Review: Different Techniques for Transmission Line fault Classification and Detection

[1]Amruta R. Dudhe, [2]Prof. Lata B. Awale

[1]Reseach Scholar, [2]Assistant Professor,
[1,2] Electrical Engineering Department,
[1,2] Government College of Engineering, Chandrapur, Maharashtra, India.

Abstract : Any protective relaying systems must be able to identify defects on transmission lines quickly and accurately. Time spent clearing faults and isolating the faulty line from the rest of the power system aids in speedier power supply maintenance and restoration. For single-pole tripping and auto-reclosing action, fault detection and classification are required to determine the fault type and pick the problematic phase. Furthermore, these functions increase the power system's dependability, stability, and economy. As a result, having an effective algorithm for identifying and categorizing transmission line defects is critical.
A study of alternative fault classification and detection strategies in transmission lines is presented in this work. Efforts have been made to incorporate practically all of the transmission line techniques and approaches documented in the literature. For dependable and high-speed protective relaying, fault classification is required, followed by digital distance protection. As a result, a thorough examination of these procedures is required.

***Index Terms* – Fault classification, Fault detection, Transmission Line.**

I. INTRODUCTION

Transmission line protection against uncovered deficit is the most basic task in power system assurance. Faults in overhead wires are a rare occurrence, caused by a variety of factors including weather, human error, fires, and mechanical failures such as rotating machines and transformers.
These problems disrupt electric streams, destroy hardware, and even result in the deaths of people, flying species, and wildlife. These problems jeopardise the power supply's consistency. Fault is a term used to describe a state that is out of the ordinary. This study compares transmission system failures to human diseases to make it easier to grasp. For example, a healthy person's day-to-day existence is disrupted if he encounters any aberrant condition, which includes diseases such as colds, coughs, fevers, heart attacks, cancer, and so on. Similarly, when a power transmission system experiences an abnormal state, the system quantities (voltage, current, phase angle, etc.) surpass their threshold values, which is referred to as a fault.
Because the majority of an overhead transmission line is exposed to the elements, the odds of a fault occurring on an overhead transmission line are higher than on subterranean cables. There are two types of faults in overhead transmission systems: series (open conductor) faults and shunt (short circuit) faults. By analysing each phase voltage, series problems may be easily discovered. When the voltage readings rise, it means there is an open conductor defect. There are two types of open conductor faults: one open conductor faults and two open conductor faults. These are flaws that only happen once in a while.
Short circuit problems may be easily found by looking at the current in each phase. When the current values rise, it means a short circuit has occurred. Asymmetrical and symmetrical short circuit faults are the two forms of short circuit faults. Line to ground (LG), line to line (LL), and double line to ground (LLG) faults are asymmetrical, whereas triple line (LLL) and triple line to ground (LLLG) faults are symmetrical. Figure 1 depicts the fault classification in an overhead transmission system; A, B, C, and G represent phase A, phase B, phase C, and ground, respectively.
The frequency of incidence and severity of the flaws will be compared to human diseases once more. The LG defect is the most prevalent type of defect, and the most prevalent ailments include headache and cold. As we all know, headaches and colds are less severe than other ailments; similarly, LG defects are less severe than other defects. The LL defect is the following fault in terms of severity and incidence. It may be compared to diseases such as fever and LLG fault with viral fever, and 3-phase (LLL and LLLG) faults may be compared to major diseases such as heart attack, since if a 3-phase fault occurs, the entire system would collapse, therefore it was likened to major diseases such as heart attack. To avoid catastrophic damages, the protection scheme must identify the defect, identify the nature of the defect, and locate the defect in a short period of time. For this, several approaches have been devised, each with its own set of benefits and drawbacks. As a result, customers have a significant challenge in selecting a fault categorization approach. It's been compared to diseases like fever and LLG fault with viral fever, and 3-phase (LLL and LLLG) faults have been compared to large diseases like heart attack, because when a 3-phase fault occurs, the entire system collapses, therefore it's been compared to large diseases like heart attack. To avoid catastrophic consequences, the protection mechanism must quickly detect the fault, determine the nature of the flaw, and locate the flaw. Several ways have been proposed for this, each with its own set of advantages and disadvantages. As a result, choosing a defect classification methodology presents a substantial difficulty for consumers.

II. DIFFERENT TECHNIQUES FOR TRANSMISSION LINE FAULT CLASSIFICATION DETECTION

2.1 Fuzzy Logic Approach

The author describes a technique [1] for employing a fuzzy system to improve the performance of transmission line directional relaying, fault classification, and fault locating systems. For a full transmission line protection method, three distinct fuzzy inference systems have been devised. Under varying fault inception angles, fault resistances, and fault location, the suggested approach can reliably detect the fault (both forward and reverse), locate, and identify the defective phase(s) involved in all ten types of shunt faults that may occur in a transmission line. The suggested approach requires current and voltage measurements at the relay position and can identify and classify faults in less than a half-cycle period. The suggested fuzzy logic-based relay has a lower computational complexity and outperforms conventional AI-based approaches that need training, such as artificial neural networks, support vector machines, and decision trees (DT). For the most part, the percentage error in fault location is less than 1 km. The fault localization technique was validated using a two-test with a significance level of 5%.

