A Comparative Study of Different Techniques to Detect Fault During Power Swing

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Abstract: This paper describes the application of different techniques to detect power swing in power systems when it subject to a wide range of small or large disturbances during operating conditions. The power system should be designed to survive larger types of disturbances, such as faults, loss of a large generator, or line switching. Certain system disturbances may cause loss of synchronism between a generator and rest of the utility system, or between interconnected power systems of neighboring utilities. If such a loss of synchronism occurs, it is imperative that the generator or system areas operating asynchronously are separated immediately to avoid widespread outages and equipment damage. In this paper it is described how different techniques behave to distinguish between power swing and real fault. In addition to that the behavior of distance relay element during power swing and during fault is simulated using MATLAB and SIMULINK simulation

Keywords: Power Swing, Out of Step, Out of step tripping, Out of Step blocking, R-dot, Swing Center Voltage

I. INTRODUCTION

Power systems in the India have experienced a number of large disturbances. These major system disturbances also impacted several million customers in India. All of these disturbances caused considerable loss of generation and loads and had a tremendous impact on customers and the economy in general. Typically, these disturbances happen when the power systems are heavily loaded and a number of multiple outages occur within a short period of time, causing power oscillations between neighboring utility systems, low network voltages, and consequent voltage instability or angular instability.[1-2]

Power system faults, line switching, generator disconnection, and the loss or application of large blocks of load result in sudden changes to electrical power, whereas the mechanical power input to generators remains relatively constant. These system disturbances cause oscillations in machine rotor angles and can result in severe power flow swings. Depending on the severity of the disturbance and the actions of power system controls, the system may remain stable and return to a new equilibrium state experiencing what is referred to as a stable power swing.

Severe system disturbances, on the other hand, could cause large separation of generator rotor angles, large swings of power flows, large fluctuations of voltages and currents, and eventual loss of synchronism between groups of generators or between neighboring utility systems. Large power swings, stable or unstable, can cause unwanted relay operations at different network locations, which can aggravate further the power-system disturbance and possibly lead to cascading outages and power blackouts.

The main reason for the system blackout is wrong operation of some protective relays. Therefore in this paper various power swing detection methods are simulated to study their ability to detect power swing and distinguish stable and unstable power swings.

II. POWER SWING DETECTION METHODS

Fast detection of power swings is of interest in distance protection of transmission lines. In distance protection, the main goal is to prevent high speed distance protection to operate during stable swing. This requires the detection of a power swing to be done within milli-seconds. The possibility to accurately determine the swing frequency and damping within such a short time is naturally limited.

The task of a power swing detector in a distance protection relay is to prevent unintended operation of the relay during a stable power swing. Ideally we would also like the detector to trip the relay when an unstable power swung is detected. Depending on when the unstable swing is detected we can choose to trip before or after a pole slip occurred. Normally, it is desirable to trip before the out of step condition occurs. However the unstable swing is detected when the swinging machines are close to phase opposition it might be advantageous to trip after the pole slip has occurred. The reason is that the wear and tear of the circuit breaker will be reduced when it does not have to operate at its maximum rating.

A 4 machine 10 bus system [3-4] for testing of the power swing detection methods is considered here. This model has been chosen for a comparative evaluation of various methods of power swing detection. The single line diagram of the system is shown in the fig 1.

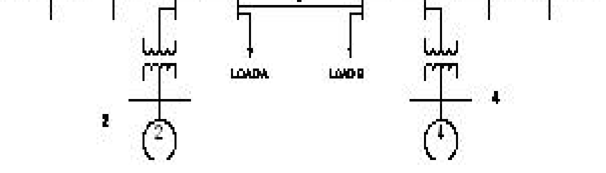

Fig.1. Four machine ten bus system

In this paper, a comparative evaluation of the various methods of power swing detection, namely the blinder

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schemes, Rdot method and the rate of change of SCV have been carried out.

The system is simulated using MATLAB/Simulink. The simulation model for synchronous machines is taken from ref [6].

III. CONVENTIONAL RATE OF CHANGE OF IMPEDANCE METHODS

A. *Mho relay*

Mho relay is the classical distance relay[5]. This relay gives a trip signal when power swing enters the mho characteristics. The relay is often set to a sensitivity of 120° load angle since return to stable operation is usually unattainable when angle further increases. As the tripping in these relays occur before change in voltage angle to 180° hence stability studies are not required for setting of these relays. It has the limitations of mal operating for recoverable swings i.e. this relay works only with OOS tripping function and not for power swing blocking (PSB) function.

