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Third Zone Distance Relay Enhancement in Power Swing Conditions using IDNN and SMO Algorithm

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Abstract: In the event that the primary protection fails, remote backup protection is offered using a zone 3 distance relay. However, under demanding conditions like high loads, voltage, and transient instability, the risk of a distance relay malfunctioning is relatively considerable because it jeopardises the stability and dependability of the system. The relay does not run the gearbox line effectively when it is malfunctioning. An advanced power swing blocking strategy has been designed to solve this issue. To prevent distance relay malfunction and boost system dependability, a better DNN-based power swing blocking system is suggested. The improved discrete wavelet transform (IMDWT) is fed sensed data that includes the current and voltage signal of the system. By using the IMDWT, the standard deviation (SD) is computed from the coefficient value of the sensed data, which is used to determine whether a system is in a normal or stressed state. The IDNN's (enhanced Deep Neural Network) most valuable algorithm is given the SD value. The improved DNN in the proposed work functions in two operating modes: RDL-1 (normal condition) and RDL-2 (power swing condition). The threshold-based blocking method improves the performance of the IDNN. The suggested technique determines a suitable system condition based on the threshold value. The results of the suggested method are validated in the Western System Coordinating Council (WSCC) IEEE 9 bus system Software MATLAB/Simulink. The proposed method's total accuracy is 97%. The suggested technique enables quick operation and recognises the power swing state to trip the relay at a distance.

Keywords: zone 3 distance relay; power swing; Improved Discrete Wavelet Transformation (IMDWT); Improved Deep Neural Network (IDNN)

1. Introduction

The third zone distance relay is mostly used to secure UHV and EHV transmission lines because it provides a rapid power swing or fault clearance and system coordination [1].

In addition, it offers both backup and primary protection by setting the zonal region correctly to coordinate among the distance relays [2]. A distance relay generally consists of zone 1, zone 2, and

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zone 3. A zone 1 distance relay covers the area of the transmission line, i.e., zone 1 covers 80% of the transmission line [3]. Zone 2 covers 120% of the area of the transmission line, and zone 3 covers 180% and protects all transmission lines from power swings [4]. Even under the most unfavorable system conditions, a distance relay should not function for problems outside the remote bus [5]. To put up the relay overreach triggered through power system suspicions, the nominal reach of a non-pilot relay is fixed smaller than the projected length of the line [6]. Load encroachment, voltage instability,[7] and power swings are the most prevalent conditions [8] in the system that affect distance relay operation [9]. The load encroachment issue is considered a static event [10]. Voltage instability and power swings are dynamic processes that create encroachment into the distance relays to cause maloperation [11].

The whole system's transmission line is in isolation due to circuit breaker tripping because of a breakdown in a respective transmission line [12]or incorrect operation of circuit breakers attached to the transmission line due to zone 3 maloperation, causing power flow to be redirected through other transmission lines [13]. Load encroachment is one of the effects of this type of situation. Therefore, nearby transmission lines are, in turn, overloaded, causing cascaded circuit breaker tripping, resulting in power system black- outs and instabilities [14]. An investigation of blackouts in North America and Canada on 14 August 2003, in the Malaysian grid in 2003 and 2005, and in India on 30 July 2012 found that the primary reason was the distance relay's maloperation owing to load encroachment due to transmission line overloading [15]. Distance relays have a power swing blocking (PSB) mechanism to prevent relays from maloperation [16].

Main Contribution

Mitigation of maloperation in third zone distance relays enhances the system's protec- tion and reliability. The main objectives of the proposed method are described below:

- A Western System Coordinating Council (WSCC) IEEE 9 bus system with a third zone distance relay is structured and validated.
- Zone 3 distance relay acts on maloperation at stressed conditions, such as power swing and voltage instability. The effect of maloperation is tripping of the transmission line.
- In the proposed method, the voltage and current signals are analyzed to generate the coefficient value through an improved discrete wavelet transformer (IMDWT). Standard Deviation values are computed using these coefficients.
- Based on the SD value, the improved deep neural network (IDNN) predicts the blocking or unblocking class to generate an appropriate command signal.

