A Brief Review on Fault Detection, Classification and Location on Transmission Lines Using PMUs

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Abstract : Modern power system require real-time monitoring and fast control in order to be protected from faults on transmission lines. To achieve this objective, phasor measurement units (PMU) have been extensively deployed at the strategic points of the network and thus they have become indispensable elements to make the system reliable. PMU capture voltage and current phasors and also provides a dynamic state of the power system. This paper describes a brief review of transmission line fault detection, classification and localization techniques which utilize synchrophasor measurements. The content of this study may be useful as quick guide to the work on fault detection classification and location of faults on transmission line using PMUs.

Key words: - ***Phasor Measurement Unit, Event detection, Classification, Localization, Transmission line.***

1. Introduction

Modern power network is always prone to faults. Transmission line forms a significant part of the power system network and therefore the chances of the fault occurrence is more in the transmission line, as it is exposed to atmospheric environmental condition. The fault on transmission line affects the health of power system. Situational awareness (SA) is a key factor in transmission line protection and fault restoration with timely decision [1]. The transmission line SA is headed by the event detection /perception event status, comprehending the fault type.

Effective SA is possible to achieve only by adopting effective detection methodology, classification, localization along with efficient and quicker methods of protection scheme. Traditionally, power system SA rely on Supervisory Control and Data Acquisition (**SCADA**) system which update a sample in 2-3 second representing only quasi-steady state condition of the system. Due to slower rate of acquisition capability and lack of dynamic event capturing SCADA was not effective for efficient SA. Today's advanced PMUs has the ability of sensing the current and voltage phasor up to 60 samples per second providing dynamic visibility of state of the power system making the SA robust. The integration of time stamp with the phasor data enhances the wide area SA effectively [2]. There are so many literatures available on fault detection, classification and location of faults on transmission lines. But to the best of author's knowledge, the articles on the above theme that is fault analysis using PMUs are very few. This paper gives a brief review on detection, classification and location of faults on transmission lines using PMUs. Section 2 provides a brief theory on the detection, classification and location of faults on transmission line and a brief review of articles on the proposed theme. Finally conclusion and scope for future work are discussed in section 3

2. Brief Theory on Transmission Line Fault Detection, Classification and Location

Lack of the SA in the transmission line may cause the blackouts incurring lot of losses in the state economy. Therefore the accurate and rapid detection of the transmission line is indispensable in today complex power system, which can prevent the potential damage in a timely manner by activating the protective breakers and isolating the faulty lines/branches. Quick identification of the transmission line fault, identifying the fault type and precise location estimation of the fault provides the faster protection against transmission line fault, preventing potential damage.

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2.1. Fault detection

There are several methods reported in the literature Cumulative Differential Sum (CDS) is one of the basic method in which the current is used to detect the fault. The symmetrical component based detection scheme detects the fault by checking its negative and positive sequence components comparing them with the threshold limits. Wavelet transformation gives the time-frequency resolution by comparing the signal with the Fourier transform. By using the pre-fault steady state model and the present fault phases at the fault condition, the voltage change detects the faults. The Koopman mode is one of the fault detection scheme in which the faulted line identification is done by using the current phasors. Clarke transformation is another method in which the fault is detected by using the two terminal phasors. Principal component analysis(PCA) is one of the methods used in fault detection which reduce the data dimension by mapping data into low-dimensional subspace.

2.2. Fault classification

Fault classification is equally significant to provide protection in the transmission line event. Artificial neural network (ANN) is one of the computational techniques used in fault classification. In this method, the neural network is trained with the known data base. Based on the data with known fault type, the trained model is used for identifying the online unknown fault type. The neurons update its weight values during training process and that updated weight values are used by the network for classifying the fault. The Fuzzy Inference system (FIS) is another type of the fault classifier, which works on the Fuzzy logic membership function. The process happens in three different stages. In first (fuzzification) stage, the membership function is defined with the degree of the membership. The second stage (inference engine) is designed, based on the set of rules and the fuzzy data is fed to this stage. In the last stage (defuzzification), the final decision based on the fuzzy rule gives the result to classify the fault type. A machine learning technique is another type of the classification used by some of the researcher. This computing technique divides the fault classes by separating them in to groups by an optimal hyper plane. Support vector machine (SVM), logistic regression and ANN are some of the machine learning techniques use for this propose.