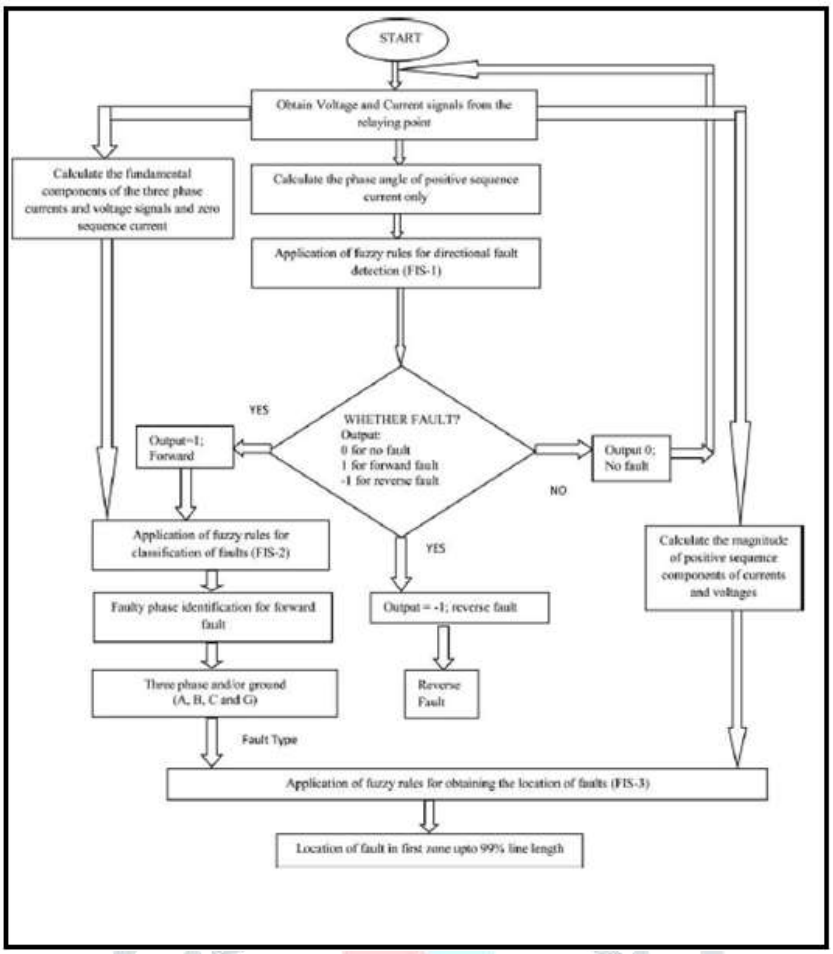

Fig.1. Flowchart of the proposed fuzzy based protection scheme [1]

Under diverse fault circumstances, the suggested fuzzy inference system-based fault direction detection, classification, and localization methodology [1] has proven to be quite successful. In comparison to ANN, ANFIS, SVM, and DT-based schemes, the suggested system is relatively simple and does not require training.

Different failure conditions, such as fault kind, fault distance, fault inception angle, fault resistance, and so on, have no effect on the scheme's dependability. The suggested technique efficiently identifies the fault direction and kind within half cycle time, according to the results. The majority of problem instances have a fault localization inaccuracy of up to 2%, with a few exceptions. The 2 test is used to validate the fault location error. The suggested fuzzy logic-based solution protects 95 percent of the line length and provides backup protection in the event of reversal faults.

2.2 DWT-BPNN based on Clarke's Transformation

Using discrete wavelet transform (DWT) and back-propagation neural network (BPNN) based on Clarke's transformation on parallel transmission, the author presented [2], a new algorithm for fault detection and classification using discrete wavelet transform (DWT) and back-propagation neural network (BPNN). Clarke's transformation created alpha and beta (mode) currents, which were utilised to convert the signal of a discrete wavelet transform (DWT) into wavelet transform coefficients (WTC) and wavelet energy coefficients (WEC) (WEC). To breakdown the high frequency components of the signal error, Daubechies4 (Db4) was employed as a mother wavelet. PSCAD / EMTDC was used to model the transmission system in this simulation. On a specific power system model, simulations were run at several sites along the transmission line with various types of fault and fault resistance, fault position, and fault start angle. In this work, four statistical approaches were used to determine the accuracy of defect detection and categorization. The best Clarke transformation occurred on the configuration of 12-24-48-4, according to the results.

