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A Novel Methodology for Identifying Cross-Country Faults in Series-Compensated Double Circuit Transmission Lines

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Abstract

In this paper, a competent mechanism for classifying cross-country faults in series-compensated (SC) double circuit transmission line (DCTL) is presented. Cross-country faults are usually different from frequently occurring short-circuit faults in the transmission system. The faults that strike up at the same time but on different positions in the transmission network and can involve same or different phases are termed as cross-country faults. An occurrence of such abnormality in the transmission network significantly hampered the functioning of traditional distance relaying. This paper presents a novel methodology for discriminating normal short-circuit faults and cross-country faults in SC double circuit power network based on empirical mode decomposition (EMD) and intelligent technique. The efficacy of the proposed mechanism for discriminating normal short-circuit faults and cross-country faults in the series-compensated DCTL system, various cases of normal short-circuit faults and cross-country faults (with varying system conditions) have been simulated in Real Time Digital Simulator (RTDS). The results acquired after performing several test cases reveal the practicability of applying proposed EMD and intelligent techniques based mechanism for classification of cross-country faults from normal short-circuit abnormality in the transmission network.

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Keywords: Transmission line protection; Cross-country fault; Empirical mode decomposition; Support vector machine; Naïve-bayes; PNN

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1. Introduction

Power transmission unit plays as a vital clinch between the power producer and its buyer. Double circuit transmission system along with compensation technology has been significantly utilized in the modern energy system. It not only helps in amelioration of the system reliability but also curtailing the burden of the transmission network. However, compensation technology and the addition of advanced electronic devices in the transmission network adversely affected the traditional distance protection management system [1]. Cross-country faults are the additional abnormality along with short-circuit faults (SCF) generally observed in double circuit lines. The cross-country faults (CCF) are defined as those faults that strike up at the same time but on different positions in the transmission network and can involve same or different phases. Conventional distance relaying management system finds limitations during cross-country faults and may lead to abnormal and unwanted operation of relaying unit. Hence a quick protection mechanism, well competent with changing conditions of the network is essential for conferring secure and hindrance free operation of power system. In a couple of years, considerable works have been proposed by several authors dealing aforementioned issues of protection. Major parts of the approaches available in the literature are based on wave theory, signal processing techniques [(i.e., Fast Fourier transform (FT), discrete wavelet transform (DWT)] and artificial techniques [2]. However, only a few researchers have focused on the issues of cross-country fault in the compensated double circuit transmission system. In [3] the effects of CCF on the conventional relaying system have been explained. In [4] the authors have discussed the consequences of CCF in power system and have proposed a methodology for identification of CCF in differential protection. The impact of CCF on current differential relaying mechanism has been analyzed in [5]. In [6] the authors have proposed a DWT with ANN based approach for locating CCF and evolving faults. However, classification of CCF with normal SCF has not been discussed. A fuzzy-based approach for directional relaying of parallel lines has been explained in [7-8]. In [9] a novel relaying algorithm has been presented for grounded CCF in parallel network

This paper proposes the application of EMD and machine learning (ML) technique [i.e., Support vector machine (SVM), Naïve-Bayes (NB), and probabilistic neural network (PNN)] for discriminating the cross-country faults with generally occurring short-circuits faults in the series compensated network. EMD has been applied for decomposing the 3-phase current samples for acquiring the intrinsic mode function (IMF). Afterward, the fault characteristic features are deduced in terms of energy of the selected IMF. Ultimately those features have been utilized as training and testing samples by the designed classifier models of SVM, NB and PNN for isolating CCF in SC double circuit system. For examining the efficacy and feasibility of the proposed mechanism for a series-compensated DCTL system, single line to ground fault and CCF (with varying system conditions) have been simulated in Real Time Digital Simulator (RTDS). The results acquired after performing several test cases reveal the practicability of applying proposed EMD and intelligent techniques based protection mechanism for classifying CCF with generally occurring SCF in a parallel transmission network.The rest of the paper is structured as: In the coming section, the procedure of EMD are discussed. The draft of the proposed methodology along with ML techniques fundamentals has been discussed in section three. Section four focuses on the simulated case study. Applicability and competency of the proposed approach have been explained in result and discussion section. Finally, section five concludes the paper.

