

An Advanced Alarm Processor using Two-level Processing Structure

Y. Wu, *Student Member, IEEE*, M. Kezunovic, *Fellow, IEEE* and T. Kostic, *Member, IEEE*

Abstract-- With the growth of system complexity, dispatchers are often overwhelmed with system alarms. This situation requires that an alarm processor be developed to help the dispatchers recognize the nature of the disturbances. Many existing alarm processors lack the ability to analyze complex events efficiently within a time constraint. This paper presents a new processing structure for the alarm processor. The proposed alarm processor is implemented both at the substation automation system (SAS) and the energy management system (EMS) level. The SAS level is able to obtain more accurate analysis of substation-wide events using extra substation measurement data that are not available at the EMS level. The EMS level correlates events from different substations to generate system-wide scenarios. Test results show the effectiveness and correctness of the proposed alarm processor.

Index Terms—intelligent alarm processing, energy management systems, substation automation systems, alternative transient program.

I. INTRODUCTION

IT is very important to examine power system disturbances associated with abnormal system conditions. Despite today's increased use of automation, dispatchers still play a significant role in modern energy management systems (EMS). With the increase in system complexity, the dispatchers are often overloaded with alarm messages generated by the system [1]. Alarms are typically generated in power system control centers any time one of two categories of events happens [2]:

- An analog value measured by a transducer passes an operating constraint, e.g., an overload in a transmission line, an under-voltage or an over-voltage at a bus.
- A digital status value changes state, e.g., the opening or closing of a circuit breaker, or the detection of an excessive temperature in a transformer.

A major power system disturbance could trigger hundreds of thousands of individual alarms and events, clearly beyond the capacity of any dispatcher to handle [3]. From a survey of 87 electric companies [2], the largest complaints from dispatchers are that there are too many alarms during a

disturbance, there is a lack of prioritization in alarms, and too many alarms arise from communication errors. The same problems, unfortunately, seem to persist for more than a decade, as another survey of 36 electric companies reports in [4].

Nowadays almost all supervisory control and data acquisition (SCADA) systems employ intelligent alarm processing (IAP). The job of an intelligent alarm processor is to analyze thousands of alarm messages and relate the messages to the specific network events. More specifically, the intelligent alarm processors are developed to meet the following needs [5]:

- Reduce the number of alarms presented to the dispatcher;
- Convey a clearer idea of the power system condition causing the alarms;
- Recommend corrective action to the dispatcher if such action is needed.

The concepts of filtering and suppressing alarms have been used in many practical systems [6], i.e., alarms are prioritized and processed before being presented to the dispatcher.

A number of attempts to build knowledge-based alarm processing systems were made due to the symbolic nature of the reasoning associated with alarm processing. A substation level logic-based alarm analyzer targeted to the Italian power system ENEL was developed in [7]. A model-based transformer alarm processor was developed in [8]. An intelligent alarm processor SPARSE was proposed in [9] to assist dispatchers in control centers to interpret enormous quantities of alarm messages during incidents. "Smart One" is another example of an IAP that is currently used in a control center [10]. Many of the knowledge-based systems (KBS) suffer from the slowness in analysis, which restricts the depth that the analysis can go into and the amount of useful information that helps the dispatchers.

This paper presents an advanced alarm processor that combines alarm processing techniques at both the substation automation systems (SAS) and the EMS level. The SAS level alarm processor aims at more accurate analysis of substation-wide events using the extra substation measurement data that are not available at the EMS level. The EMS level alarm processor emphasizes the idea of correlating events from different substations to generate system-wide scenarios. Section II discusses the overall software structure and simulation environment for the proposed alarm processor. Section III presents the descriptions and algorithms of the

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two-level alarm processing. Results and discussions are listed in section IV and conclusions are provided in section V.

II. SOFTWARE STRUCTURE AND SIMULATION ENVIRONMENT

The alarm processor proposed in this paper includes two modules, one at the substation and one at the system level respectively. A two-level structure is introduced to effectively use the enormous amount of data available at the substation automation system (SAS) level. Not all that data are directly transmitted to the control center, instead, local processing at the computers in substations is carried out and the results of such analysis are transmitted to assist the energy management system (EMS) level alarm processor.