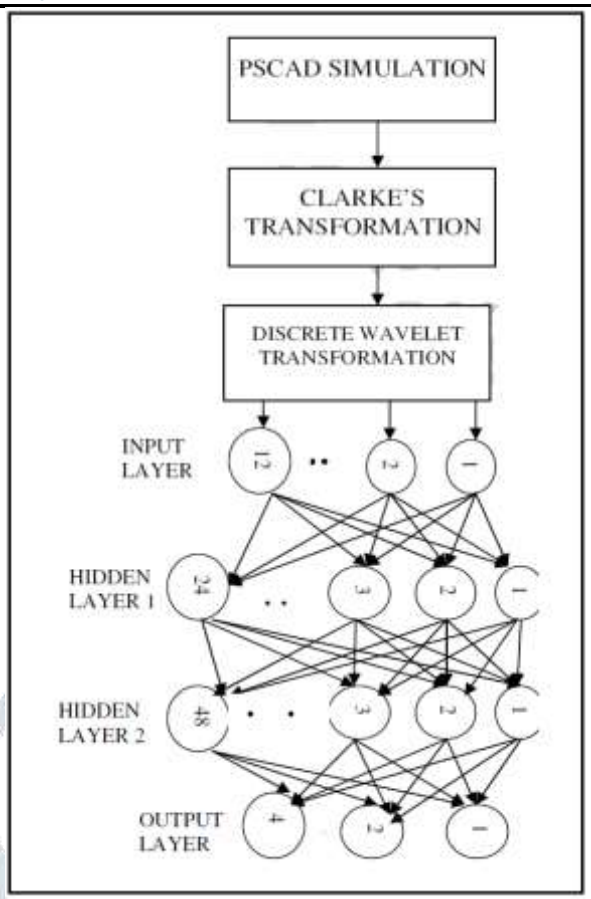

Fig.2. Architecture of Proposed DWT-BPNN based on Clarke's Transformation [2]

The mother wavelet in this approach is Daubechies4 (Db4). Variation distance, beginning angle, and fault resistance have all been investigated in various case studies. The outcomes of training BPPN and DWT with and without Clarke's transformation are compared, and the findings reveal that using Clarke's transformation produces less MSE and MAE than without using Clarke's transformation. The Architects' result was the best of the three, with a score of 12-24-48-12. In this study, four statistical approaches are used to assess the accuracy of defect detection and classification, with the Back Propagation Neural Network producing the lowest error and so being the best when compared to Pattern Recognition Network and Fit Network.

2.3 DWT and SVD Approach

A unique approach for identifying and categorising faults in high-voltage transmission lines is suggested by the author [3]. The discrete wavelet transform (DWT) and singular value decomposition are used in the approach (SVD).

Under fault circumstances, the DWT is utilised to extract the high-frequency components of currents. To create a wavelet matrix, signals under each fault state are scaled in frequency. The maximal singular value is determined and used in this proposal using the SVD. The obtained findings show that the greatest single value is a reliable indication of the problem. Maximum wavelet singular value is an unique methodology for identifying and categorising defects in power systems. DIgSILENT Power Factory simulates phase-to-ground, two-phase-to-ground, and three-phase failures under a variety of fault impedances. The proposed solution is assessed against the investigated fault situations, proving that it minimises the computational cost and detection time.

The assessment of the MWSV for fault detection and classification is proposed using simulated signals from a test power system. Through the DWT, the MWSV enables for accurate detection and classification based on time–frequency analysis. This is performed by using sliding-window data and updating it in a sequential manner. The MWSV is calculated to offer details on the fault situations at each window.

The estimates are based on a quarter of a current cycle. This unique fault detection method based on the MWSV was investigated, yielding a precise result with a window of 5 ms, demonstrating a competitive fault detection time. The obtained results are quite good, indicating that the algorithm has a lot of potential for use in transmission line protection relays. Furthermore, a unique fault classification criterion is provided. The MWSV's Euclidean norm and classification criteria specified by coefficients and set-up values underpin this criteria. Because of its one-of-a-kind judgement threshold, it makes a strong case. The performance of the detection and classification algorithms was evaluated for single-, two-, and three-phase faults with varying fault resistance and time inceptions. As a result, the MWSV is a dependable approach for detecting and classifying faults in power systems.

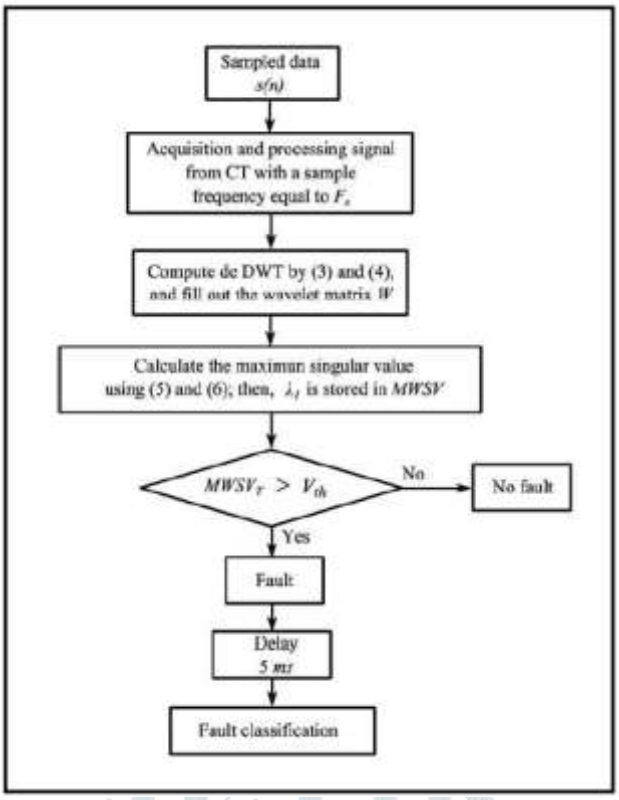

Fig.3. Fault detection by proposed MWSV algorithm [3]

