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A Review on Power Swing Blocking Schemes Of Distance Relay During Stable Power Swings

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Abstract*: *Distance relays operate very fast compare to over current relays against faults to protect the transmission lines. Besides faults, distance relays can also operate due to power swings, it would be treated as relay maloperation. This maltripping of distance relays may lead to severe blackouts. So, primary requirement is to differentiate the short circuit fault and the stable power swing and need to block the mho type distance relay operation when the power swing is stable and unblock the distance relay operation when the power swing is unstable. This review paper discusses about different Power Swing Blocking (PSB) proposed schemes used for detecting and blocking the operation of relay when the power swing is stable and to avoid maltripping of the relays and severe blackouts. Comparison is made among different PSB schemes.

***Index Terms*: - Distance Relay, PSB Schemes using ANFIS, FZC, PCF and dQ/dt methods.**

I. INTRODUCTION

With day by day increase in demand of power the distribution system is also increasing with increase in number of loads and sources connected to the grid system. Because of these increment of devices faults occurred also are increasing on transmission or distribution lines. The effect of faults on the lines tend to damage the equipment connected to the grid system. In power systems, distance relays play an important role to the protect the transmission lines against faults. Rather than overcurrent relays, distance relays are very fast in nature. Distance relays will operate only if the measured voltage to current ratio (i.e., impedance) seen by the distance relay and is entering into the R-X characteristics which it would be possible only due to faulty conditions. But if there is any sudden change in load or transmission line switching takes place, then there will be variation of power flow which also decreases the measured impedance which is seen by the distance relay and will enter into the R-X characteristics and the relay responds. With this phenomenon, distance relay will operate wrongly. There is no actual fault took place but the relay is treating the change in impedance due to other than faults as a fault and relay maltrips. This will cause to parallel tripping of transmission lines and may also lead to severe blackouts.

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The steady state power system will maintain the power balance between the generated power and the demanded power, which operates at an equilibrium state. When the disturbance occurs such as transmission line switching or short circuit symmetrical or unsymmetrical faults or sudden change in load or generator switching or excitation loss etc., will cause oscillations in the rotor of the machine angles and leads to power swings. This power swing is actually a phenomenon of power flow variation that takes place in transmission line conductors. The power swing is considered as stable power swing if the system remains stable after the fault clearing or any disturbance clearing and will return back to a new steady operating state. During stable power swing, will leads to enormous variations in currents and voltages, results to maloperation of distance relay and may lead to loss of synchronism between any two or more synchronous generators.

Distance relays basically operates due to change in the value of impedance which are mostly affected by stable power swings, leads to maloperation.It is necessary to differentiate the fault and the stable power swing, helps the distance relay would operate only for short circuit fault but not due to power swing.

Many Power Swing Blocking (PSB) schemes have been introduced to block the tripping signals sent to the distance relay when the power swing is stable. By using the current angle differentiation, helps to discriminate the stable power swing and fault which is discussed in [1]. This scheme is moderately fast by sending the signals to block the tripping of distance relay in half of the cycle. Power Swing Centre Voltage (PSCV) detects the swing center voltage with respect to time to determine either the swing is due to fault or stable power swing discussed in [2]. This method did not discuss about large power system networks. A wavelet transforms also used to discriminate thestable power swing and fault discussed in [3]. Advanced technique Artificial Nuero Fuzzy Inference System (ANFIS) also introduced to block the tripping signals sent to distance relay by pattern recognition discussed in [4]. The variations in relative speed of a synchronous generator is used to differentiate the stable power swing and the fault which is discussed in [5]. Polynomial Curve Fitting (PCF) method is introduced to differentiate the stable power swing and the fault using the polynomials of synchronous machine rotor angles discussed in [6]. The rapid change of transmission line wattless (i.e., reactive) power with respect to time is alsohelpful to separate the stable power swing and the fault discussed in [7].

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Research also started on clearing the blocking signals when the power swing is stable, especially for symmetrical or balanced faults. Detecting the unsymmetrical fault is easy especially during the stable power swing but symmetrical fault detection is quite difficult because both are balanced phenomena discussed in [8] [9].

The outline of this review paper follows as: Section II briefs about the PSB Schemes discussed in [4] [5] [6] [7]. Section III discusses about results of the proposed schemes and discussions of the related papers. Section IV compares all the PSB Schemes and Section V provides conclusions of the paper.