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- The DNN's prediction performance is enhanced by using a based-on threshold ap- proach that chooses the correct class of IDNN to provide a superior operation.
- The proposed method is analyzed under normal and power swing conditions, and the outcome is contrasted with the present approach.

The organization of the rest of the paper is as follows. Section 2 presents the literature survey related to the mitigation of maloperation in distance relay and system security. The proposed method architecture and working procedures are explained in Section 3. The outcome of the proposed approach is validated in Section 4. Section 5 concludes the paper.

2. Proposed Methodology

A third zone distance relay is a crucial component in enhancing the reliability and security of the power system through rapid mitigation[17] of power swings in a transmission line. During a power swing, a certain value of the angle difference and the magnitude ratio are fulfilled, and the impedance flow in the distance relay under zone 3 causes relay maloperation [18]. Convolutional blocking methods are the measure of the amount of change of impedance that passes through the relay's zone. In the proposed method, the zone 3 distance relay performance is enhanced by using a supervision-based blocking scheme under normal and fault or power swing conditions. The voltage and current quantities of the transmission line are sensed to give as an input to improved discrete wavelet transform (IMDWT). IMDWT analyzes the sensed data to produce a coefficient value. The coefficient value is fed to the IDNN classifier, which analyses the coefficient value to create an appropriate command signal for the third zone distance relay to protect the transmission line. Figure 1 illustrates the architecture of the proposed method.

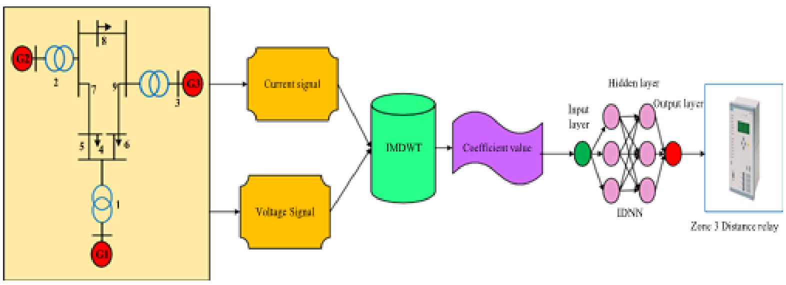

Figure 1. The architecture of the proposed approach.

The WSCC IEEE 9 bus system contains three generators and three loads. The trans- mission line's voltage and current are sensed to create a dataset. The sensed value is given as an input of IMDWT.

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IMDWT is a component that splits a signal or data into a different frequency. It values the input signal in Fourier transform to handle the sudden variation of signals competently. IMDWT has many useful power swing/faults transient features.

3. Modeling of Proposed Parameters

The supervision-based blocking system works on the basis of recognition of power swing/faults in the system. The operation of the third zone distance relay is on the base of the IMDWT coefficient value. A power swing is identified by measuring the current and voltage of the transmission line, its corresponding coefficient, and the classifier. An in-depth description of IMDWT and IDNN is presented below section.

4. Improved Discrete Wavelet Transform

DWT is a group of finite impulse response (FIR) filters that split the low-frequency sig- nals and high-frequency signals from the input signal at different scaling factors [19]. Each scaling stage provides an estimated outcome of an input signal. The estimated outcome is very useful for classifying an appropriate class and detecting a power swing/fault. In the proposed work, improved DWT (IMDWT) is utilized as it is very fast and efficiently analyses the current and voltage signals from the WSCC 9 bus system. IMDWT offers input signal into frequency band and Fourier transforms for low and high-frequency components. The scaling factor of the IMDWT is based on the frequency of the system. The first scaling factor is based on the high-frequency end of the spectrum; during this period, the resolution time is very high. The lower frequency is based on the higher scaling factor; during this period, the resolution time is the worst.