2. Empirical Mode Decomposition

In recent years the application of signal processing techniques in the transient analysis of power system has been considerably increased. Several processing techniques peculiarly FFT, Wavelet Transform (WT) are applied in analyzing abnormalities in a transmission system. Although WT approach has been outperformed the limitations of FFT, it also involves a big concern, i.e., opting of appropriate mother wavelet and decomposition level. No such issues are evolved in EMD technique. EMD is an adaptive and highly competent signal decomposing algorithm. It locally decomposes the signal into a chain of various IMF's and final residual. Firstly Huang has introduced the idea of IMF and explained that the decomposed IMF's significantly reflects the physical characteristics of the original signal. In [10-12] EMD has been applied for abnormality detection in a transmission system. The two mandatory criteria of IMF are as follows:

- The extreme and number of zero crossing should be same or at most differ by one.
- At any location, mean of upper and lower envelopes defined by local extremal is zero.

The EMD based decomposition of fault current signal is demonstrated in Fig. 1. The steps of EMD are given below:

- Identify the local minima (M) and maxima (m) of input current signal $I(t)$
- Execute interpolation between M and m for acquiring envelopes $e_{min}(t)$ and $e_{max}(t)$
- Compute average of the envelopes using

$$m(t) = \frac{\left[e_{max}(t) + e_{min}(t)\right]}{2} \tag{1}$$

- Extract $C_1(t) = I(t) - m(t)$
- $C_1(t)$ is an IMF if it meets the aforementioned criteria. If $C_1(t)$ is not an IMF, than repeat steps 1to 4 on $C_1(t)$, so long as new acquired $C_1(t)$ meets the criteria.
- Compute the residue, $r_1(t) = I(t) - C_1(t)$
- If the $r_1(t)$ is more than a threshold value, than repeat steps for acquiring next IMF and a new residue.

