OPTIMUM PERFORMANCE OF PROTECTION IEDS AT OOS IN POWER SYSTEM

Ali M. Eltamaly
Professor, Electrical Engineering Dept., Mansoura University, Mansoura, Egypt
eltamaly@ksu.edu.sa

Amer Nasr A. Elghaffar
Electrical engineering Dep. Minia University, Minia, Egypt
amernasr70@yahoo.com

Abstract: *Protective equipment's in high voltage substations should be providing fast, reliable localizes faults and selectivity. But, some abnormal condition in power system such as out of step (OOS) condition which mechanical power for the generator not equalized with electrical power for the load which is not a real fault but protection equipment's will consider this condition is a fault. This situation will cause the loss of synchronism between areas within the power system or between interconnected systems that's will lead to blackout for the national grid. This paper will study the out of step condition, philosophy of protection relay device and how to overcome this condition by optimal method to avoid the false operation for distance function by Out of Step Blocking (OSB) to improve stability of power system.*

***Key words**: Power System, OOS, IEDs and Transient.*

NOMENCLATURE

OOS	*Out-Of-Step*
OSB	*Out-Of-Step Blocking*
OST	*Out-Of-Step Tripping*
PSC	*Power Swing Condition*
EPS	*Electrical Power System*
IED	*Intelligent Electronic Device*
P	*Active Power*
E_s	*Sending-end source voltage magnitude*
E_R	*Receiving-end source voltage magnitude*
δ	*Angle difference between two sources*
X	*Total reactance of the transmission line*
SLG	*Single Line to Ground Fault*
LL	*Line to Line Faults*
DLG	*Double Line to Ground Faults*
LLL	*Three Phase Faults*
OHTL	*Over Head Transmission Line*

1. Introduction

It's important to use the protection system with Over-Head Transmission Lines (OHTL), since, it's mostly extended across large geographical regions to transport the power from generators to load centers. So, it is possible to simulate faults along the OHTL which ranges from conduction that failure to loss of insulation [1] [2]. Power Swing Condition (PSC) can be defined as a variation in three phase power equalized for voltage and also three phase current flow. The power flow from generator to the grid is a high dynamic network connecting via (OHTL). At stable conditions in power system, its operate very compact to their nominal frequency (50 or 60 Hz) and typically maintain absolute voltage differences varies between 5%. The frequency in stable system varies between ± 0.02 Hz. The equalized in active power and reactive power between power generated and consumed exists during stable operating conditions [13]. The power flow in the power system, its effect by any change or unstable in the loads or power generated, this change in power flow still in the network until reach to equalization between load demand and power generation. These changes conditions in power flow happen more times, but it's immediately compensated by control systems, and normally have no detrimental effect on the power grid or its protective systems [3]. There are some abnormal conditions in power system, that's may lead to loss of synchronism between power generator and the rest of the utility system for the load, or between adjacent utility interconnected with power systems. At out of synchronism condition in power system, it is important to separate immediately the power generator or the system areas that's operating asynchronously, this separation to avoid widespread outages or lead to black out and equipment damage. An effective mitigating way to contain such a disturbance is done through control in the power system using the OOS function in protection systems. Researchers study OOS condition in power system by adjusting the IEDs to detect OOS by the time interval required by the apparent impedance locus to cross the two characteristics (buffer area), if the time exceeds a specified value, then the power swing blocking function is initiated [4]. But this method is not easily to simulate. Also, may lead to false operation for OSB at some actions in power system such as starting inrush current. This inrush current generate at energizing the power transformer that's a one from loads for the OHL which need to design the OOS. So, this paper shows optimum design for distance protection function to control system by using IEDs that is achieved with an Out-Of-Step Blocking (OSB). However, OSB systems must be balanced with Out-Of-Step Tripping (OST) of distance relay elements or other IEDs functions to operate during unstable power swings. Using OSB by the design that's shown in this paper will prevent system black out or separate un-synchronizing area by false operation [5].