2.3. Fault Localization

The precise and timely estimation of the transmission fault location can avoid time consuming and manual fault examination and fault restoration. Accurate fault location is essential for the maintenance; repair and inspection of the transmission line fault and enhance the quality and reliability of the transmission line, which provide lower operating cost. Numerous research works aimed to address this fault location issue. The FFT based fault location is widely employed by using Parks transformation by finding equivalent voltage phasor and equivalent current phasor. Some of the techniques are based on the phase angle difference of both ends of the transmission line. The Sparse Estimation based fault localization is another type reported in the literature discussed in the following part of the paper. The most conventional fault location method is impedance focused method (phasor or time-domain Based) and traveling wave method. The findings of the researchers for the transmission line fault detection, classification and localization are described as follows.

In [3] the author presented an review and assessed a state of art related to the wide area protection (WAP) system to demonstrate how the PMU data sources and the associated communication can be integrated to enable new protection scheme. A case study was presented for the future decentralized power system WAP architecture and validated the new tools to provide cost effective solution for today's protection system, focusing on the fault detection and the location approaches. A robust fault analysis using PMU data in the transmission line is presented in [4]. The authors proposed a methodology for detection, classification, and localization of an event based on the symmetrical component of voltage and current phasor. The technique can analyze the fault within 2-3 cycles after the event has occurred, enabling the faster detection and fault restoration process accurately. The algorithm is validated in three bus system and Western System Coordinating Council (WSCC) system. An algorithm is presented in [5] for the fault detection and classification in a transmission line using only its synchronized current signal taken at both ends of a transmission line. The algorithm is based on Stock Well Transform of time-frequency analysis. It uses a differential sum over a half cycle for the detection of the fault and it computes energy over half cycle of the signal for the fault classification. A fault localization technique is presented for multi-terminal transmission lines in [6] based on the PMU voltage and current data. The authors optimized the number of PMUs using the genetic algorithm (GA) to enhance complete observability of the system. The algorithm can find the accurate distance of the event along with the latitude and the longitude of the location of the event. The algorithm is validated in 49 bus system using MATLAB tool. The authors in [7] presented a protection technique of double circuit compound untransposed transmission line using PMU voltage and the current phasor for detecting, classifying and then localizing the transmission line event including the identification of the faulty branch of the transmission line network. A space-time approach is presented in [8] to detect multiple events to identify affected area and the location using virtual PMU voltage measurement using the K-mean algorithm. The algorithm is validated using IEEE 39-Bus system real-time EMULAB based synchrophasor network test-bed. In reference [9] the authors proposed a rule-based analytics method for fault detection of fault driven by PMU data, which has the capability to detect the faulty line and bus in a power grid and classify the fault type whether it falls in the category of either single line to ground, line to line or three-phase fault. The rule in this method is based on the theoretical values and recorded PMU data in Bonneville Power Administration's large power grid. In reference [10] the authors presented a wavelet-based fault detection and classification algorithm using PMU voltage and frequency measurements. The algorithm is validated with real-time data provided by the Korea electric power corporation.