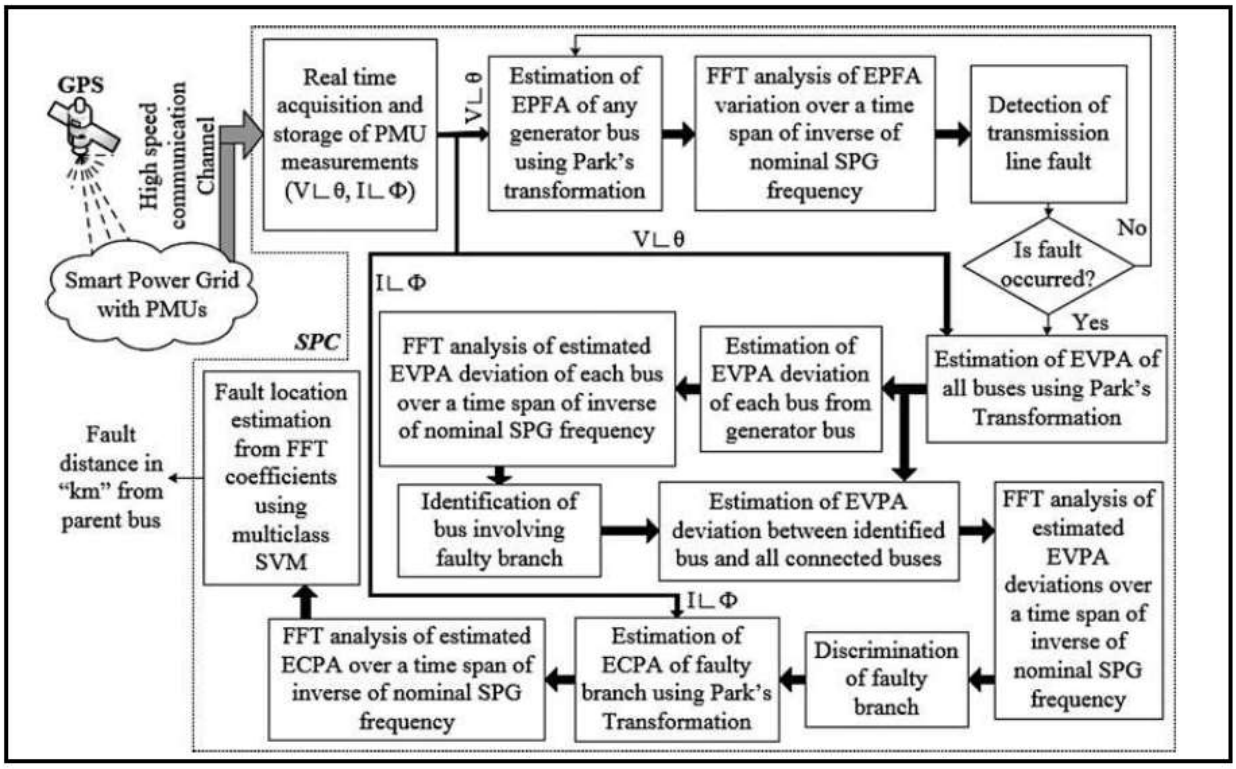

Fig.4. Functional block diagram of the proposed methodology [4]

Rapid advances in measuring and computing technologies have ushered in a paradigm shift in power grid operational design throughout the world. Self-healing, a key element of developing power grids, demands the real-time detection and localization of transmission line problems throughout the whole network. Based on phasor measurement unit (PMU) readings, this work offers a unique support vector machine-based fault localization approach to precisely identify and locate all forms of transmission line faults occurring at any position in the power grid. Only PMU readings from a single generator bus for the whole grid are used to detect faults. Fast Fourier transform analysis of fluctuations in equivalent voltage phasor angle (EVPA) and equivalent current phasor angle (ECPA) is used to compute the bus associated with the problem, the faulty branch, and the location of the problem in the faulty branch (ECPA). Extensive case studies for the Western System Coordinating Council (WSCC)-9 and IEEE-14 bus systems have verified the suggested technique.

2.4 Support vector machine Approach (SVM)

For predicting the location of the defect, a multiclass SVM classifier was used. The suggested approach can precisely pinpoint any transmission line fault occurring at any place inside the power grid based on single generator bus PMU data, which is the method's major contribution [4]. The fault location information obtained using the suggested approach can help SPC repair the damaged line

as soon as possible and launch appropriate wide-area control actions to heal smart grid stability concerns caused by the occurrence and isolation of the fault. Extensive case studies for WSCC-9 and IEEE-14 bus systems were used to verify the technique.