2. Analysis of Transient Condition in Power System

It's important to analyzing accurate stability for the power system since the generator trip or islanding areas, its will reduce the stability for the system [12]. For a simple lossless in OHTL connecting between two equivalent generators, as shown in Fig. 1 it is well known that the real power, P, transferred between two sources can be expressed as shown in equation (1).

$$P = \frac{E_s * E_R}{X} * \sin\delta \quad (1)$$

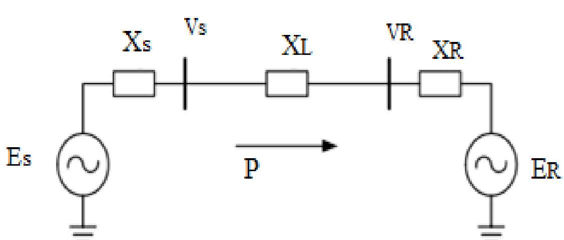

Fig. 1. Two source system

Where E_s is the sending-end voltage magnitude, E_R is the receiving-end voltage magnitude, the angle δ is the difference between two sources, and X is the total reactance of the OHTL and the two sources which shown in equation by (2).

$$X = X_s + X_L + X_R \quad (2)$$

If system resistance is not neglected, different equations apply for the sending and receiving-end power. The variables are essentially the same, if phase-to-phase voltages are used, equation (1) yields three-phase power. For this discussion, E_s, E_R are taken as per unit quantities, and equation (1) gives per unit power. If E_s, E_R and X are held constant in equation (1), the power flow is changed by varying the angle δ. As the load increases at the receiving end, synchronous machines are momentarily slowed down, and the machine rotor inertia meets the increased load requirements. That is, an increase in load results in a small reduction of system frequency until there is a change in mechanical input via the governor or manual action [14]. To restore system frequency, the mechanical input to the machines must be increased. This input must be greater than the steady-state load requirements, since the machines must be accelerated to a new and larger angle. When the new angle δ is reached, the mechanical input will exceed the load requirements by the amount required to accelerate the machines [6].

2.1 Stable power system condition

The extreme unstable condition occurs when angle δ is 90 degree. At this point, increased load conditions could only be met by increasing voltage source E_s, E_R. In Fig.2 shown the power angle curve, the relationship between active power P and angle δ with fixed sending and receiving voltage E_s, E_R and X values. Starting from angle $\delta = 0$, the power transfer increases as δ increases [15]. The power transferred from one source to another reach to maximum value P_{MAX} when angle δ is 90 degrees, by increase the angle δ, this will cause a decrease of power transfer. At exact operation of a generation system without losses, this means mechanical power P_0 from a prime mover its converted into equal amount of electrical power and transfer by the OHTL. At this balance, the angle operation between two generators is δ_0 [7].

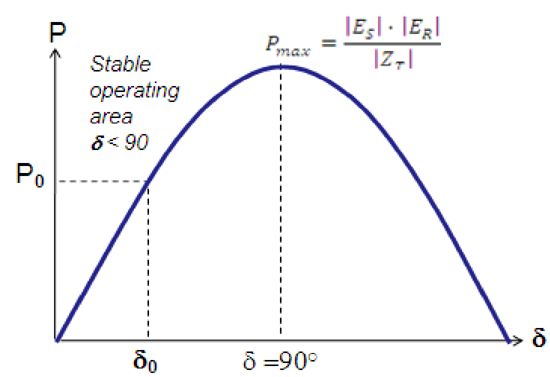

Fig. 2. Power angle curve

2.2 Transient stable power system

During steady state operations of power system, the output of electric power produces an electric torque that equalized with the mechanical torque which applied to the rotor shaft for the generator. Generator rotor runs at a constant speed at balance between electric power and mechanical torques. At fault condition, the amount of power output from generator will be reduced, but the mechanical torque can't be instantaneous decreased. So, the generator rotor will accelerate unless another control for thee mechanical torque input. In Fig.3 assumes that, the two sources power system at steady state operation have balance point of δ with transferring electric power P_0. At fault condition the power output is reduced to P_F, the generator rotor starts to accelerate, but the mechanical input not changed so the δ will be increase. At this time, the fault is clear, the generator angle reaches to δc, because the electric power output P_C at the angle δc is larger than the mechanical power input P_0 and the generator speed will begin to decreases. However, the inertia of the rotor system will cause the angle δc not to return back immediately to δ. But, the angle continues increase to δ_F. (Area - 2) is the energy lost at deceleration its equal to the energy gained at acceleration in (area - 1) this is called equal area criterion [8].

