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ANN-based Improved Zone-3 Decision

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***Abstract*—Early detection and discrimination of symmetrical fault from non-fault transients is the need of hour for reliable operation of power system. Incorrect Zone-3 decision may cause mal-operation of relay and subsequent cascading outages. To mitigate this, an artificial neural network (ANN) based Zone-3 supervision scheme is proposed in this paper. The proposed algorithm comprises of two stages. In Stage-1, ANN architecture is proposed to estimate the current samples. The reconstructed samples are compared with actual samples to detect for any transients in the line. In case of detection of transients, Stage-2 is employed to compare the phase angle of the positive sequence impedance with a threshold. The threshold is selected such a way to segregate fault from stressed conditions. Various stressed and fault conditions are simulated using PSCAD/ EMTDC software. The proposed method is tested in MATLAB environment and significant results are achieved.**

***Index Terms*— third zone; distance relaying; power swing; load encroachment; symmetrical fault, artificial neural network.**

I. Introduction

SECURED ZONE-3 decisionunder stressed conditions is necessary to ensure reliable operation of power system. To ensure correct Zone-3 decision, it is necessary to identify stressed conditions viz. power swing, load encroachment, voltage instability, etc. Mal-operation of Zone-3 element during stressed conditions is the root cause for catastrophic outages. At the same time, correct identification of three phase fault is also necessary to ensure timely isolation of faulty portion of the network. Often, it is a challenge to distinguish them as both conditions are balanced in nature. [1]- [3].

Several methods on the correct Zone 3 decision during stressed conditions are presented in the literature. Synchrophasor based secured zone 3 protection during load encroachment is proposed in [4]. The method computes an index based on magnitude and phase angle of voltage obtained from various PMU buses. A logical approach to supervise back up protection is proposed using relay pick up and status signals of circuit breakers of adjacent lines is illustrated in [5]. A method based on monitoring the transient function to evaluate correct zone 3 decisions is proposed in [6]. In [7], a method based on magnitude of maximum value of decaying dc component is proposed to discriminate fault and a stressed condition [7] is demonstrated.

Online based intelligent classification technique OSELM is proposed in [8] to identify and differentiate symmetrical fault during power swing. The secured zone 3 operation using Impedance prediction approach is

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illustrated in [9].In [10], wide area data from adjacent relays is used to achieve zone 3 distance protection. An algorithm for secured zone 3 operation based on the ratio of negative and positive sequence impedance is proposed in [11]. A method based on super imposed components of voltage magnitude including rate of change of voltage magnitude is examined in [12].

In this paper, a two stage process is proposed for correct identification of fault events and non-fault transients. The mathematical of the power system is expanded to segregate the known and unknown vectors. The unknown state vector is estimated precisely using a multi layer perceptron feed forward neural network (MLP). The estimated vector is used to reconstruct the current samples. Thereafter, the reconstructed current samples are compared with actual current sample to compute error. Then, the evaluation process is carried out into two stages. The stage-1 comprises of error function estimation criteria to detect transient events. In the event of any transient, stage 2 is used to further segregate three phase faults from the non-fault transients to enable correct zone-3decision.

II. PROPOSED METHOD

A. Modelling of Power System

The instantaneous current signal of power system including decaying dc is modeled as,

$$i(t) = I_m \sin(\omega_0 t + \psi) + k_o e^{\frac{-t}{\tau}} \qquad (1)$$

Where, I_m is the peak value of fundamental component of current, ω_0 is the fundamental angular frequency, $\phi$is the initial phase angle,$\theta = \tan^{-1}(\omega_0 L)/R)$, $\psi = \phi - \theta$ and τ is the time constant.

The discrete value of current sample at k^{th} sample is,

$$i(k) = I_m \sin(k\omega_0 T_s + \psi) + k_o e^{\frac{-kT_s}{\tau}} \qquad (2)$$

where, k is the sample number and varies from 1 to N. N is the number of samples per cycle.