II. POWER SWING BLOCKING(PSB) SCHEMES

A. PSB Scheme Using ANFIS

A novel PSB scheme is proposed which uses an Artificial Nuero Fuzzy Inference System (ANFIS) [4]. By using pattern recognition, this technique is developed to operate the distance relay in blocking position during the stable power swing. Power swing is identified by gradual variations of voltages, currents and impedance. The input signals to the novel scheme ANFIS is by choosing PSCV, the negative sequence current, the rate of change of positive sequence current and impedance.

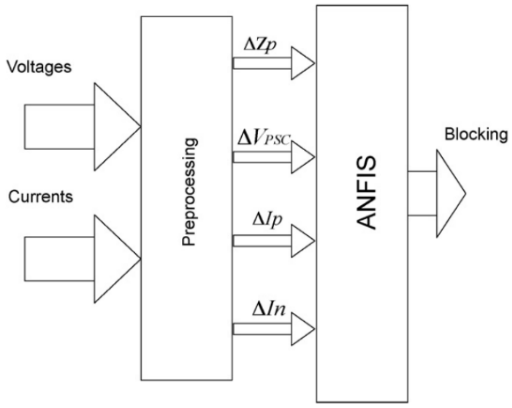

Fig.1. Basic Structure of proposed PSB Scheme

Mathematically, inputs to this proposed structure are mainly based on composition of various measured quantities using the equations below:

$$\Delta Z_p = |Z_p(n) - Z_p(n-N)| \quad (1)$$

$$\Delta V_{PSC} = |V_{PSC}(n) - V_{PSC}(n-N)| \quad (2)$$

$$\Delta I_p = |I_p(n) - I_p(n-N)| \quad (3)$$

$$\Delta I_n = |I_n(n) - I_n(n-N)| \quad (4)$$

In ANFIS outputs, if the output is less than the reference value 0.5 then it will be considered as unstable power swing. Therefore, no blocking of tripping signal to distance relay is generated. Or else, the output is considered as stable power swing and blocking signal is generated. However, there is justification done on settings of zone 3 distance relay where zone 3 is most sensitive zone for a stable power swing.

B. PSB Scheme using First Zero Crossing (FZC)

The main objective of FZC technique is to evolve a most efficient method to detect power swing. Using First Zero Crossing (FZC), it is easy to identify either the swing is a stable power swing or unstable power swing which is encroaching to third zone [5]. This FZC scheme blocks the zone 3 distance relay operation when the swing is stable power swing in order to avoid maltripping of protective relay to maintain continuous supply.

This novel scheme proposes algorithm to determine the fictious reactance X of the equivalent network which is shown in the below figure.

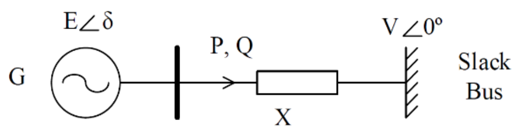

Fig.2. SMIB Equivalent Network.

The true power P and the wattless power Q flow in the Single Machine Infinite Bus (SMIB) equivalent network given by the equations below:

$$P = \frac{EV}{X} sin\delta \quad (5)$$

$$Q = \frac{E^2}{X} - \frac{EV}{X} cos\delta \quad (6)$$

where also E is the Bus1 voltage magnitude, V is Bus2 voltage magnitude, X is equivalent fictious reactance, δ is the load angle difference between bus 1 and bus 2.

Eliminating load angle δ in (5) and (6),

$$\left(\frac{PX}{EV}\right)^2 + \left(\frac{E^2 - QX}{EV}\right)^2 = 1 \quad (7)$$

Simplifying the value of fictious reactance X using the above equation, calculate also the machine relative speed (ω) during a power swing. Differentiating equation (1) we get,

$$\frac{dP}{dt} = \left(\frac{EV}{X}\right) cos\delta \left(\frac{d\delta}{dt}\right) \quad (8)$$

Since $\omega = \frac{d\delta}{dt}$ and cos δ can be obtained from (6)

The relative speed ω_r is given by

$$\omega_r = \omega - \omega_s \quad (9)$$

where $\omega_s = 2\pi f_s$ rad/sec.

