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A knowledge-based architecture for distributed fault analysis in power networks

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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

Power industry around the world is facing several changes since deregulation with constant pressure put on improving security, reliability and quality of the power supply. Computational fault analysis and diagnosis of power networks have been active research topics with several theories and algorithms proposed. This paper proposes a distributed diagnostic algorithm for fault analysis in power networks. Distributed architecture for power network fault analysis (DAPFA) is an intelligent, model-based diagnostic algorithm that incorporates a hierarchical power network representation and model. The architecture is based on the industry's substation automation implementation standards. The structural and functional model is a multi-level representation with each level depicting a more complex grouping of components than its predecessor in the hierarchy. The distributed functional representation contains the behavioral knowledge related to the components of that level in the structural model.

The diagnostic algorithm of DAPFA is designed to perform fault analysis in pre-diagnostic and diagnostic levels. Pre-diagnostic phase provides real-time analysis while the diagnostic phase provides the final diagnostic analysis. The diagnostic algorithm incorporates knowledge-based and model-based reasoning mechanisms with one of the model levels represented as a network of neural nets. The relevant algorithms and techniques are discussed. The resulting system has been implemented on a New Zealand sub-system and the results are analyzed.

1. Introduction

Fault analysis and diagnosis in power system networks has been a constant topic of research since 1977 (Kirschen and Wollenberg, 1992). Several decision support systems have been developed to solve problems (CIGRE Task force, 1995; Karapidakis, 2007; Matijevics and Jozsa, 1976) and continue to be a research topic of interest (Yang et al., 2004; Maurya et al., 2006). The primary reason for this interest lies in the complexity of the problem and the demand by the power industry.

With the deregulation of the power industry worldwide, a power system is normally run under tighter conditions with a low margin of human error. Hence, there is a need for an effective decision support system in real-time power system control. Management of unplanned outages is one such activity performed in real-time control of power networks and is the topic of this paper (Edwards, 2003).

One of the drawbacks of previous solutions proposed for fault analysis and diagnosis is that the complete network is analyzed as a single entity. Since power networks are complex networked systems (Amin, 2000), it is impossible to analyze a power network as a single entity. Recently, EPRIs initiative on IntelliGrid (Amin and Wollenberg, 2005) and CIN/SI (Amin, 2000) identified the need for distributed real-time power control. The research discussed in this paper is carried out in line with the IntelliGrid initiative.

In this paper, the approach towards the design of a fault diagnostic system is discussed. In the following section, a general fault analysis process in power networks is discussed. Section 3 provides a review of related work. Section 4introduces a distributed architecture for fault analysis (DAPFA) algorithm and describes the structural and functional hierarchy of the algorithm. Finally, some case studies are discussed and the paper is concluded.

2. Power network fault analysis

2.1. The problem

Upon an occurrence of a fault, protective devices such as relays and circuit breakers operate quickly in order to isolate the faulty portion of a network. This causes a surge of alarms to be registered at the control centre within a few seconds. Alarms

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are generated or triggered by events, such as:

- a circuit breaker trip or excessive temperature in transformer (discrete events);
- an over-voltage or under-voltage, overload in transmission line (violation of operating constraint);
- telecommunication faults;
- hardware and software problems.

Upon an accident, such as a lightning strike, several events as stated above may be caused and each of them will issue an alarm (Rayudu et al., 2001). Within a few seconds, the control centre is flooded with alarm messages.

The controllers of the power system need to understand these alarms and determine the events that led to them. The controllers have to identify the important alarms in the list, analyze the alarms, determine the causes and plan a restoration procedure. The controllers can then take appropriate actions to restore equipment and the service to customers (Uraikul et al., 2007).

When the controllers are overwhelmed by a surge of alarms, efficient decision-making becomes stressful (Allen et al., 2005). Therefore, a support system is needed.