Equation (2) is re-written after expanding sine and exponential terms as follows,

$$i(k) = I_m[\sin(k\omega_0 T_s)\cos\psi + \cos(k\omega_0 T_s)\sin\psi] + k_o\left[1 - \frac{kT_s}{\tau} + \frac{k^2 {T_s}^2}{2!\,\tau^2} - \cdots\right] \qquad (3)$$

Equation (3) is further expanded as,

$$i(k) = (I_m \cos\psi)\sin(k\omega_0 T_s) + (I_m \sin\psi)\cos(k\omega_0 T_s) + k_o - \frac{k_o k T_s}{\tau} + \frac{k_o k^2 {T_s}^2}{2\tau^2} \qquad (4)$$

Equation (4) is represented in matrix form for sampling time T_s as follows,

$$[I] = [A][W] \qquad (5)$$

Where, $[A]$ is the sample vector which is mentioned as,

$$[A] = \begin{bmatrix} \sin(\omega_0 T_s) & \cos(\omega_0 T_s) & 1 & -T_s & {T_s}^2 \\ \sin(2\omega_0 T_s) & \cos(2\omega_0 T_s) & 1 & -2T_s & (2T_s)^2 \\ \vdots & \cdots & \vdots & \vdots & \vdots \\ \sin(N\omega_0 T_s) & \cos(N\omega_0 T_s) & 1 & -NT_s & (NT_s)^2 \end{bmatrix}^T \qquad (6)$$

$[I]$ is a column vector of measured samples and $[W]$ is the unknown state vector which are represented below in equation (7) and (8). To estimate the unknown vector $[W]$, ANN architecture is proposed in Part B.

$$[I] = [i_1 i_2 \quad \cdots \quad i_N]^T \qquad (7)$$

$$[W] = \left[I_m\, cos\,\psi \quad I_m \sin\psi \quad k_o \quad \frac{k_o}{\tau}\, \frac{k_o}{2\tau^2}\right]^T \qquad (8)$$

B. ANN archietecture to estimate state vector $[X]$

Fig. 1 depicts ANN architecture to estimate the unknown vector $[\mathrm{X}]$using known vectors $[A]$and$[I]$. The number of elements of input and output layers of ANN are determined according to number of elements of $[A]$and$[I]$. As per (6) and (7), the number of elements of input and output matrices are 5and 1 respectively. According to [13], a single node in hidden layer is sufficient in power system protection applications. Hence, a hidden layer of one node is chosen.

The data set is initially pre-processed by scaling using normalization technique. Keeping the range of data set in view, the activation functions opted for hidden and output layers are hyperbolic tangent and linear respectively. To estimate the unknown vector, the MLPs are trained using Levenberg-Marquardt (LM) training algorithm. 80% of data is used for training and 10% each is used for validation and testing. The unknown vector $[w]$so obtained from the weight matrix of ANN is used to reconstruct the current samples $[\hat{\mathrm{I}}]$ as follows,

$$[\hat{\mathrm{I}}] = [A][W] \qquad (9)$$

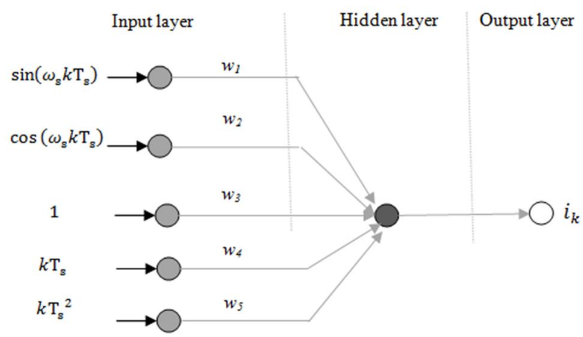


Fig. 1. ANN architecture to estimate unknown vector $[W]$

Now, for secured zone -3 decisions, it is vital to detect occurrence of three phase faults correctly. This is achieved by two stages. Stage-1 is to track current signals continuously for transients which include both non-fault transients and three phase faults. In case of any detection of transients, stage-2 is employed to monitor phase angle of positive sequence impedance to segregate non-fault stressed conditions and three phase faults.