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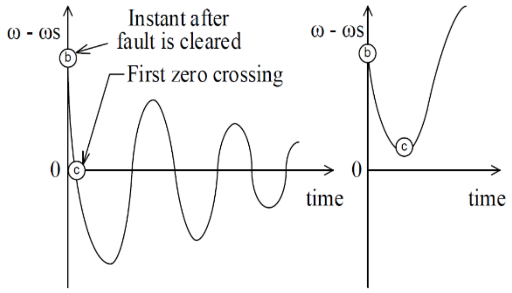

Fig.3. Synchronous machine relative speed (ω) during a stable power swing and an unstable power swing

If the relative speed of synchronous machine crosses to first zero called as First Zero Crossing (FZC), will be treated as power swing due to stable condition, but if the relative speed does not cross zero, will be treated as power swing due to unstable condition.

C. PSB Scheme using Polynomial Curve Fitting (PCF) Method

To improve the relay operation especially at zone 3, this scheme proposed a prediction of a transient stability of a power system based on Polynomial Curve Fitting method (PCF) [6].

Numerically, the machine rotor angle δ_i (i=1, 2,……n)for each machine in the network is given by

$$\frac{d\omega_i}{dt} = \frac{1}{M}\left(P_{m_i}(t) - P_{e_i}(t)\right) \quad (10)$$

where

$$\frac{d\omega}{dt} = \frac{d\delta_i(t)}{dt} = \omega_i(t) - \omega_0 \quad (11)$$

where Pm mechanical input power, M is the angular momentum, Pe is electrical output power and ω is generator rotor speed.

If there is no fault, then the relative speed (ω) of generator is equal to zero. But whenever a fault exists, electrical output power experiences sudden change, but whereas the shaft input power remains constant. This abrupt change of power either accelerates or decelerates the speed of synchronous generator, therefore the relative speed is not zero.

The sampling interval,

$$\Delta t = t_k - t_{k-1} \quad (12)$$

$$\Delta\omega_i(t_k) = \frac{P_{m_i}(t_k) - P_{e_i}(t_k)}{M_i}\,\Delta t \quad (13)$$

$$\omega_i(t_k) = \omega_i(t_{k-1}) + \Delta\omega_i(t_k) \quad (14)$$

$$\delta_i(t_k) = \delta_i(t_{k-1}) + \frac{1}{2}\left(\omega_i(t_{k-1}) + \Delta\omega_i(t_k)\right)\Delta t \quad (15)$$

The rotor angles values for every instantof time t_k are computed by measuring of phase angles and voltage magnitudes.

The rotor tendency of each synchronous generator is calculated by using a polynomial function:

$$\delta(t) = P_n t^n + P_{n-1}t^{n-1} + \ldots\ldots + P_2 t^2 + P_1 t^1 + P_0 \quad (16)$$

where P_n are the coefficients of the polynomial function using the method of least squares criterion and computes values of rotor angles.

$$\begin{bmatrix}\delta_0\\ \vdots\\ \delta_k\end{bmatrix} = \begin{bmatrix} {t_0}^n & {t_0}^{n-1} & \ldots t_0 & 1\\ \vdots & \vdots & \ldots \vdots & \vdots \\ {t_k}^n & {t_{k-1}}^{n-1} & \ldots t_k & 1\end{bmatrix}\begin{bmatrix}P_n\\ \vdots\\ P_0\end{bmatrix} \quad (17)$$

where the rotor angle values of δ_k(k varies from 0,1,2, 3…) are calculated values of synchronous machine for each time instant t_k.

D. PSB Scheme using dQ/dt

This scheme introduces a novel detection of stable power swing mainly based on rapid change of transmission line wattless (i.e., reactive) power with respect to time which is seen by the distance relay to avoid the incorrect tripping of distance relay when the power swing is stable.

The apparent (volt ampere) power of network is the vector sum of complex power of transmission line and the complex power of load, shown in the equation below

$$S_s = S_{line} + S_{load} = P_{line} + jQ_{line} + P_{load} + jQ_{load} \quad (18)$$

Assuming $P_{line} \ll Q_{line}$, then it can write as

$$S_s = jQ_{line} + P_{load} + jQ_{load} \quad (19)$$

The impedance of a load is higher than the impedance of a transmission line during a power swing.

$$Z_{line} \ll jZ_{load} \quad (20)$$

The simplified sending end complex power is given by

$$S_s' = \frac{|V_{load}|^2}{Z_{load}} = P_{load} + jQ_{load} \quad (21)$$

Subtracting (21) from (19), the transmission line reactive power is

$$jQ_{line} = 0 \quad (22)$$

It can be concluded that no wattless power is absorbed by the transmission line during power swing.

