

# **Control of Unbalanced Power Fluctuation Using Out-of-Step Tripping (OST) Method**

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**Abstract.** Power systems are being exposed to a wide range of disturbances during operations and those disturbances could be smaller and larger. In the provided study we are going to discuss that disturbances in electrical power systems are common and result in electromechanical oscillations which could be also defined as power swing. The interconnected generator with a synchronous system might be severe and may occur into the loss of synchronism due to power fluctuation. Step tripping could be defined as the method which differentiates between stable and unstable power fluctuations and controls the swings and keeps on initiating network shield during synchronism among power system targeted zones. The current & voltage have fluctuated when the out-of-step condition occurs and it damages power system equipment as well as of step condition involved in protective devices requires a more effective algorithm. This research concerns step state many protective devices. For correct recognition of out in power system network, and discusses in what way to enhance the attainment of protective devices during power swing. In the provided study we would be designing the algorithm by using MATLAB code the required needful simulation and PSCAD. The procedure followed here identifies the faults in the system, reliability concerns, sustainability and effectiveness and it will predict loss of synchronicity to make it smoother for operations.

**Keywords:** Power System, Voltage Swing, Protection System, MATLAB Simulation, PSCAD.

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## **1. Introduction**

When a disturbance takes place in a power system, it is very essential to figure out the changes as quickly as possible and to take precise actions against the fault. Modern power networks utilize distance relays with the detection of power fluctuations to identify out-of-step conditions. Pre-set tripping relays in the electrical power system to get free of the oscillations and to continue important components operating without disturbances. As, an alternative to using distance

relays to identify Out-of-Step conditions, new measurement techniques are available where it is possible to detect phase angles in the complete power system with the same time and angle as a reference shown in Fig. 1. Studies have been done with the new technique to calculate voltages and currents in power systems and also to measure the difference between mechanical rotor angle and electrical power (SEL, 2017). This research goes one step further in the way of making the new techniques in the power system network to discover electric power swing oscillations and avoiding Out

of Step. During steady-state operating conditions, power systems operate on the nominal frequency (50Hz or 60Hz)  $\pm 0.02\text{Hz}$  and Voltage=Nominal voltage  $\pm 5\%$  (PSRC, 2005). During steady-state conditions, a balance exists between consumed and generated active power that is essential for the stability of the electrical power system. There are various disturbances in the power system e.g., variation in the system, loss in generation or transmission side, and clearance of fault. Due to these variations in power system imbalance is created in the input and output of power. During steady-state conditions output is considered as electrical and input as mechanical, so electro-mechanical oscillations are created because of unbalanced input and output and can result in electrical power flow swings (Abdelaziz et al. 2010). These oscillations affect the current and voltage waveforms of the power system. Current and voltage waveform during steady-state and power swing conditions are shown in Fig. 2 & Fig. 3, respectively (Elmore, 2009). Due to the reaction of disturbance, two types of power swings stable and unstable are produced in a power system.

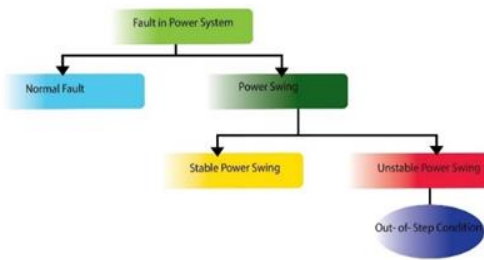


Fig. 1. Block diagram of the System

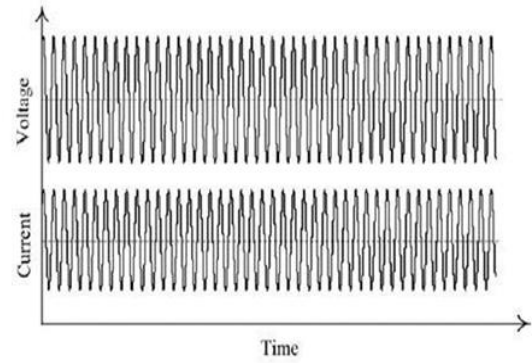


Fig. 2. Current and Voltage curves during Constant State Condition (Elmore, 2009)

