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Development of Automated Power Efficient and Load Modeling System Utilizing IEC 61850 File Transfer Service

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Abstract

Conventional load modeling methodologies consist of two existing approaches, which are the component based approach and the measurement based approach. The measurement based approach offers several advantages and can overcome certain limitations resulted from component based approach implementation. By using the measurement based approach, the load model parameters can be estimated using power system disturbance records. Automated disturbance record collection can be performed by utilizing IEC 61850, i.e. the international communication standard for substation and power utility automation. This paper presents the design and development of automated load modeling system utilizing IEC 61850 file transfer service. The system architecture was designed based on the centralized disturbance record concentrator for distributed recording devices. The system was developed to perform event triggered disturbance record acquisition, where IEC 61850 file transfer service was utilized for automatic disturbance record retrieval. The proposed system was tested to automatically retrieve disturbance records from three multivendor IEC 61850 compliant relays. It was found that the root directory for each relay are not standardized eventhough the communication is standardized according to IEC 61850. The proposed system was then tested and verified by simulating actual disturbance measurements into the relays. The system was able

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to automatically retrieve the disturbance records and perform a fairly accurate curve fit to the actual disturbance measurements based on the automatically generated load model parameters. The results are encouraging for the actual implementation and deployment of actual substations.

Keywords: Load Modeling; IEC 61850, File Transfer, Dynamic Model, Parameter Estimation.

1 Introduction

Conventionally, there are two load modeling methods that have been predominantly used in the electricity supply industry, which are the component based approach and the measurement based approach [1]-[3]. The component based approach requires bottom-up knowledge on the details from the aggregated load. This methodology requires the following information [1]:

- Load characteristics of typical load component
- Proportion of load components for each load class
- Composition of load classes in the aggregated load

The resulting load model from this methodology might be inaccurate since it takes into account a certain types of loads and it is not applicable to any changes in load due to factors such as consumer behavior, geographical location and weather [3].

The measurement based load modeling is a top-down approach, where the recorded power system disturbance were utilized to develop the load model [2]. This methodology can overcome certain limitations in component based approach since:

- It is simpler as it does not require detailed information on the load composition and the load classes
- The resulting load model is based on actual measurement at any specific location and time
- The resulting load model is generic and can be applied to any types of loads

In general, the steps required to perform measurement based approach are disturbance record collection, data processing and load model parameter derivation [4], [5]. An automated load modeling system is required to have the ability to systematically execute the above steps.

2 Material and Method

An automated load modeling system is a system that is able to perform load modeling and analysis based on defined inputs, and generate the load model parameters.

2.1 IEC 61850 And Disturbance Recording

As a prerequisite for measurement based approach, an automated load modeling system is required to retrieve disturbance recorded data from field devices such as relays, disturbance recorders and power quality recorders. A standardized communication solution is deemed required for seamless integration with the field devices.

As IEC 61850 is the communication solution, it is a vital communication standard for substation and power utility automation [6]. The three fundamental objectives of IEC 61850 are interoperability, flexible allocation of functions and future-proof. The standard ensures interoperability between multivendor devices through predefined data models and communication services over open communication technologies.

Actual substation equipment, devices, functions and information are virtually represented in IEC 61850. Based on object oriented modeling approach, the information is modelled and organized by functions (i.e. logical nodes), data objects and data attributes. The IEC 61850 logical nodes related to disturbance recorder function are shown in Table 1.

The RDRE logical node is essential in providing status, information and trigger the acquisition of required disturbance records. The two important and mandatory data objects in the RDRE logical node are:

- RcdMade – status for recording made
(TRUE = disturbance recording complete)
- FltNum – fault number

Table 1: IEC 61850 Logical Nodes for Disturbance Recorder

IEC 61850 Logical Nodes	**Description**
RDRE	Basic functionality for disturbance recording (acquisition)
RADR	Analogue channel for disturbance recording (acquisition)
RBDR	Binary channel for disturbance recording (acquisition)
RDRS	Disturbance record handling (for station level devices)

The communication services required for information exchange are specified in the Abstract Communication Service Interface (ACSI) as per IEC 61850 Part 7-2. The predefined communication service that can be utilized for disturbance record acquisition is the IEC 61850 ACSI file transfer model. This ACSI model contains specific attributes and services that facilitate the function for transferring disturbance records. The two important and related file transfer services are:

- GetFile service is used by a client to transfer the contents of a file from the server to the client
- GetFileAttributeValues service shall be used by a client to obtain the name and attributes such as timestamp and file size for a specific file in the server's file store.

