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CIGRE US National Committee
2012 Grid of the Future Symposium

The Need for Next Generation Grid Energy Management System

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SUMMARY

The first supervisory control and data acquisition system were installed in the 1960s to enable grid operators to manage the power system through digital control. Over the decades the advancement of information technology has enhanced these control centers, but the underlying architecture of collecting and processing measurement data has not changed. Measurements at the substations are sampled every few seconds and collected at the remote terminal units (RTU) which are then polled by the SCADA system. The slow scan rates of the present communication system is adequate for sending automatic generation control (AGC) signals, but not those needed to control fast power electronics-based controls. This paper explores new requirements of EMS systems regarding control architecture, data modeling, computation, visualization, and integration. Although we explore these issues in separate sections below, the intent is to show the inter-relationships between these issues. For example, the communications architecture influences the data modeling and management, and limits or enables the new and faster controls. Although much of the research and development are still done in silos – visualization, controls, optimization, etc. – we try to show in this paper that these issues are highly interconnected and the next generation of control centers will have to be designed by considering all these issues as a whole.

KEYWORDS

Supervisory control and data acquisition
Energy management system
Control architecture
Computation
Visualization
Integration

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Introduction

The first digital control centers were introduced in the 1960s to replace the hardwired analog control centers whose functions included supervisory control, data acquisition and automatic generation control (SCADA-AGC). In the intervening decades the advancement of information technologies has enhanced the functionality of these control centers many fold, but the general architecture of collecting and processing all measurement data at a central place has not changed. It is clear that this centralized architecture will not be able to handle the increasing volume of measurements and the faster wide-area controls that will be required for the operation and control of the future grid.

Measurements at the substations are sampled every few seconds and collected at the remote terminal units (RTU) which are then polled by the SCADA system. The new phasor measurement units (PMU) are sampling voltages and currents at 30-60 times per second at the substations but the present SCADA communication systems cannot transmit this rate of data to the EMS. The slow scan rates of the present communication system are adequate for sending automatic generation control (AGC) signals but not those needed to control fast power electronic controls, like static VAr controllers or high voltage DC transmission lines.

In addition, more measurements are being installed in the lower voltage distribution systems all the way to smart meters at the customer level. Cheap communications can bring back at least the feeder measurements to a DMS for monitoring the distribution feeders and remote control of sectionalizers. The modern DMS is consolidating several separate functions like trouble call analysis, crew dispatching, automatic sectionalizing, integrated volt-VAR control, conservation voltage control, etc. The main issue for DMS is less the development of technology and more the payback in energy savings and reliability.

The new measurement and control technologies have raised the expectation of more secure and optimal operation of the grid, which will be enabled by the evolving computation and communication capabilities. This paper explores what this means in terms of the needed evolution in control architecture, data modeling, computation, visualization, integration, etc. Although we explore these issues in separate sections below the intent is to show the inter-relationships between these issues. For example, the communications architecture influences the data modeling and management, and limits or enables the new and faster controls. Although much of the research and development are still done in silos – visualization, controls, optimization, etc. – we try to show in this paper that these issues are highly interconnected and the next generation of control centers will have to be designed by considering all these issues as a whole.

Control Architecture

The complexity of the emerging grid is growing rapidly and the power system controls must become more powerful regarding functionality and computational capabilities. Therefore, the control systems used to control the power infrastructure and their underlying architecture must be revisited. The present day control architecture for an interconnection consists of a hierarchy of control centers: (1) at the lowest level a SCADA system gathers all substation measurements from a defined region at a sampling rate of a few seconds; (2) the load-generation balancing function is performed by the balancing authority (BA) at the next level control center in the hierarchy; (3) to coordinate the grid reliability of the interconnected BAs a control center for the reliability coordinator (RC) at the next level of hierarchy is designated to oversee the reliability of a large geographic region; (4) in North America the RC is the highest level resulting, for example, with about 11 RCs overseeing the Eastern Interconnection whereas in other regions in the world (China, India) there is one control center over the RC level that oversees the whole interconnection. All large interconnections in the world have evolved control center architectures of this type (Figure 1).