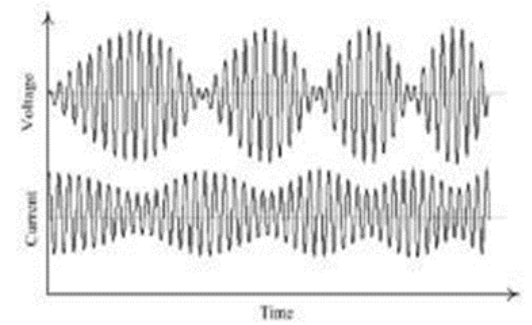


Fig. 3. Current & Voltage Curves in Electrical Power Swing (Elmore, 2009)

When produced oscillations in the power system return to a steady-state point, it is considered as a stable power swing. But if there are huge oscillations and if it does not return to a steady-state point then it is considered as unstable power swing that is also called out-of-step situation. These out-of-step phenomena can result in huge oscillations in current and voltage waveform which affect the stability of the power system (Kimbark, 1948).

## 2. Relationship for different fluctuations

The generated electric power  $P_a$  transmitted from the generator to a load of the electric machine is given by Eq. (1) (Tziouvaras, 2004).

$$P_g = \frac{E_g E_l}{X} \sin \dots \dots \dots 1$$

$$P_a = P_m - P_g \dots \dots \dots 2$$

As turbine generates the electric power by using mechanical power and according to electric power equation if one parameter will change due to disturbance in the power system it will affect the overall system. Electrical power is changed due to two parameters one is reactance (X) and the second is load voltage  $E_l$  of load side. Load voltage will be decreased due to short circuits and reactance will be increased due to the opening of the circuit breaker. When one of the generators in the power system is tripped, the load will have to shift on other generator units and this change will affect the stability of the power system (US-CAN, 2012). In such conditions, instantaneous electrical power by the load is not equal to instantaneous mechanical power by the load (Tziouvaras, 2004). So, rotor angular velocity will go on decreasing due to a sudden increase in load on other generator units. As a result, large power flow swings will be produced due to oscillation in rotor angle. The accelerating torque  $T_a$  is determined by the difference between electro-mechanical torque  $T_m$  and shaft torque  $T_m$  in a machine as presented by Eq. (3).

$$T_a = T_m - T_e \dots\dots 3$$

$$P = T * \omega \dots\dots 4$$

Where,

P = Power in watt

T = torque in N.m

$\omega$  = Angular velocity in rad/s

$$\omega = \frac{d\theta}{dt} \dots\dots 5$$

$$T = J * \alpha \dots\dots 6$$

$$M = J * \omega \dots\dots 7$$

$$P_a = T_a * \omega = M * \alpha = M * \frac{d^2\theta}{dt^2} \dots\dots 8$$

$$\theta(t) = \omega_{syn} * t + \delta \dots\dots 9$$

While the angular velocity  $\omega$  is:

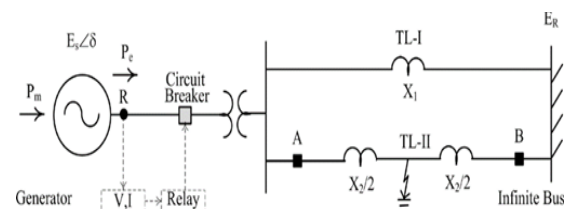
$$\omega = \frac{d\theta}{dt} = \omega_{syn} + \frac{d\delta}{dt} \dots\dots 10$$

$$P_a = M * \frac{d^2\delta}{dt^2} \dots\dots 11$$

$$P_a = P_m - P_e = \frac{2H}{\omega_{syn}} * \frac{d\omega}{dt} \dots\dots 12$$

### 2.1. Proposed Method

The proposed approach is categorized into three conjectures, (I) Firstly to define the three conditions when fault occurs at different angles of the rotor of the generator, which shows that how to power system response and what can be the behavior of fluctuations curves during three conditions included before-fault, during fault and after a fault. (II) Secondly explaining why, a threshold value of rotor angle is set to determine the type of the fault, whether it is normal fault or power swing. Compare the rotor angles value if the gap is more than 0.1 so then fault moves to power swing region, otherwise this normal fault can easily be detected with normal relay operation. (III) Thirdly to differentiate between stable and unstable fault by comparing the mechanical power of rotor and electrical power of generator (Kundur; Paudyal, 2018). If the electrical power is greater than mechanical power then the curve will not come back originally to the mechanical power line. To make the algorithm accurate and perfect enough time is consumed to make the out-of-Step conditions hold in all the perspectives (Fig. 4).



