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Generic scalable fault diagnosis system for multimachine power grids

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A R T I C L E I N F O

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A B S T R A C T

A new approach for fault diagnosis in power grids is presented in this paper. The approach is capable of detecting, classifying and locating, with high speed and accuracy, any type of faults anywhere in the grid using bus voltage or line current measurements only. Fault detection and classification is accomplished by applying logic on measured data while fault location is determined by fault location identification functions generated off-line by using a least-square support vector machine. The high speed and accuracy aspects of the proposed approach are verified through case studies in three test power systems.

1. Introduction

Modern world power grids comprise a large number of interconnected synchronous generators, transformers, transmission and distribution lines, loads, and associated control and measuring devices. Power grids extend over large geographical areas to ensure power supply to distant locations and therefore are susceptible to a variety of faults and equipment malfunction. Short circuit faults in transmission and distribution networks, caused by lightning, external object coming in contact with the lines, insulation damage, etc., are most frequent. Statistics show that almost 50% of power system faults occur in the transmission and distribution lines [1]. Short circuit faults in these networks result in heavy currents being drawn, which may then cause significant damage to the lines and to other components connected to them if they persist for longer than permissible. In order to ensure continuous and reliable operation of power grids, it is highly desirable to have a highly reliable fault diagnosis system to detect, classify and locate the fault in earliest possible time.

Several fault analysis algorithm have been reported in the literature over the years to address fault related problems associated with the power grids and some are being used in the daily operation of power grids. A brief summary of and commentary on most widely used and reported fault detection and location identification approaches is presented next.

Impedance based [2–5] techniques have been extensively used in conjunction with the traditional relays [6] for transmission/distribution line fault diagnosis. They use data from either single end [5] or double end [2–4] of the line to calculate apparent impedance between the local end and the fault location. Both methods are heavily constraints by pre-fault loading conditions, large amount of data acquisition and pre-processing required. Travelling wave based approaches have been used in [7–10] to diagnose faults in transmission or distribution networks faster than traditional impedance methods but problems arise when the faults are close to a bus terminal and when it occurs near zero inception angle [11]. Moreover implementation of travelling wave based approaches requires highly accurate sampling devices at both ends of the faulted line. The above issues initiated investigation into the use of knowledge based approaches [11–27] for fault monitoring purposes. Commonly used knowledge based approaches are *Multi Layer Perceptron* (MLP) [11,18,20,26], *Radial basis function* (RBF) [12], *Self Organised Mapping* (SOM) [13], *Linear Vector Quantization* (LVQ) [14], *Adaptive Resonance Theory* (ART) [15,16], *Elman recurrent network* [17], *Support vector machine* [19,24], *adaptive neuro fuzzy system* [22,25,27].

The major problems with above referred knowledge based approaches compared to our proposed method is summarised as shown in Table 1.

An alternative to knowledge based approaches is the so called model based approaches [28,29], where an accurate mathematical dynamical model of the system understudy is required. Such approaches could be very attractive because of their potential fast fault detection capability, however there are impediments with respect to practicality for the following reasons: (i) The majority of

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Nomenclature

JK line	line connecting buses *J* and *K*
$\bullet^{(s)}$	'*s*' sequence quantities. *s* = 1 (positive), 2 (negative), 0 (zero)
y_{JK}	admittance of line *JK*
$B_{c_{JK}}$	susceptance of line *JK*
V_{ref_i}	reference signal of the excitation system in *i*th generating unit
P_{ref_i}	Reference signal of the speed governing system in *i*th generating unit
SLG, *LLG*, *LL*, 3φ	single line to ground, double line to ground, line to line and three phase fault respectively

existing approaches requires linear fault dependent state space model of the system, where the fault appears affinely in the state and output equations. Since power systems are highly nonlinear, it is extremely difficult *if not impossible* to obtain such a linearised fault dependent state space model; (ii) Although there has been rapid progress in development of theory [30,31], existing nonlinear model based fault detection theory is not yet capable of dealing with multi-machine nonlinear power systems, which explains the absence of any useful results in this regard; (iii) Existing model based fault diagnosis methods have not been successfully used for the identification of the type of fault or for fault location, again mainly due to lack of theory.