The proposed alarm processor is developed using a simulation environment as shown in Fig. 1. The simulation environment aims at simulating what typically exists in EMS and SAS systems (shown on the left side), and having the proposed new processing as natural extensions (shown on the right side). The *substation measurement data simulator* is developed using ATPDraw software [11] and Java program code to simulate the IEEE 14-bus system. The results of the data simulator are data files in common format for transient data exchange (COMTRADE) [12]. The simulation results go into the *RTU data simulator*, which generates snapshots of the phasor values of the analog measurements and the status values of the digital measurements. These values are processed by the *alarm simulator*, which detects over-limit values or changes of status and creates alarm messages. In this context, the alarm simulator represents the combined role of data acquisition and basic alarm processing at control centre. The alarm messages are then passed to the *EMS-level alarm processor*, where important alarms indicating a contingency are filtered out and suspicious substations involved are identified. A command is then sent to the corresponding *SAS-level alarm processors* requesting further investigation of the

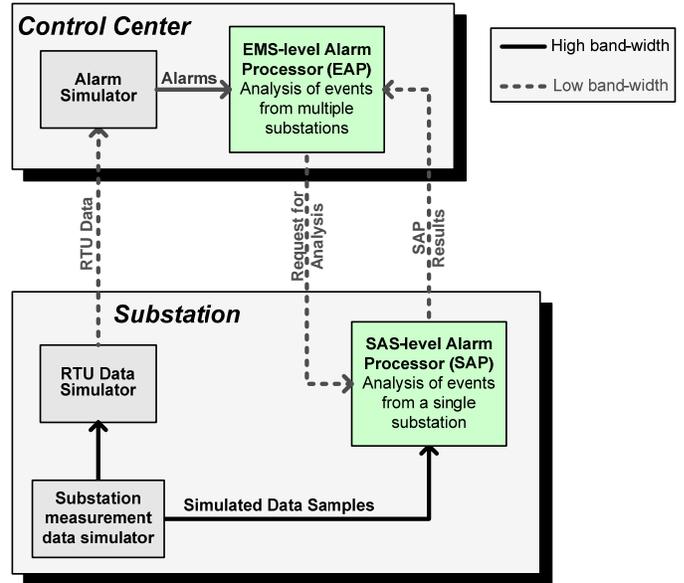


Fig. 1. Overall software structure.

substation measurement data. The SAS-level alarm processor analyzes the COMTRADE files created by the substation measurement data simulator and sends back its conclusions to the EMS-level, where information from multiple substations is merged and system-wide scenarios are analyzed.

The modules that create the simulation environment for the proposed alarm processor will be introduced below.

A. Substation Measurement Data Simulator

ATPDraw was used to create input file for the Alternative Transient Program (ATP). Fig. 2 displays the overall configuration of the IEEE 14-bus system that was used for simulation. Model objects were grouped and compressed to create a clearer view of the network configuration. For convenience, per unit values (as appear in the standard IEEE