4.1 Modeling of Improved Deep Neural Network

An Improved Deep Neural Network (IDNN) contains three layers, namely, the input layer, hidden layer, and output layer as shown in Figure 2. Each layer involves several nodes that are united step by step into whole nodes in an ensuing layer [20]. Typically input and output layers are single layers, but the hidden layers are expanded to more than two. In the proposed work, six input layers and seven hidden layers are provided to analyze the input data. This IDNN consists of 64 input neurons and 64 output neurons per cycle of rapid current. A lot of neurons are overfitting, so only a small number of neurons are underfitting. Due to the above reason, the hidden layer neuron size and numbers are chosen carefully. Each layer of neurons is computed practically. Because the hidden layer size is set as hyperparameters, it is executed by the Tensor flow. The problem solving and the fault learning ability of the IDNN is based on activation function. The coefficient value is fed into the input layer of the IDNN, and the

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predicted classes are provided in the output layer. The weight of each node is computed, and appropriate values are predicted by using an activation function. In the proposed work, rectified linear unit (ReLU) is used as an activation function that finds an appropriate weight between the nodes to reduce the error that happened in the system. This weight shift is done in reverse by pack propulsion, from the output layer to the input layer, until the cost function is reduced.

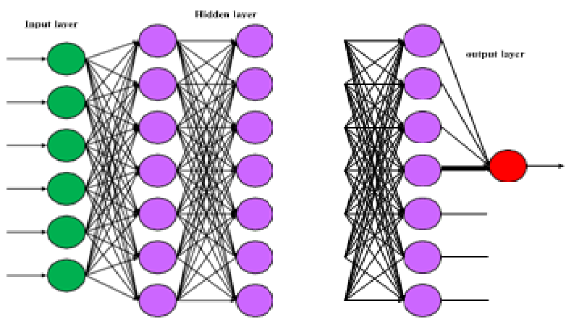

Figure 2. Proposed IDNN Structure.

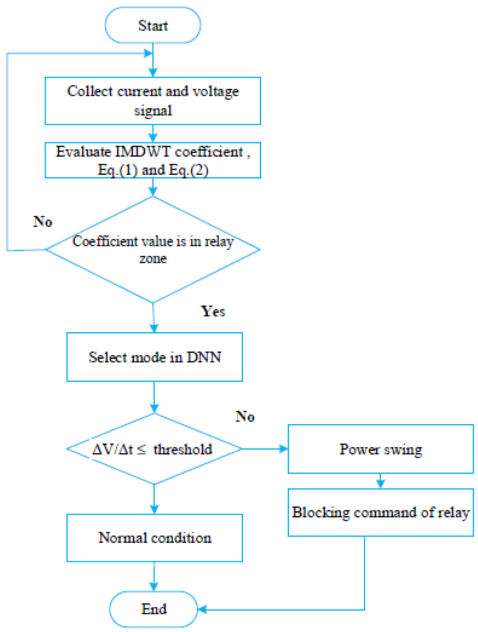

Figure 3. Flow chart of the proposed method.

5 Result and Discussion

The proposed IDNN-based blocking scheme is integrated, and performance is vali- dated in the WSCC IEEE 9 bus system. The proposed method contains a system to identify the power swing and block the third zone distance relay. Power swing in a system is caused due to unexpected changes in loads and

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voltage deviation. Recognition of power swing is a complex task in a power system because the variation of voltage and loads are caused in seconds. The proposed IDNN-based blocking scheme provides a rapid operation to identify the power swing/fault in a system to turn OFF the distance relay. The proposed method is designed, and the performance is validated by using MATLAB 2021a Simulink software; the system configuration is described as an Intel (R) Core (TM) i5-10300H Processor, CPU @2.50 GHz, 32 GB Memory (RAM), and System type of 64-bit operating system. Based on the current and voltage of the line, the IMDWT generates a coefficient, and the IDNN analyses the coefficient to generate a suitable command signal for a distance relay. The prediction performance of the IDNN is enhanced by using a threshold-based blocking method. A threshold value of proposed methods is taken as 2.8915. Figure 4 shows the WSCC 9 bus test system.

