Information Management System for Detecting Cascading Events

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***Abstract*--Detecting and preventing cascading blackouts is crucial to maintaining the power system reliability and security. This paper discusses implementation of a method used to detect and prevent the cascading events by coordinating the system-wide and local monitoring and control tools. The framework of the information management system for the proposed method is given. The data requirements for all the system/local level algorithms are discussed in detail. The methods for obtaining the needed data are presented, which include data acquisition through traditional Supervisory Control and Data Acquisition (SCADA) system, modern Intelligent Electronic Devices (IEDs), or add-on high speed data acquisition system based on virtual instruments. The proposed information management system is helpful in storing and managing the obtained data, as well as supporting and running the monitoring and control tools.**

***Index Terms*--Cascading events, information systems, data requirement, data management, SCADA, IED**

I. Introduction

WITH the development of flexible electricity markets operation under the deregulation rules, power system became more stressed and power network security and reliability criteria became more complex. Power systems are exposed to all kinds of disturbances, which may come from animal contacts, human errors, equipment malfunction, natural disasters, etc., and some of these disturbances may cause major power service interruption [1]. Among the disturbances, cascading outage, especially the large-scale cascading outage, draws special attention since it can cause great economic loss to utility companies and other businesses and devastating impact on people's life. For example, Northeastern System Blackout in 2003 led to the load loss of 61.8GW, which influenced more than 50 million people [1].

The many solutions proposed so far are aimed at understanding and finding ways for detecting, preventing, and mitigating the cascading events. Some of the proposed techniques include dynamic and probabilistic study of the cascade model, application of dynamic decision-event tree analysis, expert systems for wide area back-up protection, inclusion of relay hidden failure analysis, application of special protection schemes, controlled islanding, generalized line outage distribution factors calculation, etc. [2-8] It appears that relaying problems and inadequate understanding of unfolding events are two major contributing factors in inability to predict or prevent cascading events, which is discussed in the reports for the August 1996 US Western Coast System Blackout and August 2003 US Northeastern System Blackout [1,9]. For relaying problems, relay failure and misoperation contribute the most to the inadequate handling of power system disturbances. According to historical data, relaying problems were the contributing factor in almost 70% of the US disturbances from 1984 to 1991 [10]. Another problem is that power system operators lack sufficient analysis and decision support tools to take quick corrective actions needed to mitigate unfolding events. Considering the above factors, a novel interactive scheme of system/local monitoring and control tools for detection, prevention and mitigation of cascading events was recently introduced [11-15]. This scheme is aimed at identifying the disturbance leading to cascading events and providing control means for preventing further unfolding of the cascading events while keeping the stability of the power system. The scheme determines system vulnerability and initiates local monitoring to verify correctness of protective relay operations.

A special information management system aimed at supporting detection, prevention and mitigation tools for handling cascading events is introduced in this paper. It also discusses the data requirements for each monitoring and control tool, and identifies the potential benefits of integrating information from traditional SCADA data and newly introduced IED data. After an introduction, Section II discusses the overall scheme and implementation of system/local monitoring and control tools for detection, prevention and mitigation of cascading events. The data requirements of each algorithm are presented in Section III. Section IV discusses the means for obtaining data, and gives the framework for information management system. Section V shows examples of how to use data for different algorithms. Conclusions are given in Section VI followed by a list of references.

This work is supported by Power System Engineering Research Center (PSerc) under the project S-29 tilted "Detection, Prevention and Mitigation of Cascading Events – Prototype Implementations".

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II. Architecture of Proposed Monitoring and Control Scheme

The proposed monitoring and control scheme for detection, prevention and mitigation of cascading events coordinates the system-wide side and local side algorithms. The overall interaction is conceptually shown in Fig. 1.