The mho relay characteristics have been modeled using equation (3.1). Here R and X are the swing impedances as seen by the relay. R_1 and X_1 are the p.u. resistance and reactance of a line. Fig 2 explains this clearly. The swing locus entering the circular mho characteristics initiates the switching action.

$$(R-R_1)^2+(X-X_1)^2 \le \left(\frac{R_1}{2}\right)^2+\left(\frac{X_1}{2}\right)^2 \qquad (3.1)$$

The centre of the mho characteristics is considered

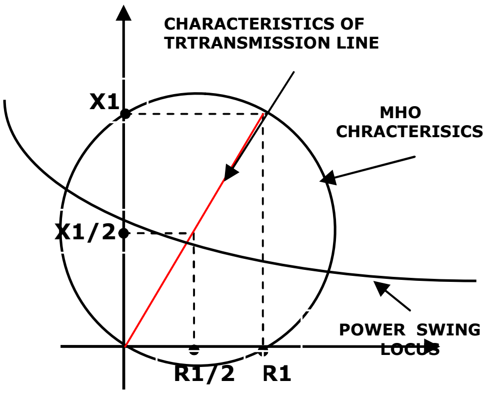

Fig.2. Mho characteristics

Coinciding with the centre of the line characteristics fig.3 for the sake of simplicity. Also 100% of the line length is considered for the sake of power swing detection.

B. *Blinder Scheme*

Single Blinder Scheme

A single-blinder scheme [7] uses only one set of blinder characteristics on either side of the system impedance. When power swing occurs, the apparent impedance travels across the impedance plane. A trip condition exists if the impedance locus enters the outer load blinder unit. The locus must enter from one side and leave from the other for tripping to occur. Single blinder scheme is shown in Fig. 3

Equation of a straight line is given by y = mx + c, where c is the y intercept and m is the slope of the line. In this case both the blinders are considered parallel to the line characteristics having slope X1 /R1,. The intercept c is considered to be +X1 and –X1 for right and left blinders respectively. With reference to fig 3 the OOS condition is given when (X-c)/m<R and (X+c)/m>R. Additional condition s satisfying the trip ping criteria are R>0 AND R<R1 AND X>=0 AND X<=X1

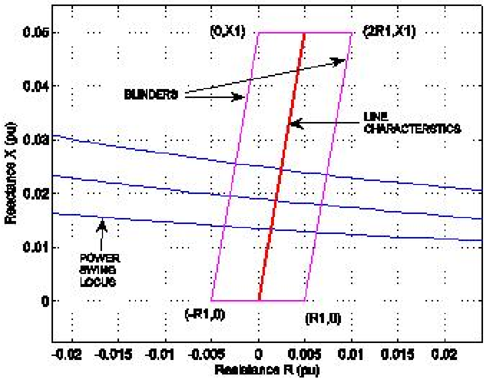

Fig.3. Single blinder scheme

Double Blinder Scheme:

The two-blinder scheme [2-7] shown in Figure 4 is based on the same principle of measuring the time needed for an impedance vector to travel a certain delta impedance. The time measurement starts when the impedance vector crosses the outer blinder (RRO) and stops when the inner blinder (RRI) is crossed. If the measured time is above the setting for delta time, a power swing situation is detected. If the blinders are set in parallel to the line impedance, then they are optimized for the delta impedance measurement because the power swing impedance vectors will normally enter the protection zones at an angle of nearly 90 degrees to the line angle.

The single blinder algorithm has been modified to create a double blinder scheme. If t_1 and t_2 are time of crossing of inner and outer blinders by the power swing and R_1 and R_2 are the swing resistance during crossing of the blinders, the rate of change of impedance is given by $(R_2-R_1)/(t_2-t_1)$.Various stability studies have been carried out to get a suitable setting for the rate of change.

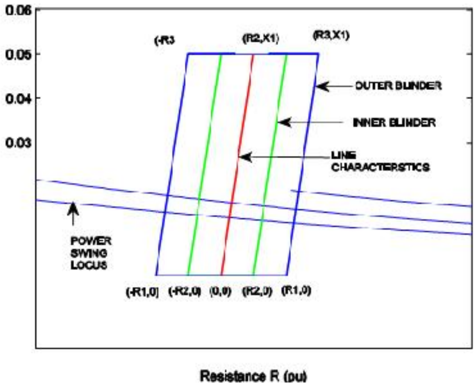

Fig.4.Double Blinder scheme

If an unstable swing is detected, the mho element can be allowed to trip immediately (not recommended) or tripping can be delayed until the swing passes through thereby minimizing over-voltages across the opened breaker.