The authors in [11] presented a machine learning based fault detection algorithm by taking the PMU data from pacific north region of the United State of America. The author demonstrated 5-stage cascade of support vector machine within the PMU fault line domain. In reference [12] the author presented a fault location and localization technique in an extra high voltage transmission line using PMUs voltage and current data at both ends of the transmission line by using Modal transformation. The proposed algorithm is tested in ATP and implemented in MATLAB tool. A fault detection, classification, and localization scheme presented in [12] based on the PMU voltage and current measurement collected from the both sides of the transmission line. The algorithm is also able to detect the symmetrical fault as well as the asymmetrical fault. The proposed algorithm is simulated in ATP-EMTP environment using the IEEE 14 Bus system. In the reference [13] the authors presented a backup protection technique for a transposed two terminal compound lines using PMU voltage and current data in the phase domain for detection, classification of transmission line event. The algorithm has the ability to recognize the internal line fault from other lines. The simulation is implemented using the MATLAB tool. In reference [14] the authors proposed a fault detection, classification and localization scheme using PMU time synchronized voltage and current data without any iteration. The authors in reference [15] proposed a non-iterative algorithm in a untransposed transmission network for fault localization with the limited number of PMU voltage and current measurement without knowing the faulted line a-priori. The algorithm is validated by an offline simulation in New England 39-bus system. A Koopman based algorithm is proposed for faulted line identification in series compensated power network using PMU current data. The proposed algorithm is implemented on Dig-Silent power factory commercial software in England 39 bus system to evaluate the performance of the system. In the reference [16] the authors presented a support vector machine (SVM) based Event detection, classification and localization using PMU voltage and current phasor using Park's transformation and it is validated in WSCC-9 and IEEE-14 bus systems. The SVM outperforms the artificial neuro fuzzy inference system (ANFIS) and artificial neural network (ANN). Reference [17] presented a fault localization technique using P Class PMU data. The algorithm is validated using real-time digital simulator using 24 transmission lines, 16 buses and 13 source system. In reference [18] the authors proposed a combined wavelet and ANN algorithm for fault identification and localization in a double circuit transmission line using single ended PMU voltage and current data. The proposed algorithm is validated using MATLAB wavelet transform toolbox. The author in reference [19] the author conducted a case study of a power system fault in the Indian grid for detection and classification of symmetrical and unsymmetrical fault. In the reference [20] the author presented a transmission line fault detection technique using its voltage and current phasor of PMU data based on its voltage dir and phasor angle variation caused by the event. The algorithm is validated using IEEE 9 bus system in MATLAB Simulink toolkit. The authors in reference [21] proposed an adaptive fault detection and classification methodology based on the PMU voltage and current phasor angle using Park's transformation. The method is validated using the IEEE 14 bus system using MATLAB Simulink toolkit. In the reference [22] the authors presented a PMU data event detection using Fast Fourier Transforms, Yule-Walker and matrix pencil-based methods along with large swing in PMU data based on voltage phase and frequency signal. The report identified and described the characteristics extracted from the power system event. A PMU based fault location technique is presented in [23] based on the fault node synchronized voltage of both the nodes of the faulted line. By calculating the line current, the fault location is evaluated. The method is validated in IEEE14 bus system in ATP/EMTP simulation. In the reference [24] the authors presented a power line outage detection scheme using voltage phasor. Using the least squares method, an iterative solution is developed to reduce the computational complexity. The proposed algorithm is validated in 118 bus system using MATLAB tool. In the reference [25] the authors proposed arcing and permanent fault detection and localization technique in extremely high voltage and ultra high voltage transmission line based on PMU measurement. The authors in reference [26] proposed a fault detection, classification, and localization scheme based on the PMU data in the transmission line using modal transformation incorporated with the distribution line model. The algorithm is validated using EMTP/ATP simulator. The author in reference [27] proposed an adaptive protection scheme based on PMU measurement with detection, classification and fault direction identification using Parks transformation theory. The algorithm is validated using EMTP simulation showing faster tripping time decision within a half cycle. In the reference [28] the authors presented a line protection algorithm for an extra high voltage transmission line using voltage and current phasor using Clarke transformation discriminating the internal and external faults. In the reference [29] the authors presented an adaptive fault detection and localization techniques using voltage and current phasors of gathered from both sides of the transmission line.The authors in reference [30] presented an effective mechanism to detect the possible cyber attack of the PMU data of transmission line transferred in wide area transferred through the internet. The method is based on the continuous monitoring of impedance of transmission line by testing its data integrity. In reference [31] the authors proposed a method based on PMU phasor data to classify the power distribution event using the distributed parameter estimation and the clustering technique. The algorithm is validated using power standard lab micro PMU.

In the reference [32] the authors proposed a detection and classification of multiple real-time events based on principal component analysis employing moving windows approach by measuring the frequency component. The algorithm was validated using the real-time data collected from United Kingdom power system. The authors in the reference [33] presented a wide area protection and faulted line identification technique for a transmission line using Koopman algorithm. The algorithm is validated using The New England 39 bus system developed on Dig-Silent power factory commercial software (PF4C) platform. In the reference [34] the author proposed a fault localization method using PMU located separately using sparse estimation problem using only a fewer number of voltage phasors. In the reference [35] the author presented a fault localization, isolation and fault restoration technique for micro-grid using only the current phasor collected from both sides of the line. The authors in the reference [36] proposed a transmission line outages using hidden Markov model. The performance of the algorithm is evaluated on the IEEE 4 bus, 6 bus, 14bus, 57 bus, 118 bus and 300 bus systems using Matpower. In the reference [37]the authors presented a review of PMU, investigating its application, performance, evolution of PMU and its reliability functions. In the reference [38] the author proposed an algorithm to detect the transmission outages using the bus voltage phasors with the minimum number of PMUs. The proposed algorithm validated using IEEE 14-bus and IEEE 30 Bus system using MATLAB and MiPower software. In the reference [39] the authors presented a fault detection and faulted line identification in a distribution network by using parallel phasor based state estimator. The algorithm is validated using a real-time simulator. In reference [40] the authors presented a technique to detect cyber attack and power system disturbance from heterogeneous time synchronized data of PMUs. The reference [41] proposed a method for event localization in a distribution network by using the voltage data during the fault and pre-fault using a smart meter and PMUs. The proposed method is developed in DIgSILENT and MATLAB tool and validated using a real-time distribution network.