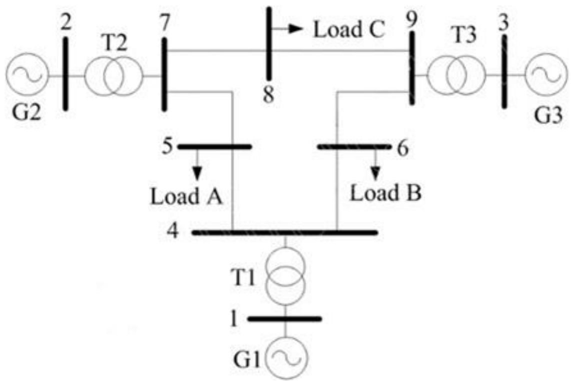

Figure 4. WSCC 9 bus test system.

The structure of the WSCC 9 bus system contains three generators, three loads, and nine buses. The WSCC 9 bus system was designed using MATLAB/SIMULINK. Afterload flow was converged, faults were applied at different locations in the network, and the voltage and current variations were verified. A classifier that helps to decide whether the disturbance is due to fault or power swing was designed. The distance relay is attached to disconnect the line with a fault/power swing. The proposed method was validated under two situations, namely, normal condition and power swing condition.

5.1 Situation 1: Normal Condition

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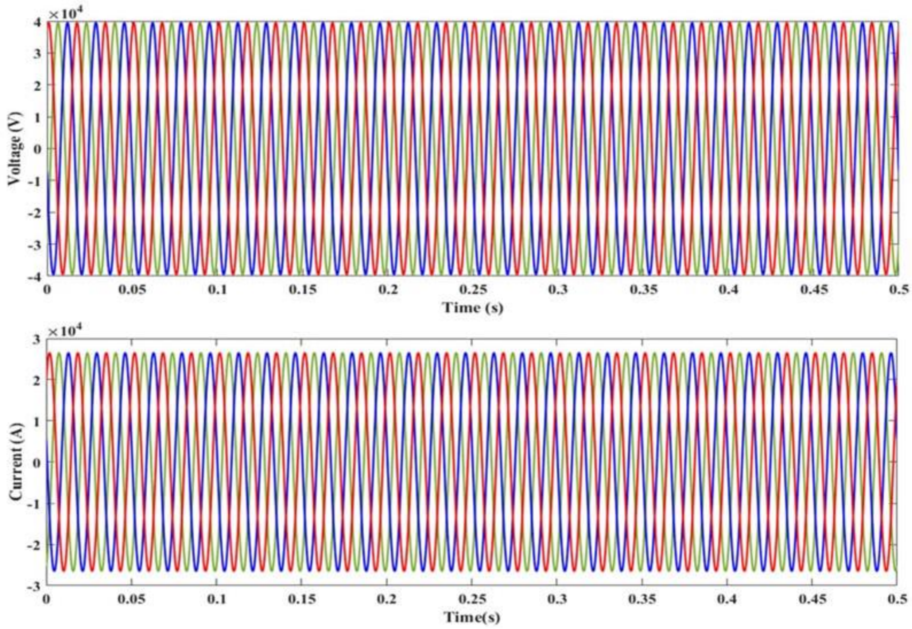

Figure 5. Voltage and current flow under normal conditions at Bus 2.

Under normal conditions, the flow of voltage and current is not varied because the load is not much varied. Therefore, the system does not face a power swing/fault condition. Figure 5 shows the waveform of voltage and current under normal conditions at Bus 2. It shows that the voltage of the system flows from −40 kV to +40 kV. Similarly, the current varies from −26 kA to +26 kA.

5.2 Situation 2: Power Swing Condition

The flow of voltage and current are varied because a power swing occurred due to a variation in voltage and current due to a sudden variation in load. In this proposed work, the power swing happened in the second generator. Figures 6–9 show the voltage and current waveforms during the power swing at Bus 2, Bus 5, Bus 6, and Bus 8, respectively, which occurred at the period of 0.3 s to 0.5 s.

