a new method has been introduced in the form of intelligent LS. LS Subsequently, when LS is required in the system, excessive load of the system will not have eliminated resulting in network efficiency.

REFERENCES

[1] D. Meng, "China's protection technique in preventing power system blackout to world", *Int. Conf. Adv. Power Syst. Autom. Prot.*, pp. 1838-1844, 2011.

[2] A. Pama et al., "Static voltage stability improvement with battery energy storage considering optimal control of active and reactive power injection", *Electr. Power Syst. Res.*, vol. 79, pp. 303-312, 2019.

[3] D. Marujo, A. Zambroni, B. Lopes, M. Santos and K. Lo, "On control actions effects by using QV curves", *IEEE Trans. Power Syst.*, vol. 30, pp. 1298-1305,2017.

[4] H. Li, A. Bose and V. Venkatasubramanian, "Wide-area voltage monitoring and optimization" *IEEE Trans. Smart Grid*, vol. 7, pp. 785-793, 2016.

[5] Y. Wang, C. Wang, F. Lin, W. Li, L. Wang and J. Zhao, "Incorporating generator equivalent model into voltage stability analysis", *IEEE Trans. Power Syst.*, vol.28, pp. 4857-4866, 2013.

[6] R. Sodhi, S. Srivastava and S. Singh, "A simple scheme for wide area detection of impending voltage instability", *IEEE Trans. Smart Grid*, vol. 63, pp. 1020-1031, 2013.

[7] M. Mohammadniaei, F. Namdari and M. R. Shakarami, "A new algorithm for zoning of power system to protect from voltage collapse", *31th Int. Power System Conf.*, pp. 2147-2151, 2016.

[8] A. Chandra and A. Pradhan, "Online voltage stability and load margin assessment using wide area measurements", *Int. J. Electr. Power Energy Syst.*, vol. 6, pp.392-401, 2019.

[9] S. Dasgupta, M. Paramasivam, U. Vaidya and V. Ajjarapu, "Real-Time Monitoring of Short-TermVoltage Stability Using PMU Data", *IEEE Trans. Power Syst.*, vol.28, pp. 3702-3711, 2013.

[10] V. Balamourgan, T. Sidhu and M. Sachdev, "Technique for online prediction of voltage collapse", *IEEE Proc. Gener. Transm. Dist.,* vol.15, pp. 453-460, 2004.

[11] R. Tiwari, K. Niazi and V. Gupta, "Line collapse proximity index for prediction of voltage collapse in power systems", *Int. J. Electr. Power Energy Syst.*, vol. 8, pp.41-51, 2012.

[12] I. Musirin and T. Rahman, "Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system", *Proc. student conf. res. Dev.*, pp. 265-268, 2002.

[13] S. Pérez-londoño, L. Rodríguez and G. Olivar, "A simplified voltage stability index (SVSI)", *Int. J. Electr. Power Energy Syst.*, vol. 63, pp. 806-813, 2014.

[14] K. Sajan, V. Kumar and B. Tyagi, "Genetic algorithm based support vector machine for on-line voltage stability monitoring", *Int. J. Electr. Power Energy Syst.*, vol. 8, pp. 200-208, 2015.

[15] H. Aliyari, R. Effatnejad and M. Savaghebi, "Solving Multi-Objective Optimal Power Flow Using Modified GA and PSO Based on Hybrid Algorithm", *J. Oper. Autom. Power Eng.*, vol. 5, pp. 51-60, 2017.

[16] A. Saffarian and M. Sanaye-Pasand, "Enhancement of Power System Stability Using Adaptive Combinational Load Shedding Methods", *IEEE Trans. Power Syst.*, vol. 26, pp. 1010-1020, 2011.

[17] W. Council, "WECC coordinated off-nominal frequency load shedding and restoration requirements", 2005.

[18] H. Shayeghi and A. Younesi, "Mini/Micro-Grid Adaptive Voltage and Frequency Stability Enhancement Using Q-

learning Mechanism through the Offset of PID Controller", *J. Oper. Autom. Power Eng.*, vol. 7, pp.107-118, 2019.

[19] H. Shayeghi and A. Younesi, "A Robust Discrete FuzzyP+FuzzyI+FuzzyD Load Frequency Controller for Multi-Source Power System in Restructuring Environment", *J. Oper. Autom. Power Eng.*, vol.5, pp.61-74, 2017.

[20] T. Cutsem and C. Vournas, "Voltage stability of electric power systems", Springer, 2008.

[21] A. Eshraghi and R. Ghorbani, "Islanding detection and over voltage mitigation using controllable loads", *Sustain. Energy, Grids Networks*, vol. 6, pp. 125-135, 2016.

[22] J. Jones and W. Kirkland, "Computer algorithm for selection of frequency relays for load shedding", *IEEE Comput. Appl. Power*, vol. 1, pp. 21-25, 1988.

[23] W. Council, "WECC coordinated off-nominal frequency load shedding and restoration requirements", 2005.

[24] K. Hornik, M. Stinchcombe, H. White and P. Auer, "Degree of Approximation Results for Feedforward Networks Approximating Unknown Mappings and Their Derivatives", *Neural Comput.*, vol. 6, pp. 1262-1275, 1994.

[25] B. Kosko, "Fuzzy systems as universal approximators", *IEEE Trans. Comput.*, vol. 43, pp. 1329-1333, 1994.

[26] K. Seethalekshmi et al., "A Synchrophasor Assisted Frequency and Voltage Stability Based Load Shedding Scheme for Self-Healing of Power System", *IEEE Trans. Smart Grid*, vol. 2, pp. 221-230, 2011.