2.2 System Design and Development

In general, an automated load modeling system is required to perform the following functions:

- Automated disturbance record acquisition from field recording devices
- Disturbance recording storage and management
- Data processing and load model parameter derivation

The system is designed to run on commercially available substation embedded computer. In the preliminary design stage, the hardware requirements were developed. Hardware that comply with IEC 61850-3 and IEEE 1613 standards were taken into consideration since the system is designed to be installed in substations. Adequate processing capability such as processor and random access memory (RAM) were specified to ensure that the system is capable of processing disturbance data and compute complex nonlinear optimization algorithm for the load model parameter derivation.

2.3 Automated Disturbance Record Acquisition and Storage

The system was designed and developed based on centralized disturbance record concentrator architecture for disturbance recording devices (i.e. relays) as proposed in [7], [8]. The conceptual architecture is shown in Figure 1. The system architecture is scalable, which allows for future addition of relays, intelligent electronic devices (IEDs), power quality devices or other disturbance recording devices that are compliant to IEC 61850.

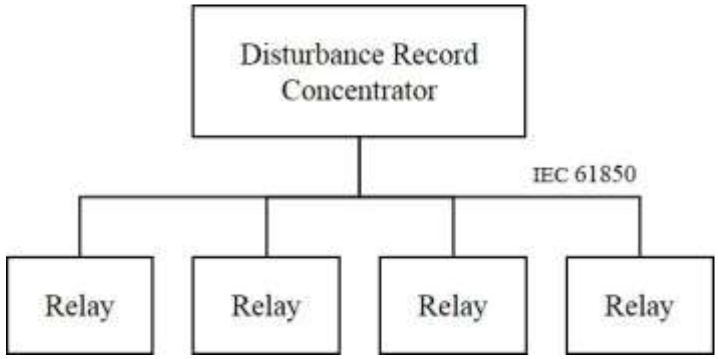

Figure 1 Conceptual Architecture For Centralized Disturbance Record Concentrator For Distributed Recording Devices (I.E. Relays)

There are two methods of retrieving disturbance records by utilizing IEC 61850. The methods are status polling for disturbance record acquisiton and event triggered disturbance record acquisition. The status polling method is where the client repeatedly request the status of new disturbance record based on specific time interval. This method is inefficient and introduces additional network traffic into the communication bus. The event triggered disturbance record acquisition is where the server reports to the client whenever there are new disturbance records available for retrieval. Automated load modeling system that was designed and developed based on the event triggered disturbance record acquisition approach. The sequence diagram proposed in [9] was implemented and shown in Figure 2.

Based on the sequence diagram in Figure 2, the following actions were executed for a successful event triggered disturbance record acquisition.

- The disturbance recording in the server device was initiated by a predefined trigger. In this paper,undervoltage function where voltage change of more than 0.1pu was implemented as the predefined trigger.
- Disturbance recording starts. If supported, the server sends the message “Recording Started” (i.e. RDRE/RcdStr) to the client.
- Upon disturbance recording completion, the server sends the information “Recording Made” (RDRE/RcdMade) and “Fault Information” (RDRE/FltNum) to the client.
- The client requests for the new disturbance record via IEC 61850 ACSI file transfer service (i.e. GetFile)
- The server sends the requested disturbance record to the client
- The client saves the disturbance record and stores it in the local storage memory.

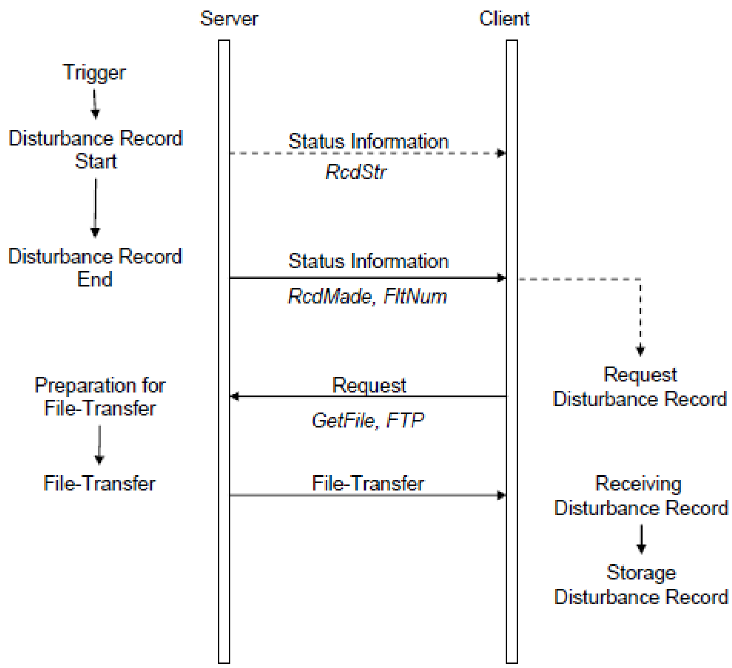

Figure 2 Sequence Diagram Of Event Triggered Disturbance Record Acquisition Utilizing IEC 61850 Communication Service [9]