To find the correct settings for the blinders is not always simple and requires a sophisticated grid analysis In these schemes the blinders are set parallel to the line elements.

IV. ADVANCED POWER SWING DETECTION METHOD

The advent of digital technology has given relay design engineers the ability to develop and implement new methods for detecting power swings. A number of the new techniques do not require user-entered settings, thus greatly simplifying the application of power swing detection and protection. Others still require study. Which can sometimes be very extensive and time consuming?

A. *Rdot Scheme*

Out-of-step tripping initiation on major EHV interconnections sometimes is required before the voltage at the electrical center reaches a minimum value. This prevents severe voltage dips throughout the power system with possible uncontrolled loss of loads and loss of synchronism within sub-areas of utility network.[8]

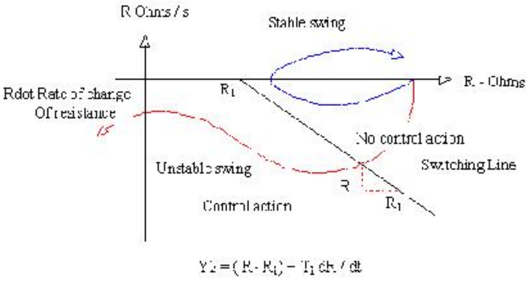

Fig.5. Phase – plane Diagram illustrating the concept of R-dot principle

The OST relay was augmented with the rate of change of apparent resistance and it was termed the Rdot scheme. The Rdot scheme aims at early tripping for non recoverable swings while avoiding tripping on recoverable swings. This is achieved by using the phase-plane between the apparent resistance R and the rate of change of resistance Rdot. The tripping conditions in case of Rdot scheme is given by equation (4.1)

1. Conventional OST relay : $Y1 = (R - R1) \le 0$
2. R-dot relay :

$$Y2 = (R - R_1) + T_1\left(-\frac{dR}{dt}\right) \le 0 \qquad (4.1)$$

Where Y1 and Y2 are control outputs, R is the apparent resistance measured by the relay and R1 and T1(slop of line) are relay-setting parameters. The above characteristic of the R-dot relay[8] can be best visualized in the R-Rdot phase-plane shown in Figure 5. Y1, and Y2 then become "switching lines" in the phase-plane and the Rdot relay develops an output when the power-swing trajectory crosses a "switching line" in the R-Rdot plane. For a conventional OST relay without rate of change of apparent resistance augmentation is just a vertical line in the R-Rdot plane offset by the R1 relay setting parameter. Switching line Y2 is a straight line having slope T1 in the R-Rdot plane. System separation is initiated when output Y2 becomes negative. For low separation rates (small Rdot : dR/dt) the performance of the Rdot scheme is similar to the conventional blinder relaying schemes. However, higher separation rates dR/dt would cause a larger negative value of Y2 and will initiate tripping much earlier. Hence the tripping is faster in Rdot case than in the blinder schemes. The amount of anticipation would be determined by T_1.

B. *Rate of Change of Swing center voltage (SVC)*

Swing-center voltage (SCV)[8] is defined as the voltage at the location of a two-source equivalent system where the voltage value is zero when the angles between the two sources are 180^0 apart. When a two-source system loses stability and goes into an OOS situation after some disturbance, the angle difference of the two sources, δ(t), will increase as a function of time. Figure 6 illustrates the voltage phasor diagram of a general two-source system.

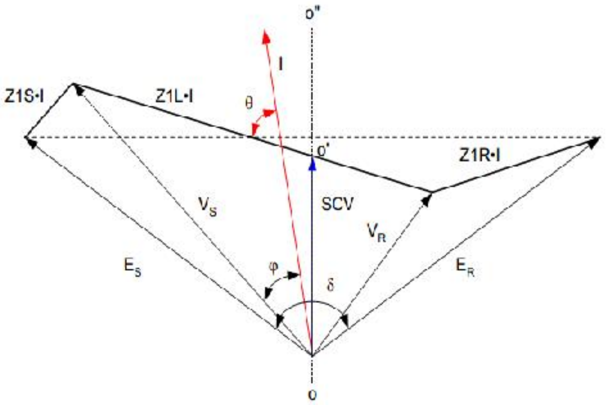

Fig.6. Voltage phasor Diagram of a Two Source System

We can represent the SCV by Equation (4.2), assuming an equal source magnitude, E.

$$SCV(t) = \sqrt{2}E\sin\left(\omega t + \frac{\delta t}{2}\right)\cos\left(\frac{\delta t}{2}\right) \qquad (4.2)$$

SCV(t) is the instantaneous SCV that is to be differentiated from the SCV that we estimate locally. Equation (3) is a typical amplitude-modulated sinusoidal waveform. The first sine term is the base sinusoidal wave, or the carrier, with an average frequency of ω + (1/2)(dδ / dt). The second term is the cosine amplitude modulation.