**Fig. 4. Single-Machine Infinite Buses System (SMIB)**

Fig. 4 shows the single-machine power system and

parallel transmission line TL-1 and TL-2 with impedance  $X_1$  and  $X_2$  respectively. The electrical power from the generator to the motor is given by,

$$P_e = P_{max} \sin \delta \dots \dots \dots 13$$

The maximum power relocated from generation to motor end is given by,

$$P_{max} = \frac{E_s E_r}{X} \dots \dots \dots 14$$

$\delta$  = phase angle between  $E_s$  and  $E_r$

$X$  = total impedance

Power changes due to change of impedance during a fault in the system in three cases are before-fault, during fault and after-fault.

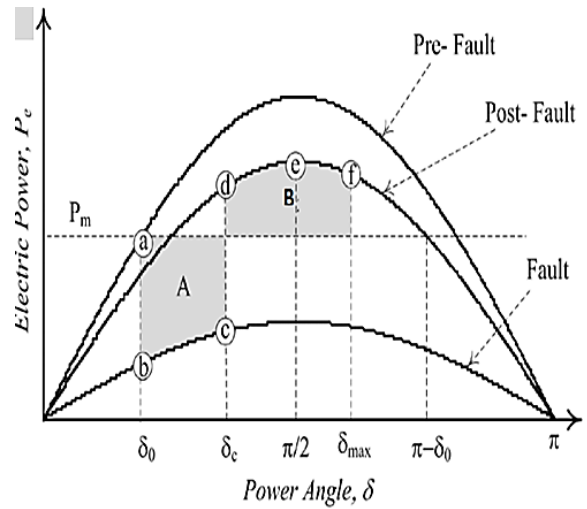
Fig. 5 shows that mechanical power  $P_m$  is equal to electrical power  $P_e$  at angle  $\delta_o$  and at the pre-fault steady-state condition (Adibi, 2013; Cheng and Sachdev, 2015). Electrical output power rapidly drops and follows the fault curve when fault is applied to the power system as shown in the figure. 5. Output electrical power suddenly changes and monitors the post-fault curve when fault is cleared at  $\delta_o$ . The area **A** and area **B** represent the transient energy for  $P_m > P_e$  and  $P_m \leq P_e$  respectively.

$$A = \int_{\delta_n}^{\delta_e} \frac{w_s}{H} (P_m - P_e) d\delta \dots \dots 15$$

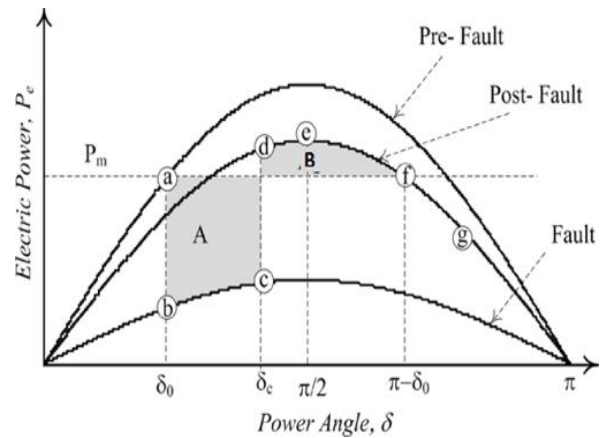
$$B = \int_{\delta_n}^{\delta_{max}} \frac{w_s}{H} (P_m - P_e) d\delta \dots \dots \dots 16$$

**A** will be equal to and less than **B** for the stable power system.

As shown in Fig. 6, the power angle  $\delta$  swings up to  $\delta_{max}$  where  $\delta_{max} = \pi - \delta_o$ . **A** will be greater than **B** for an unstable power system.