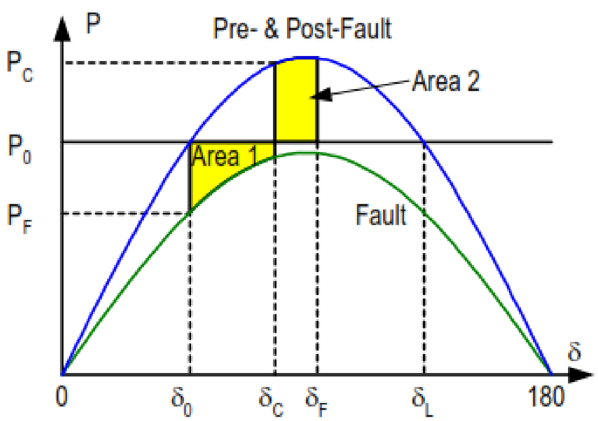

Fig. 3. Transiently stable system

2.3 Transient unstable power system

If δ_F is smaller than δ_L, the system is transiently stable as shown in Fig.3, and the two sources angle difference eventually return back to original balance point δ_0. However, if (area – 2) is smaller than (area -1) the angle δ increase to angle δ_L . This lead to the electric power output from the generators is lower than the input mechanical power. Therefore, the rotor will accelerate again and δ , it's will increase beyond recovery. This a transiently unstable condition in the system, as shown in Fig.4. At condition in the power system, the two equivalent generators rotate at a different speed which leads to unstable in the system. This event is called a loss of synchronism or an OOS condition in power system [16].

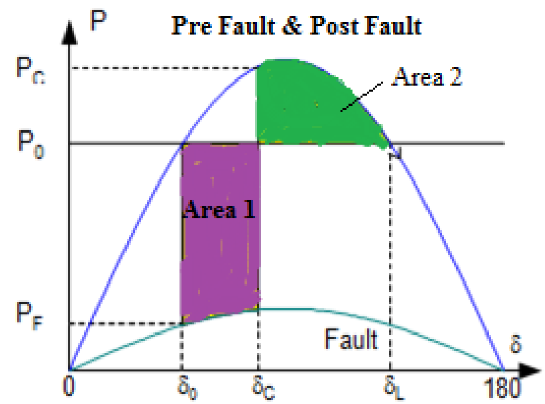

Fig. 4. Transiently unstable system

3. Classifications for Faults in Power System

By analysis the faults in the power system, it can be classified to symmetrical faults which occur only at three phase faults, all other faults are unsymmetrical faults. AT, the insulation of the system fail or a conducting object touch with a live point, a short circuit or a fault occurs. This breakdown can be occurred at different factors as lightning, wires touching together in the wind, animals or plants touch with the wires and or pollution on insulators [17]. A three-phase fault is a condition that's the three-phase system shorted to each other, or all three phase of the system are earthed as show in Fig.5 and Fig.6 respectively. This is in general a balanced condition, so it's important to simulate the positive-sequence network to analyze the fault. By using single line diagram, can be simulate the power system, as all three phases equalized currents which phase shifted by 120 degrees. Typically, 5 % from the actual faults are three phase faults with or without earth. And 80 % from faults are the unbalanced faults of one line to ground and 15% from faults are line to line faults touching with or without ground [9].

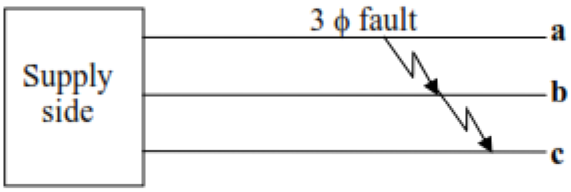

Fig. 5. Symmetrical three phase fault

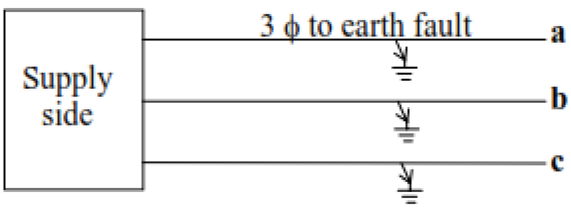

Fig. 6. Symmetrical three phase to ground fault

3.1 Fault level calculations

Maximum fault current (or fault MVA) in power system can flow into zero impedance fault, it's necessary to be known for switch gear solution. This can simulate by the balanced-on phases current value or the value at asymmetrical condition [9]. The fault level defines the value for the symmetrical condition and it's usually expressed in MVA (or corresponding per-unit value). The maximum fault current value being converted using the nominal voltage rating, can be discuss in the following equations.

