A Next Generation Alarm Processing Algorithm Incorporating Recommendations and Decisions on Wide Area Control

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***Abstract*— The number of alarms for a typical power system event may be overwhelming to power system operators and may delay the operator from taking appropriate corrective action. Worldwide, a number of alarm processing techniques are used to reduce the number of alarms that the operator 'sees', so as to better comprehend the situation at hand and make accurate decisions faster. This paper proposes an alarm processing algorithm that goes beyond the prioritization of alarms. The conceptual algorithm proposed has additional features that offer the operator recommendations and decisions for the event that has caused the alarms, as well as a feature that may execute controls if the event is non critical. In this sense, the proposal is a bridge from wide area measurement to wide area control systems.**

***Index Terms*— alarm processing, power system control, reactive power control, sensors, switched capacitors, transformer tap changing, wide area control systems, wide area measurement systems.**

I. INTRODUCTION

POWER system operators may encounter an overwhelming number of alarms due to system-wide events in their area of responsibility. These alarms can be a source of confusion for the operator, especially if the system events that have caused the alarms require immediate action. For example, a transformer fault can possibly have 150 alarm messages that are displayed in only two seconds [1]. The need for the development of alarm processing and prioritization algorithms has been recognized since the 1960s [2]. This need is even more pressing today due to the increased size and complexity of power systems, the interconnections between large geographical areas, and the deregulation of power systems which introduces complexity in the control decisions. As an example, under deregulation, transmission circuits may be operated at relatively high power levels more frequently in order to fully implement power marketing. These high levels of power transfer generally suggest that high speed and accurate operator actions are imperative. Further, there is a trend of performing wide area control and monitoring activities in a centralized fashion by having a small number of control centers [3].

A number of alarm processors have been developed and are in use today. Some examples include [4] and [5]. Alarm processors such as these provide a number of tools including alarm suppression, alarm prioritization, reduction of alarms on the basis of area of responsibility, and control recommendations to the operator. For example, De Souza et al. [6] present a methodology that combines the use of artificial neural networks (ANNs) with fuzzy logic to form alarm processing identification of faulted components. Inputs to the ANNs are alarm patterns while fuzzy relations are established to form a database employed to train the ANNs. Each neuron of the ANN is responsible for estimating the degree of membership of a specific system component into the class of faulted components. Results of an application on an actual system show that the proposed method allows for good interpretation of the results, even in the presence of corrupted alarm patterns.

Lin, Lin, and Sun [7] present fault detection and alarm processing in a loop system using a fault detection system (FDS). The FDS has an adaptive architecture with a probabilistic neural network (PNN). The training of the PNN uses the primary/backup information of protective devices to create the training sets. When the topology changes, the PNN can be retained and estimated effectively. Computer simulations were conducted to show the effectiveness of the proposed system. The basis of neural network solutions to alarm processing appears to be the recognition of events seen in a training set. In many cases, this approach is satisfactory when the training set spans a large range of operating scenarios.

Khosla and Dillon [8] introduce a generic neuro-expert system (GENUES) architecture for training neural networks in alarm processing. The GENUES architecture can be used to develop a real-time alarm processing system. The GENUES

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architecture has five phases; preprocessing, decomposition, control decision and post processing. The GENUES architecture addresses the issues of alarm reduction, case isolation, temporal reasoning, fast response time, and incomplete and noisy information.

McArthur et al. [9] discuss a model based reasoning application to system protection. Three main tasks are used in the decision support system: alarm processing, fault diagnosis, and comprehensive validation of protection performance. Alarm processing and fault diagnosis are achieved through the use of two knowledge based systems. Model based reasoning is applied to the comprehensive validation of protection performance. All of these are integrated with SCADA.

Considering the number of alarms for a given event scenario and the complexity of contemporary power systems, the next generation of alarm processing is expected to go beyond simple alarm processing in that the bridge to system control is suggested. Contemporary software tools for alarm processing include:

- Prioritization on the basis of area of responsibility
- Root cause identification of alarms
- Elimination of multiple alarms from the same cause
- Prioritization on the basis of a predetermined list of alarm weights of importance
- Prioritization on the basis of recency.