**Fig. 5. Power- Delta bend displaying an even state (Kundur, 2007)**



**Fig. 6. Power- Delta bend displaying an uneven state (Kundur, 2007)**

### 3. Flowchart

Fig. 7 shows the flow chart of the common algorithm and the following table.1 shows the result of this algorithm.

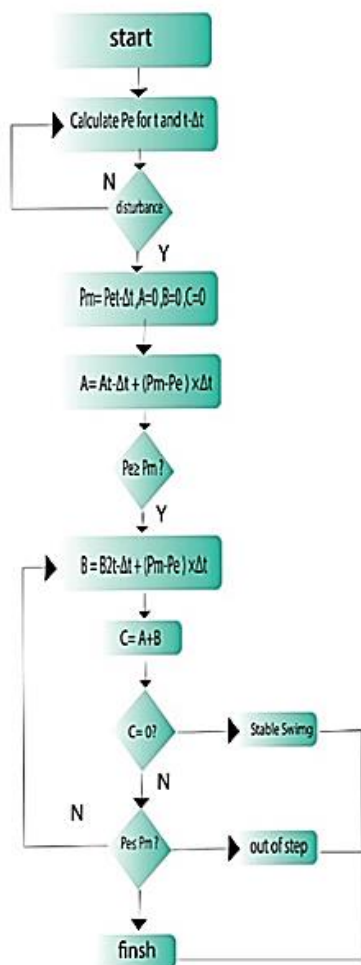


Fig. 7. Flowchart Algorithm (Paudyal et al. 2018)

Table 1. Summary of Steady and OOS swing of a single-machine infinite-bus System

Case	A	B	C	D
Power	30°	30°	30°	30°
Angle $\delta_0$				
Fault	0.158	0.22	0.244	0.358
Duration				
Time ,s				
Part (A)	0.059	0.064	0.051	0.057
pu-s				
Part (B)	-0.046	-0.064	-0.037	-0.036
pu-s				
A+B	0	0	0.044	0.041
Decision	0.0740	0.950	0.688	0.604
Time ,s				
Decision	Steady	Steady	OS	OS

The following flow chart shows the proposed algorithm. Figure. 8 explain as, at the beginning of the algorithm, at  $t=0$  consider that initial condition is stable and just to check the value of mechanical

power and rotor angle as well. In the second step, iteration starts and goes through each next value of the angle. The IF condition in this segment looks at the difference of two values close to one another in the phase angle vector, if the values show dissimilarity a larger part of the algorithm that detects power swings will begin.

Here assumes a threshold value which is equal to 0.1, if the value is greater than the threshold algorithm will start and move to the next step (Rebizant et al. 2011). Similarly in the opposite case-algorithm goes a step back. After calculating the value of angles, the IF statement is used to measure the value of change in the angle and electric power output.

This IF condition is the most significant part of the algorithm if the angle has changed excessively and the electric power output has diminished to a level beneath the mechanical power input (Cheng and Sachdev, 2015). It is without a doubt that the framework will encounter a power swing, and this algorithm starts observing the value of electrical power  $Pe$  and mechanical power  $Pm$  and also compares all these values to differentiate between normal condition and power swing fault.

Therefore, if the statement is decided at the end, this IF statement compares the areas as shown in Figure. 9. For whatever length of time that part A is lesser than part B the IF condition will get NO and the algorithm proceeds. Yet on the off chance that the angle becomes excessively enormous and part A is more prominent than part B, the IF condition gets a YES and the algorithm stops.

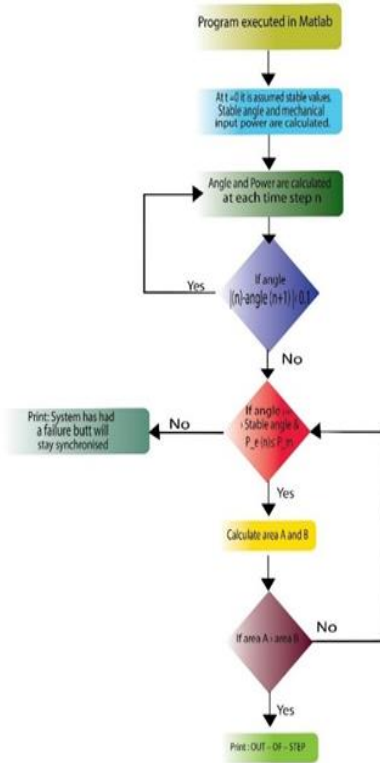


Fig. 8. Flowchart of Algorithm Proposed

4. Results and Discussions

The main goal of this research is that first of all we have differentiated between normal faults and power swings are afterward to separate among steady and unsteady power swings (out-of-step condition) (Adibi et al., 2013). Defining the all three conditions focus is only to describe the different steps of before-fault, during fault, and after fault condition and it is achieved by using the formula,