$$MVA_{base} = \sqrt{3} * V_{nominal\ voltage}(KV) * I_{base}(KA) \quad (3)$$

$$MVA_{Fault} = \sqrt{3} * V_{nominal\ voltage}(KV) * I_{SC}(KA) \quad (4)$$

Where

MVA_{Fault} : Fault level at point in MVA

I_{base} : Base line current

I_{SC} : Current in the line at short circuit

The per unit value of the Fault Level may thus be written as

$$\text{Fault level} = \frac{\sqrt{3} * V_{nominal\ voltage} * I_{SC}}{\sqrt{3} * V_{nominal\ voltage} * I_{base}} = \frac{\sqrt{3} * I_{SC}}{\sqrt{3} * I_{base}} = I_{sc.pu} = \frac{V_{nominal\ .pu}}{Z_{pu}} \quad (5)$$

Per unit for nominal voltage value shown as,

$$\text{Fault level . pu} = \frac{1}{Z_{pu}}$$

$$\text{Fault MVA} = \text{Fault level (pu)} * MVA_{base} = \frac{MVA_{base}}{Z_{pu}} \quad (6)$$

4. Distance Protection Performance

Many years, the world have been successfully used for distance protection functions with OHTL [18]. It's considered the main protection for OHTL. The development in the protection relays from electromechanical relay and solid state relays with mho quadrature to Intelligent Electronic Device (IEDs), numerical relay is the important factor in the widespread acceptance of this type of protection functions at different voltage levels all over the world. The first zone in distance function protection is used to provide primary high-speed protection which operates instantaneous, to a significant portion of the transmission line. The second zone is used to cover the rest of the protected line and provide some backup for the remote end bus [18] [19]. The third zone is the backup protection for the first and second zone for all the lines connected to the remote end bus. The applications for the distance function in IEDs is required for understanding of operating principles, with consideration the factors that affect on the performance of the protection relays under different abnormal conditions in power system. The setting of distance IEDs should ensure that the relay is not going to operate when not required and will operate, only when it's necessary [18]. IEDs distance protection effectively measures the impedance between the relay location and the fault by measuring voltage and current in the transmission line. If the resistance of the fault is low, the impedance calculated is proportional to the distance from the current transformer which supplied the distance relay to the fault [25]. A distance protection function in IEDs is designed to protect the faults occurring in OHTL between the current transformer location, the selected reach point and remains stable for all faults outside this region or zones. The adjusted time for zones is designed by stepped distance scheme this ensures adequate discrimination for faults that may occur between different line stations [10]. Fig.7 shows the quadrature distance for forward fault in the overhead transmission line.

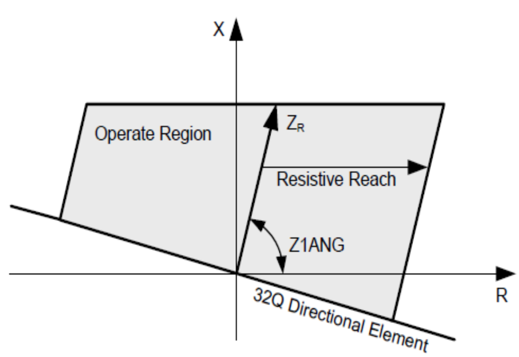

Fig. 7. Quadrature function for ground distance

4.1 Simulation three phase distance protection function

This experiment shows the test for distance protection in IEDs. The test applied by using a secondary injection kit type Freja300.The nominal operating voltage for this system is 132 kV. The voltage transformer ratio is 132/0.115 kV and the current transformer ratio is 1000/1 Amps. Maximum load is 1000 Amps at a ±30-degree power factor. The Zone 1, Zone 2, Zone 3 and distance element reaches are set to be 85 %, 130%, 180% forward direction and Zone 4 adjusted by 30 % reverse of the line impedance, respectively. This three-phase symmetrical fault test simulated by a protection IEDs type SEL411L. Fig.8 shows the scheme quadrature operation for the test results created by Freja win software. Table (1) and table (2) shows the report for the impedance results at symmetrical fault simulation.