Differentiating the power swing and the fault using the magnitude of the derivative of current angle $\left|\frac{d\theta}{dt}\right|$

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The range of $\left|\frac{d\theta}{dt}\right|$ is approximately between 2100 degrees/sec to 9500 degrees/sec during the fault, but the range of $\left|\frac{d\theta}{dt}\right|$ is between 9 degrees/sec to 45 degrees/sec.

III. RESULT DISCUSSION

A. PSB Scheme using ANFIS

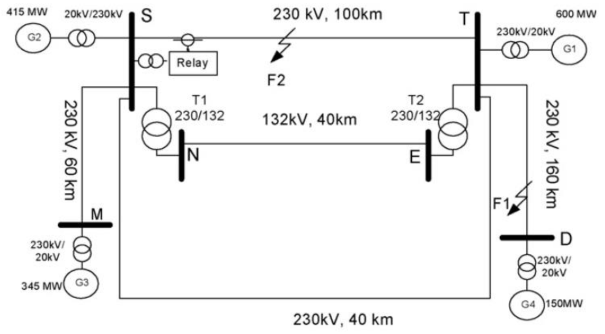

Fig.4.Disturbances due to faults F1 and F2 in transmission line DT and ST

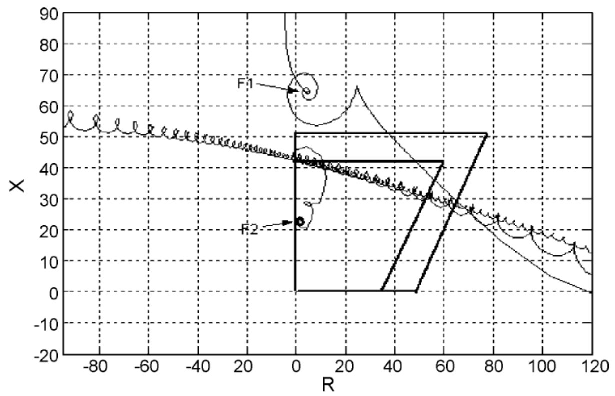

Fig.5. Distance Relay measured impedance for F1 and F2 faults

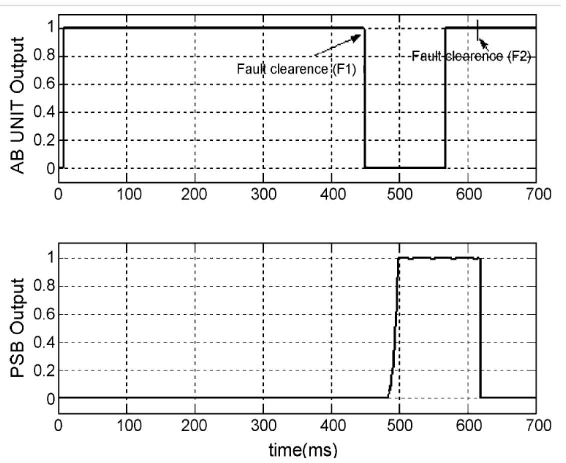

Fig.6. Outputs of Blocking of Power Swing Scheme and Distance relay for F1 and F2faults

The proposed scheme for the system shown in the fig.4. has been tested. Where a F2 fault takes place in transmission line ST in the period of a stable power swing which is produced by a fault F1 that took place in transmission line DT.

From the Fig.6, the PSB output unit comes to zero after the F2 fault occurrence. Therefore, the distance relay will operate for fault F2 without being blocked by PSB unit.

B. PSB Scheme using FZC

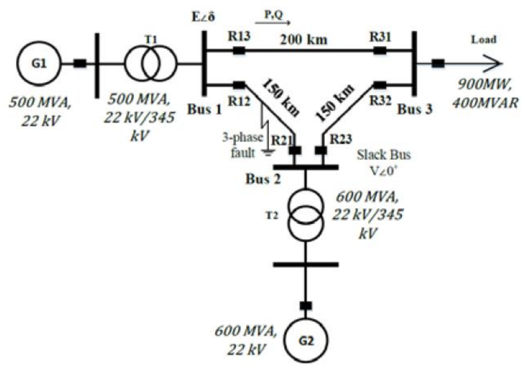

Fig.7. Three bus, 345 kV power system

The FZC scheme is applied on WSCC 9 bus test system. One additional 250 MVA synchronous generator has applied to load on bus 8 of WSCC original test system as shown in the Figures 7,8 and 9 discriminates the fault and the stable power swing.

