The Next Generation EMS Design

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SUMMARY

The concept of Supervisory Control and Data Acquisition (SCADA) system was introduced in the late sixties and subsequently the Energy Management System (EMS) solution with set of functionalities that relied on SCADA data was introduced in the seventies. This EMS design was based on the notion that power system goes through distinct states such as normal, alert, emergency and restorative, and hence the EMS functionalities need to support operators' ability to monitor the system behaviour as it goes through various operating states and make decisions to steer it back to the normal state. As the time went by, many things have changed in the area of power systems: introduction of the electricity markets to accommodate competitive trading, the growth of the power system infrastructure to meet demands for renewable resources, EMS technology to improve computations, communications and visualization. Hence, almost 50 years after the initial proposals for the EMS solution as we know it today, the question whether we need a new EMS design and if so, how the next generation EMS design is going to look like may be raised. While this is a complex question requiring analysis well beyond what may be achieved through a discussion in a single paper, there are a few requirements of the next generation EMS design that are becoming rather obvious. They revolve around three simple questions: a) can the operator's ability to monitor the system be improved and how, b) what are the requirements for the better decision-making tools for the operators and how such tools may be implemented, and c) how the design may evolve from the current legacy design to the stages of future EMS implementation. This paper is focused on trying to answer those three questions. The discussion is facilitated by using specific examples of the developments that the author was or is involved with. The examples include the discussion of spatial and temporal improvements in data management by merging operational and non-operational data, development of improved operator decision-making tools by better matching data and models, and introduction of a development and implementation strategy that relies on gradual transition from legacy to future design.

THE IMPACT OF FIELD DATA

The Intelligent Electronic Devices (IEDs) that have been introduced in the last decade have increased the amount of field-recorded data dramatically. They fall into three categories in terms of their operating modes and measurement properties:

- *Remote Terminal Units (RTUs)* support SCADA systems by performing scanning of measurement points every few seconds. They are typically reporting by exception and do not capture changes in the transient waveforms and fast-changing transitions in breaker contact statuses (autoreclosing sequences). The collection of data is not time-synchronized but rather scanned with analog measurements expressed typically as RMS values
- *Event Recording Devices (ERDs)* such as Digital Protection Relays (DPRs), Digital Fault Recorders (DFRs), Sequence of Event Recorders (SERs), and Dynamic Disturbance Recorders (DDRs) are tracking (sampling) changes in the waveforms and/or contact statuses very closely once the recording is triggered by an event. Their sampling rates are in the order of kHz and the sampling is time-synchronized across all measurement channels
- *Phasor Measurement Units (PMUs)* are high precision IEDs that sample waveforms and contacts at high sampling rate (several kHz) and then compute phasors and determine contact state. The sampling is time-synchronized via Global Positioning System (GPS) receivers, which allows time-correlation of measurements taken across large distances. The sampling is continuous and phasors are calculated and streamed to the final destination continuously.

The first question that needs strategic answer is how the mentioned devices and related data may impact the EMS functionality and ability of the operators to better track the system operating states and make decisions. The answer is rather obvious: instead of using such data in different measurement infrastructures developed for different utility/groups and purposes, all the data should be integrated into one data management system. Initially, this may involve just a software solution but down the road as the SCADA and EMS design evolve, certain hardware changes should also take place. An example of how the integration may take place is given in Figure 1.
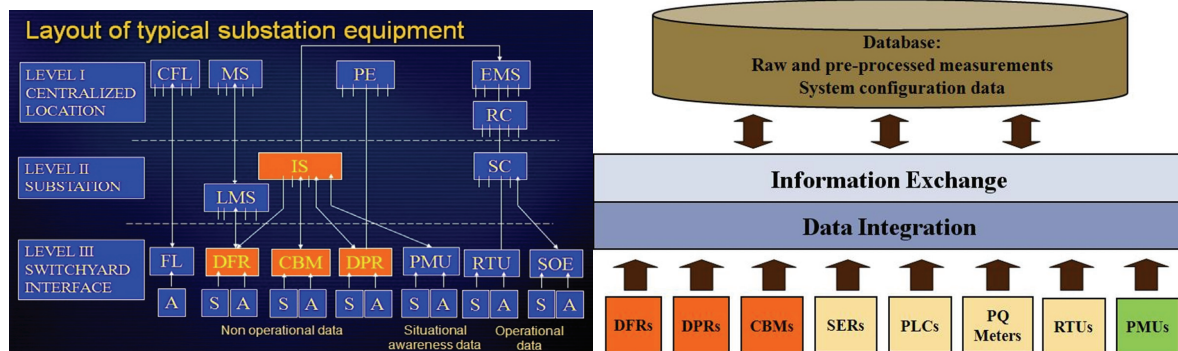

