Various Techniques used for Protection of Transmission Line- A Review

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Abstract- This paper presents various techniques for protection of transmission line. For a modern power system, high speed fault clearance is very critical and to achieve this objective various techniques have been developed. This paper discusses the various techniques to achieve fault detection, classification and isolation for distance protection of transmission line. The most recent techniques includes Artificial neural network (ANN), FUZZY, Adaptive NEURO-FUZZY, Wavelet, Genetic Algorithm and Phasor measurement unit (PMU).

Keywords – ANN, Fuzzy, Wavelet, ANIF, GA, PMU, Protection of transmission lines, Distance relay.

I. INTRODUCTION

Transmission lines are vital part of the electrical power system and are defined as conductor or conductors designed to transmit electrical energy from generating centre to the load centre. When faults occur in the power system, they usually provide significant changes in the system quantities like over-current, over or under voltage, power factor, impedance, frequency and power or current direction. Mostly 80-90% of the fault occurs on transmission line and rest on substation equipments and bus-bars combined. The key challenge to the protection of transmission line lies in reliably detecting and isolating faults compromising the security of the power system. And, if any fault or disturbances are generated in transmission lines & not detected, located & eliminated quickly, it may cause instability in the power system. The appropriate percentage of occurrence of various types of faults are given below:-

1. Single line to ground fault – 70-80%
2. Line-to-Line to ground fault – 10 -17%
3. Line-to- Line fault – 8-10%
4. Three phase fault - 3 %

Thus, a well coordinated protection system must be provided to detect & isolate various types of faults rapidly so that damage & disruption caused to power system is minimized. And, the time required in determining the fault point along the transmission line affects the quality of power to be delivered. For this purpose, the protective relays operates after a fault has occurred and helps to minimize the period of trouble and limit the outage time, damage and related problems.

Distance protection scheme is considered here and it depends on the fact that on occurrence of a fault, the distance between any point in the power system and the fault point is proportional to the ratio of voltage and current at that point [1].

The techniques for protection of transmission lines can be broadly classified into the following categories

- Impedance measurement based methods
- Travelling-wave phenomenon based methods
- High-frequency components of currents and voltages generated by faults based methods
- Intelligence based method

From quite a few years, intelligent based methods are being used for protection of transmission line.

In this paper, various techniques for protection of transmission line are discussed. The various techniques include – ANN, FUZZY, Adaptive NEURO-FUZZY, Wavelet and PMU. For a modern power system, high speed fault clearance is very critical and to achieve this objective various techniques have been developed. This paper discusses the various techniques to achieve fault detection, classification and isolation in transmission line. The most recent techniques include ANN, FUZZY, adaptive NEURO-FUZZY, Wavelet, Genetic Algorithm and phasor measurement unit. Distance protection is considered covering various effects such as variable source impedance, non-linear arc resistance and high fault impedance.

II. ANN TECHNIQUE

Artificial neural network is composed of number of inter-connected units (artificial neurons) and these networks are inspired by the learning processes that takes place in biological systems. An artificial neural network is composed of many artificial neurons that are linked together according to a specific network architecture. ANN has three layers i.e. input layer, hidden layer and output layer. ANN has primarily a high degree of robustness and ability to learn and have capability to work with incomplete and unforeseen input data [2].

Conventional distance relays may not operate correctly under certain conditions such as non-linear arc resistance, high impedance fault and variable source impedance. But if such relays are implemented with ANN, such problems can be addressed[3]. Also, ANN techniques can adapt dynamically to system operating conditions at high speed and solves the problem of reach and over-reach. Neural approach is considered to be fast, robust and accurate [4].

For protection of transmission line with ANN, it doesn't require any communication link to retrieve remote end data rather it takes data from local end only i.e. voltages and currents are taken from the bus bar. Then, pre-processing of obtained signal can be done to bring it into ANN level. Signal which needs to be pre-processed has to be passed through certain steps which includes A/D conversion, anti-aliasing filtering, normalization (-1, +1) and finally through DFT filter to extract fundamental components of voltages and currents. Then, after obtaining inputs, ANN performs its function of fault detection, classification and isolation by considering different networks. These networks takes different neurons for different layers and different activation functions between input and hidden layer and hidden and output layer to obtain desired output. These networks may include either of the neural network back-propagation or radial basis function for this task. Back propagation algorithm is the most widely used for such applications [5]. It is observed that the radial basis function neural network have ability to identify the precise fault direction more rapidly. This makes it suitable for the real-time purposes also[6].Firstly, fault detection task is performed which defines whether there is a condition of fault or not and if fault is detected , then fault is classified and finally, fault is isolated by providing the output obtained from this network to circuit breaker in the form of trip signal. This process involves training and testing of different network configurations until satisfactory performance is obtained.