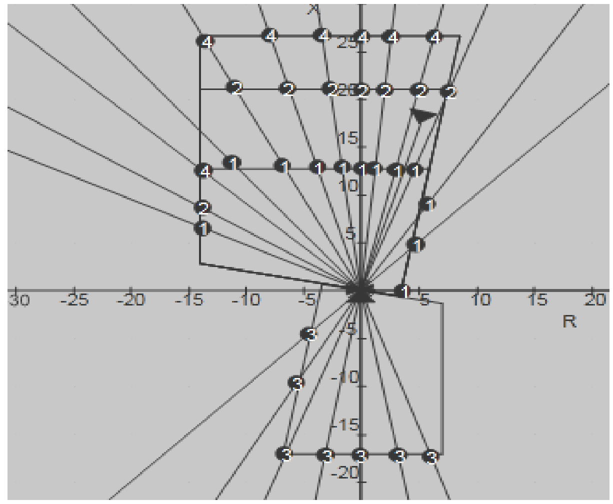

Fig. 8. Actual quadrature three phase distance

Table 1. Test result for three phase fault in all setting zone

NO	R (Ohm)	X (Ohm)	Z (Ohm)	Z phi	Z Tol. (%)	Z diff. (%)	Zones	Pass / Fail
1	3.599	0	3.599	0	5%	0.60%	1	Pass
2	4.748	4.748	6.714	45	5%	0.7%	1	Pass
3	0	12.784	12.784	90	5%	0.60%	1	Pass
4	0	20.979	20.979	90	5%	0.30%	2	Pass
5	0	26.518	26.518	90	5%	0.10%	4	Pass
6	-11.151	13.29	17.349	130	5%	3.30%	1	Pass
7	-4.481	-4.481	6.338	225	5%	0.50%	3	Pass
8	-6.58	-17.142	18.362	249	5%	0.30%	3	Pass
9	0	-17.238	17.239	270	5%	0.20%	3	Pass
10	6.072	-17.336	18.37	289.3	5%	0.70%	3	Pass
11	-3.85	12.915	13.477	106.6	5%	0.30%	1	Pass
12	-6.285	21.086	22.003	106.6	5%	0.70%	2	Pass
13	-7.946	26.656	27.816	106.6	5%	0.60%	4	Pass
14	5.826	9.098	10.803	57.4	5%	0.90%	1	Pass
15	3.042	12.668	13.028	76.5	5%	0.10%	1	Pass
16	5.018	20.899	21.492	76.5	5%	0.10%	2	Pass
17	6.361	26.493	27.245	76.5	5%	0.10%	4	Pass
18	-13.743	6.505	15.205	154.7	5%	0.40%	1	Pass
19	-6.77	13.062	14.712	117.4	5%	0.10%	1	Pass

Table 1. Test result for three phase fault in all setting zone

NO	R (Ohm)	X (Ohm)	Z (Ohm)	Z phi	Z Tol. (%)	Z diff. (%)	Zones	Pass / Fail
20	-10.962	21.148	23.821	117.4	5%	0.00%	2	Pass
21	-13.502	26.05	29.341	117.4	5%	0.50%	4	Pass
22	4.595	12.624	13.434	70	5%	0.30%	1	Pass
23	7.581	20.827	22.164	70	5%	0.20%	2	Pass
24	-13.705	12.472	18.531	137.7	5%	0.20%	4	Pass
25	-13.762	8.6	16.229	148	5%	0.10%	2	Pass
26	-1.625	12.869	12.972	97.2	5%	0.10%	1	Pass
27	-2.662	21.074	21.242	97.2	5%	0.70%	2	Pass
28	-3.362	26.615	26.827	97.2	5%	0.50%	4	Pass
29	1.272	12.74	12.803	84.3	5%	0.40%	1	Pass
30	2.095	20.983	21.087	84.3	5%	0.30%	2	Pass
31	2.65	26.549	26.681	84.3	5%	0.20%	4	Pass
32	3.264	-17.27	17.576	280.7	5%	0.40%	3	Pass
33	-5.587	-9.677	11.175	240	5%	0.10%	3	Pass
34	-3.092	-17.187	17.464	259.8	5%	0.20%	3	Pass