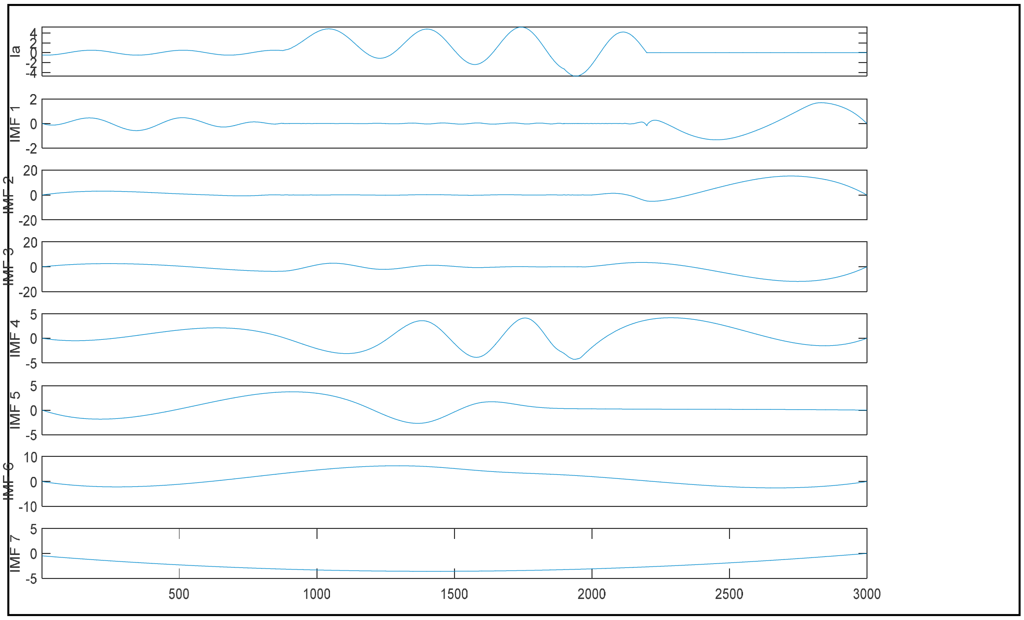

Fig. 1. Decomposition of phase A current (AG fault) using EMD

3. Proposed Methodology

This section presents the draft of the proposed categorizing methodology for CCF in compensated DTCL system. The proposed methodology is a combination of EMD and ML techniques, shown in Fig. 2. Three different shorts of ML-based classifiers (i.e., SVM, NB, and PNN) have been applied in this paper. Post faults 3-phase current samples are decomposed using EMD for acquiring the IMFs. EMD decomposes the current samples into different frequency components from higher to lower. After that, FFT has been applied on different acquired IMFs for ascertaining the desirable IMF which is having similar transient frequency band.

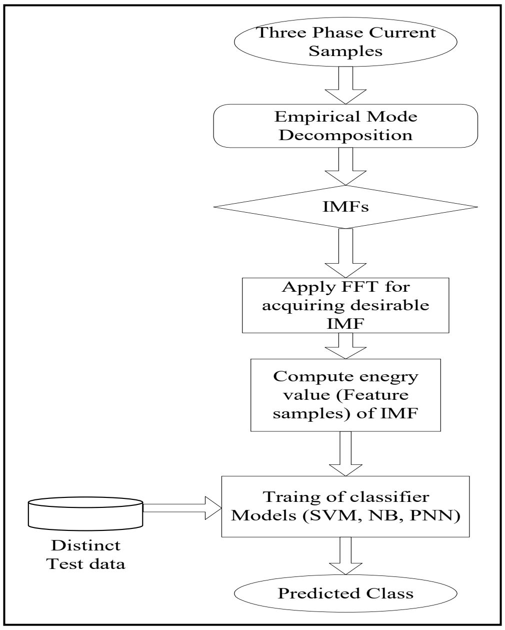

Fig. 2. Proposed Methodology Flow

Once, the particular IMF is picked than the fault characteristic features are deduced in terms of its energy using equation (a). The feature opting technique in terms of the energy value of the desirable picked IMF significantly helps in reducing the dimensionality of input samples to classifier models. Ultimately the energy based features of 3-phases have been employed as training and testing samples by designed classifier models of SVM, NB and PNN for isolating CCF in SC double circuit system.

$$Energy = \sum \left| IMF(t) \right|^2 \tag{2}$$

3.1. Support Vector Machine

SVM is one of the ML-based approaches that have frequently been applied in multiple problems of the power system. During classification, it endeavors a hyper plane for isolating the samples points according to their individual categories. When the separations between individual classes are optimal, then it is called as optimal hyper-plane [13]. It has better generalization and is effectual in handling large feature space [14]. In this paper, SVM has been used for categorizing two specific faults classes one is CCF and other is normally occurring SCF. Linear kernel, i.e., the dot product has been used as the kernel function, and sequential minimal optimization method is applied for the separation of hyper-plane. Let the two classes training set (as given in equation below) composed of n data samples.

$$\left\{ E_i , F_i \right\}_{i=1}^{n} \tag{3}$$

$$W^T E_i + b = 0 \tag{4}$$

Where, E_i ϵ energy value i.e. characteristic feature and F_i ϵ {-1,1} i.e. corresponding category (CCF of SCF). It is demonstrated in Fig.3. Equation (4) represents the needed hyper-plane which discriminate data samples in its corresponding category. Here, W is weight vector, while b is bias. Its values have been derived such that the separation in classes is optimal. Separation margin S_m is given by

$$S_m = \frac{2}{\|W\|} \tag{5}$$

For optimal S_m, $\|W\|$ should be minimum. Hence, the required SVM can be formulated by minimizing $\upsilon(W)$, where $\upsilon(W) = \frac{1}{2} W^T W \ \|W\|$ subject to $F_i\left(W^T E_i + b\right) \geq 1$.