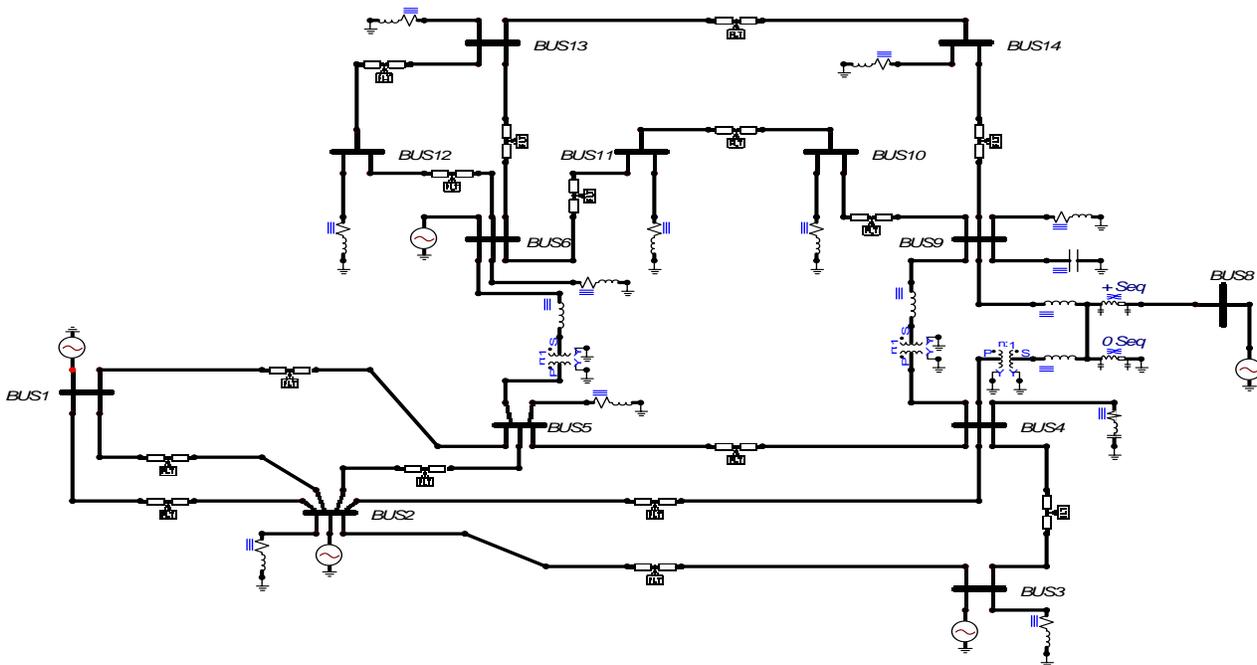


Fig. 2. The IEEE 14-bus system model in ATPDraw.

14-bus system data) were used. The following assumptions and approximations were made during the modeling:

- Substation circuit breaker (CB) configurations were arbitrarily chosen;
- Ideal voltage sources were used to replace the slack bus and PV buses;
- Static RLC branches were used to represent the load;
- Zero-sequence impedances of branches were estimated according to their positive-sequence values;
- Transformers were assumed to be in Y-Y or Y-Y- Δ connection (with neutral node grounded).

B. RTU Data Simulator

The Remote terminal unit (RTU) data simulator extracts data with low sampling rate from the ATP simulation results, and then feeds this data to the alarm simulator.

In a real-world situation, a supervisory control and data acquisition (SCADA) application gathers measurement data from RTUs either by polling the present values from the measurement devices, or by receiving report-by-exception messages from RTUs when there is an event, such as state changes, values exceeding some threshold, etc. [13]. In this study, the RTU data simulator is designed to work as if being polled by the SCADA at a fixed rate of once per second while generating data whenever there is an exception for immediate response.

Both steady state situation and disturbances can be simulated by the RTU data simulator. The steady state situation can be simulated by running a case without any switching events in the ATP model. The disturbance data may be obtained by assigning certain switching activities in the ATP model.

C. Alarm Simulation

The alarm simulator uses data generated by the RTU data simulator, analyzes the data, and then generates an event report with timestamps.

The function of the alarm simulator is to prompt alarm messages when there is a status change or when some values exceeds the preset thresholds.

Three types of alarms are provided by the alarm simulator:

- Changes of status associated with a CB. These alarms are triggered by the opening or closing of CBs.
- Over-limits associated with a current transformer (CT). These alarms are triggered whenever the current magnitude level crosses settings designating normal, over-current or near zero conditions.
- Over-limits associated with a voltage transformer (VT). These alarms are triggered whenever the voltage magnitude level crosses settings designating normal, over-voltage or under-voltage conditions.

III. TWO-LEVEL ALARM PROCESSING

This paper emphasizes the idea of utilizing data recorded by individual intelligent electronic devices (IEDs) to help analyzing transmission line faults and CB switching events. Unlike the existing approaches that only interpret raw alarm

messages using a set of rules, this paper expands the source of information by looking into IED data in the substations, which are not available in the alarms. By doing this, more comprehensive conclusions can be obtained.

The two-level alarm processing structure consists of the EMS-level and the SAS-level.

A. EMS-level Alarm Processor (EAP)

The purpose of the EAP is to analyze events from multiple substations and try to conclude what has happened during a system-wide disturbance that involves different substations. The EAP obtains inputs from multiple substations. Two types of inputs are obtained: the alarms from the alarm simulator and the SAS-level alarm processing (SAP) results. Data from different sources are compared and the timestamps are synchronized when there are corresponding reports for the same event with slightly different timestamps.

The first task of the EAP is to find those alarms that are important and need to be analyzed. The following alarms are considered important:

- Changes of status alarms associated with a CB. These alarms might indicate a transmission line fault and further investigation is needed.
- Over-current alarms associated with a branch. These alarms indicate an abnormal power flow condition on a transmission line, which is likely caused by a short-circuit fault.

The EAP searches through the alarms for alarms in the above categories. Once any of these alarms are spotted, the EAP will decide what substations are suspicious to have a fault. It then sends a command to the SAS-level alarm processors in those suspicious substations, requesting the SAS-level alarm processing results. The intra-substation data are processed by the SAP separately in each substation (see III.B), and the results are pulled by the EAP to form complete analysis results for a multi-substation scenario.