The next generation of alarm software may be able to provide power system operators with tools that have enhanced features that border on system control such as:

- Identification and recommendation of control actions
- Decision making assistance
- Actuation of controls.

A conceptual *automated* system that performs the above actions is presented in this paper. The term *autonomous* also applies to the concept in that separately designed agents are used to process and prioritize alarms, and these technologies are self-contained [10]-[12].

II. Concept of Alarm Processing Techniques

A next generation alarm processing tool is envisioned to be augmented with a number of additional features that make the life of the operator easier. Fig. 1 shows the main concept of an alarm processing unit (APU) that receives as inputs the incoming alarms and operator decisions or directives. The APU is expected to process and prioritize the incoming alarms, and to issue recommendations and decisions that will help the operator to overcome or alleviate the root cause of the alarm.

A necessary feature of an alarm processing tool is to allow it to implement some of its decisions in the form of controls. Possible control actions that the proposed tool may be allowed to perform are described in the next section. Since controls, recommendations and decisions will be made by the APU, it is necessary to have as additional inputs wide area measurements from the power system. The controls envisioned are in operational real time, and could be enabled or disabled by operators. The concept is to use the enabled mode as the default mode.

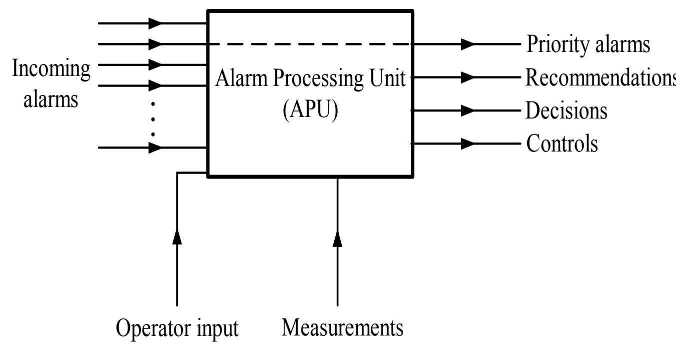

Fig. 1. An alarm processing tool with decisions, recommendations, and controls

The alarm processing unit needs to overcome a number of practical problems. These problems are [3]:

- Speed of operation of the system
- Time-stamping of alarms (e.g., delayed alarms, simultaneous alarms)
- Missing alarms
- Arrival rate of alarms
- Preprocessing and post-processing for the distinction of separate events when alarms arrive simultaneously
- Designing the area of responsibility for each sensor that sends the alarms (depending on the type of the alarm).

III. Automatic Wide Area Controls

The issue of allowing alarm processors to perform controls in the power system network has been discussed extensively in the past [1], [3] and it may be possible that certain alarm processors have that capability in some limited form or for some simple actions. Nevertheless, since the complexity of the power system is steadily increasing and since the computational time required with today's computers is decreasing, it is possible to design even more powerful alarm processors with additional features.

Some examples of simple control action that can be performed by an automated system are on-load tap changing and shunt reactor and capacitor switching. It is also possible for such a system to issue (limited) raise/lower signals to generators to improve the response of the system. A more optimistic control (and certainly a more serious one) is the ability of such a system to perform load shedding. Since this is a control with potentially wide implications, it may not be a fully automatic control, but rather a recommendation to the operator requiring approval. As more experience is gained using this system, this type of control may become an automatic control at a later stage. In most cases, the controls implemented utilizing wide area measurements as sensory inputs will be autonomous. That is, they are self standing and if they fail, the system utilizes the existing traditional controls.

A further comment on alarm processing for automated system control relates to the potential for the interruption of power marketing. Under deregulation, a fully enabled power market is highly desirable. Operators can not tolerate automation that falsely interrupts the marketing process. However, wide area controls, driven by wide area sensory signals, may also be viewed as controls that implement the power market by operation at operational maxima [13]. Obviously, like all other power system controls, decisions on when and if to implement are rarely made on the basis of a single consideration; rather, a range of considerations need to be assessed in control system designs. The automated control proposed here is similar to a special protection system (SPS) or a remedial action scheme (RAS) except to say that SPSs and RASs are generally designed with a single event in mind, rather than envisioning system wide operational conditions.