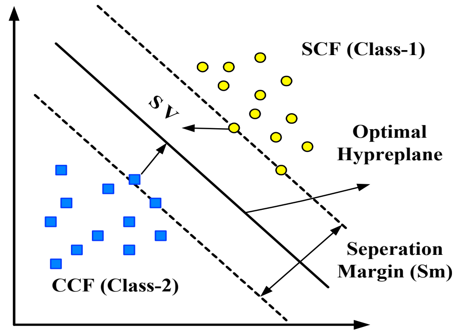

Fig. 3. Two-class separation using SVM

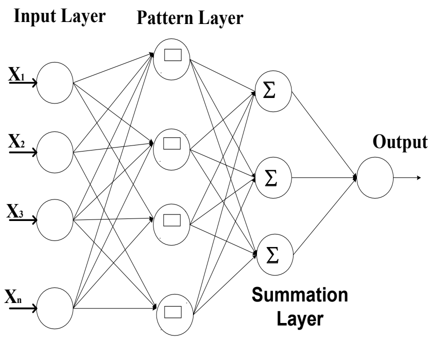

Fig. 4. PNN Structure

3.2. Naive Bayes Technique

NB classifiers are based on statistical supervised learning. Its functioning is dependent on Bayes rule and it presumes conditional independence of all feature samples. The expression of Bayes rule, is given in equation (6).

$$P_r(Y=k|X=x) = \frac{P_r(X=x|Y=k) * P_r(Y=k)}{P_r(X=x)} \tag{6}$$

Let the distinct classes are C1,C2…..Ck. It computes the posterior probability using equation (7) for forecasting the probability of individual class.

$$P_r\left(C=c_i \middle| \{F_1=e_1, F_2=e_2, \ldots\ldots\ldots\ldots, F_n=e_n\}\right) \tag{7}$$

Where F_1, F_2....., F_n are feature samples and e1, e_2 ...., e_n are are individual energy values of IMF. According to Bayes rules, it can be converted as

$$P_r\left(C=c_i \middle| \{F_1=e_1, F_2=e_2, \ldots\ldots\ldots\ldots, F_n=e_n\}\right) = \frac{P_r\left(\{F_1=e_1, F_2=e_2, \ldots\ldots\ldots\ldots, F_n=e_n\} \middle| C=c_i\right) * P_r(C=c_i)}{P_r\left(F_1=e_1, F_2=e_2, \ldots\ldots\ldots\ldots, F_n=e_n\right)} \tag{8}$$

NB based classifier deduces the associated class by observing the posterior probability level, which is represented by the left side expression of above equation.

3.3. Probabilistic neural network

PNN is another ML algorithm and has been significantly applied for classification task in several fields like medical, engineering and much more. The structure of PPN is demonstrated in Fig. 4. As the new feature vector is passed from input layer to pattern layer, the existing neurons estimated its closeness (distance) from trained features. The outputs of the pattern layer are aggregated by summation layer and it provides the net probability. Ultimately, the value of maximum probability is the final criteria for ascertaining the actual category of the new test sample.