Also, with the help of adaptive setting of distance relay if it is implemented with ANN, zone settings can be extended and sensitivity of protection can be increased, enhancing system security. Thus, ANN helps in protection of transmission line against different fault conditions. The ANN relay can operate correctly when faced with different fault conditions as well as network changes presenting a much better performance if compared to ordinary relays [7].Thus, it provides fast and reliable operation. ANN tool opens a new benchmark to relay philosophy, which would be widely investigated in order to some various problems associated with distance protection of transmission lines.

III. FUZZY TECHNIQUE

Fuzzy logic systems are subjective and heuristic and in general, they are simpler than the wavelet transform or the neural network based techniques. The application of fuzzy logic for exploring complex, non-linear systems, diagnosis systems and other expert systems, particularly when there is no simple mathematical model to be performed provides a very powerful and attractive solution to classification problems [8].This proposed scheme may not get widely affected by wide variety of pre-fault system loading level, fault level and fault distance far from relay point.

Fuzzy-logic based technique may be used to identify the various types of faults that usually occurs in power transmission lines. Only three line currents are sufficient to implement this technique and the line currents at relaying point were first processed to discrete fourier transform. The angular differences between the obtained

sequence components of fundamental during fault and pre-fault current phasors are used as inputs of the fuzzy logic system. In fuzzy logic inference system, singleton fuzzifier method and mamdani inference systems are usually employed to obtain the crisp output of the fault type. And, for defuzzification centroid method is the most considerable method to defuzzify the output [9]. The steps involved in fuzzy logic system (FLS) is as shown in fig below:-

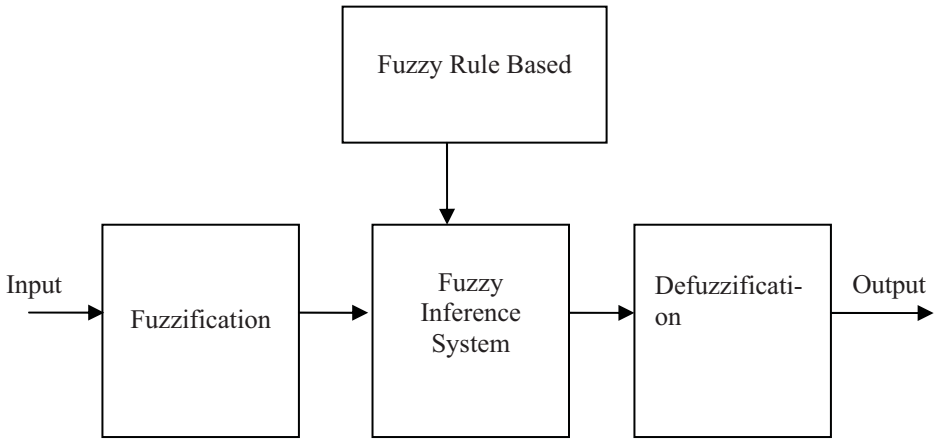

Fig 1 :- Fuzzy Logic Based fault classifier

Another way to employ fuzzy technique for protection of transmission line is to incorporate wavelet technique with it. The main feature of this tool is its ability to employ localized time/frequency analysis of fuzzy data for fault detection and identification purposes.