Figure 1. a) layout of IED infrastructure   **b) layout of IED data integration**

Figure 1 a) illustrates the different measurement infrastructures established for calculating fault location using Fault Locators (FL), recording events using Digital Fault Recorders (DFRs), Digital Protective Relays (DPRs), Circuit Breaker Monitors (CBRs), Sequence of Event Recorders (SOEs), and Remote Terminal Units (RTUs) of SCADA, and tracking voltage and current phasors using Phasor Measurement Units (PMUs). Figure 1 b) shows how the data integration may be done through a software solution.

Several applications that have been developed around this concept [1-5] reveal the following improvements in the operators' ability to track the system and make operational decisions:

- ***Topology Processor and State Estimation***. Essential function in an EMS solution is state estimation. It allows measurements to be "calibrated" against the system model. The crucial portion of the process is to accurately determine topology of the system, which is done through a topology processor. The improvements in state estimation may be obtained through a right "mix" of direct state measurements (voltage synchrophasors) and breaker status changes detected by ERDs. The substation state estimation to enhance topology determination process for the substations where the switching takes place is desirable [6].
- ***Risk-based Circuit Breaker Monitoring***. SCADA system typically collect "a" and "b" contacts from the breakers, and quite often the status signal is combined with some other status signals from switches to create virtual status signal. As the power system expands and grows in its complexity, determination of the topology will be absolutely crucial to correct operation. An ability to track CB control signals and develop a statistical method for determining the level of CB performance deterioration is a new capability not previously used in EMS solutions [7].
- ***Detection and Classification of Cascades***. Detecting and classifying cascades is not possible with existing EMS on-line tools. This was demonstrated with several major blackouts that were caused by cascading events that operators did not detect. Recent developments use combination of local and centralized assessments that lead to both detection and classification of cascades [8]. This is achieved by using integrated data concept discussed in this section. Hence the impact of using integrated field data on implementing functions is demonstrated.

In summary, the impact of field data is quite significant and the opportunities for EMS design improvements based just on that concept are quite substantial. The remaining questions is how to incorporate such solutions into the future EMS design. One point of caution: the continuation of the deployment of independent SCADA, ERD and PMU infrastructures is unsustainable due to cost of infrastructure, equipment maintenance, operator training, and data integration. To reduce the cost and improve performance, EMS solutions will have to result in a new design of an integrated data acquisition and management infrastructure going forward.

MATCHING DATA AND MODELS

With the increase in data volume and quality, the question opens whether the decision making process that operators go through can gain any benefits from this data improvement. Recent studies have shown that the process of matching data to hypothesis models at various levels of complexity can help the decision making process [9]. In such cases the decision making process is enhanced with cause-effect analysis embedded in the match between the data and model. This process of extracting knowledge from data, often termed Data Analytics, is shown in Figure 2. (data management) and Figure 3 (type of data that may be processed)
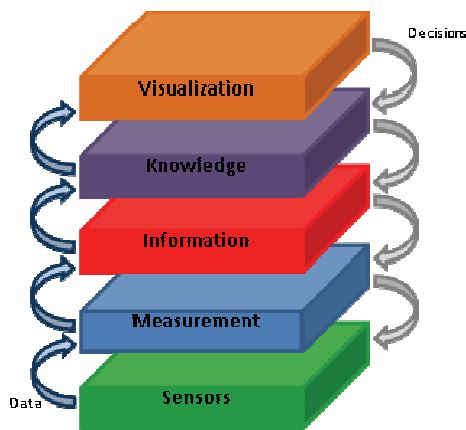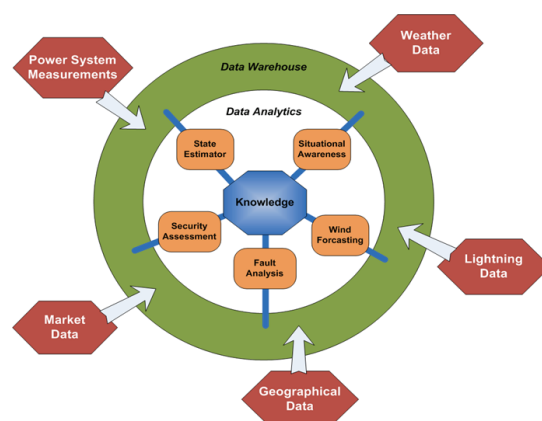