$$P = \frac{E * v}{X} \sin\delta \dots\dots\dots 17$$

F = 60Hz generator 60 MVA supplying 60 MW with inertia constant 'H' = 3.8 MJ/MVA at rated speed. E = 2.06 pu, V = 2 pu, X1 = X2 = 0.5 pu 3 phase fault.

Fig. 9 shows the power system response and behavior of swing curves during three conditions that are before-fault, during fault and after fault.

Power changes because of change in impedance during a fault in the system and when fault takes place in the system, the power curve will show all three set conditions during fault.

Fig. 10 shows a fluctuation curve for a sustained fault up to a time of 5 secs. When the fault occurs in the system, the angle changes concerning time. This power curve shows the unstable condition because fault sustained in the system for only a few seconds.

Fig. 11 shows the fluctuation curve if the only fault is removed by confining line in 0.1 seconds. Similarly, during a fault, the angle changes concerning time. This power curve shows the stable condition because the fault is removed by confining line in 0.1 seconds.

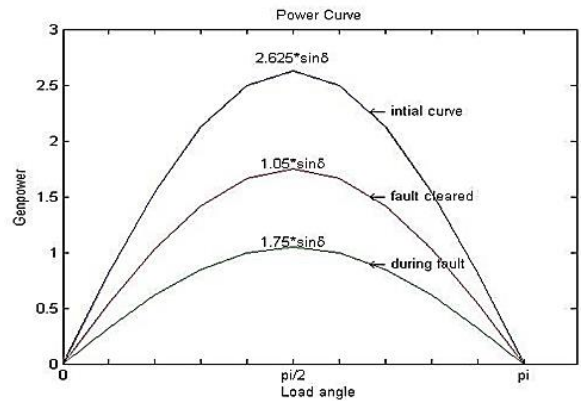


Fig. 9. Power Curve w.r.t load angle during fault

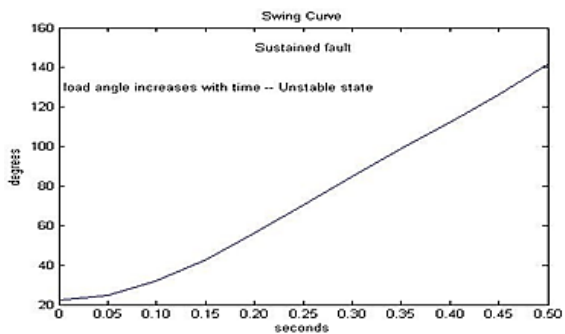


Fig. 10. Curve for Unstable State

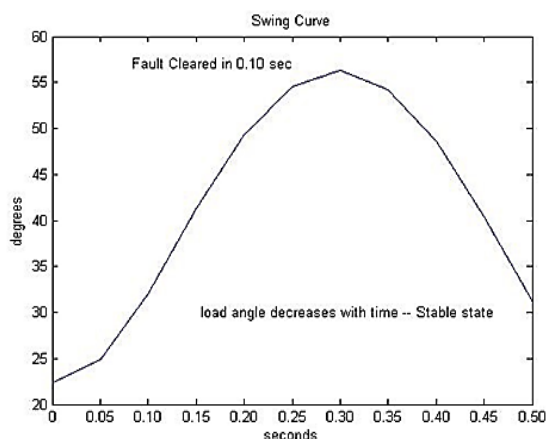


Fig. 11. Swing Curve for Stable State

#### 4.1. Simple AC System

A simple single line AC system is drawn in PSCAD to perform an experiment to detect the fault in the transmission line. Fault “Flt1” is created in a system; in which breaker “Brk1” detects the ground fault for a limited time.