C. Evaluation of Error function and Discrimination Index (DI)

In Stage-1, the current samples reconstructed in (9) are compared with the actual current samples to compute error vector $[\mathrm{E}]$as follows,

$$[\mathrm{E}] = [\hat{\mathrm{I}}] - [I] \qquad (10)$$

where, [E]= [e_1, e_2 …., e_k]. Error function,E_F is obtained from the absolute sum of elements of [E] and it is represented as,

$$E_F = \sum_{k=1}^{N} |E_k| \qquad (11)$$

To identify transients such as stressed conditions and fault in the transmission line, the discrimination index DI is used. DI is the largest value of error function in all the three phases which is obtained as follows,

$$DI = max[E_F^a,\ E_F^b,\ E_F^c] \qquad (12)$$

If DI is less than threshold (h_1), then we can conclude that system is in steady state condition. Else, it is declared that the system is subjected to transients. In case, the value of DI is more than threshold h_1, then stage-2 is proposed, in Part D below, to identify and segregate fault condition from the transients. .

D. Monitoring of phase angle of positive sequency impedance to ascertain fault

Phase angle of positive sequence impedance (φ_z) is a critical parameter to distinguish fault and non-fault transients. φ_z is compared with threshold h_2 for this purpose. Practically, Z1 the value of h_2 for steady state conditions will be less than 45degrees whereas, in case of fault, the same will be between 65 to 85 degrees.

III. RESULTS AND DISCUSSION

Performance of proposed method has been tested for WSCC nine-bus system as in Fig. 2. The system is simulated using PSCAD/EMTDC software considering one axis flux decay dynamics model for generators and distributed parameter model for lines. Distance relays are assumed to be available for line protection. Mho relay characteristics having zone 1 setting 80% and zone 2 setting 120% of the line impedance and zone 3 covering longest adjacent line are considered for line protection. The unknown vector $[W]$is computed using ANN method. The proposed method is tested for various stressed conditions such as voltage instability, power swing, load encroachment and three phase faults.

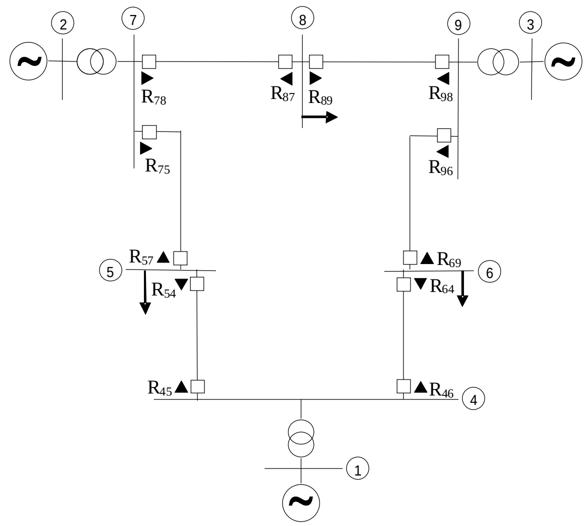


Fig. 2. WSCC nine-bus system

A. Three-phase fault case

Circuit breaker is a critical element in protection chain which fails at times to clear a fault. If circuit breaker at local end fails, remote backup relay should clear the fault. To check the performance of proposed method for a fault in the adjacent line, a three-phase fault is created at 1 s in middle of line 6-9 and results are shown in Fig. 3. It is observed that, the fault is detected in zone 3 by backup relay R_{46} at bus 4 as shown in Fig. 3 a. In this case R_{46}will operate if primary protection of line 9-6 failed to clear the fault. The proposed method applied to this case and identified that the value of φ_z is greater than the threshold value. It shows that there was a fault in the network so the distance relay R_{46} is allowed to operate. The decision of the relay is depicted in Fig. 3 b.