2.2. Computational solution

Fault analysis systems (FAS) is a decision support system developed for fault analysis, which tackles the problem by analyzing alarms and determining the important alarms that can lead to identifying a fault (Ukil and Zivanovic, 2007). Alarm filtering is a component of FAS, to filter out the important alarms. After performing this alarm filtering, the FAS will find the reasons behind the symptoms or alarms. An FAS needs more in-depth knowledge than simple knowledge to filter alarms (Perdisci et al., 2006). The main functions of FAS are:

1. upon an event, identify all important alarms from the alarm list;
2. check the consistency of all alarms;
3. identify any malfunctioning equipment;
4. determine the location of the fault;
5. identify multiple faults and cascading effects;
6. identify the cause of the fault;
7. suggest corrective actions.

The FAS diagnostic process closely follows the process performed by the human system controllers of a power system (Sainz Palmero et al., 2005). This involves the following knowledge and information sources (EPRI Report, 1986):

- knowledge of component operation;
- knowledge of state-based topological relations between components and their operational dependence;
- alarm analysis knowledge;
- knowledge of the geographical location of components and their operational dependence
- fault analysis and diagnosis knowledge;
- real-time analog and digital data;
- network topological information;
- temporal information analysis.

In this paper, we develop FAS as a distributed architecture, distributed architecture for fault analysis (DAPFA). The system discussed in this paper is also based on the same knowledge used by human controllers and the information available to them. The heuristic knowledge related to the process is acquired from the human controllers and the knowledge that is difficult to extract from experts is derived from model-based reasoning. Model-based reasoning is performed by simulation analysis of a qualitative model of the power system (R. Benjamins, 1993; Davidson et al., 2003). The heuristic knowledge is used to drive the diagnostic procedure, select the most appropriate solutions and solve domain-specific diagnostic problems. The heuristic knowledge is also used in model-based reasoning as cause-effect relationship representation. The framework developed is described in the following section.

3. Related work

Power network fault diagnosis has been an active research topic since 1977 (Kirschen and Wollenberg, 1992). During this time several solutions have been proposed with some of them being implemented in the industry (Rayudu, 2000). Traditionally many of the implementations have been single-system architectures implemented at the control centre level where the data is accessed via supervisory control and data acquisition (SCADA) (Rayudu and Maharaj, 2002; Zhang and Kezunovic, 2007). The main reason is the availability of network data at SCADA.

The need for distributed analysis in power networks originated from the need to utilize current internet and communication technologies (da Silva et al., 2005; da Silva and Klusch, 2006). Several initiatives, such as complex interactive networks (Amin, 2000) and Intelligrid (Amin and Wollenberg, 2005), have been developed to incorporate distributed architectures into power system analysis. Our algorithm has been developed in line with these initiatives.

Several distributed architectures have been developed in computer and telecom network fault analysis (Amin, 2000; Peacock, 2000; Zeng-Kai and Jiu-Bin, 2003, Chen and Wang, 2007) and transportation (Bazzan, 2005). Regarding distributed approaches in power system analysis, there are various research results worth noting. The Archon system for power system fault analysis has been discussed in (Corera et al., 1996) and a framework for security analysis is proposed in (Di Santo et al., 2004). Archon (Corera et al., 1996), an agent-based system, was developed as a co-operative system that made use of pre-existing software. Archon incorporates several modules for monitoring, control and situation assessment. For fault diagnosis application, the system has four agents, each responsible for some functions such as alarm analysis, breaker and relay analysis, black-out area and control system interface. In (Di Santo et al., 2004), the authors discuss a distributed algorithm for online power system security analysis. The architecture is presented in three tiers: presentation, middle and storage tiers. The middle tier incorporates the main algorithm and also includes power system sensors such as intelligent electronic devices (IED) and field power motors (FPM).

Archon's processes are distributed at module level. That is, a processor performs a function such as alarm filtering and blackout analysis. This is a logical choice as Archon uses previously developed modules in the analysis. But the drawback of this system is that the processor load is unevenly distributed. The system in (Di Santo et al., 2004) incorporates a set of mapping algorithms to map tasks to servers. Hence system performance can be measured against the number of processors in the cluster.

DAPFA's distributed architecture is based on the power transmission network structure. The process distribution is based on the geographical hierarchy of the power network rather than being 'analysis-based' as in Archon (Corera et al., 1996) or based on 'task allocation' as in (Di Santo et al., 2004). The major advantage of DAPFA is that the analysis can be performed locally thereby providing quick response and reducing the alarm traffic to the main control centre.