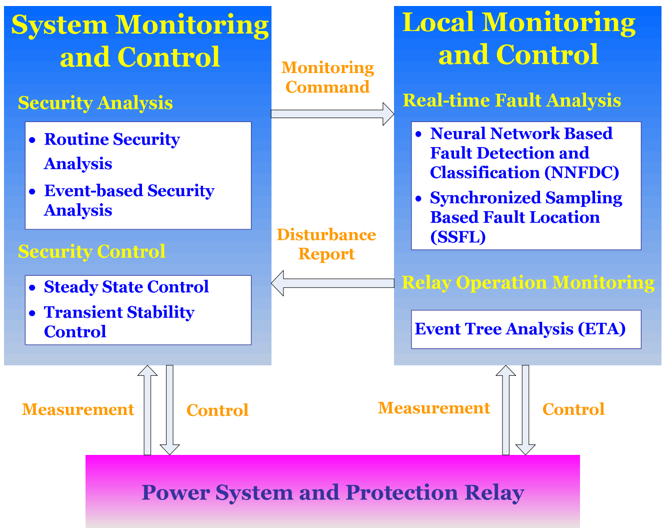

Fig. 1. Overall interactive monitoring and control scheme

The system tool consists of the routine and event-based security analyses based on the power flow method and topology processing method, along with the security control schemes for expected and unexpected events. Vulnerable elements are identified using calculated Vulnerability Index and Margin Index [11] and related relays are closely monitored. The event-based security analysis is triggered when an unexpected disturbance occurs. It indicates whether the emergency control is needed to mitigate the transient stability problem or not. Steady state control tools are based on Network Contribution Factor (NCF) [12], Generator Distribution Factor (GDF) [16], Load Distribution Factor (LDF) [16], and Selected Minimum Load Shedding (SMLS) used for early detection and prevention of cascading outages as analyzed utilizing steady state method. Transient stability control tools are based on Potential Energy Boundary Surface (PEBS) method [17], Admittance-based Control (ABC) and Generator-input-based Control (GIBC).

The local monitoring and control tool intended for installation at local substations consists of an advanced real time fault analysis tool and a relay operation monitoring tool utilizing neural network based fault detection and classification algorithm (NNFDC), synchronized sampling based fault location algorithm (SSFL), and event tree analysis (ETA) [14-16]. The advanced on-line fault analysis tool will detect the disturbance by analyzing local measurements. Once the disturbance is detected and classified, event tree analysis process will be invoked to validate relay operations. The combination of the two algorithms performs a more accurate fault analysis than conventional relays do. This provides a reference for monitoring and verification of the distance relay operations. The substation-based solution can provide the system-wide tool with local disturbance information and diagnostic support so that the system-wide tool can have utilize local information to take better control action to ensure the secure operation.

System-wide tool uses wide-area information to generate a comprehensive view of the system security and vulnerability conditions. It can notify the local tool to engage in careful monitoring of vulnerable elements during abnormal conditions. Local tool collects the exact real-time local disturbance information. It has the ability to detect, classify and locate the fault with high accuracy and provide good reference for evaluating relay operation. Both the system-wide and local tools work together to fulfill the major task: help detect, and classify the cascading outages. The block diagram of the implementation is shown in Fig. 2.