Table I. Summary of literature review Event detection, Classification and Localization

Ref	System considered	In put considered	detection	classification	localization	Algorithim used	Software/Tool used
[4]	WSCC	Three phase Voltage and Current	Y	Y	Y	------	Matlab/ SimuLink
[5]	2 bus system	Three phase Current	Y	Y	------	Stock Well Transform	Malab/ Simulink
[6]	49 BUS	Three phase Voltage and current			Y	Genetic algorithm	Matlab
[7]	double circuit untransposed compound transmission line	Three phase Voltage and current	Y	Y	Y	------	Matlab
[8]	IEEE 39 Bus	Three phase Voltage	------	------	Y	K-mean algorithm	EMULAB
[10]	2 bus System	Three phase Voltage	Y	Y	------	WAvelet transform	------
[11]	Pacific Northwest region	Three phase Voltage	Y	------	------	Machine learning	------
[12]	IEEE 14 Bus	Three phase Voltage and current	Y	Y	Y	Modal transformation	Matlab
[13]	2 bus	Three phase Voltage and current	Y	Y	------	------	Matlab

[14]	New England 39 Bus	Three phase Voltage and current	------	------	Y	Koopman	Dig-Silent power factory commercial
[15]	WSCC) -9 and IEEE-14	Three phase Voltage and current	Y	Y	Y	SVM	Matlab/ Simulink
[17]	16 Bus	Three phase Voltage and current	------	Y	Y	Wavelet and ANN	Matlab
[19]	IEEE 9	Three phase Voltage and current	Y	--------	--------	-----	Matlab
[20]	IEEE 14	Three phase Voltage and current	Y	Y	--------	Parks transformat iom	Matlab /Simulink
[25]	2 Bus	Three phase Voltag e and current	Y	Y	Y	------	EMTP/ATP
[31]	IEEE-9		Y	Y	------	PCA	DIgSILENT PowerFactory
[32]	The New England 39 Bus	Three phase Current	Y	------	------	Koopman Algorithm	DIgSILENT PowerFactory

The authors in [42] proposed a tool to enhance the SA in modern power systembased on PMU measurements and decision trees focusing on the voltage magnitude violation, thermal limit violation, voltage stability, and transient stability. In the reference[43] the authors analyzed the importance of multiple real-time event for the reliable SA and secured power operation . The algorithm utilizes the frequency data from the PMU detection of the event. The event is validated in IEEE 118 Bus system using DIgSILENT powerfactory. In the reference [44] the authors presented a LabVIEW based online fault detection and classification technique using fuzzy logic. The algorithim is implemented in a two bus system.

Table I summarizes the work done so far on fault detection, classification and location on transmission line using PMUs. It discusses about the type of inputs considered and algorithm used for detecting and identifying the faults. It can be observed from the table that not all the articles have addressed fault detection, classification and location. It also shows which type of platform the authors have used in performing fault analysis.

3. Conclusion

This article has captured and categorized the main methods for detection, classification and location of faults on transmission line. The techniques used were parks transform, PCA, Koopman algorithm, transform, Wavelet transform, ANN, Machine learning, K-meaning algorithm, S-transfor. It has been observed realistic communication delays for PMU data have not yet considered. It is a known fact that LabVIEW is an ideal platform for performing real-time experiments. From this article we have found that there is only one article using LabVIEW and rest of the articles use MATLAB, ATP/EMTP, DIgSILENT power factory and Mipower. So there is great scope for performing real time fault analysis using LabVIEW.

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