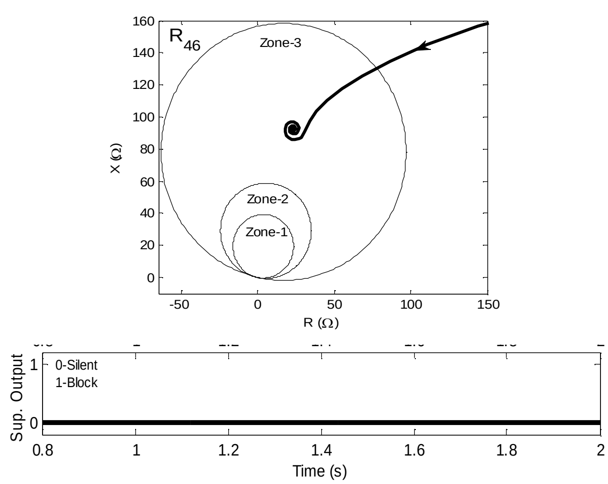
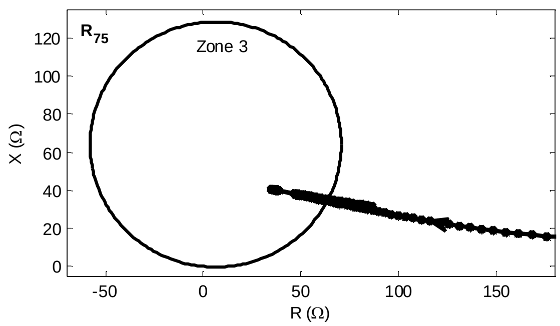


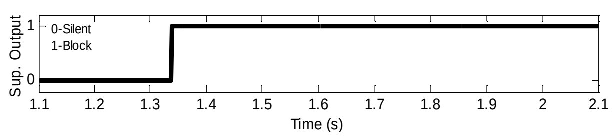
Fig. 3. Results for three-phase fault at middle of the line 6-9
a) Impedance seen by distance relay R_{46} b) Decision of the proposed method

B. Load Encroachment Case

When a line gets overloaded during contingency, the impedance seen by distance relay may enter zone 3 and remains inside. It causes unwanted tripping of the healthy line. To test proposed method, a load encroachment scenario was simulated. To increase the power flow in line 7-5, load connected at bus 5 is increased with increase in generation at bus 2. As a consequence, the impedance seen by the distance relay R_{75}at bus 7 for line 7-5 enters into zone 3 region as shown Fig. 4 a) and it may trip the line unnecessarily. To avoid such unnecessary tripping, proposed method compute the indices using ANN method and it is observed that the indices are less than threshold value. Hence the proposed method blocks the distance relay at 1.35 s as shown in Fig. 4 b) to avoid unwanted tripping. It shows that the method can block zone 3 operations correctly during load encroachment.



(a)

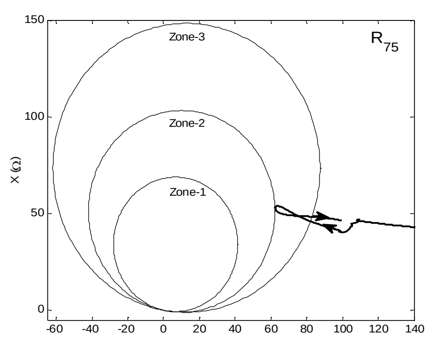


(b)

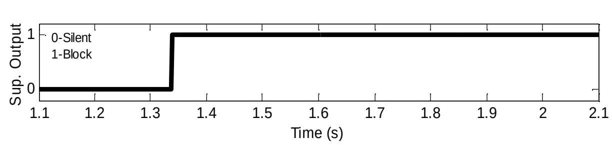
Fig. 4. Results for load encroachment case a) Impedance seen by distance relay R_{75} b) Decision of the proposed method

C. Power Swing Case

Power swing is a dynamic phenomenon. Sudden change of line flow in power system causes oscillations in rotor angles, voltage and current magnitude. During this period, impedance seen by distance relay may enter into its operating characteristic depending on severity of the disturbance.