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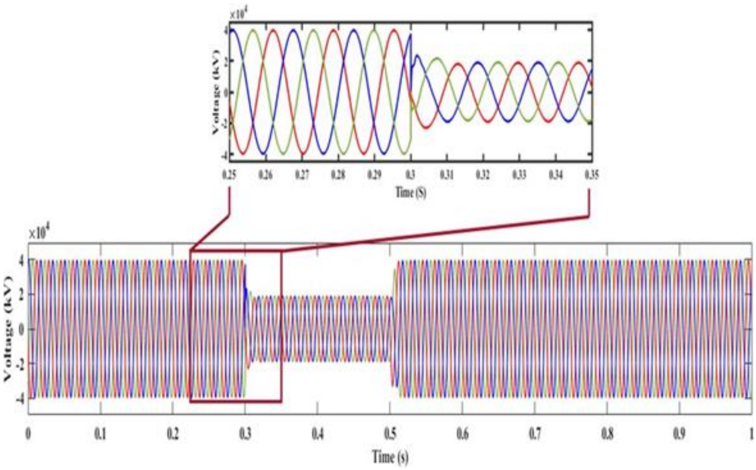
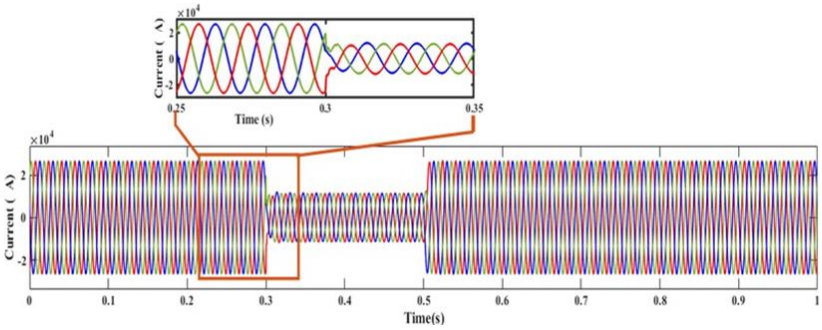


(a)



(b)

Figure 6. Analysis of (**a**) Bus 2 voltage and (**b**) Bus 2 current under power swing conditions.

The ROC and AUC of the proposed method are illustrated in Figure 10. The ROC curve is a performance measure for classifying tasks at different levels of the threshold. The ROC is a probability curve, while AUC stands for separable size or quantity. This shows how different the model is amongst classes. The AUC forecasts that class 0 will be 0 and class 1 will be 1. The AUC indicates the appropriate class prediction of the proposed method. If the AUC is high, the proposed model predicts 0 classes such as 0 and 1 classes as 1. The proposed technique obtained the best fault detection validated by performance matrices based on the ROC characteristics. The proposed SBS is used to examine the blocking scheme utilizing the impedance approach based on the fault detection phase.

The proposed method 2 2 confusion matrix is provided in Table 2. The matrix is formed as the predicted value and actual value of the system. The parameter of a confusion matrix is True, False, Negative, and Positive, which are further computed as True Negative, which is the number of negative events correctly classified as ordinary. The total number of positive