5. OOS Effect on Distance Function in IEDs

OOS can affect the calculations of load impedance in IEDs, where, at steady state conditions is not within the IED operating zone characteristic, to enter the calculations into the IEDs operating zone characteristic as show in Fig.9 When impedance due to power swing matches with the operating impedance of the distance relay, it will send false tripping to the circuit breaker. During OOS the IEDs may cause undesired tripping of OHTL or other power system elements, by weakening the system and possibly lead to cascading outages and the shutdown of major portions of the power system [20] [26]. Fig.10 shows the three-phase current and voltage at OOS, so at the point of the voltage is low, the protection relay impedance calculation will sense this point as a fault in the system.

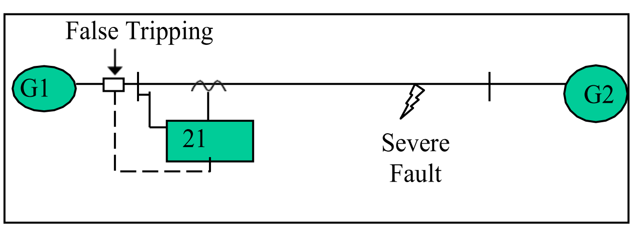

Fig. 9. IEDs wrong operation of distance function at OOS

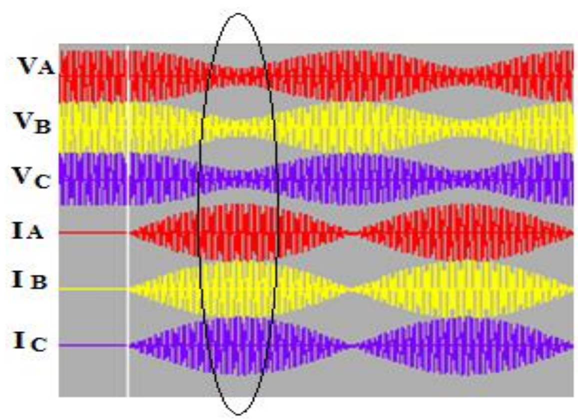

Fig. 10. Voltage and current curve forms at OOS

5.1 Distance IEDs requirements at OOS

OOS functions in IEDs detect stable OOS conditions by using the fact that the voltage and current calculations during a power swing is gradual changing while it is virtually a step change during a fault. Both faults and OOS may cause the measured apparent positive-sequence impedance to enter into the operating characteristic of a distance relay element [5]. In Fig.11, plot of the current and voltage over the entire 60 second at OOS. Because of the complexity and the rare occurrence of power system at OOS, many of utilities haven't clear performance that requirement for distance IEDs during OOS [10]. So, the performances of distance elements at OOS conditions must be blocking the distance function in IEDs during stable power swings in the system [21].

But the OST function should be taken into account to accomplish differentiation stable from unstable power swings, and separation to system areas at the predetermined network locations and at the appropriate source-voltage phase-angle difference between systems, in order to maintain power system stability and service continuity [22].