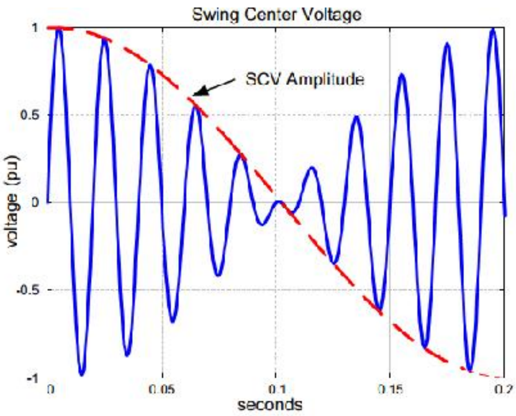

Fig.7. Swing center voltage during OOS condition

The magnitude of swing center voltage changws between zero and one per unit of system nominal voltage. With a slip frequency of 5 Hz, the voltage magnitude is forced to zero every 0.2 sec.

One popular approximation of SVC obtained through use of locally available quantities is as follows[8].

$$SCV \approx |Vs|\cos\left(\frac{\delta}{2}\right) \approx |Vs|\cos(\varphi) \qquad (4.3)$$

The absolute value of the SCV is at its maximum (or one) when the angle between the two sources is zero, and this value is its minimum 9 or zero) when the angle is 180 degrees. This property has been exploited so one can detect a power swing by looking at the rate of change of the swing center voltage. The time derivative of SCV then becomes

$$\frac{d(SCV)}{dt} = -\frac{Vs}{2}\sin\left(\frac{\delta}{2}\right)\left(\frac{d\delta}{dt}\right) \qquad (4.4)$$

Equation 4.4 provides the relation between the rate of change of the SCV and the two- machine system slip frequency dδ/dt.

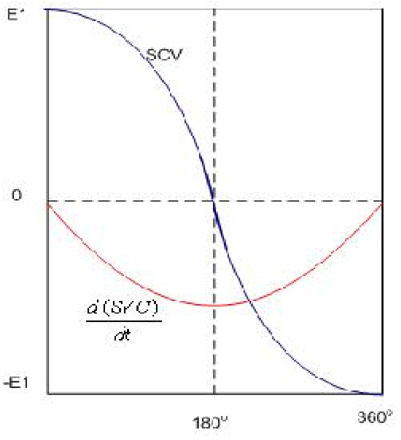

Fig.8. SCV and its Rate of Change with Unity source voltage magnitude.

The derivative of the SCV voltage is independent from the network impedances. It is reaches its maximum when the angle between the two machines is 180^0 . When the angle betweenthe two machines id zero, the rate of change of SCV is also zero. The maximum value of the derivative of the SCV occures when the δ is $180^{0.}$

V. SIMULATION AND COMPARISION

By the implementation of algorithms for various types of power swing detection schemes, stability studies have been carried on the 4 machine 10 bus system [3-6]. A 3 phase fault for a different duration has been simulated on bus 5 and 6 of the system. As it is required to study the speed and accuracy of OOS condition, there is no tripping of lines initiated on detection of OOS.