The output of the EAP contains multiply entries. Each entry consists of four parts: 1) Timestamp; 2) Analysis result; 3) Suggested actions; 4) Additional information. The timestamp of an entry is the same timestamp from the alarm that is associated with this entry. If there is more than one alarm of the same type associated with the entry, then the earliest timestamp among all these alarms will be used (and consequently, the later alarms suppressed). The analysis result lists the conclusion of scenario that the EAP obtains and the suggested actions provide the dispatcher with choices for corrective actions. A more detailed layer of information is copied from the SAS-level alarm processing results. The EAP searches through the results of all the SAPs that it polls to see if any associated record can be found. If more than one SAP records can be found around the same timestamp, the EAP needs to consolidate multiple records into one entry.

The algorithms of the EAP are discussed below based on the source of alarms that are associated.

1) *CB status change alarms.* Whenever a CB's open/close status changes, the EAP receives an alarm. The EAP needs to look back to see if there are analog measurement alarms around that time. It also needs to look up which substation this CB belongs to. It then notifies the SAP in that substation,

asking it to gather data recorded from local IEDs, around the time of occurrence of the alarm. If such IED data are available and the SAP reports that the CB status change is due to a relay operation, then the operation is considered correct and no suggested action is provided. Otherwise, the CB status change will be considered as the result of a manual operation by a dispatcher, or a mis-operation. The categorization procedure of the cause of a CB status change is shown in Fig. 3.

2) *Over-current alarms*. When an over-current alarm is received, the device name of the CT that measures over-current is available from the information associated with the alarm. The analysis result part needs to report on which branch the over-current is found. If the over-current persists, the dispatcher needs to be instructed which CBs need be tripped in order to disconnect the branch with over current condition from the network. Which CBs need to be tripped can be obtained by analyzing the connectivity information of breakers and branches which is available to the EAP. All the CBs that connect any one end of the branch need to be tripped. Furthermore, the EAP needs to request the SAP to analyze whether a relay trip signal has been sent to the corresponding CBs and whether the CBs operated in time. The analysis procedure of the over-current alarms is shown in Fig. 4.

B. SAS-level Alarm Processor (SAP)

The SAP draws conclusions about what happened solely based on raw data from a single substation. This function is expected to be installed in the substation where local area network (LAN) is available, therefore large amount of IED measurement data (up to 100Mbps) can be retrieved in real-time.

The aim of the SAP is to dig out more information from the detailed measurement data. Since high-sampling-rate data are available, the SAP is able to draw conclusions more accurately than the conventional alarm processor at the EMS level, where those detailed data samples are not available.

The SAP mainly analyzes the correlations between analog

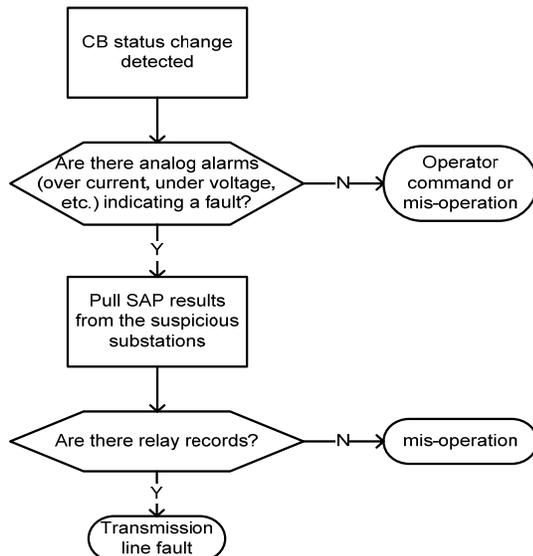


Fig. 3. Categorization of the cause of a CB status change.

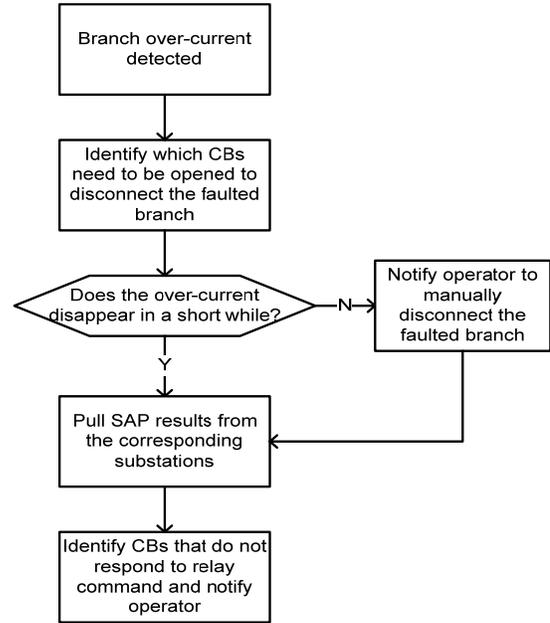


Fig. 4. Analysis procedure of the over-current alarms.

measurements and the corresponding status measurements or signals, and then infers the cause-and-effect relationships between the changes in these measurements [14, 15].