In this technique, firstly, data is collected and then pre-processed. The next step is feature extraction which defines distinct pattern of data that is associated with a particular fault. It uses wavelet transform technique to extract feature of different faults. The wavelet transform generates wavelet coefficients which are non-linearly combined with fuzzy inference mechanism. Fuzzification is done to fuzzify the features which means it provides a special kind of flexible filtering, faster measuring algorithms that speed up the relays may be used[10].Then intelligent decision making is performed by comparing the fuzzified feature with the templates stored in knowledge base. And to measure robustness of the process, to terms are defined i.e. identifiability and detectability. These two measures aims at minimizing the sensitivity of detection performance to modeling uncertainties, errors and noise in the system. Detectability is the extent to which the presence of feature signature (smallest) is detected and is related to percentage of false alarms. Identifiabilty is the step which distinguishes between various feature modes once the feature is detected. Detectability and identifiablity depends upon number of factors which vary from one system to another. Learning is done to enhance the knowledge base which helps in detection and identification process.
Thus, combined fuzzy and wavelet technique has opened a new avenue for fault detection and identification of complex systems [11].Fuzzy system incorporated with neural network is discussed in the next section.

IV. ANIF TECHNIQUE

Adaptive neuro-fuzzy inference system (ANIFS) is the advanced application of artificial intelligence which was introduced recently for protection of transmission line. ANIFS can be viewed as fuzzy system, neural network or fuzzy-neural network. A fuzzy neural network or neuro-fuzzy system is a learning machine that finds the parameters of a fuzzy system (i.e., fuzzy sets, fuzzy rules) by exploiting approximation techniques from neural networks. This technique is divided into three different tasks of fault detection, classification and isolation. With this technique, less operating time and reduced mean-squared error can be achieved.

For protection of transmission line with ANIF, following steps need to be implemented to obtain fundamental voltages and currents as required by ANIF network. These steps are given in the below table:-

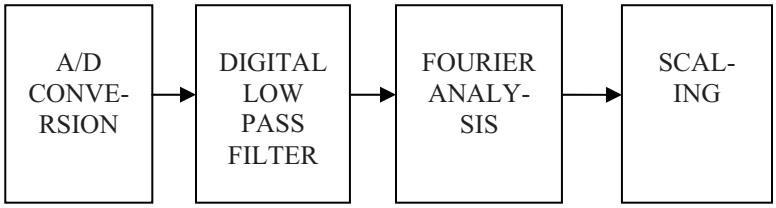

Fig 2:- Digital signal processing

Initially, analogue signal which is obtained from power system simulation is converted into digital form and then passed through low pass filter, followed by fourier analysis and finally scaling to done to achieve ANIF level.

ANIF protection scheme consists of four units which are as follows:-

1. Fault detection unit
2. Fault classification unit
3. Fault location unit
4. Control unit

Then, fault detection unit takes processed measured data as input and this data is trained at various conditions of fault or no fault conditions. And, if fault is detected, then this unit activates the other two units i.e. fault classification and fault location unit. Data is trained for both units at various conditions of faults.

And, finally, control unit after receiving results from all three units performs its desired control action. Thus, adaptive neuro-fuzzy technique has an advantage of less operating time and reduced mean-square error which provides more accurate result [12].

V. WAVELET TECHNIQUE

Wavelet analysis is a relatively new signal processing tool and is applied recently by many researchers in power systems due to its strong capability of time and frequency domain analysis. The two areas with most applications are power quality analysis and power system protection. The definition of continuous wavelet transform (CWT) for a given signal x(t) with respect to a mother wavelet $\psi(t)$ is

$$CWT\ (a, b) = 1/(a)^{1/2} [\int_{-\infty}^{\infty} x(t)\ \psi\ ((t-b)/a)\ dt\ ] \quad (1)$$

Where a is the scale factor and b is the translation factor.
Unlike the Fourier transform, the wavelet transform requires the selection of a mother wavelet for different applications. To select the mother wavelet is one of main factor for maintaining the important data in wavelet domain. There are two main criteria for the selection of the mother wavelet in power system relay protection. First one is that the shape and the mathematical expression of the wavelet must be set such that the physical interpretation of wavelet coefficients is easy. Secondly, the chosen wavelet must allow a fast computation of wavelet coefficients [13]. The different type of mother wavelet has its own shape and its own characteristics. There are various kinds of mother wavelets such as Daubechies (db5), Coiflet (coif5), Biorthogonal (bio5.5), and Symlet (sym5) which are considered for signal processing. Usually db5 is used as a mother wavelet in most of the applications [14]. The application of wavelet transform in engineering areas usually requires a discrete wavelet transform (DWT).