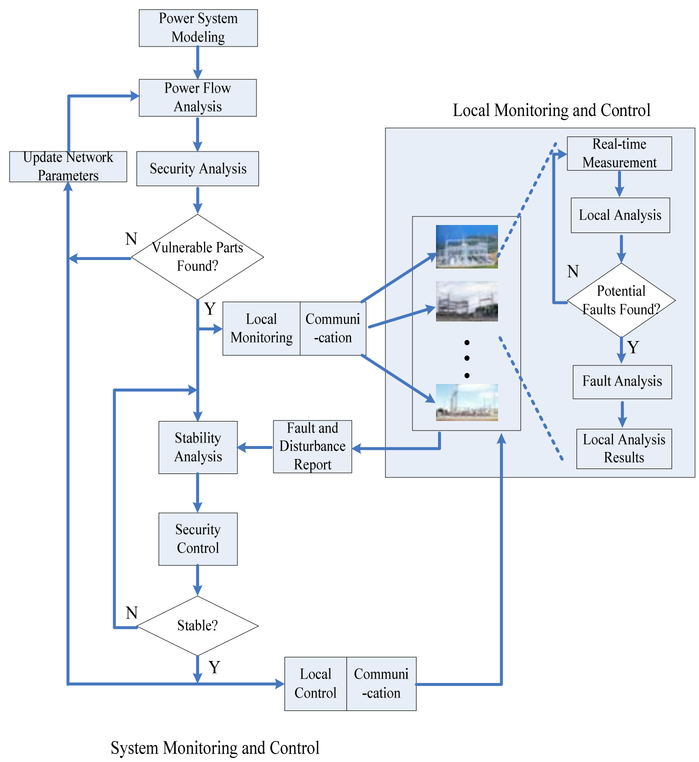

Fig.2 Block diagram of the implementation

III. Data Requirements

Data availability is the key factor in making the automatic monitoring and control feasible. In order to implement the proposed algorithms at system/local level, two issues need to be cleared: what type of data is needed and how to extract the useful information from obtained data. To solve these issues, different types of data from various sources are needed, which are naturally divided into two classes: system level data and substation data.

A. System Level Data

The data required for system level analysis aims at getting the power system network topology and establishing the steady state status. The power system model and real time network topology change information are also needed. Different utilities may use various commercial programs for power system analysis but the main functions of those programs are the same. To meet the data requirement for system analysis and control tools, the following detailed data are necessary:

- *Power Flow Analysis Data*

This data contains the basic power system network topology. It is used to run the power flow analysis to establish the steady state status of the whole system.

- *Short Circuit Analysis Data*

This data is needed for running short circuit calculation. It will be updated whenever the system topology changes.

- *Dynamic Analysis Data*

This data contains all the dynamic models for generators, exciters, compensators, stabilizers, etc, which is used to perform dynamic analysis to check system dynamic stability under various disturbances.

B. Local Level Data

The data required for local level analysis aims at getting detailed configuration for each substation, as well as measured data for any disturbance. To meet the data requirement for local fault analysis and control tool, the following detailed data are necessary:

- *Relay Setting and Event Reporting Data*

Data for relay setting contains the relay configuration information. Data for relay event reporting contains the results of relay operation under disturbances. This data is used for reconstructing relay operation by simulating relay behavior under given disturbances.

- *Fault Record Data*

Fault record data contains analog and digital sample values for all input channels for a specific fault or disturbance. It is used for the training set and testing set of fault scenarios for Neural Network based Fault Detection and Classification (NNFDC) Algorithm.

- *Synchronized Samples of Fault Voltages and Currents*

The synchronized sample data of fault voltages and currents contains time stamps from the Global Positioning System (GPS) of satellites on all the pre- and during-fault sample signals [16]. This data is used to verify the results of the Synchronized Sampling based Fault Location (SSFL) Algorithm.

IV. Obtaining and Managing Data

After the data requirements are clarified, the next issue is how to collect the desired data or information.

A. Obtaining System Level Data

It may be relatively easy to get the system level data to build power system model. No matter what kind of operation programs the utilities used, they will definitely cover the power flow analysis, short circuit analysis and dynamic analysis. The only differences are coming from the data formats, which depend on the adopted programs. Table I shows an example of obtained data for system level analysis based on Siemens' PTI PSS/E program.

B. Obtaining Data from Recording Equipment

Methods for obtaining data from the local level devices varies from one site to the other. With the development of new technologies and equipments used in substations, utilities keep upgrade or construct their substations according to their operation needs and strategic importance of the substation. The data recording equipments are very versatile, since they came from various vendors and were installed in different time periods [19].