Similar to EAP, the output of the SAP also contains multiple entries. Each entry consists of three parts: 1) Timestamp; 2) Analysis result; 3) Suggested actions. The size of the result file is controlled such that it can be transmitted to the EMS through low-bandwidth communication media.

The execution of SAP is triggered by commands from the EAP. Currently, the following two algorithms are used to trigger the analysis of SAP.

1) *CB status change alarms*. When the SAP is initiated by EAP due to a CB status change alarm, EAP has also found corresponding CT/VT alarms that indicate a potential transmission line fault. The SAP needs to retrieve the substation IED data that relate to the CB and transmission line in question. If such records exist, the SAP then looks into the IED data to figure out whether the CB status change is due to a transmission line fault followed by a relay operation, or to a mis-operation of the CB. Upon being initiated by EAP, the SAP needs to look backward to search for the corresponding trip/close signal that causes the status change of the CB. If no such trip/close signal can be found within a predefined time period (e.g., 0.5 second), a mis-operation and security violation will be reported in the “analysis result”, and maintenance request will be added to the “suggested actions”. Otherwise, the CB will be considered to have operated correctly and no Suggested Action will be added.

2) *Over-current alarms*. When the SAP is triggered by the EAP because of over-current alarms, the SAP needs to verify whether a relay has detected an in-zone fault and sent trip signal to corresponding CBs. If the SAP is unable to find a CB status change within a predefined time period (e.g., 0.5 second), the conclusion that the CB’s opening is delayed will be reported in the “analysis result”, and maintenance request will be added to the “suggested actions”. Otherwise, the CB

will be considered to have operated correctly and no suggested action will be added.

IV. RESULTS AND DISCUSSIONS

A. Test Results

Fig. 5 shows the detailed substation configuration diagram for Substations 6 and 13 in the IEEE 14-bus system ATP simulation model. Branch 0602-1305 connects the two substations. Three current sensors (CT1301, CT0601 and CT0602) are placed in these two substations and their measurement data are made available to the EMS level by the RTU data simulator. It is assumed that digital relays capable of recording relay signals are available in both Substation 6 and 13 and these relay signals are simulated by the substation measurement data simulator. The following events are simulated:

1. A three-phase fault occurs in the middle (50%) of branch 0602-1305 on Mar 01, 2007 at 00:00:01.000.
2. Transmission line relays in both substations successfully detect the fault and issue trip signals to corresponding CBs 0.1 second later.
3. CB0601 opens immediately. CB1304 does not open.
4. Breaker-failure relay in Substation 13 then issues trip signal to CB1301 after 0.5 second.
5. CB1301 opens immediately and branch 0602-1305 is disconnected.

Tables I shows the simulated alarms messages from Substation 6 and 13. The result of the EMS-level alarm processor is shown in Table II.

It can be seen that the proposed alarm processor successfully explained to the dispatcher that over current condition appeared on branch 0602-1305 and the branch was later disconnected by relays. It also pointed out that CB1304 did not open successfully to disconnect the branch and maintenance of CB1304 is recommended.

The report to the dispatcher is organized in such a way that a brief explanation of the scenario is presented first. If needed, the dispatcher may then choose to see the additional information from the SAP.

B. Discussions

A preliminary study of a two-level alarm processor has been proposed in this paper. The two-level alarm processor works on a simulated power system using ATP. Although a real-world implementation is yet to be developed, the applicability issue of the proposed method has been taken into account.

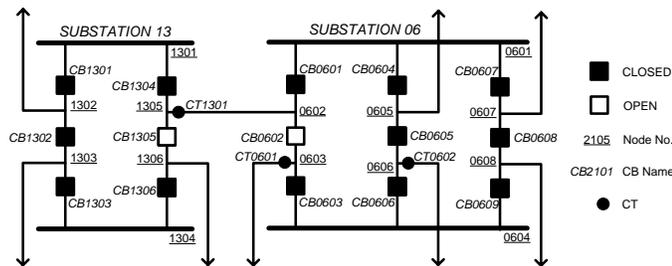


Fig. 5. Diagrams of Substation 6 and Substation 13 in the IEEE 14-bus system.