IV. Proposed Alarm Processing Algorithm with Wide Area Controls

Fig. 2 shows the proposed algorithm for a next generation alarm processing methodology enhanced by operating recommendations and wide area controls, based on the ideas presented in Fig. 1.

The incoming alarms are first pre-processed to distinguish significant alarms from isolated uneventful alarms such as temporary faults due to severe weather conditions (e.g. a transmission line temporarily comes into contact with a tree; the circuit breaker opens and then recloses). It should be noted, that all alarms (important or unimportant) are displayed either on the main screen or on a secondary screen so that the operator has a full view of the system status at all times. If the decision is to "reject" an alarm, there is a time delay associated with that decision in order to make sure that no other incoming alarms are related to this alarm. Further, the operator has the option to reject an alarm if by experience it is a redundant alarm. The subject of decision theory for large systems is addressed in [14].

In case that the alarm is not classified as a single, not significant alarm, then there is an important decision to be made. If the alarms are potentially critical, threatening the stability of the system, the alarms are displayed immediately in a prioritized manner so that the operator is aware of the situation. This ends the algorithm at this point, since the experience of the operator and the necessity to have a fast reaction to the event, necessitate action from the operator and possibly coordination with other control centers.

If the decision is that the alarms are not critical, but are serious, then the algorithm continues to process the information received and the alarms go through the alarm processing module of the algorithm.