The signal preprocessing stage eliminates most of the influences from pre-fault loads, system conditions, and power swings. In this technique, a sampled signal is first passed through high pass as well as low pass filters and the output from both these filters are decimented by half amount to obtain detailed and approximated coefficient at first level 1. Then the approximated coefficients are send to next level to repeat the procedure. And, finally the signal is decomposed at expected level and the useful information from the original signal into different frequency bands can

be easily extracted and at the same time the information is matched to the related time period. Daubichies's wavelet family may be used to make the different level decomposition as desired. The information of original signal is clearly represented at each frequency band. The original signal can be reconstructed by adding up those wavelet signals at the same sample point. Wavelet technique is used to decompose signal into low and high frequency and thus this output may be provided to fault detection, classification and isolation circuit [15].The fault detection, classification and isolation may be done simply by firstly detecting whether there is a fault or not and if it is detected then classifying the various types and thus isolating it[16]. Another way to approach for this is to give the output given by wavelet transform to ANN as an input for detecting, classifying and isolating the fault. In this both high frequency as well as low frequency approximations are generally used avoid confusing faults with other kinds of non-fault disturbances.

Thus, the wavelet transform provides an efficient way to extract signal components at different frequency bands. Wavelet transformation is one of the most popular candidates of the time-frequency-transformations. In order to apply wavelet technique for protection purpose to some specific systems such as parallel lines, multi terminal lines, some adjustments are required.

VI. Genetic Algorithm Technique

A Genetic Algorithm (GA) is a search algorithm which is based on the mechanism of natural selection and natural genetics. The fundamental principle involved behind this is that the fittest member of a population has the highest probability for survival. There is a fitness value associated to each chromosome. The better the solution the chromosome represents, the larger its fitness and its chances to survive and produce offspring. In this context, the objective function establishes the basis of selection.

The GA depends on two basic kinds of operators: genetic and evolutionary. Genetic operators, namely crossover and mutation, are responsible for establishing how individuals exchange or simply change their genetic features in order to produce new individuals. Evolutionary operators deal with determining which individuals will experience crossover or mutation. Essentially, a GA tries to minimize or maximize the value presumed by the fitness function. In many cases, the development of a fitness function can be based on this return and can represent only a partial evaluation of the problem. Additionally, the algorithm must be fast, because it will analyze each individual from a population and its successive generations. Thus, Genetic Algorithm (GA) solves optimization problems based on natural selection principles.

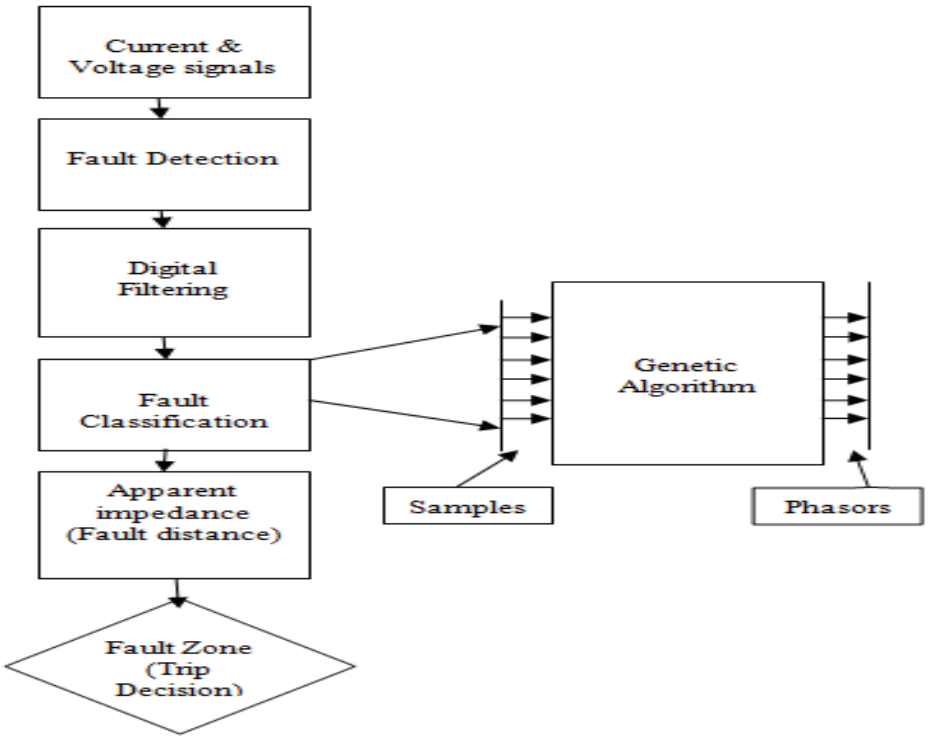

Fig 3:- illustrates the diagram for distance protection relay(GA)