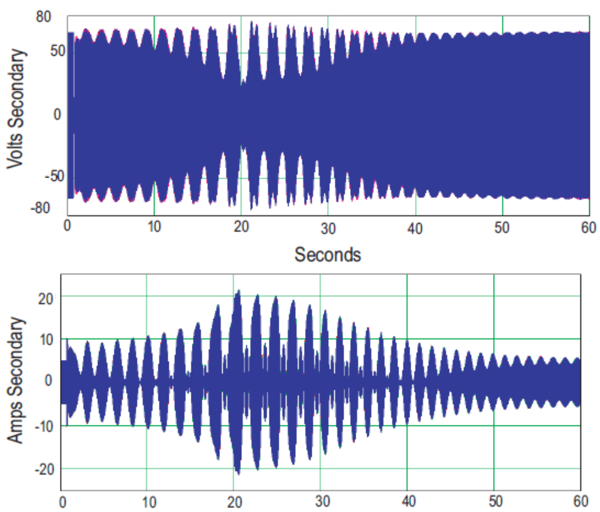

Fig. 11. Voltage and current over the entire 60- second at OOS

6. Solution for Distance IEDs at OOS

The IEDs design ability to develop and realize new methods for detecting power swings [21]. In Fig.12 the design for anew zones over from higher actual setting for tripping zones. Line impedance based design calculations for detecting OOS on the power system; these methods depending on measuring apparent impedance and timing between two elements. If the apparent impedance remains between the inner and outer characteristics new zones for the set time delay, this time delay depends on the number of cycles at swing in the system which, the average time between 3 to 5 cycles. After that, the PSB element activate and selected distance element zones for three phase symmetrical fault are blocking from operation to ensure that the generator rotor return to steady state operation. Calculation of the maximum transient time used to adjust the blocking time of the OOS function [24] [25]. OST schemes require for tripping scheme to separate the power system at key locations to achieve a new steady-state operating condition [23]. OST scheme uses the same measuring element or a different set of measuring elements depend on the IEDs type. A timer determines if the change in impedance is a result of a fault or a power swing. If it is an unstable power swing, then IEDs can select tripping on the way into the characteristic. In some OST applications, the locus of OOS may not be the ideal location for separation generations. So, the system stability studies must be applying to determine the best location for detection of OSB and the best location for the OST for separation [21] [23].

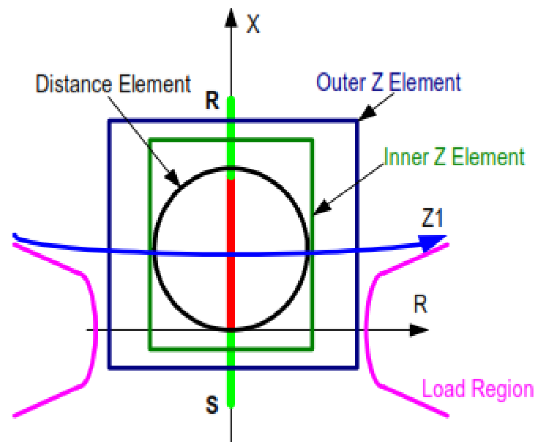

Fig. 12. Design for anew zones for OOS

6.1 Simulation new zones for OOS

The test applied by using a secondary injection kit type Freja 300, using Freja win software to draw the new quadrature zones, which over from the actual tipping zones. This test applied on IEDs type RED670, this simulation for132 kV OHTL by a maximum load of 1000A. The voltage transformer ratio is 132/0.115 kV and the current transformer ratio is 1000/1A. Fig.13 and Fig.14 show the test results which created by the software simulation and table (3) and table (4) include report results.

Table 3. Test result for new inner zone for blocking OOS

NO	R (Ohm)	X (Ohm)	Z (Ohm)	Z phi	Z Tol. (%)	Z diff. (%)	Zones	Pass / Fail
1	31.343	86.115	91.641	70.0	5%	0.5 %	1	Pass
2	0.000	86.138	86.138	90.0	5%	0.5 %	1	Pass
3	-23.020	-85.915	88.946	105.0	5%	0.3 %	1	Pass
4	31.637	-37.703	49.219	230.0	5%	0.6 %	1	Pass
5	0.000	-85.883	85.884	270.0	5%	0.2 %	1	Pass
6	26.177	31.195	40.723	310.0	5%	0.1 %	1	Pass
7	-28.990	32.969	43.901	48.7	5%	0.8 %	1	Pass
8	-26.238	-39.833	47.698	123.4	5%	0.2 %	1	Pass
9	30.517	-86.047	91.300	250.5	5%	0.4 %	1	Pass
10	-23.001	85.839	88.868	285.0	5%	0.2 %	1	Pass
11	25.832	0.000	25.833	180.0	5%	0.4 %	1	Pass
12	25.976	0.000	25.976	0.000	5%	0.2 %	1	Pass