A. Mho Relay :

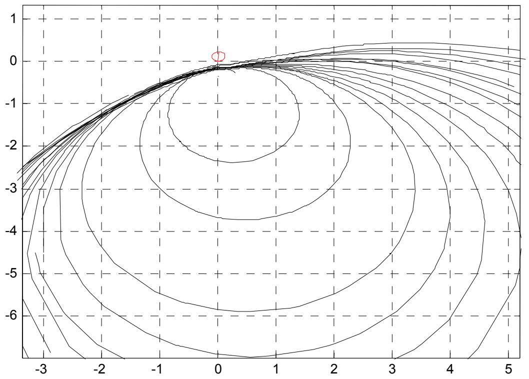

Fig.9. Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.25 second on bus 5

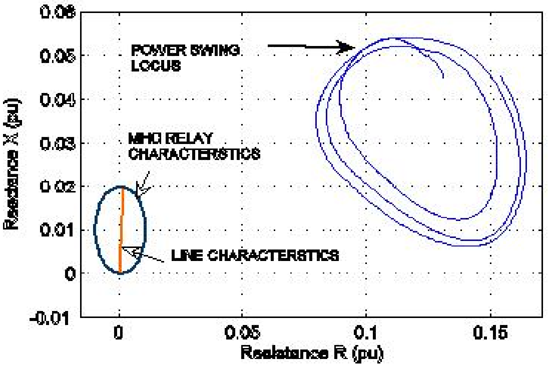

Fig.10. Power swing locus for Line 7 for a Stable swing fault duration 0.25 sec. on bus 5

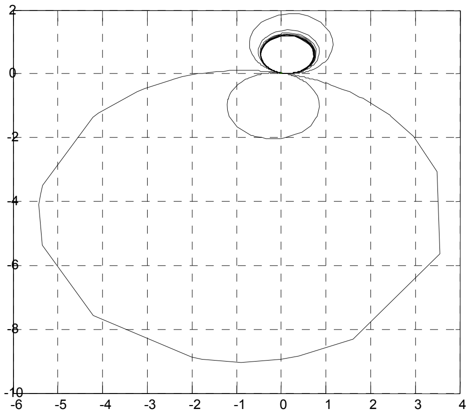

Fig.11(a). Line Power swing locus for Line 8-9 for a UnStable swing fault duration 0.25 sec. on bus 5

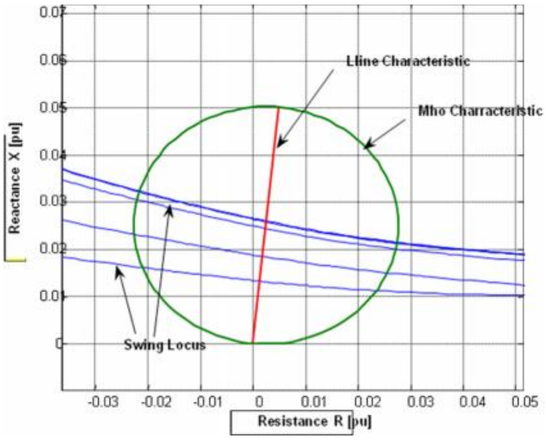

Fig.11(b). Line Power swing locus for Line 8-9for a UnStable swing fault duration 0.25 sec. on bus 5

Observations:

- This relay gives a trip signal when power swing enters the mho characteristics.
- As the tripping in these relays occur before change in voltage angle to 180^0 hence stability studies are not required for setting of these relays.
- It has the limitations of mal operating for recoverable swings i.e. this relay works only with OOS tripping function and not for power swing blocking (PSB) function

Advantages :

- Simplest, no stability study required.
- Tripping before power angel 180 deg.
- No PSB function

B. Single Blinder Scheme

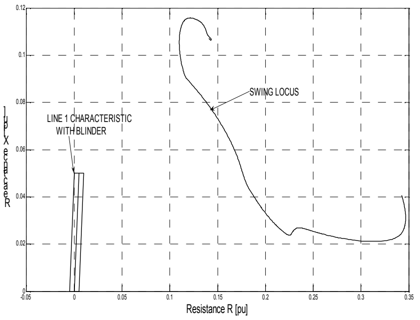

Fig.12. Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.2 sec. on bus 5

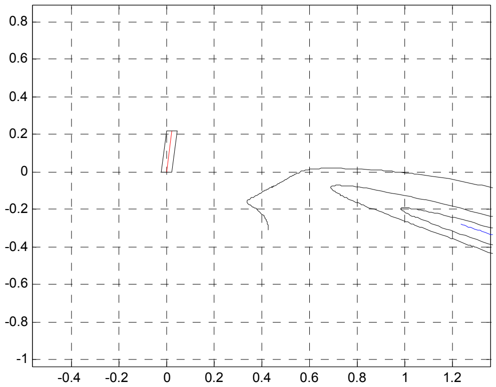

Fig.13. Power swing locus for Line 8-9 for a Stable swing fault duration 0.2 sec. on bus 5