(a)



(b)

Fig. 5. Results for stable swing case a) Impedance seen by distance relay R_{75} b) Decision of the proposed method

Zone 3 is more vulnerable to operate even during stable swing and may trip healthy line which deteriorates the stability of the system.Most of the swings are stable in nature aroused by minor disturbances which are quite common in power system network. Such a scenario is simulated by initiating a three-phase fault at 1 s on line 9-6 which is isolated by opening the line breakers at 1.1 s.

As a result, the impedance seen by relay R_{75} is inside zone 3 characteristic as shown in Fig. 5 (a) and it may trip line 7-5 unnecessarily, if PSB fails to block. Under such circumstances, proposed method is useful to block R_{75} operation. Since the indices of the proposed ANN method are less than the threshold value the method initiate blocking the distance relay operation at 1.33 s. The decision of the relay is depicted in Fig. 5(b).

D. Voltage Instability Case

Voltage at a bus gradually reduces in case of deficient reactive power support in the power system. During such a situation, the apparent impedance trajectory for a relay may enter zone 3 and trip the healthy line. This unwanted tripping can be avoided using proposed method.

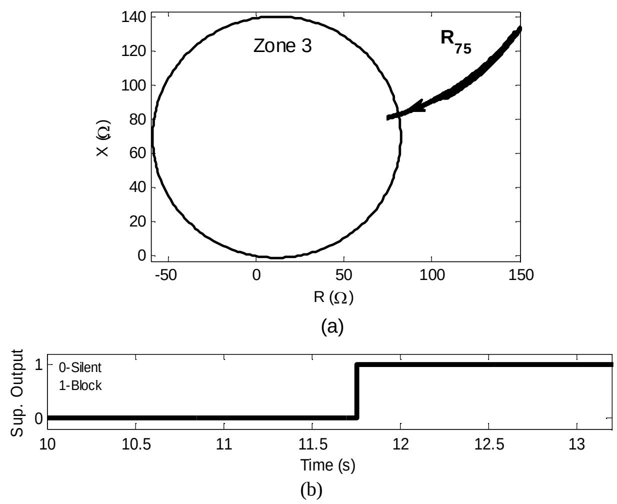


Fig. 6. Results for voltage instability case a) Impedance seen by distance relay R_{45} b) Decision of the proposed method

A voltage instability scenario is simulated by isolating line 9-6 and gradually increasing inductive load at buses 5 and 8. As a result, system voltage gradually decreases and the apparent impedance of relay R_{75} is inside zone 3 as in Fig. 6 (a) which may cause mal-operation of the relay. It is observed that, impedance seen by R_{75} is inside zone 3 at 11.75 s and it remains inside. Indices computed by the proposed method are less than the threshold value therefore blocking signal for relay R_{75} has been enabled by the proposed method as shown in Fig. 6. The result clearly shows the strength of the method.

IV. CONCLUSIONS

Zone-3 element is prone to mal-operation under stressed conditions. The early detection and correct identification of three phase fault is also necessary to ensure timely isolation of faulty portion of the network. In this paper, an ANN based Zone 3 decision is proposed. The improved Zone decision is proposed in a two stage process for correct identification and discrimination of non-fault transients and fault events. The stage-1 comprises of error estimation criteria to detect transient events; and to stage-2 is designed to segregate three phase faults from the transient events. The method is tested for various stressed conditions such as such as load encroachment, power swing, voltage instability and three phase fault and it is evident that the method segregates the three phase fault correctly.

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