Systematic disturbance record management was ensured through standardized file naming convention. Upon disturbance file retrieval, the disturbance records were renamed according to the IEEE C37.232 COMNAME standard [10]. The fields for the file naming convention are shown in Figure 3. The disturbance record handling was designed and developed based on the First-In-First-Out (FIFO) file handling sequence to ensure a smooth operation throughout the system lifecycle.

Start Date, Start Time, Time Code, Station ID, Device ID, Company Name

Figure 3 IEEE C37.232 COMNAME File Naming Convention [10]

2.4 Data Processing And Load Model Parameter Derivation

An overview of the data processing and conversion component of automated load modeling system is shown in Figure 4.

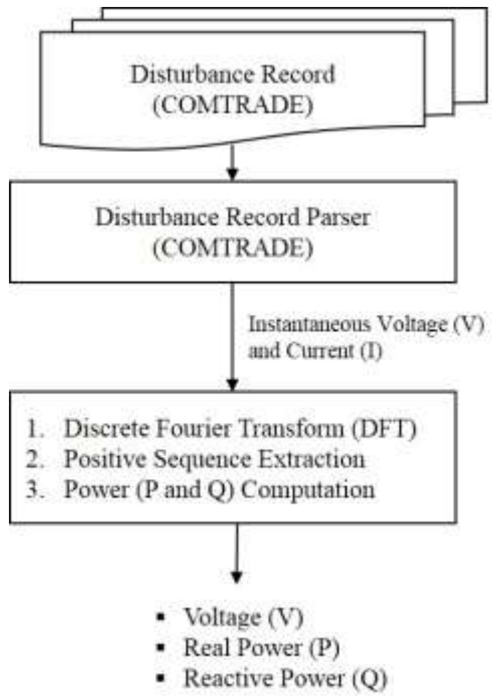

Figure 4 Process Flow For Data Processing And Conversion

The system was specifically developed to parse disturbance record that complies with IEEE C37.111 COMTRADE standard format [11]. The standard defines a format for files containing disturbance waveform and event data collected from power systems. The format consists of two mandatory files, which are the configuration file (*.CFG) and the data file (*.DAT). The configuration file (*.CFG) contains information such as station name, conversion factors, sampling rate and trigger time. The data file (*.DAT) which can either be in BINARY or ASCII format, contains the actual disturbance data samples. The Disturbance Record Parser as shown in Figure 4, was developed to integrate and merge the (*.CFG) and (*.DAT) files. The output was the instantaneous voltage and current measurements based on the conversion factors specified in the (*.CFG) file. Discrete Fourier Transform (DFT) was applied to extract the fundamental frequency (i.e. 50 Hz) component of the disturbance waveform. Positive sequence and power computations were then performed to obtain voltage (V), real power (P) and reactive power (Q) samples required for the load model parameter derivation process. The overview of the load model parameter derivation process is shown in Figure 5.