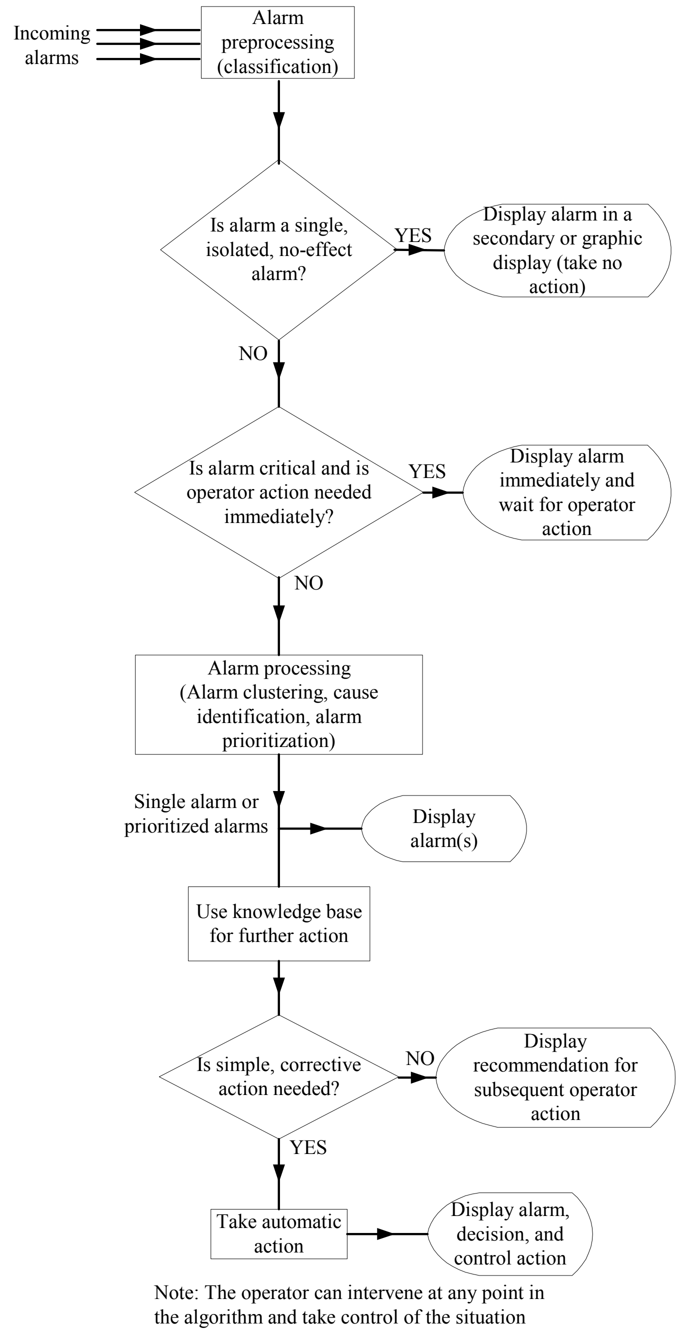

Fig. 2. A holistic alarm processing / decision-making / action-taking algorithm

The alarm processing module is the most important and complex component of the algorithm. The purpose of this module is to output less alarms than the ones that it receives so that it can aid in the identification of the root cause of the alarm and allow the next modules of the algorithm to make appropriate decisions and recommendations. The alarms received by this module are clustered based on a number of important principles such as the area of responsibility of the sensors that emitted the alarms. Redundancy is another important concept that this module should take into consideration when reducing the number of alarms. Two or more alarms may point to the same element that is involved in the event scenario and therefore, only one of these alarms needs to be processed. Further, a severity index needs to be used for each alarm so that prioritization can be achieved. The severity index may be an indicator of the amount of active power that is impacted by each alarm. One or more of the existing alarm processing algorithms that are either in use or proposed in the literature can be used for this module [4]-[9].

Other ideas for alarm filtering include:

- *Timed alarm suppression:* Each alarm is indexed with a duration value, and only long duration events are displayed. Temporary faults can fall into the "short events" category.
- *Knowledge based alarm suppression:* The alarms are linked through a network database. Each alarm is categorized as primary or secondary. The secondary alarms are then dropped if they are linked (caused) by the same event as a primary alarm. For example, a feeder locks out and sends endless alarms of low voltage and current to the operator. Since this is a single event, the secondary alarms may be dropped.
- *Alarm point priority filtering:* Each alarm is assigned a priority index; lower priority alarms are filtered out.

The one or more (prioritized) alarms that comprise the output of the alarm processing module are displayed on the main screen of the operator, while the rest of the alarms are displayed on a secondary screen. This is to keep the operator informed and allow him/her to intervene at any point and take the responsibility of handling the ongoing situation.

The prioritized alarms are then used as an input to the knowledge base module that will determine if and what further action needs to be taken. This is the end of the alarm processing procedure and the beginning of the control decision and implementation.

The knowledge base module needs to be aware of the current status of the system; therefore, current topological data and the most recent state estimator output need to be used as inputs to this module. The decisions of the knowledge base module (based on the alarms received) can be made either through heuristic rules, fuzzy logic, or neural network based techniques. One simple rule may be formulated as an IF-THEN rule,

IF ($|V_k|$ < 0.87 p.u.)
THEN (switch on all capacitors in area near bus k)

Significant work has been done in knowledge based expert systems for control and restoration in power systems [15]-[17].

Once the knowledge base module has determined the problem that has caused the event, it is necessary to decide the appropriate action to be taken. If there is an appropriate control to tackle the problem (a control that belongs to the group of the allowable automatic controls), then automatic action can be taken by the system. The decision and the control action are displayed next to the group of alarms that initiated this process. The operator can then verify the appropriateness of the control action taken and supplement it with further control actions if necessary.

On the other hand, if the control decision is not in the list of allowable automatic controls, then the alarm or group of alarms will be displayed along with a control recommendation to aid the operator in his/her decision.

The wide area control module of the alarm processing unit should be able to initiate automatic control actions for reactive support of the system. For example, one of the allowable control actions may be the switching of capacitor banks at different locations in the system. The alarm messages that, after the filtering process, indicate a low voltage magnitude in an area of the system, initiate the global control decision process of capacitor switching. In this process, capacitors that are on or near low voltage magnitude buses are switched on to raise the voltage level. The global control decision process may be so designed that all capacitor banks in an area are switched on if low voltage alarms are received from two or more busses in that area.

V. Conclusions

The concept of a next generation alarm processing algorithm augmented with control decisions and recommendations was presented and discussed in this paper. The addition of decision-making and action-taking modules or agents is significant for future alarm processing tools. This is the case since the enabling of automatic and autonomous controls for non-critical events offer the potential to improve power system response. It is important to carefully choose the allowable control actions and to guarantee that any automatic controls do not jeopardize the stability of the system. Considerations of retaining fully enabled power marketing are also an issue to be considered in control system design.

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