2.5 Convolution sparse auto encoder (CSAE) Approach

Based on a convolution sparse auto encoder, the author presents a novel method [5] for fault detection and classification in power transmission lines (CSAE). Unlike traditional approaches, the suggested technique automatically learns characteristics from a dataset of voltage and current signals, allowing for the creation of a framework for problem identification and classification. For half-cycle multi-channel signal segments, convolution feature mapping and mean pooling are used to construct feature vectors with local translation invariance. The feature vectors are used to detect and classify faults using a softmax classifier. The suggested approach is also put to the test with various sampling frequencies and signal kinds. The suggested method's capacity to generalize is also tested by including noise and measurement mistakes in the data.

With unique training and testing methodologies, a CSAE-based framework capable of identifying and classifying defects is provided, which considerably decreases the computational cost and enhances performance. The suggested technique identifies faults within 7 milliseconds of their occurrence and diagnoses defects with near-perfect accuracy for all fault kinds, according to the results. Using both voltage and current signals ensures positive performance over the frequency range evaluated, according to tests with various sampling rates and signal types. The suggested approach is then tweaked to guarantee that it performs well even when there is noise and measurement mistakes. The suggested approach is resilient to noise and measurement errors, and has a high generalization ability, according to a comparison with current approaches.

2.6 FIR and SVM based Approach

One of the author [6] proposes a unique technique for detecting, categorizing, and finding short-circuit defects in power transmission lines. A hybrid framework based on the suggested methodology is implemented in Proteus 6/MATLAB settings, consisting of a suggested two-stage finite impulse response (FIR) filter, four support vector machines (SVMs), and eleven support vector regressions (SVRs). Short-circuit faults are detected and classified using the suggested two-stage FIR filter and SVMs, while short-circuit faults are located using SVRs. For training the SVMs and SVRs, the developed framework just requires a few training data. As will be demonstrated, just 6 training samples are required to train each SVR for a 50 km power transmission line. The fault detection, classification, and localization operations are carried out by the trained hybrid framework in only one cycle, which is significantly less than the fault clearance time. It indicates that the suggested hybrid framework can detect, categorise, and identify short-circuit problems in power transmission lines quickly before protective relays cause a power outage.

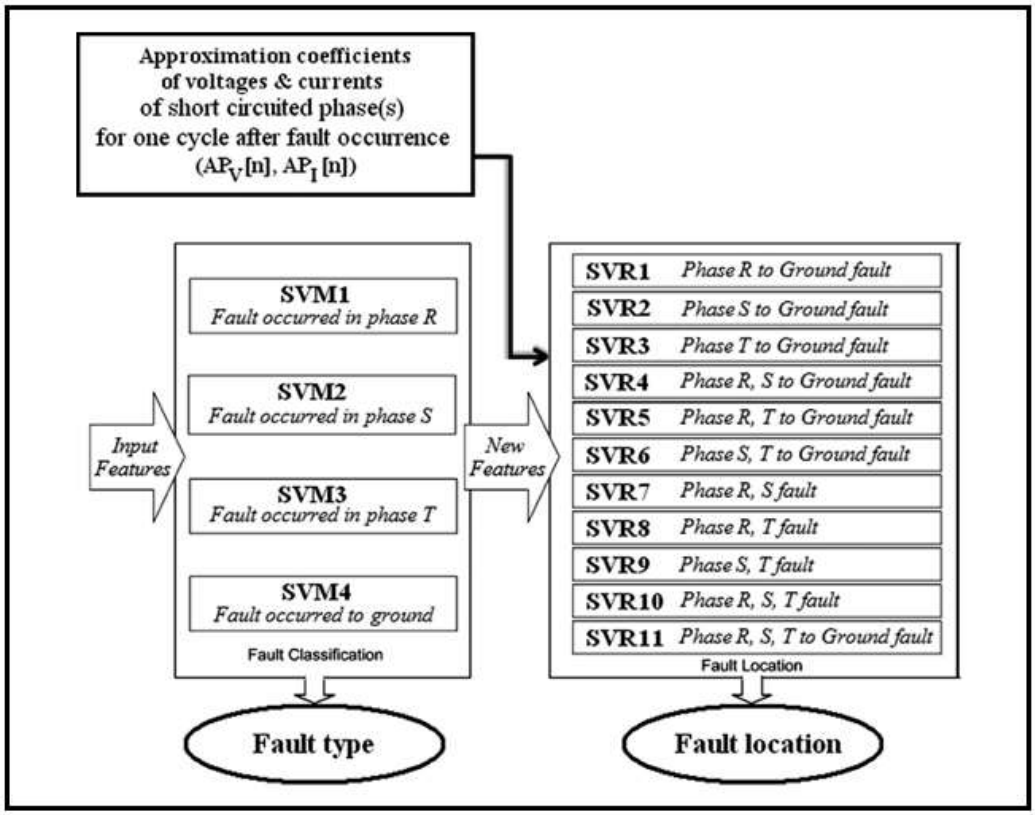

Fig.5. Block diagram of ANN, SVM and SVR approach for short circuit fault detection [6]

A innovative methodology to detecting, classifying, and locating short-circuit defects in power transmission lines was presented in this work. A two-stage FIR filter, four SVMs, and eleven SVRs were used to create a hybrid framework. It was discovered that the framework only requires a small number of training samples to train the SVMs and SVRs.