230 kV transmission line system with a passive load is shown in Fig. 12. This demonstrates the use of the single line of a transmission line directly connected with the sending and receiving ends (Bahbah and Girgis, 2017; Hashiesh et al., 2010; Adibi and Milanicz, 2009).

Three-phase transformer of value 100 MVA is used in the conversion from delta ( $\Delta$ ) to star (Y). Three-phase impedance type source is used and its value is 100 MVA with a base voltage of 13.8 kV. Set the input voltage constant time of source as 0.05 sec. The sending end currents are measured on the transformer secondary windings inside the transformer component.

A timed phase C to earth fault is applied at 0.25 sec & lasts for 50 msec. The timed breaker logic is set to trip at 0.26 sec and reconnects at 0.31 sec. After setting the values of each component set the fault duration, fault time and run the system. The below figures show the result that is easy to understand the concept of detection of a fault in the

transmission line of the power system (Paudyal, 2018).

Fig. 13 shows the disturbance in current when the fault occurs in the system for 50 msec. Similar behavior of breaker current and load voltage during fault conditions are shown in Figs. 14 and 15, respectively.

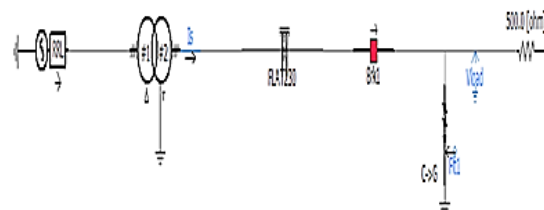


Fig. 12. Simple AC System

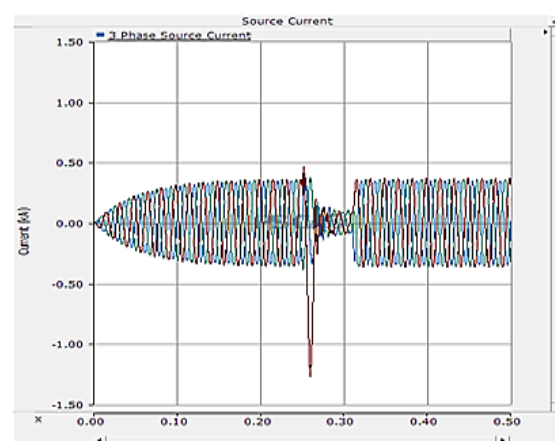


Fig. 13. Three Phase Source Current as for Time

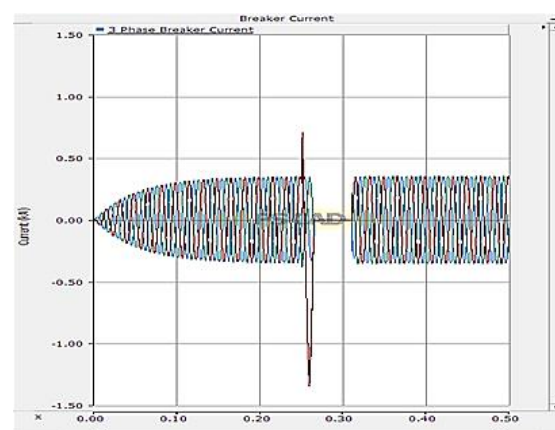


Fig. 14. 3-Phase Breaker Current as for time

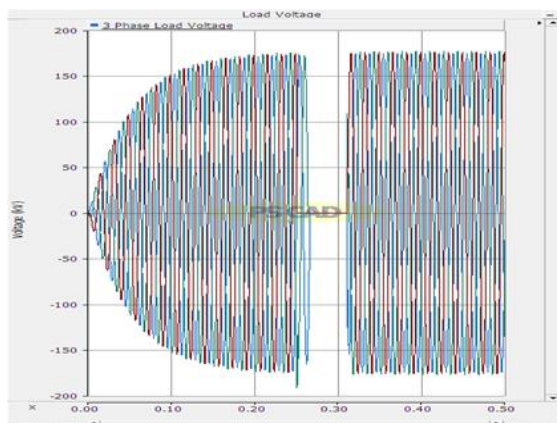


Fig. 15. 3-Phase Voltage as for time

## 5. Conclusions

In the research work, we developed a modified technique for the control of power fluctuations using the out-of-step method. In this study, we used the power area technique in which we are not only calculating power concerning time but can also calculate phase angle and also the phase angle difference concerning time to calculate the power. If part A is smaller than or equivalent to part B, the system will be stable/firm. Say if part A is larger than B, the system will be unstable (out-of-step). The result of all measurements of this research work shows that the algorithm works properly. The algorithm is designed to identify power fluctuations and it discriminates the unstable and stable power swing correctly. Hence it is promising to use this method in a procedure to find out OOS conditions. The results of the simulation in the simple circuit was performed in PSCAD shows that if you set a time of fault duration and other time in which fault occur properly it will result in clearing fault and to get stable power swing. The result of the power fluctuations curve shows the criteria in which the defined three conditions can easily determine the before-fault, during fault and after fault condition on different values of power angle are attained. Furtherly this research work presents an alternate method to detect power fluctuations and vibrations in a power system. The results of the simulation