For distance protection of transmission line, the fundamental values of currents and voltages are obtained from power system simulation. The first step is to detect the fault and for this purpose, the current signals are stored in memory. With the occurrence of new sample, it is compared with the corresponding sample one cycle earlier. If change is greater than certain value, the fault condition is detected. The next step is digital filtering and for this GA algorithm is utilized to estimate the fundamental frequency phasors. Then, fault classification is done to choose the voltage and current involved in fault adequately to calculate the apparent impedance seen by distance relay. The apparent impedance and fault distances are calculated for various types of fault conditions. Finally, the calculated apparent impedance is proportional to distance to the fault, protection zone is inferred. The algorithm involved here is shown in fig 3.

Various conditions may be considered such as different types of faults, faults resistances and fault distances. Better performance is obtained with GA as compared to conventional techniques [17].

VII. PMU TECHNIQUE

Phasor Measurement Unit (PMU) is one of the technique which provides real time measurement of synchronized component of sequence voltages and currents in the form of phasors for monitoring and controlling a power system, especially during stressed conditions. This technique refers phase angle to a global reference time which helps to capture the wide area snap shot of the power system. Effective utilization of this technique is very useful in mitigating blackouts and learning the real time behavior of the power system. Due to advancement in this technology, the micro-processor based instrumentation such as protective relays and disturbance fault recorders (DFRs) incorporate PMU module along with other existing functions as an extended feature. Thus, this scheme can be used for protection of both single and double-circuit transmission line [18].

This technique uses sequence voltages and currents at both ends of transmission line to determine various parameters of the transmission line and location of fault on transmission line and is based on communication between two modules using GPS. In each module, with PMU, there are other components like line parameter estimator and distance protection unit which are also connected to it. The synchronization is achieved through global positioning system(GPS) which can provide continuous measurement precise timing at better than 1 microsecond level. This technique requires communication system should have low error rate, high data rate and sampling

frequency should be equal to or more than 720 Hz. It may also use single pole auto re-closer for differentiating transient as well as permanent faults.
Line parameter estimator measures the impedance parameters of a transmission line using synchronized voltage and current phasors at both ends of a transmission line based on PMU measurement. And, distance protection unit consists of following components:-

1. Fault detector and classifier
2. Fault locator
3. Making decision unit
4. Conventional distance protection scheme

This technique detects, classify and locate the fault under different conditions with different fault types, fault resistances, power angles, etc. PMU based relay is based on using communication links and it can't perform correctly when these links are lost. These three phase voltages and currents being input are processed by 2nd order low pass butterworth filter, followed by anti-aliasing filter having cut-off frequency of 400 Hz. In addition, two sample FIR filters are used to remove dc component, followed by DFT from which phasors are obtained and thus magnitude are entered into six impedance measuring units. Then, the logic unit relay issues suitable order based on results obtained from phase selection and impedance measuring units.

This technique is also robust against power swings conditions due to load variations and fault clearances and have capability to differentiate transients and permanent faults. PMU based relay operates fast and accurately. This technique removes the effect of system variables such as fault resistance, source impedance and power swings on the decision made by distance relay. The major advantage of this technique is that Post-disturbance analyses are much improved because precise snapshots of the system states are obtained through GPS synchronization [19].

VIII. CONCLUSION

This paper is an effort to present the most recent techniques which are used for distance protection of transmission line. Neural network is considered to be a fast, robust and accurate technique. But, Fuzzy logic systems are subjective and heuristic and are simpler than the wavelet transform or the neural network based techniques. Better performance is obtained with GA as compared to conventional techniques. But, most of the available tools for fault detection and classification are not efficient and are not investigated for real time implementation. So, for this there is a need for new algorithms that have high efficiency and suitable for real time usage and PMU serves for this purpose. All these techniques have their own features and researches are still going on to obtain lesser operating time of relay at high speed.

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