In just one cycle, the trained hybrid framework completes the three objectives of defect detection, classification, and localization. The accuracy of the method was tested by modelling a 50-kilometer three-phase 230 kV, 50 Hz power transmission line. The simulated results confirmed the theoretical findings as well as the proposed technique's correctness.

2.7 DWT and ANN approach

Not just as a philosophy, but also as a practical implementation, digital impedance protection of transmission [7] lines has flaws. This needs the creation of a new relaying concept that addresses those flaws. This paper proposes such a paradigm, which is now being tested using field data. The idea is to use wavelet-based artificial neural networks in a novel way (ANNs). To categories transients on the protected line and its neighboring lines, the programme employs the high frequency content of a subset of local currents from one end of a protected line. The system can identify transients on a protected line, including faults, categorize transients on neighboring lines, and locate the line that caused the transient occurrence.

It is demonstrated that the event's feature vector may be derived from a subset of local currents without the need of any voltages at all. The two aerial modes of the local current make up the subset of local currents. To convert phase currents to modal quantities, modal transformation is utilized. The high frequency components of the two aerial modal currents are extracted using the Discrete Wavelet Transform (DWT). The wavelets detailed coefficients of one level of the aerial modes are utilized to create a feature vector, which is then utilized to train an artificial neural network.

Insulation breakdown is one concern that has not been addressed in this manner. In the simulations, the author has not considered any insulation failure. The signal associated with insulation failure being switched off might lead to the planned scheme being misled. To fully assess its impact on the proposed relaying method, more research is required. It should be emphasized, however, that though the surge arrester chops lightning strikes, they are still appropriately detected. Field validation is being carried out, and after all investigations have been completed, the results will be released.

2.8 Wavelet and extreme machine learning Approach

For power systems to operate reliably, accurate and fast identification of transmission line defects is critical. Expert knowledge or comprehensive feature extraction, both of which are largely reliant on expert knowledge, are used in existing defect diagnostic approaches. Furthermore, most transmission line fault diagnostic systems need numerous discrete sub-algorithms for fault classification and localization, with each function performed individually and sequentially. The Summation-Wavelet Extreme Learning Machine (SW-ELM), a novel machine learning method that includes feature extraction in the learning process, is used in this study to provide an integrated framework integrating fault classification and localization.

In addition, the Summation-Gaussian Extreme Learning Machine (SG-ELM), an extension of the SW-ELM, is presented and effectively used to transmission line fault diagnostics. SG-ELM is completely self-learning and does not require ad-hoc feature extraction, allowing it to be deployed with the least amount of expert subjectivity. Without any previous parameter calibration or ad-hoc feature extraction, the created framework is applied to three transmission-line topologies. The suggested technique can identify faults in a single cycle, is resistant to fault resistance and inception angle changes, and delivers good accuracy for both fault diagnostic tasks: fault type classification and fault location estimate, according to tests on a simulated dataset.