show that methodology to detect unstable power swing using modified OOS method remains a valuable technique to forecast loss-of-synchronism in power system linkage.

## References

- Abdelaziz, A.Y., Irving, M.R., Mansour, M.M., El-Arabaty, A.M. (2010). Adaptive Protection Strategies for Detecting Power System Out-of-step Conditions using Neural Networks. *IEEE Proceedings Generation, Transmission and Distribution*; 145 (4): 387-94.
- Adibi, M.M., Kafta, R.J., Maram, S., Mili, L. (2013). On power system-controlled separation. *IEEE Transactions on Power Systems*; 21 (4): 1894- 02.
- Adibi, M.M., Milanicz, D.P. (2009) Protective system issues during restoration. *IEEE Transactions on Power Systems*; 10 (3): 1492-97.
- Bahbah, A., Girgis, A.A. (2017). New method for Generators angles and angular velocities prediction for transient stability assessment of multi-machine power systems using recurrent Artificial Neural Network. *IEEE Trans. Power Syst.*, 19 (2): 1015-22.
- Cheng, S., Sachdev, M.S. (2015). Out-of-step protection using the equal area criterion. *Proceedings of the Canadian Conference on Electrical & Computer Engineering, Saskatoon, Sask, Canada: IEEE*; 1488-91.
- Elmore, W. A. (2009). Protective Relaying theory and applications. 2nd ed. *Rev. and Expanded*, New York: Marcel Dekker.
- Hashiesh, F., Mostafa, H.E., Helal, I., Mansour, M.M. (2010). A wide area synchro-phasor based ANN transient stability predictor for the Egyptian Power System. 11-13; *Chalmers Lindholmen Gothenburg, Sweden: IEEE*: 1-7.
- Kimbark, E. W. (1948). Power System Stability. Vol. I, II and III. *Wiley*: New York; 56.

- Kundur, P. (2007). *Power System Stability Control*. New York: McGraw-Hill.
- Paudyal, S., Ramakrishna, G., Sachdev, M.S. (2018). Application of Equal Area Criterion Conditions in the Time Domain for Out-of-Step Protection. *IEEE Transactions on Power Delivery*, Vol. 25, pp. 600-609.
- PSRC. (2005). Power Swing and out-of-step considerations on Transmission Lines. *IEEE Power Swing Relaying Committee WG, D6*.
- Rebizant, W., Feser, K. (2011). Fuzzy Logic Application to Out-of-step Protection of Generators. *IEEE Power Engineering Society Summer Meeting*, 2011 July 15-19; Vancouver, BC, Canada: *IEEE*; 927-32.
- SEL. (2017). SEL-421-5 Relay Protection and automation system. *Instruction Manual User's Guide*, SEL, INC; 20130222.
- Tziouvaras, D.A., Daqing, H. (2004). Out-of-step protection fundamentals and advancements. *Protective Relay Engineers, 57<sup>th</sup> Annual Conference*, TX, USA: *IEEE*, 282-07.
- US-CANADA. (2012). Interim Report: Causes and recommendations of the august 14th Blackout in the United States and Canada. *U.S.-Canada Power System Outage Task Force*.