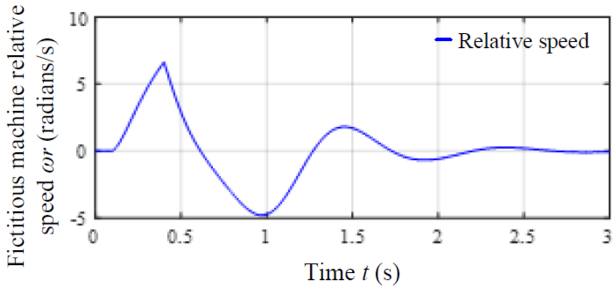

Fig.8. Syn. generator relative speed – stable power swing.

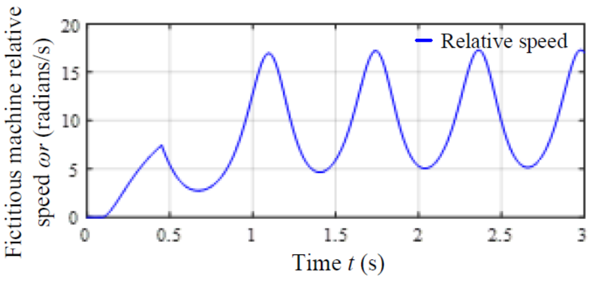

Fig.9. Syn. generator relative speed – unstable power swing

The three-phase fault is applied at time 2.0 seconds and cleared at time 2.05 seconds at bus 7. From Fig.8., it can be observed clearly that the relative speed of synchronous machine reaches to value at time 2.20 seconds, which is 0.15 seconds after the fault is cleared. The locus of impedance enters into first time at third zone is 2.78 seconds, which is 35 cycles after the First Zero Crossing shown in the Fig.9. So there will be sufficient time to block the third zone operation.

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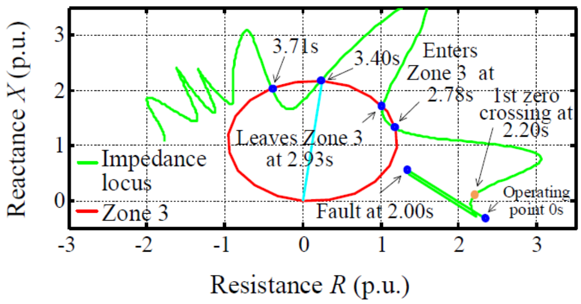

Fig.10.Impedance seen by relay R98

TABLE1

SUMMARY OF STABLE POWER SWING STUDIES ON DISTANCE RELAY R98 IN MODIFIED WSCC SYSTEM

Case No.	1	2	3	4	5	6
Fault Location Bus No.	7	6	8	8	5	8
Fault in Protection Zones (Y/N)	N	N	Y	Y	N	Y
Fault Duration (cycle)	3	3	3	6	3	9
Fault Duration (s)	0.05	0.05	0.05	0.10	0.05	0.15
FZC After Fault Removal (s)	0.15	0.20	0.24	0.25	0.18	0.33
First Zone 3 Entering (s)	0.73	1.47	0.58	0.48	1.38	0.52
Relay Reaction Time After FZC (cycle)	35	76	20	14	72	11
Zone 3 Blocking Decision (Y/N)	Y	Y	Y	Y	Y	Y

C. PSB Scheme using PCF Method

This PSB Scheme done on IEEE 14 bus system. Using PCF method, finding the machine rotor angles of the synchronous machine, it is possible to achieve the blocking of tripping operation of distance relay in third zone when the swing is stable power swing.