TABLE I
DATA OBTAINED AND RELATED SOURCE FOR SYSTEM LEVEL

Function Module	***Detailed Data***	***Related Source***	***Description***
Security Analysis	Power Flow Raw Data	Input Data Files for PSS/E (*.raw)	This file contains power flow system specification data for the establishment of an initial case. This data is used by PSS/E to get the initialization values which will be utilized for security analysis.
	Slider Binary Data or Drawing Coordinate Data	Input Data Files for PSS/E (*.sld for V30 or *.drw for V2x)	This file is used to create and modify one-line diagrams and to display a variety of results.
Stability Analysis	Sequence Impedance Data	Input Data Files for PSS/E (*.seq)	This file contains the negative and zero sequence impedance data needed for unbalanced fault analysis. It is used by PSS/E to add the impedance data to the case of interest.
	Dynamics Data	Input Data Files for PSS/E (*.dyr)	This file is used by the PSS/E Dynamics program. It contains synchronous machines and other system components data for input to the PSS/E dynamic simulation working memory.

SCADA systems are being used to provide the real time information about power system states since the late sixties. The appearance of SCADA solutions improved the performance of energy management systems (EMS) functions. Traditionally the substation data are acquired using remote terminal units (RTUs) of SCADA and sent to the EMS in every two to ten seconds. The acquired data are typically bus voltages, flows (amps, MW, MVAR), frequency, breaker status, transformer tap position), etc. But, the measured data based on SCADA system does not have the characteristics needed to implement the proposed local analysis and control tools due to the lack of sampled waveform data [20].

Nowadays, most of the substations are equipped with Intelligent Electronic Devices (IEDs), which can collect huge amounts of sampled data in addition to performing their basic functions. The modern day digital devices can record and store a huge amount of data (both operational and non-operational) with a periodicity depending upon the intended purpose of the device, such as digital protective relays (DFRs) capturing data during fault occurrence, or phasor measurement units (PMUs) capturing continuous time-synchronized data. Although the IEDs are not standardized regarding the functions they perform, they are indeed a good addition to the data recording infrastructure needed for a comprehensive analysis to be performed related to substation equipment operation [18]. The integration and use of IED data has been discussed in literature, which offers a background for building the information management system for monitoring the cascading events[19].

Table II shows the data obtained from the local level considering the data integration from SCADA system and IEDs.

TABLE II
DATA OBTAINED AND RELATED SOURCE FOR LOCAL LEVEL

Function Module	*Detailed Data*	*Related Source*	*Description*
Neural Network based Fault Detection and Classification (NNFDC)	Event File	Event File output from Relays	The relay event file is used to get the report of relay operations.
	Data Recorded During Faults	DFR and DPR files	This fault data file is used to check the results of relay operations using NNFDC
Synchronized Sampling based Fault Location (SSFL)	Synchronized Samples of Voltage and Current Data during Faults	GPS-Synchronized DFRs	This synchronized data file is used for evaluation of SSFL

C. *Framework for the Information Management System*

Based on the above discussions the framework for the information management system for monitoring cascading events is defined according to the available data from recording equipment located in substations.

For the modern or upgraded substation, which is equipped with new IEDs, the information management system is focused on the integration of substation data with SCADA data and data from other sources. Fig. 3 shows the conceptual framework based on IEDs and SCADA system. Information management center is responsible for maintaining all the data based on the different algorithm needs.

For old substations without IEDs, a high speed data acquisition system as add-on equipment is needed. Various data acquisition units function as IEDs with pre-set thresholds for triggering. For example, the data acquisition system can be built easily based on virtual instruments by using the available modules, such as PXI (PCI eXtensions for Instrumentation) system [22]. By incorporating standard computer hardware interfaces and utilizing the computational power of an embedded CPU, the data acquisition system can define its specific functions through software programming. The acquisition functions can be expediently defined, modified, and expanded as new functionality is introduced in the future. In that case, the local level framework needs to be changed, which is shown in Fig. 4.