4. Case Study

In order to appraise the efficacy of the proposed mechanism for discriminating normal short-circuit faults and cross-country faults in the series-compensated DCTL system, various cases of normal SCF and CCF (with varying system conditions) have been simulated in Real Time Digital Simulator (RTDS). A 230 kV, 200 km long series-compensated DCTL network (shown in Fig.5) has been designed in RTDS. The parameters of the designed network are as follows: positive sequence (R=0.0185 ohm/km; L=0.00233 ohm/km; C= 0.2279 Mohms*km) and zero sequence (R=0.3618 ohm/km; L=1.2277 ohm/km; C= 0.3451 Mohms*km). Line one of the being series-compensated by installing the capacitor in the mid of the line. The compensation level is kept as 35 percent. The MOV protection is 436.666 kV. In case study two kinds of faults, i.e., CCF and SCF are simulated in the system with varying different system conditions. The post current samples are acquired during various cases like different places in the network with changing inception angles. Five different inception angles (0, 30, 90, 150 and 300) are used. Six new distinct fault location samples are used for testing. The generally occurring SCF are simulated in line one at a different place, while at the same time period the CCF are simulated in the second line at 100 km. In Fig. 6 the 3-phase current samples acquired during A-G fault at 30 km in line one and at the same time CCF is actuated at 100 km in the second line of the network from the sending end are shown.

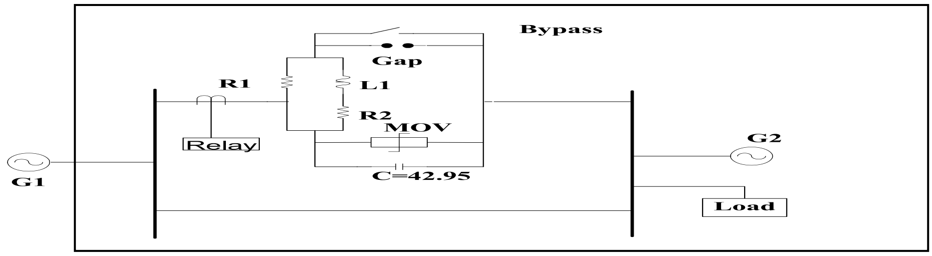

Fig. 5. RTDS simulated test system

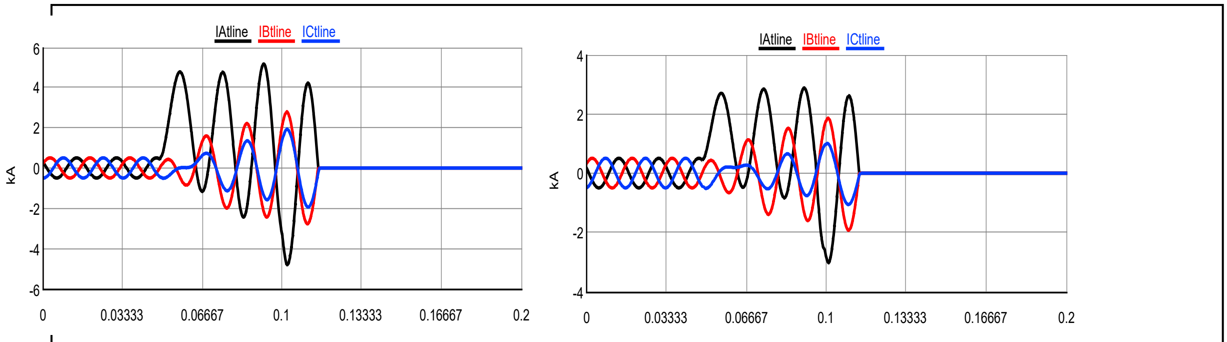

Fig.6. (a) A-G fault at 30 km (b) Cross-country fault in second line at 100 km

5. Test and Discussion

The proposed methodology of classification of CCF from normally occurring SCF in SC-DCTL system has been assessed for various simulated cases. The test samples are composed of a set of 50 percent of CCF type and 50 percent of SCF type. Three different ML-based classifiers (SVM, NB, and PNN) are used for performing the classification of CCF from generally occurring short-circuit abnormalities in the transmission network. The accuracy percentages acquired from aforementioned classifier are tabulated in Table. 1. It has been observed that the proposed methodology is well effectual for discriminating the CCF events in compensated DCTL network.