TABLE I
ALARM MESSAGES FROM THE ALARM SIMULATOR

#	Timestamp	Location/ Device	Description
1	Mar 01, 2007, 00:00:01.007	CT1301	Over current detected.
2	Mar 01, 2007, 00:00:01.008	CT0601	Over current detected.
3	Mar 01, 2007, 00:00:01.108	CB0601	Circuit breaker opens.
4	Mar 01, 2007, 00:00:01.508	CB1301	Circuit breaker opens.
5	Mar 01, 2007, 00:00:01.508	CT1301	Current returns to normal level.
6	Mar 01, 2007, 00:00:01.508	CT1301	Current is near zero.
7	Mar 01, 2007, 00:00:01.517	CT0601	Current returns to normal level.

TABLE II
OUTPUT OF THE EMS-LEVEL ALARM PROCESSOR (INCLUDING ADDITIONAL INFORMATION FROM SAP)

Timestamp	Mar 01, 2007, 00:00:01.007		
Analysis Result	Fault detected on branch 0602-1305. Branch 0602-1305 is disconnected by opening CB0601, CB1301.		
Suggested Actions	CB1304 needs to be maintained.		
	Timestamp	Analysis Result	Suggested Actions
Additional Information (From SAP)	Mar 01, 2007, 00:00:01.000	Fault detected on branch 0602-1305.	(none)
	Mar 01, 2007, 00:00:01.100	Relay issues trip signal to CB0601.	(none)
	Mar 01, 2007, 00:00:01.100	Relay issues trip signal to CB0602. CB0602 is already open.	(none)
	Mar 01, 2007, 00:00:01.100	Relay issues trip signal to CB1304. CB1304 does not open.	CB1304 needs to be maintained.
	Mar 01, 2007, 00:00:01.100	Relay issues trip signal to CB1305. CB1305 is already open.	(none)
	Mar 01, 2007, 00:00:01.108	CB0601 opens.	(none)
	Mar 01, 2007, 00:00:01.500	Relay issues trip signal to CB1301.	(none)
	Mar 01, 2007, 00:00:01.508	CB1301 opens.	(none)

1) *Differences from existing methods.* The most important difference of the proposed alarm processor from the existing ones is its idea of looking into substation IED data for the reasoning. Most existing alarm processors use different approaches to suppress the number of alarms prompted to the dispatcher and analyze the sequence of events based on the information available in the alarm messages. Although many alarms are recorded in the control center during an event, they are usually received independently from different measuring devices and the correlation of different alarms to a specific event often imposes a hard task. By creating a two-level analysis structure and using the substation IED data as a source of information, the analysis becomes much easier, mainly because the additional amount of information available.

2) *Data availability.* Nowadays more and more IEDs are being installed in the substations. Besides their own designed functions, these IEDs often record data that can be used for

other monitoring and control purposes. For example, an IED may be capable of recording event reports (a list of time-stamped logic operands in a chronological order) and analog and binary values similar to disturbance recorders and making it available in real-time.

3) *Time response issue.* Although the two-level alarm processing structure incurs delay in analysis due to the need of IED data retrieval and telecommunication, the length of delay is usually still acceptable. The initiation command of SAP and the data transmission of SAP results back to the control center are expected to take only a few seconds. While waiting for the results from SAPs, the EAP can show the preliminary analysis results done at the EMS level on time-sensitive alarms. After the SAP results arrive, it may replace the original simple alarms with a single one that gives the consolidated information on what happened.

V. CONCLUSIONS

This paper proposes a two-level advanced alarm processor. Compared to the current IAPs, the proposed alarm processor has the following advantages:

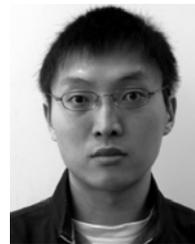
- The SAS-level alarm processor uses measurement data that are only available within the substation and therefore is more capable of recognizing the nature of disturbance in the substation.
- The EMS-level alarm processor relies largely on the results of SAS level alarm processor. Since most of the analysis work has been done separately at the substation level, the EMS-level alarm processor is efficient.
- Due to the two-level structure of the proposed alarm processor, more complicated analysis functions can be finished in reasonable time. The dispatchers are prompted with more useful and distilled information, including suggested actions to be taken.

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VII. BIOGRAPHIES



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