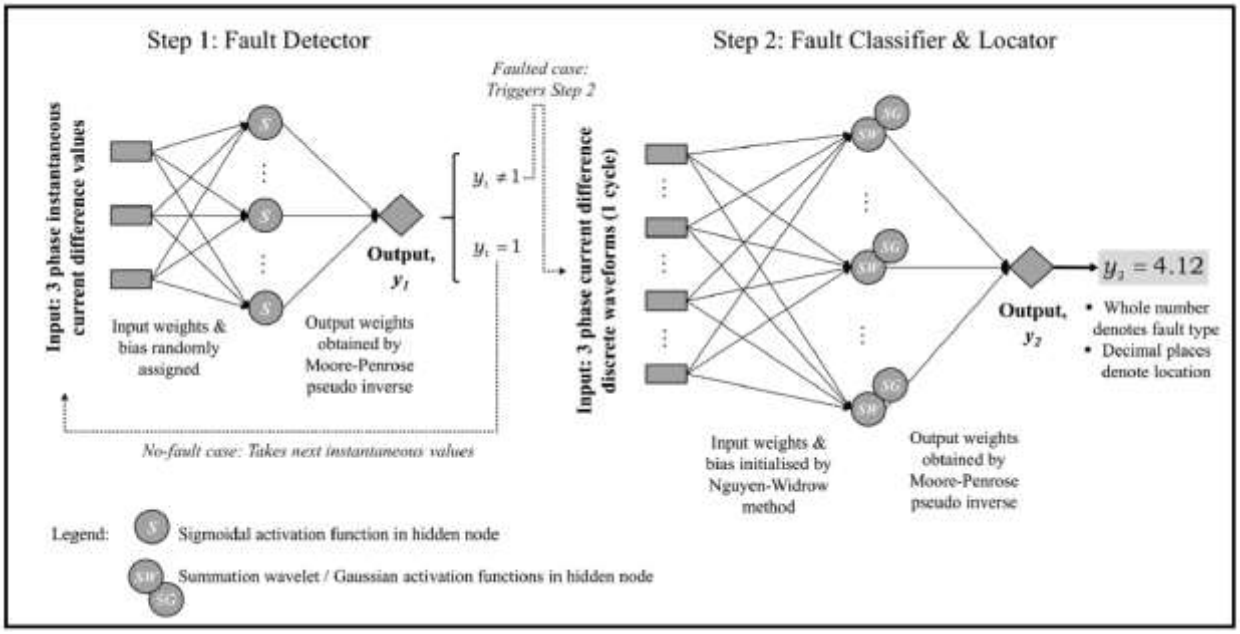

Fig.6. Schematic representation of the proposed fault diagnosis method [8]

Furthermore, the suggested methods are unaffected by fault resistance or variations in inception angle. The algorithms achieve fault classification accuracy of greater than 95% and average fault placement errors of 1.3 percent to 4.8 percent. The performance of this fault diagnostic approach is comparable to that of other methods already in use. Previously suggested methods, on the other hand, rely on complex feature extraction and include many sub-algorithms for fault classification and placement.

Since the development of distribution and transmission systems, fault location detection has been an aim of power system engineers. Quick fault detection can assist safeguard equipment by allowing defective wires to be disconnected before they cause major harm. Accurate fault localization can assist utility staff in removing persistent faults and locating regions where faults occur frequently, minimizing fault occurrence and minimizing power outage duration. As a result, while fault location detection systems have been created in the past, a number of algorithms are still being developed to improve the accuracy and effectiveness of this activity. The identification and localization of problems on power transmission lines is critical for a power system's protection and maintenance. The majority of fault detection and locating methods rely on current and voltage transformers to give measurements of electrical values.

Our research reveals that employing existing technology, a transmission line monitoring framework based on WSN is achievable. The proposed method with formulation is generic and takes into account a variety of factors such as asymmetric data generation at

towers, wireless link reliabilities, link utilization dependent costs, non-uniform cellular coverage characteristics, and cost-optimized incremental deployment requirements.

The biggest constraint in cost reduction, according to the assessment studies, is wireless link bandwidth. Furthermore, when flow bandwidth grows, the restricted wireless link bandwidth necessitates a practical but costly design owing to greater reliance on the cellular network to meet limits.

2.9 K-NN approach

A string level defect identification and diagnosis methodology for photovoltaic (PV)systems based on the knearest neighbours (kNN) rule was proposed by the author [10]. Open circuit faults, line-line (LL) faults, partial shading with and without bypass diode faults, and partial shading with inverted bypass diode faults are all detected and classified in real time. The authors provide a complete modelling of PV systems based on experimental data that only requires data from the manufacturer's datasheet provided under standard test conditions (STC) and normal operating cell temperature (NOCT).

The junction thermal voltage (Vt), diode quality factor (A), and series resistance are all temperature dependent factors in this model (Rs). Matlab/Simulink were used to run simulations of the created model. The I (V)characteristics of a PV module are measured using a PV analyzer (Solar I-V) from HT instruments. The created model accurately tracks the I (V)characteristics of PV systems at various levels of irradiance and temperature. The simulation results show that the error between the observed data and the created model is lower than that of previous models.

The absolute inaccuracy is limited to 0.61 percent to 6.5 percent. Finally, the data generated by the suggested model and experimental setup is utilised to validate and verify the suggested fault detection and classification (FDC) technique's performance. The average of fault categorization delivers a high accuracy of 98.70 percent, according to the data.