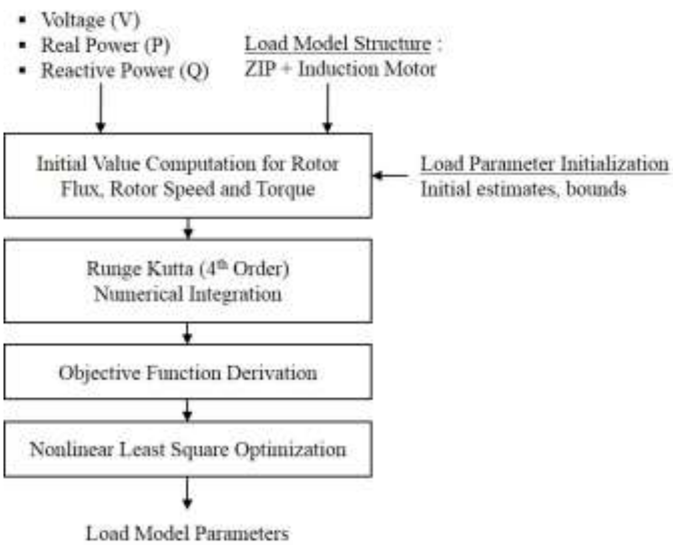

Figure 5 Process Flow For Load Model Parameter Derivation

The ZIP with Induction Motor (IM) as proposed in [2], [4]. [5] and [12] [13,14,15]was implemented for the automated load modeling system. The ZIP load model consists of constant impedance (Z), constant current (I) and constant power (P) components. The Induction Motor (IM) load model mainly represents the dynamic part of the load. A third order IM model was implemented in the system. The ZIP with IM is a complex load model where initial estimates and bounds for the load parameters are required in order to derive and estimate the load parameters. Runge Kutta (4th order) numerical integration was implemented to solve differential equations introduced by the third order IM load model. The objective function was derived and nonlinear least square optimization was applied to determine the best fit between the actual measurements and the predefined load structure with the estimated parameters. The Trust-Region Reflective algorithm was implemented for the nonlinear optimization using MATLAB Optimization Toolbox.

3 Results and Discussion

The automated disturbance record acquisition component of the automated load modeling system was verified in a controlled environment using three IEC 61850 compliant multivendor relays. Actual test setup was prepared at System Verification and Simulation (SVS) Laboratory at TNB Research [8], as shown in Figure 6. The proposed test setup requires the integration of the developed system with multivendor relays, as shown in Figure 7.

Figure 6 Actual Test Setup At SVS Laboratory, TNB Research

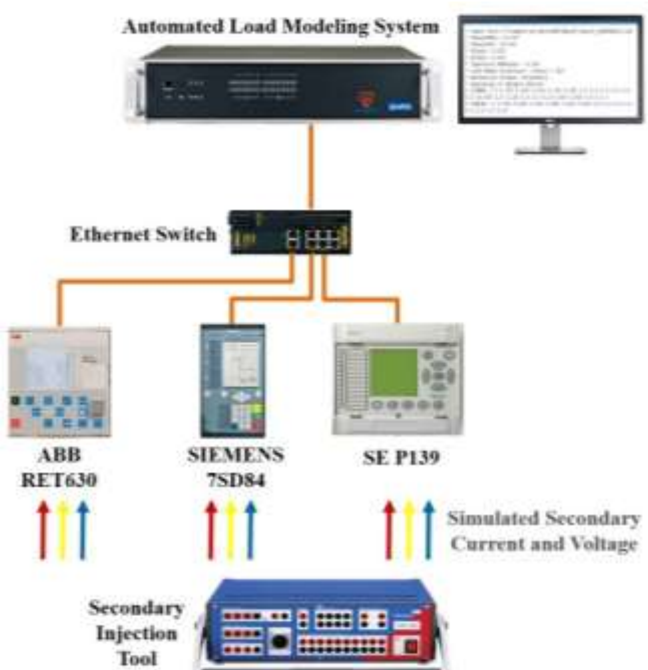

Figure 7 Test Setup For Automated Disturbance Record Acquisition

The developed system is able to automatically retrieve disturbance records by utilizing IEC 61850 standardized file transfer service. However, it is found that the root directory of the disturbance record for each relay is not standardized. The different root directories are listed in Table 2.

Table 2 Root Directory for Disturbance Records

Relay	Root Directory
ABB RET630	= (None)
SIEMENS 7SD84	\ = (Backslash)
SCHNEIDER ELECTRIC P139	. = (Dot)

It is important to take note that the relays utilized are IEC 61850 Edition 1 compliant, therefore the standardized and predefined "/COMTRADE/" root directory in IEC 61850 Edition 2 may not be implemented within these relays.