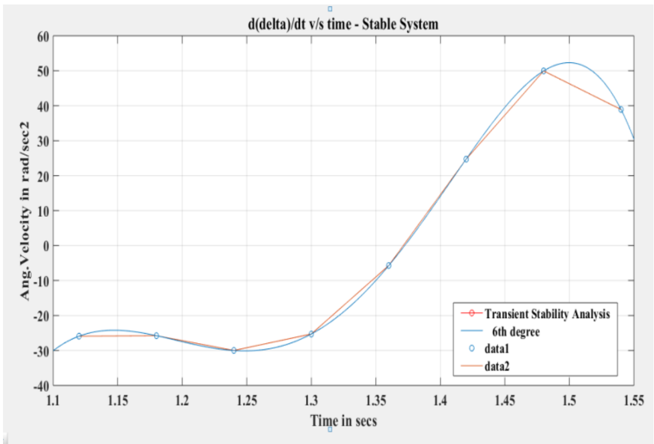

Fig.11. Relative angular velocity-Stable Power Swing

Discrimination between a stable and unstable power swing shown in Fig.11 and Fig.12. This detects the stable power swing and blocks the operation of relay which is shown in Fig.13 and relay clears the blocking operation during fault shown in Fig.14.

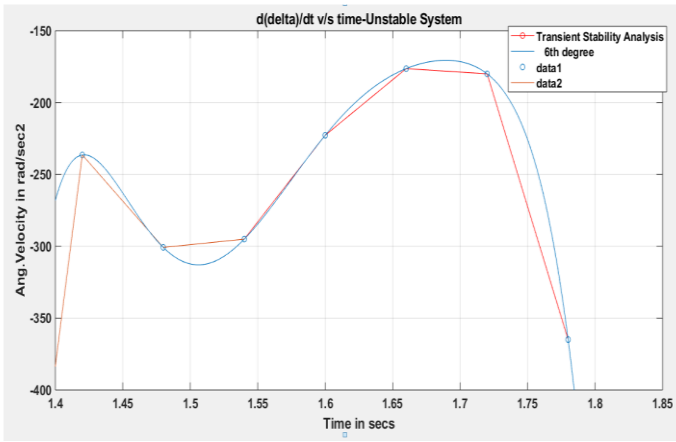

Fig.12. Relative angular velocity-Unstable Power Swing

D. PSB Scheme using dQ/dt

For the purpose of power swing studies, the following five cases the simulation done as follows:
Case 1: Severe 3-phase fault applied at transmission line 5-8, which is again followed by clearance of fault and tripping of line
Case 2: Severe 3-phase fault applied at transmission line 6-7, which is followed by clearance of fault and trip of line
Case 3: Severe 3-phase fault applied at bus 5, which is again followed by clearance of fault and disconnection of bus
Case 4: Severe 3-phase fault applied at bus 6, which is again followed by clearance of fault and disconnection of bus
Case 5: Severe 3-phase fault applied at bus 11, which is again followed by clearance of fault and disconnection of bus