Table 1. Outcomes of Classifier Models

Classifier Models	True Classification	Incorrect Classification	Avg. Accuracy (%)	Time of Response
SVM	57	3	95.00	0.030 S
Naïve-Bayes	55	5	91.66	0.012 S
PNN	58	2	96.7	0.016 S

Out of three applied classifiers, NB is parametric ML algorithm whereas other two non- parametric in nature. It also has been observed that the time for isolating CCF and SCF categories in SC transmission system is quite less.

5. Conclusion

This paper presents a methodology for identifying the cross-country faults in compensated DCTL system based on EMD and ML algorithm. EMD based decomposition has outperformed the prime limitations of DWT, i.e., opting of appropriate mother wavelet and decomposition level. The proposed approach also incorporates the feature opting technique in terms of the energy value of the desirable picked IMF. This significantly helps in reducing the dimensionality of input samples to classifier models. It is also one of the prime reasons behind the fast time response of the classifier models. By observing the acquired results during case study, it has been elicited that the proposed approach is well competent in precisely identifying CCF in SC parallel circuit power transmission network. It has been also seen that the functioning of proposed approach remains undisturbed during the variation of system conditions like fault inception and location.

References

[1] Sunil Singh and D. N. Vishwakarma. (2015) "Impact of Series FACTS Controllers on Distance Protection-A Review.", International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE): 129–134.

[2] Sunil Singh and D. N. Vishwakarma. (2015) "Intelligent Techniques for Fault Diagnosis in Transmission lines –An Overview." *International Conference on Recent Developments in Control, Automation and Power Engineering (RDCAPE)*:280–825.

[3] A. A. Mohd Zin, N. A. Omar, A. Mohd Yusof and S. P. Abdul Karim (2012) "Effect 0f 132 kV cross-country faults on distance protection system." *Aisa International conference on modeling and simulation*: 167-172.

[4] Xiangning Lin, Hanli Weng, and Bin Wang. (2009) "Identification of Cross-Country Fault of Power Transformer for Fast Unblocking of Differential Protection." *IEEE Transactions on Power delivery* **24** (**3**): 1079-1086.

[5] Krzysztof Solak and Waldemar Rebizant. (2010) "Analysis of differential protection response for cross-country faults in transmission lines." *Modern Electric Power Systems*: 1-4.

[6] Aleena Swetapadma and Anamika Yadav. (2015) "All shunt fault location including cross-country and evolving faults in transmission lines without fault type classification." *Electric Power Systems Research* **123**: 1-12.

[7] P. Jena and A. K. Pradhan. (2011) "Solution to directional relaying for double circuit line." *Int. conference* energy, automation and signal: 1-6.

[8] P. Jena and A. K. Pradhan. (2011) "An integrated approach for directional relaying of the double-circuit line." *IEEE Transactions on Power delivery* **26** (**3**): 1783-1791.

[9] Tianshu Bi, Wei Li, Zhenyu Xu and Qixun Yang. (2012) "First-zone distance relaying algorithm of parallel transmission lines for cross-country grounded faults." *IEEE Transactions on Power delivery* **27** (**4**): 2185-2192.

[10] Mohammad Amin Jarrahi, Haidar Samet and Ali Sahebi (2016) "An EMD based fault type identification scheme in transmission line." *Iranian conference on electrical engineering*: 422-427.

[11] Jing Liu, Jiandong Duan, Hialong Lu and Yuanbing Sun. (2015) "Fault location method based on EEMD and travelling-wave speed characteristics for HVDC transmission lines." *Journal of power and Energy Engineering* (**3**): 106-113.

[12] LI Bin and SHU Hongchun. (2009) "Research on fault line detection based on empirical mode decomposition (EMD) in resonant grounded systems." *Asia-Pacific power and energy engineering conference*: 1-5.

[13] Urmil B. Parikh, B. Das and R. P. Maheshwari. (2010) "Fault classification technique for series compensated transmission line using support vector machine." *Electrical Power and Energy Systems* (**32**): 629-636.

[14] Sami Ekici (2012) "Support vector machine for classification and locating faults on transmission lines." *Applied soft computing* (**12**): 1650-1658.