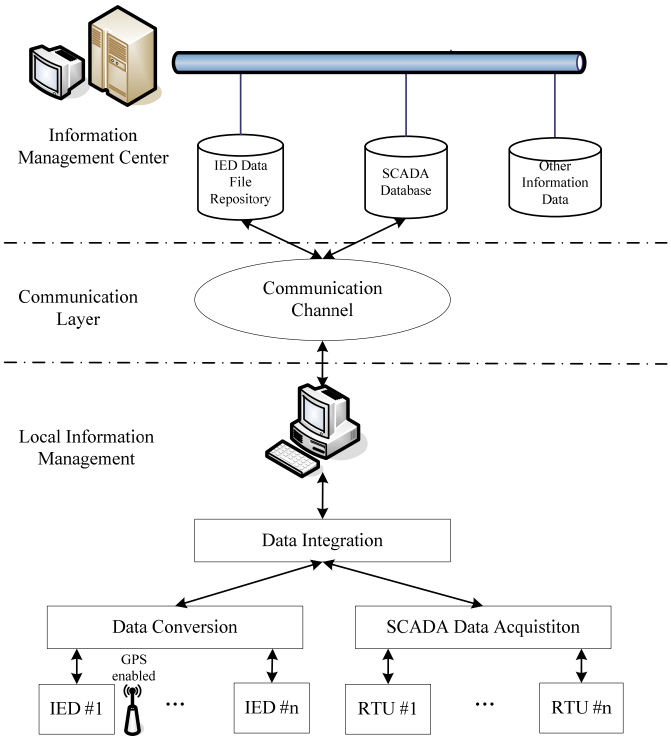

Fig.3 Framework of information management system based on SCADA system and IEDs

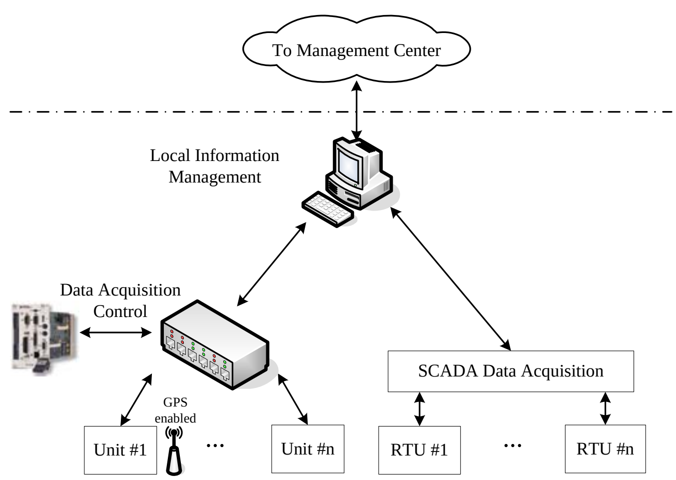

Fig.4 Framework of information management system based on SCADA system and add-on data acquisition system

V. USING THE INFORMATION MANAGEMENT SYSTEM

As discussed in Section IV, information management system is in charge of obtaining and managing data.The system/local level tools can locate the needed data files and extract them for their uses. We illustrate how the data may be used by the system/local level tools in the example below.

A. System Dynamic Stability Analysis

Dynamic stability analysis is a necessary tool for studying system behavior under major disturbances. It will tell whether the system can lose the stability before it moves to a new steady state operation point. Fig. 5 shows the framework how the dynamic stability analysis is performed. All the required data files are coming from the information management system which is discussed above.