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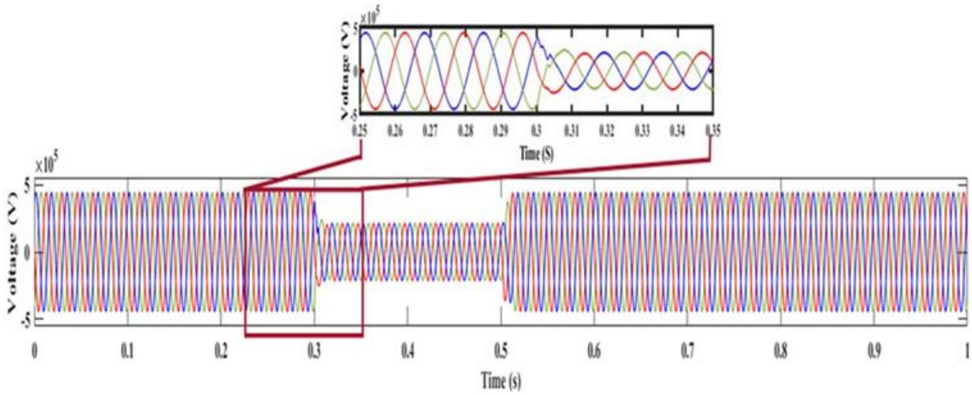
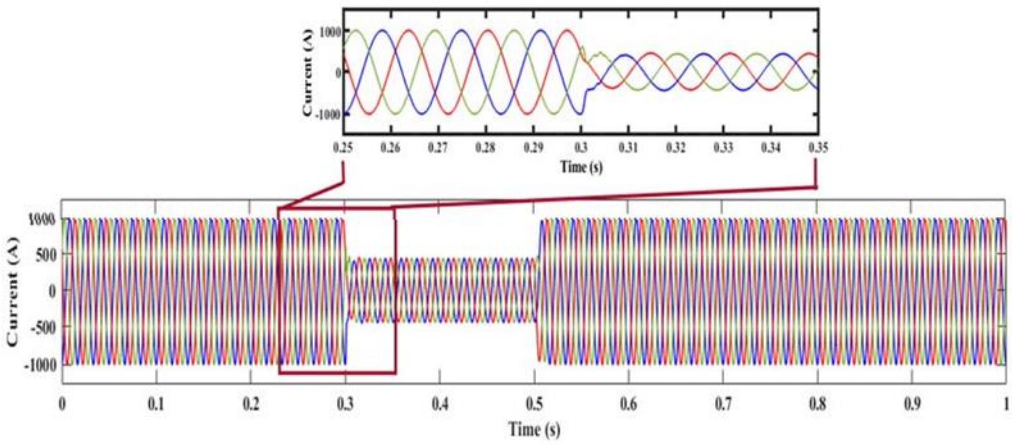


cases is correctly classified as an attack which describes as a True Positive. False Positive is termed as the number of non-attacking instances that were misclassified as attacks, and False Negative is stated as the number of assaults that are incorrectly classified as normal.

(**a**)



(**b**)

Figure 7. Analysis of (**a**) Bus 5 voltage and (**b**) Bus 5 current under power swing conditions.

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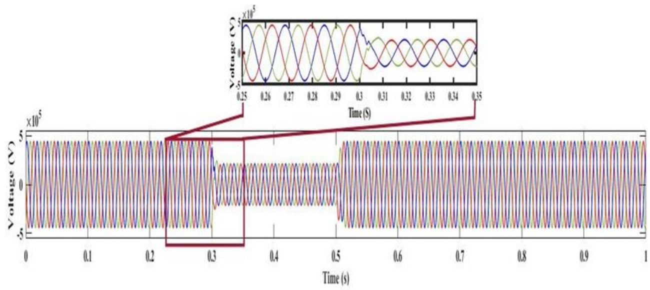

6 Conclusions

To prevent the zone 3 distance relay from malfunctioning, the IDNN-based power swing blocking technique was developed. IMDWT is provided with the sensed data after the current and voltage signals on the transmission line are individually sensed. The SD value of the coefficient is then calculated by IMDWT using the sensed data as input. The RDL-1 (normal condition) or RDL-2 (power swing condition) IDNN functions are determined by the SD value. The IDNN operates in RDL-2 mode when the system power is increased or deviates from the predetermined amount. This mode detects the power swing and sends a tripping signal to the zone 3 distance relay to protect the transmission line. Following a power swing, the magnitude of the voltage and current varies. The outcome the system's reliability and results in unfavourable tripping because of zone 3 distance relay malfunction. The suggested approach creates an acceptable system condition and a sufficient command signal for the remote relay. The proposed approach's effectiveness and relay features validated that it eliminates distance relay maloperation and successfully operates under power swing and normal settings. On the WSCC IEEE 9 bus system, the suggested method is assessed and contrasted with other approaches including SVM, ANN, and KNN. Future research may apply innovative methods or cutting-edge intelligent systems to further boost the security and dependability of the system.

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