It is to be noted that measurement and processing time has been a problem with all of the existing fault detection approaches, even with modern day digital relays and fault locators. Although the speed of response has increased considerably in the new generation of digital relays, circuit breakers are still not able to be tripped within the recommended 2–3 cycles after the occurrence of major faults to avoid potential breach of thermal limits and rotor angle stability. The reason being the relatively long time constant of the circuit breakers mechanical actuators. It is for this reason that power grids are deliberately operated under capacity to allow for short circuit fault levels.

In this paper we propose an approach that is capable of fault detection, classification and location identification with high speed and accuracy (faster and more accurate than existing approaches). The approach is scalable to multi-machine systems of any size and description. The main attributes of the new approach are: (i) it is able to detect faults anywhere in the grid in relatively short time (near real time), (ii) it identifies the faulty lines, (iii) it determines the type of fault, and (iv) it computes the exact location of the fault. The above attributes are accomplished simultaneously and in a very fast if not in almost near real time. The speed of response is due to the use of logic only for fault detection and identification, which is almost instantaneous, and the off-line training and on-line implementation of least square-support vector machines (LS-SVM) (once trained the response in almost instantaneous). The only delaying factor is the measurements and communication of the bus voltages (or line currents) and this depends on the speed of the telecommunication system used (in order to reduce the impact of communication time delay, the grid may be subdivided into loosely connected regions and zones along the same lines as for protection systems and a hierarchy of fault detection systems is used, which is currently being investigated by the authors). A comparison of the main features of this paper compared to the authors' previously published papers is shown in Table 3. The table shows

Table 1
Comparison of existing knowledge based approach with proposed method in this paper.

	Knowledge based approach [11–27]	Our proposed method
Fault diagnosis (faulted line identification, fault classification, fault location identification)	Most of the knowledge based fault diagnosis approaches are either used for fault classification or fault location identification. Hence does not provide complete fault diagnosis (i.e. faulted line identification, fault classification, fault location identification) of the system	Able to do complete fault diagnosis of the system, i.e. it can detect, classify and find exact location of faults immediately after fault occurrence
Dynamics of power system	Most of them use commercial power system simulation packages with libraries containing modules of power system components such as synchronous machines, primary control devices, transformers, SVC and lines. As detailed in Table 2, the overwhelming potion of these packages use reduced order simplified models of synchronous generators and thus do not describe the complete dynamics of the system, especially during the transient period immediately after the fault. Hence simulation of different fault scenarios using such software packages will not accurately describe dynamics of the system, and consequently accuracy of training process and diagnosis will be adversely compromised when real life data is used	Complete dynamics of the power system under both normal and fault condition (as shown in Appendix C) has been considered in our proposed method
Application to interconnected power grid	Most of these methods are shown to be applicable for simple power systems where single transmission line is connecting two power sources. It is not explained how these methods can be extended to interconnected power grid	Proposed fault diagnosis method presented is generic, scalable and may be applicable to any interconnected power grid. This has been validated by rigorous case studies performed on three different test power systems
Excitation and speed governing system	None of the knowledge based approaches referred in this paper do not account for the dynamics of the excitation and speed governing systems, which are an integral parts of LFC and QV control in power grids	Dynamics of excitation and speed governing system are considered
High speed fault diagnosis	Existing approaches require sufficiently large amount of sampled signals (voltage/current or both) after the occurrence of the fault for signal processing using, for example, Fourier transform, Wavelet transform, etc. to extract fault features. This may detract from their suitability for high speed fault diagnosis	It uses logic only for the detection and classification of faults and a simplified (least square) version of support vector machine for identification of fault location. As the approach uses real time measurements of three phase bus voltages or currents only, and involves no signal post-processing it provides very fast (near real time) detection, classification and identification of faults location anywhere in the network