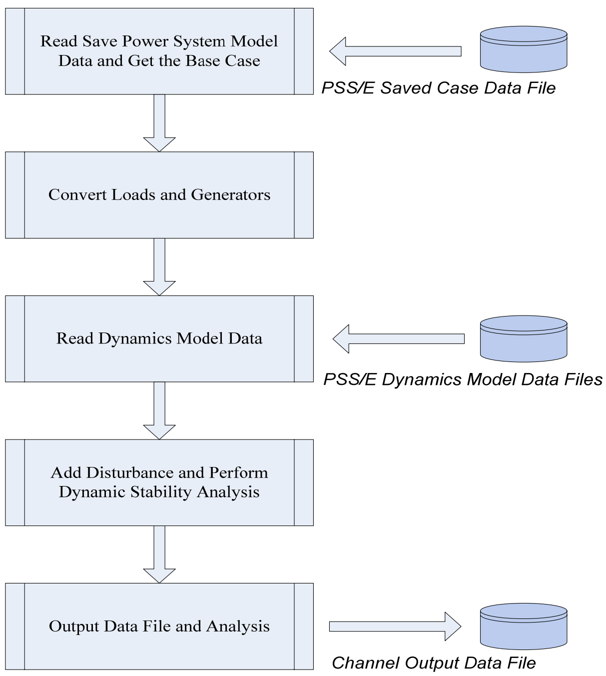

Fig.5 Framework of System Dynamic Stability Analysis

B. NNFDC Algorithm Evaluation

NNFDC algorithm needs large number of fault and non-fault cases to complete the process of training and testing for neural network tuning. Those training and testing cases are quite different for various transmission lines due to the selection of different simulation parameters and settings. To perform comprehensive tests, it may not be possible to acquire enough fault cases from the field. Alternative solution is to generate the needed data files by simulation. Fig. 6 shows a block diagram for the fault and non-fault scenarios generation program which is based on ATP/ATPDraw [23] and Matlab [24]. The power system of interest is first modeled in ATP/ATPDraw. Then User can define the desired fault or non-fault cases by initializing the simulation setting parameters in Matlab. The measured three-phase voltage and current samples, which could also include time label, are extracted in the data format files defined by user.

NNFDC algorithm can be evaluated based on the available data. The data from simulation can be used for training procedure, by which the parameters of neural network can be set. The data from recording equipments can be used to evaluate the algorithm.

VI. Conclusion

Based on the discussions presented in this paper, the following conclusions can be drawn:

- The data requirements discussed in detail for the new proposed approach for detecting and preventing the cascading events allow coordination of the system and local monitoring tools.
- The implementation approach of the information management system is capable of handling the required data integration from SCADA system with data from IEDs or add-on high speed data acquisition system, depending on the substation infrastructures.
- The information management system manages the obtained data and provides the needed data to different algorithms, which is an efficient method to handle the data integration from different sources.

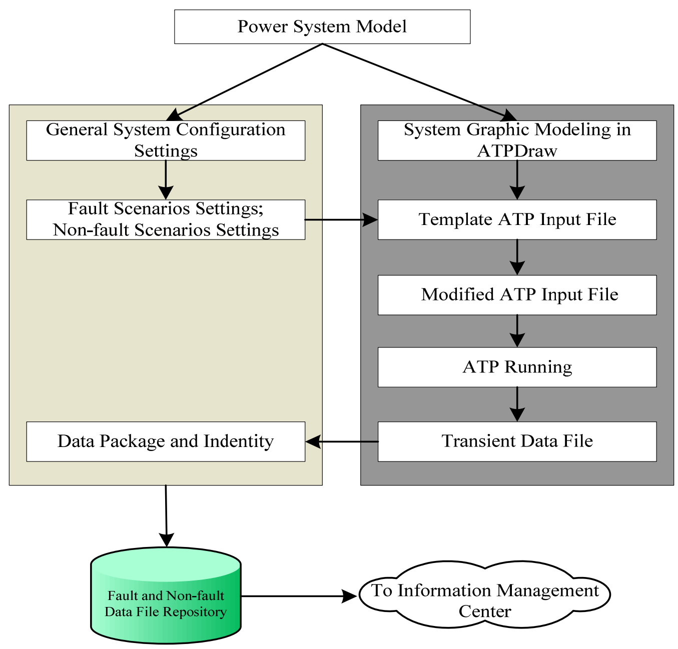

Fig.6 Block Diagram of simulation fault and non-fault scenarios generation

VII. Acknowledgment

The contributions to the developments reported in this paper that came from former graduate students Drs. S. Vasilic, N. Zhang, H. Song, and X. Luo are gratefully acknowledged.

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IX. BIOGRAPHIES

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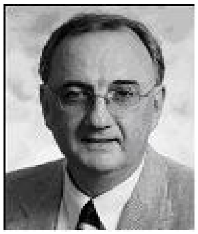

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