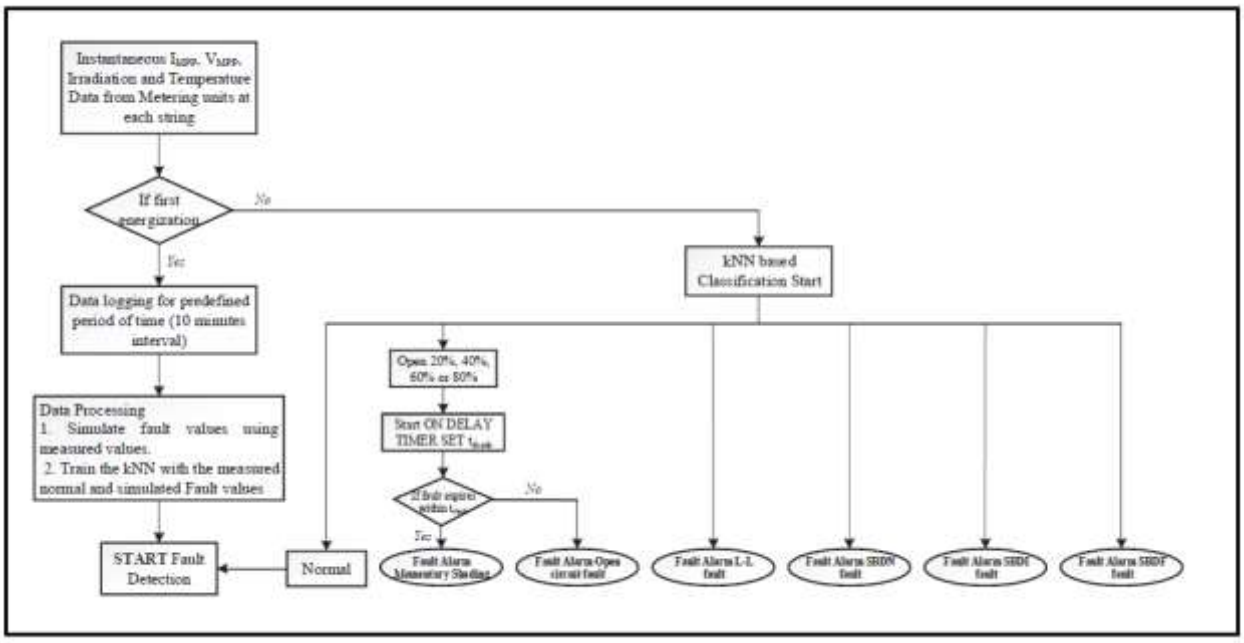

Fig.7. Flow chart of proposed FDP technique [10]

The suggested FDC technique's performance was evaluated utilising data provided by the provided PV model and experimental setup. The simulation results show that the suggested FDC methodology has high classification accuracy for the problems that were investigated, proving its suitability.

Fault categorization is critical for determining the root cause of a problem and restoring power more quickly. This technique presents a deep-learning-based fault classification solution for modest current grounding power distribution systems. When a failure occurs, the current and voltage signals are sampled at a substation. The Hilbert-Huang transform (HHT) band-pass filter is used to create the time-frequency energy matrix from the sampled fault signals.

2.10 Deep-Learning-based Approach

For fault classification, a method for image similarity identification based on convolution neural network (CNN) is utilized using the time-frequency energy matrix as the pixel matrix of a digital picture. The proposed technique can extract fault signal characteristics and properly categorize 10 different types of short-circuit problems at the same time. In the PSCAD/EMTDC and physical system environments, two simulation models have been constructed. In the MATLAB environment, the performance of the suggested approach is investigated. The flexibility of the provided technique is tested using a variety of fault circumstances and parameters such as asynchronous sampling, different network architectures, distribution generators access, and so on.

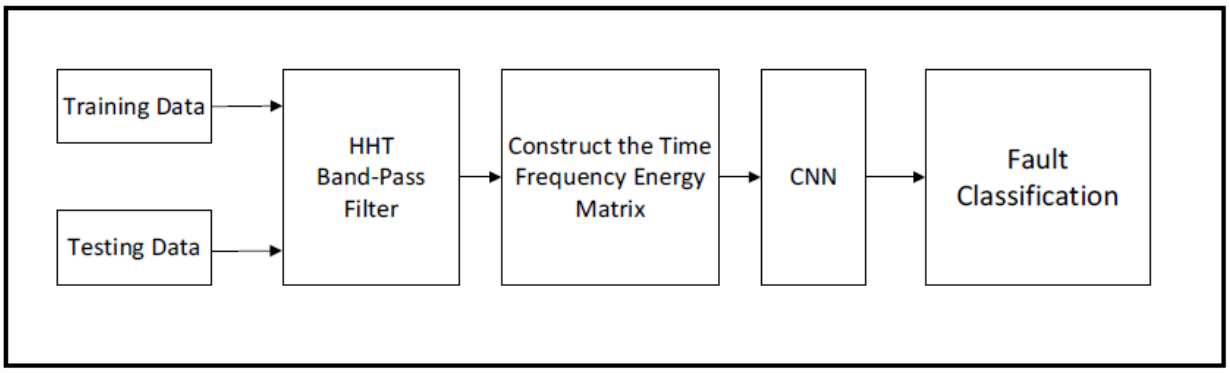

Fig.8. Block Diagram of Deep-Learning-based Fault Classification using HHT and CNN [11]

The HHT band-pass filter is employed in this approach [11] to build the time-frequency energy matrices of failure signals in distribution networks. The elements of the energy matrices, which serve as CNN's input, are viewed as the image's pixels. To overcome the difficulty of picking features and classifiers, a CNN-based fault classification approach is presented. It can extract fault signal characteristics and properly categorise 10 different types of faults at the same time. The software and physical simulation results show that the proposed fault classification approach is reliable and resilient across a broad range of fault scenarios, such as diverse network architecture, load levels, distribution generator access, and so on.

III. CONCLUSION

The approaches were categorized for the first time in this research based on the strategy utilised for fault classification, namely prominent, hybrid, and modern methodologies. This paper reviews different techniques like support vector machine, Back-propagation Neural Network approach, Deep learning-based AI approach, K-nearest neighbours technique, combine ANN, SVM and SVR approach, Discrete wavelet transform approach (DWT), DWT-BPNN based on Clarke's Transformation approach and fuzzy logic-based approach. This paper will be very much useful in future to future researcher and students those want to work in the field of transmission line different types of fault classification and detection.

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