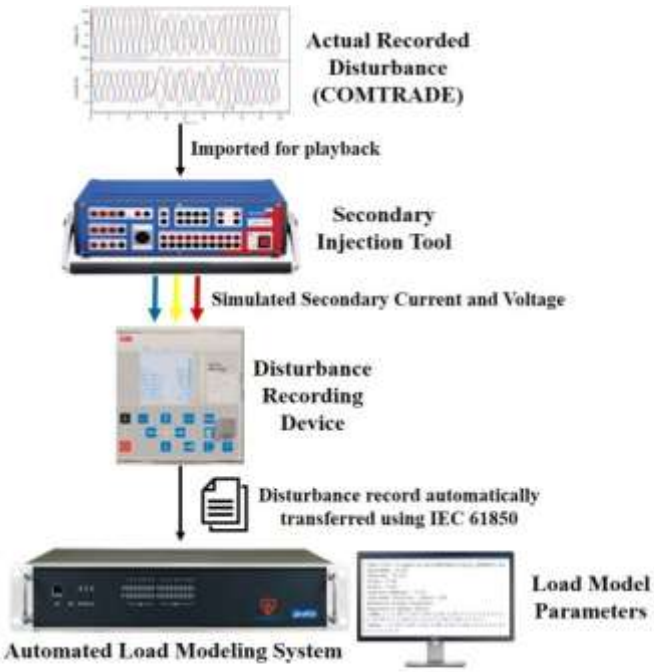

Figure 8 Test Setup For Automated Load Modeling System

The automated load modeling system is then tested and verified using the test setup shown in Figure 8. Actual disturbance records in comma-separated values (*.CSV) were obtained from field power quality recorders in existing substations [12]. The actual disturbance is imported for playback using a secondary injection tool. The simulated current and voltage were then injected to the relays in order to trigger a new disturbance record.

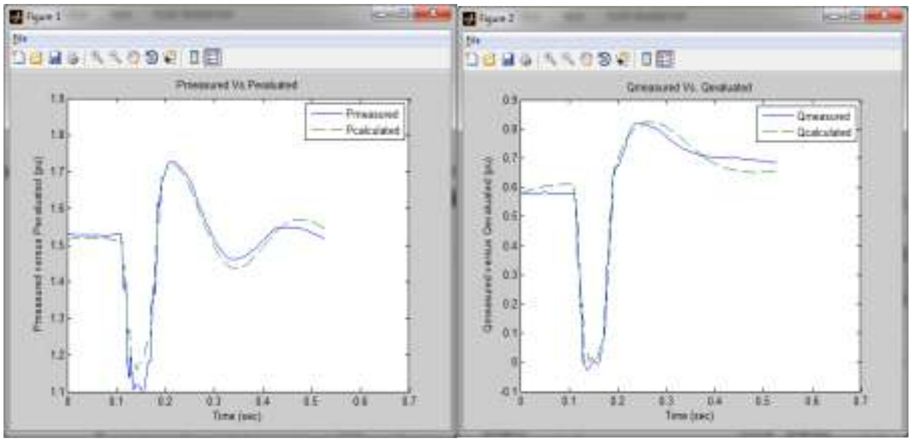

Figure 9 Curve Fit For Real Power And Reactive Power Respectively Using Actual Disturbance

The disturbance record was automatically retreived and analysed by the automated load modeling system. The developed system was then able to perform a fairly accurate curve fit to the actual disturbance measurements (as shown in Figure 9) within a few minutes based on the automatically generated load model parameters (as shown in Figure 10).

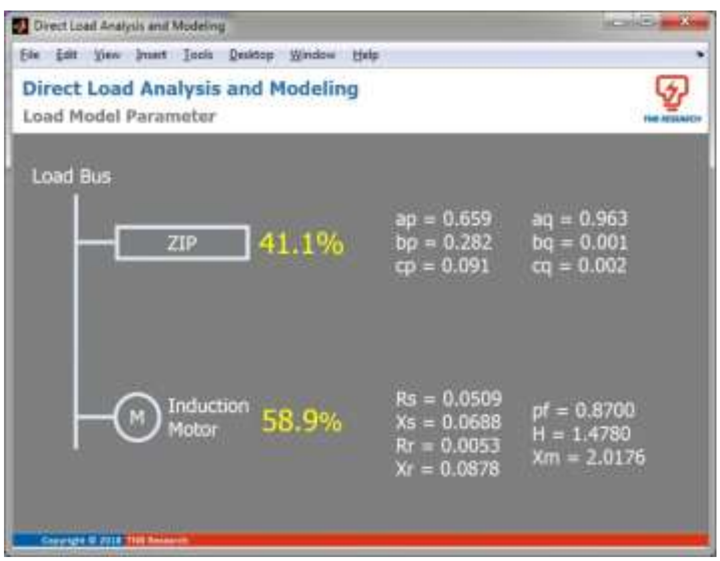

Figure 10 Load Model Parameters Generated From The Automated Load Modeling System

4 Conclusion

This paper presents the development of automated load modeling system by utilizing IEC 61850 file transfer service. The developed system was successfully tested and verified with multivendor relays by using simulated secondary injection based on actual disturbances in the field. The results are encouraging for the actual implementation and deployment into actual substations. In summary, the contribution of this paper are as follows:

- Development of event triggered disturbance record acquisition by utilizing IEC 61850 file transfer service for automated load modeling system
- Demonstration and verification of automated load modeling system with actual recorded power system disturbances

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