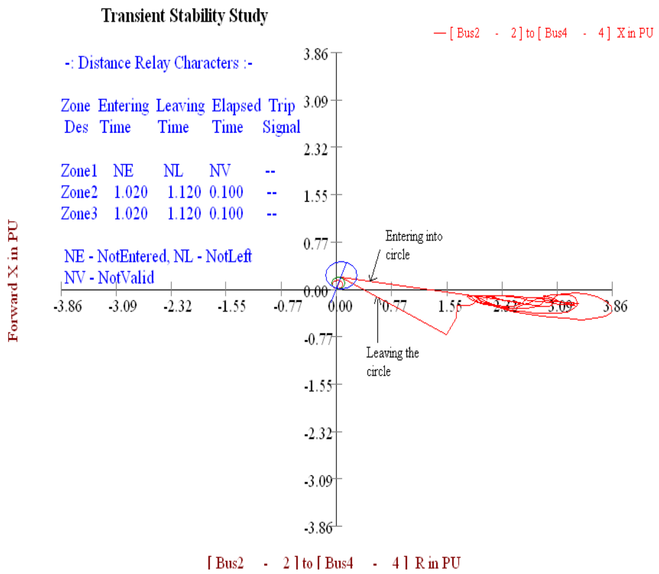

Fig.13. Relay Blocking operation Characteristics – Stable power swing

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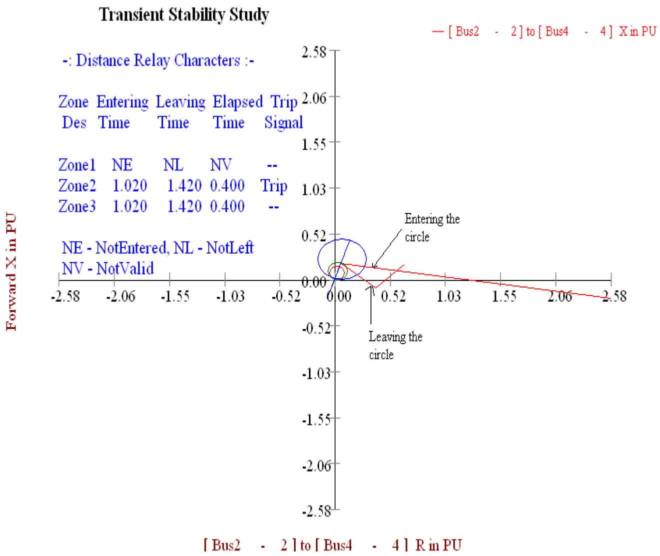

Fig.14. Relay Tripping operation Characteristics – Unstable power swing

In this study, the distance relays placed at buses are identified which are mal-operating are shown as:

Case 1: Bus no.6
Case 2:Bus no.5
Case 3:Bus no.6
Case 4:Bus no.14
Case 5:Bus no.14

The proposed scheme considering the five cases shown above and the respective change in magnitude of angle is shown in the Fig. 16. The result shows that the variation in transmission line reactive power can discriminate the power swing and the fault.

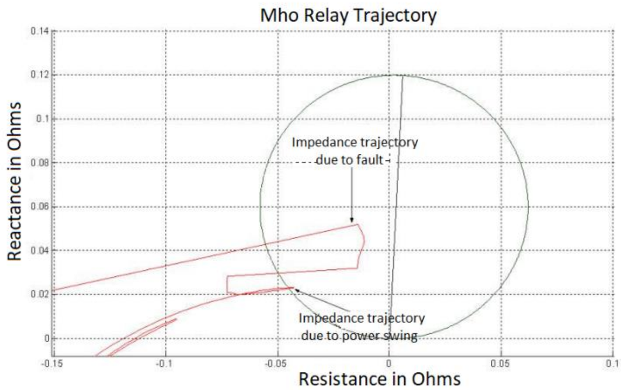

Fig.15. Distance Relay measured impedance during fault and stable power swing

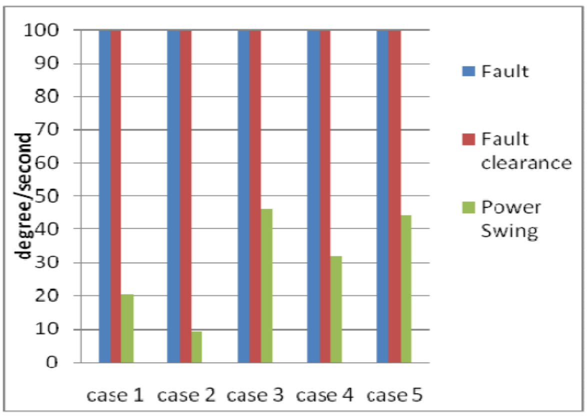

Fig.16. Result of $\left|\frac{d\theta}{dt}\right|$

IV. COMPARISON OF PSB SCHEMES

	PSB SCHEMES			
	ANFIS	FZC	PCF	dQ/dt
Time takingtodetect Power Swing	Very Fast	Very Fast	Fast	Moderate Fast
Blocking of Relay during Stable Power Swing	Yes	Yes	Yes	Yes
Accuracy	More Accurate	More Accurate	Moderately Accurate	Accurate
Disadvantages	It requires training for several offline simulation runs	Complicates to convert to an equivalent network for a large bus system	When the system is in unstable conditions, very difficult to apply this method	Possibility of false trip signals during clearance of fault

V. CONCLUSION

This review paper concludes the brief discussion on Power Swing Blocking schemes, which were used to detect the power swing and block the operation of relay during stable power swing. The PSB Schemes ANFIS, FZC, PCF and the rate of change of transmission line reactive power have its own advantages to detects the power swing and discriminate the fault and power swing. Comparative analysis is also done regarding the PSB schemes mentioning their advantages and disadvantages. Modern type distance relays are using the PSB mode of operation and if there is any power swing, the relay will block its operation. Modern distance relays are operating as inaccuracy because of using conventional methods of PSB mode of activation. To improve the accuracy of the relay, it is needed to use most accurate PSB scheme which have more advantages and very less disadvantages.

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