Figure 2. Data management steps

Figure 3. Diverse data used for new data analytics

With this approach the traditional information extraction from data is now converted to knowledge extraction from information. This will be illustrated with a few examples of new applications that were developed to demonstrate this concept:

- *Analysis of Fault Clearing Sequences*. In this case integration of data leads to an ability to match the data collected from the field to the model of a fault clearing sequence. If the model is represented with cause-effect analysis rules with thresholds represented as parameters, than each signal feature associated with fault clearance can be matched to the inputs of the model and model outputs are the answers. As an example, if certain waveform shape suggests that thresholds on current and voltages are exceeded, and based on the relay model it appears that relay should operate, than the expected relay operation is what is matched with relay outputs records to see whether they match, and if they do, whatever the expected relay operations was assumed, it is now confirmed [10]
- *Fault Classification and Location*. The knowledge about type of fault and its location are very important to the operators when they are trying to decide whether to reclose the line or keep it out of service for repair. While many approaches and algorithms for fault location are introduced in the past [4], it is common to assume the model of the line or system and then match the measurements to solve the model equations to find the distance to the fault. One obvious approach where the match of data and simulation results from the model helps determine fault location is particularly powerful since it allows such determination even when the measurements are sparse as may be the case with tapped lines [11]
- *Intelligent Alarm Processor*. One of the major issues with legacy alarm processors is that they mostly show the alarm changes but do not really allow for automated synthesis of the alarms into knowledge relating what has occurred and what the consequence is. This cause-effect analysis can be effectively performed if advanced Petri Net and Fuzzy logic models are combined [12]. In this case the measurements are run through the reasoning logic represented by the model and for certain data inputs model will draw conclusions, which are used as a resulting knowledge about what the consequence of particular alarms is. To enhance the logic model, the ERD data needs to be combined with SCADA data as discussed earlier.

This discussion leads to a final conclusion: to improve operator decision making, new applications and new models need to be developed. For existing models, additional field data may be used to improve them. So summary conclusion is that improvement in data leads to improvements in models, which in turn leads to improvement in extraction of knowledge, which finally leads to improvement in operator decision making.

IMPLEMENTATION STAGES

The most difficult question how to proceed with implementing new EMS solutions is related to the transition from legacy designs to new designs. This is not a trivial process since EMS deployment may cost over 100million, so such systems do not get upgraded frequently. In providing future implementation strategies one has to focus the attention to the difference between "circular" and "spiral" strategy shown in Figures 4 and 5. The "circular" strategy used today (Figure 4) assumes that the life-cycle of the EMS system starts with a specification and ends with decommissioning of the entire system with no major design updates during the life-cycle. The "spiral" strategy (figure 6) is highly recommended since it allows major design upgrades to be done at any time and hence the system life-cycle never ends but gets prolonged as the updates are made. The key to this new deployment strategy is to have an interoperable design that conforms to the interoperability standards framework shown in Figure 6. The discussion of the interoperability requirements is well documented in the reports from the GridWise Architecture Council (GWAC) that also maintains an elaborate website on this issue.
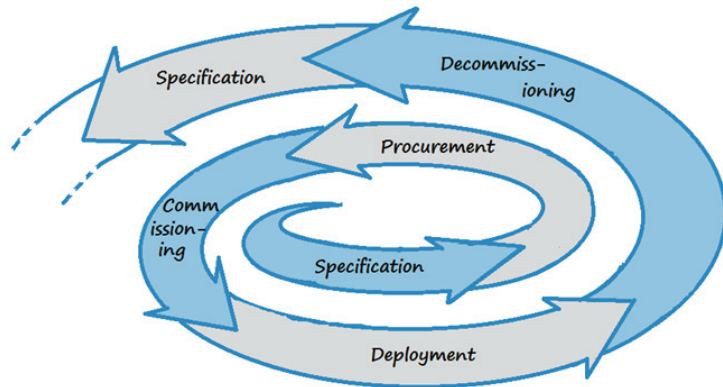
Figure 4. "Circular" EMS deployment