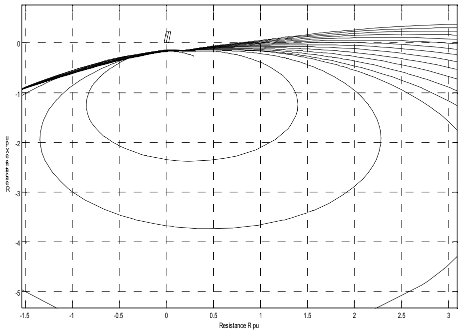

Fig.14. Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.25 sec. on bus 5

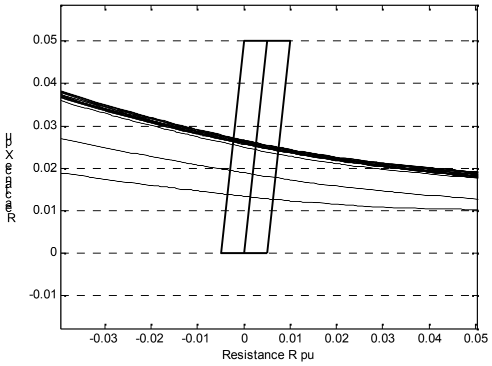

Fig.15.: Swing locus for line 8-9 for a 0.25 sec fault on bus 5

Observations:

- As such, this scheme cannot be used to block phase distance relays from tripping for unstable power swings because the relays will have tripped prior to the scheme declaring an unstable condition.
- The scheme can be used to prevent automatic reclosing for a detected unstable power swing.
- The single-blinder scheme delays OST until the swing is well past the 180 degree position and is returning to an in-phase condition.
- The basic advantage of the single blinder scheme is its use for load encroachment.

C. Double Blinder scheme:

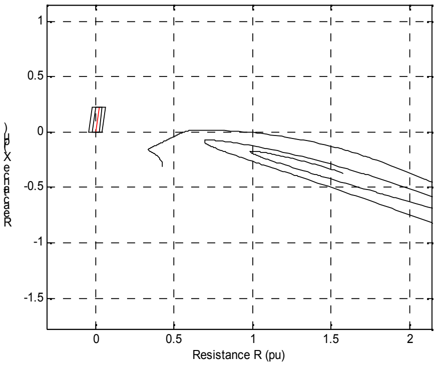

Fig.—16: Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.2 sec. on bus 5

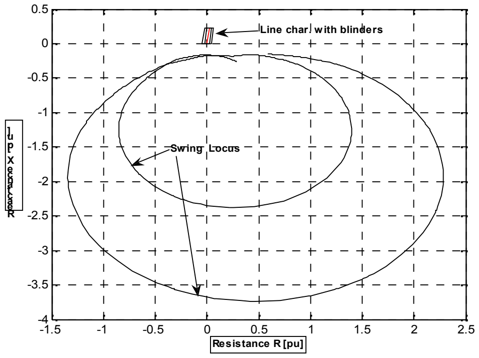

Fig.17. Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.25 second on bus 5

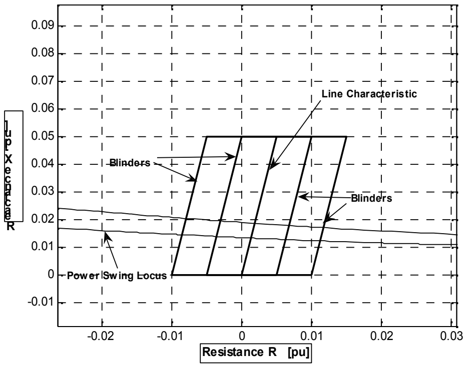

Fig.18 Power swing locus for Line 8-9 for a Stable swing fault duration 0.25 second on bus 5

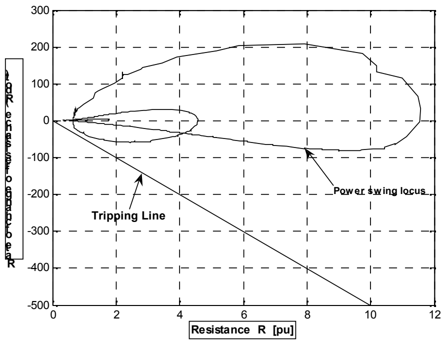

Fig.-19: Power swing locus for Line 1-2-3 for a Stable swing fault duration 0.2 sec. on bus 5