Table 4. Test result for new outer zone for blocking OOS

NO	R (Ohm)	X (Ohm)	Z (Ohm)	Z phi	Z Tol. (%)	Z diff. (%)	Zones	Pass / Fail
1	33.802	92.869	98.829	70.0	5%	0.7 %	2	Pass
2	0.000	92.540	92.540	90.0	5%	0.4 %	2	Pass
3	-24.750	-92.370	95.628	105.0	5%	0.2 %	2	Pass
4	39.019	-46.501	60.704	230.0	5%	0.5 %	2	Pass
5	0.000	-92.597	92.598	270.0	5%	0.5 %	2	Pass
6	32.579	38.825	50.684	310.0	5%	0.1 %	2	Pass
7	-36.002	40.944	54.521	48.7	5%	0.7 %	2	Pass
8	-32.759	-49.733	59.553	123.4	5%	0.3 %	2	Pass
9	32.801	-92.488	98.133	250.5	5%	0.4 %	2	Pass
10	24.805	92.571	95.838	285.0	5%	0.5 %	2	Pass
11	-33.004	0.000	33.004	0.0	5%	0.4 %	2	Pass
12	32.621	0.000	32.622	180.0	5%	0.1 %	2	Pass

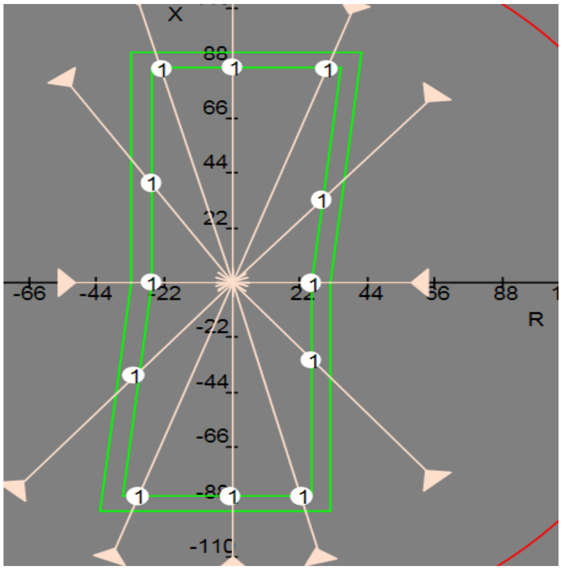

Fig. 13. Graph result for test the new inner zone

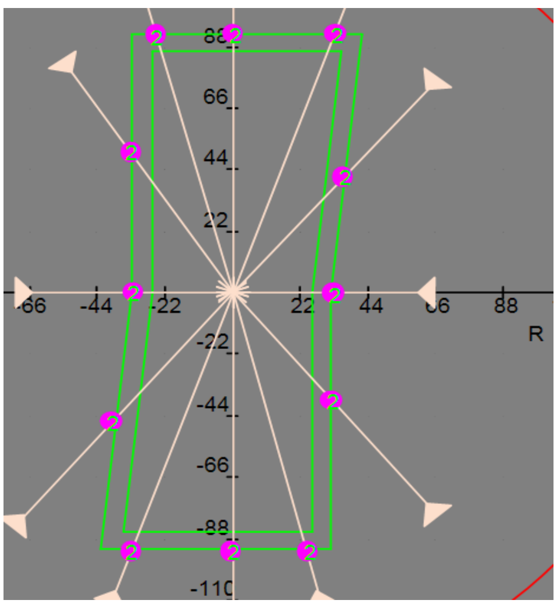

Fig. 14. Graph result for test the new outer Zone

7. Conclusion

Stable and unstable out of step can precipitate widespread outages to power systems with the result that lead to tripping of the power system elements. This paper introduces an overview of OOS, their causes, and optimum method for detecting the OOS. The detecting method for OOS in the system have been developed and elaborated. The OOS detection logic in the electrical system distinguishes between stable power swings where the system recovers and an unstable OOS condition where the grid needs to be separated. This paper shows detecting OOS, by creating new boundary two zones over from greater tipping zone, as detecting the load symmetrical impedance between new zones for a few cycles. This will lead to blocking for the symmetrical calculating zones by the time for the stable swing in the grid which will prevent from separating grid or system black out.

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