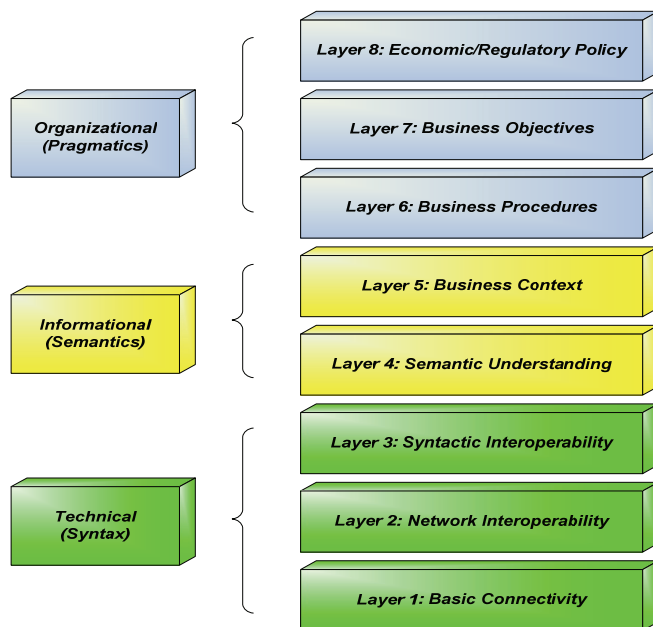**Figure 5. "Spiral" EMS deployment**

Figure 6. GWAC interoperability stack

In the context of the EMS deployment and related life-cycle approaches, the following three design steps have been well recognized:

- *Improvement of existing functions.* This approach uses an existing infrastructure including SCADA and EMS functionalities but it provides for improved performance. Examples of such approaches are improved state estimator, topology processor, alarm processor, etc. To achieve such improvements only the additional data management functions need to be implemented, which is relatively straight forward.

- *Addition of new functions.* Adding new functions requires an open system design so that functions developed by various vendors may be incorporated in the legacy EMS solution. Such new developments are primarily related to new data analytics such as economic alarms, detection and mitigation of cascades and automated fault analysis as discussed earlier.

- *Greenfield design.* This, obviously, is a totally new EMS design that is based on innovative IT solutions for distributed processing, enhanced cybersecurity, high speed/ capacity communications, very versatile visualization and most of all functionality that can cover demanding needs for controlling intermittent renewable generation, coordinating interaction between transmission and distribution operation, and enhancing power system resilience to weather disasters or physical attacks.

What remains to be defined for future EMS developments is the value proposition of all the mentioned changes. This type of analysis is dependent on many factors that are tied to specific utility circumstances, so general rules may not be easy to develop.

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CONCLUSIONS

As a result of the discussion, the following conclusions are drawn:
- After 50 years of EMS legacy, the industry is facing a need for a new EMS design. The desirable features are: integration of field data, introduction of new decision-making tools based on data analytics for knowledge extraction, and flexible implementation architecture that allows transition from legacy to new designs
- Integration of field data is the first step in the direction of improving the ability of operators to closely monitor power system operating states. The paper points out that such improvements can be gained in the areas of topology processing and state estimation, risk-based analysis of CB operation, and detection of cascading events
- Extraction of knowledge may be done through powerful data analytics based on matching between data and models. Such examples are illustrated through new solutions for analysis of switching sequences, fault classification and location, and intelligent alarm processing
- The implementation of future EMS design will take place in stages allowing seamless transition from legacy solutions to new designs through use of interoperability standards. This encompasses improvement in existing functions, introduction of new functions and eventually a green field design that supersedes previous solutions

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