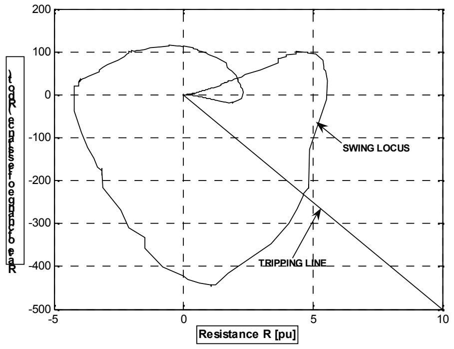

Fig.-20 Power swing locus for Line 8-9 for a Unstable swing fault duration 0.2 sec.on bus 5

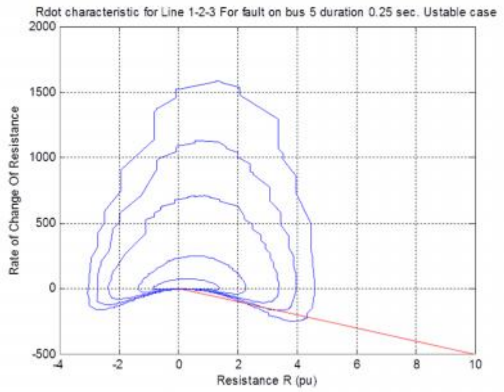

Fig.-21: Power swing locus for Line 1-2-3 for a Unstable swing fault duration 0.25 sec. On bus 5

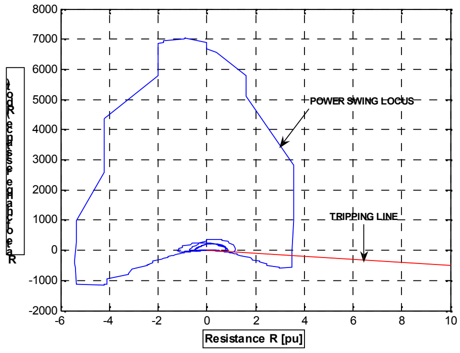

Fig. 22 Power swing locus for Line 8-9 for a Unstable swing fault duration 0.25 sec. on bus 5

Observations:

- This scheme is that it can mal-operate for recoverable swings unless very careful selection of the relay settings is made.
- Stability studies have been carried out to determine the rate of slip differentiating the stable swings form unstable swings

Advantage :

- Can be used independent of distance zone characteristics.
- Carry out PSB and OOS protection.

D. *R-dot Scheme*

Observations:

- For low separation rates, i.e. small Rdot, performance of the algorithm is similar to that of blinder scheme. But for higher separation rates, Rdot is a large negative value causing earlier separation hence anticipating probable instability. Hence the tripping is faster in Rdot case than in the blinder schemes.

E. Swing Center Voltage:

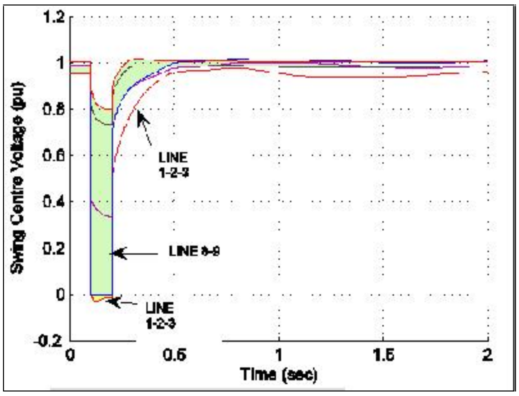

Fig-23 SCV for all line for a Stable swing fault on bus 5 for 0.1 sec.

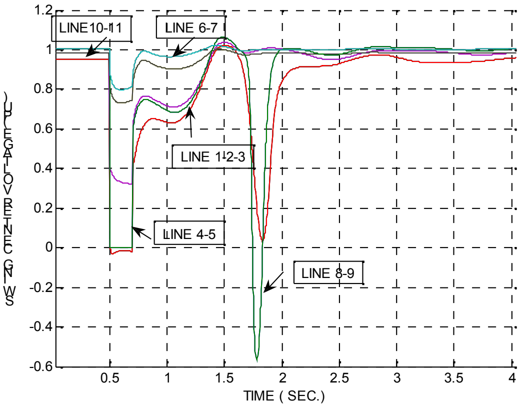

Fig. -24: SCV for all line for a Stable swing fault on bus 5 for 0.2 sec

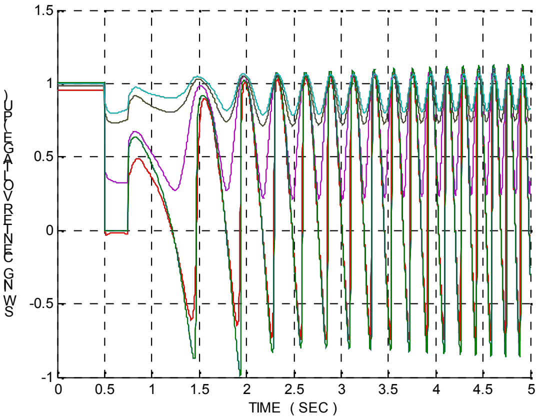

Fig.-25: SCV for all line for a Unstable swing fault on bus 5 for 0.25 sec

Observations:

- Independent of network impedances hence setting of relays not requires extensive stability studies.
- Magnitude of SCV changes between 0 and 1 pu of the system nominal votage (E), regardless of system impedance parameters

VI. RESULTS

Table-1 Comparatives study of OOS detection for lines 1-2-3 with fault on bus 5

Fault Duration	Detection of OOS condition Stable (S) or Unstable (US)				
	Mho relay	Single blinder	Double Blinder	Rdot	SCV
0.10	S	S	S	S	S
0.15	S	S	S	US	US
0.20	US	US	US	US	US
0.25	US	US	US	US	US
0.30	US	US	US	US	US

Table-2 Comparatives study of OOS detection for lines 1-2-3 with fault on bus 5

Fault Dur.	Swing Freq. (Hz)	Time taken to detect of OOS condition after fault clearance (sec)				
		Mho relay	Single blinder	Double blinder	Rdot	SCV
0.10	0.10	--	--	--	--	--
0.15	0.32	--	--	--	0.94	1.21
0.20	0.52	--	--	--	0.91	1.13
0.25	1.8	--	0.85	0.85	0.87	0.95
0.30	3.55	0.43	0.49	0.49	0.49	0.54

Table-3 Comparative study of OOS detection for lines 8-9 with fault on bus 5.

Fault Duration	Detection of OOS condition Stable (S) or Unstable (US)				
	Mho relay	Single blinder	Double Blinder	Rdot	SCV
0.10	S	S	S	US	US
0.15	US	US	US	US	US
0.20	US	US	US	US	US
0.25	US	US	US	US	US
0.30	US	US	US	US	US

Table-4 Comparative study of OOS detection for lines 8-9 with fault on bus 5.

Fault Dur.	Swing Freq. (Hz)	Time taken to detect of OOS condition after fault clearance (sec)				
		Mho relay	Single blinder	Double blinder	Rdot	SCV
0.10	0.10	--	--	--	--	--

0.15	0.22	--	--	--	0.94	1.14
0.20	0.34	--	--	--	0.90	1.02
0.25	0.53	--	0.79	0.84	0.88	0.88
0.30	3.85	0.36	0.47	0.46	0.45	0.51

VII. CONCLUSION

The paper draws a number of conclusions.

- Simulation of various methods of OOS detection has been carried on a four machine system using Matlab and Simulink tools. A comparative evaluation of these different power swing detection methods has been performed. It is observed that the response time if all scheme is inversely proportional to the swing frequency. So as system becomes more unstable, so response time becomes faster. hence sever faults are detected in least time
- A single-blinder characteristic plus auxiliary logic can be used for an OST function. It can be used to restrict tripping of the distance relay for loads outside of the blinders. The single-blinder scheme cannot distinguish between a fault and an OOS condition until the fault has passed through the second blinder within a given time. As such, this scheme cannot be used to block phase distance relays from tripping for unstable power swings because the relays will have tripped prior to the scheme declaring an unstable condition. The scheme can be used to prevent automatic reclosing for a detected unstable power swing. In addition, the single-blinder scheme delays OST until the swing is well past the 180 degree position and is returning to an in-phase condition. The basic advantage of the single blinder scheme is its use for load encroachment.
- The Rdot relays have been found to be operating in the least time whereas the rate of change of SCV method has operated for the most no of unstable cases.
- The single and double blinder schemes have similar characteristic but double blinder scheme have benefit of selection of trip on the way in(TOWI) and trip on the way out(TOWO),,hence preventing damage to the circuit breakers. Limitations of this scheme are that it can mal-operate for recoverable swings unless very careful selection of the relay settings is made . Stability studies have been carried out to determine the rate of slip differentiating the stable swings form unstable swings.
- The rate of change of SCV has a benefit that this method is independent of system source and line impedances, hence setting of relay becomes simpler as compare to other method

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