Handling of Spatial Scales

As the interconnection size has increased, this hierarchical structure of control centers has gotten bigger resulting in real time data having to travel up the hierarchy and control decisions traveling

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down. Given that the present measurements are not time-tagged and the communication times are not tightly controlled, reliable automatic controls are difficult to implement in this structure. Thus the responsibility for control decisions, either manual or automatic, are kept lower in the hierarchy. To be able to do more automatic (thus faster) control to impact larger portions of the interconnection (wide-area) will require more communications of real time data and control signals with tighter specifications on communications performance.

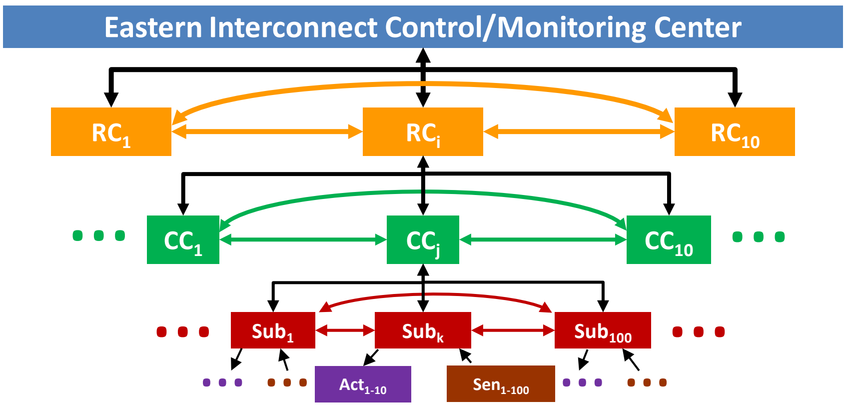

Figure 1. Communication architecture of EMS for an interconnected power grid

Handling of Temporal Scales

Although phasor measurement units (PMU) are being installed rapidly at many substations, this real time data is being handled separately from the SCADA data. The future EMS will have to be designed to handle ubiquitous PMU data, that is, all SCADA points and more may become sources of SCADA data. It is also obvious that not all of this data will be centralized even up to the SCADA control centers not to mention the control centers at the higher levels of the hierarchy. This means that the present data acquisition procedures will have to be replaced by data transmission procedures that will have to be developed to support all the new applications. The data management issues are addressed in the next section but the applications, the communications architecture and data management are intimately dependent on each other and have to be designed together.

Enterprise Architecture

The control center architecture has always been independently designed and developed with no regard to the rest of the functions in the power company, leading to many difficulties of transferring data and decisions of one domain to another. The most glaring example of this is the incompatibility between the operations planning environment and the control center environment. The schedules and reliability considerations determined in the operations planning environment have to be transferred to the real time operations environment but there is no automatic way to do this.

Another consideration is that all the control centers in a given hierarchy, although connected, are not compatible with each other. Information has to be translated from one data format to another as data (real time measurements, static system data, and control signals) traverses the hierarchy. These inefficiencies get in the way of implementing the new seamless applications that are needed in the future grid.

Data Modeling

H4-Unified Data Models

Unified models in which the divisions between temporal scales (e.g., operations and planning) and spatial scales (e.g. transmission and distribution network) are eliminated or abstracted to the application are desirable. As described in the previous section, a significant portion of the EMS applications are arising at the continuum of temporal scales from milliseconds (PMU) to day-ahead.
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Complex analytics, similar or superior to some of the existing planning tools, must be combined with enhanced functions to realize the required operational EMS tools. This will require a seamless underlying data model framework.

The lack of unification of data models is a pervasive problem in the power industry. To illustrate its complexity, consider Figure 2, which illustrates how various representations of a utility's power system network model can be found in a utility's EMS systems: Input Relational Database, Real-Time Database, Internal Bus-Branch Model, Exported Snapshot Planning Case, and CIM. None of these models are compatible with the Planning Case used in the off-line environment.

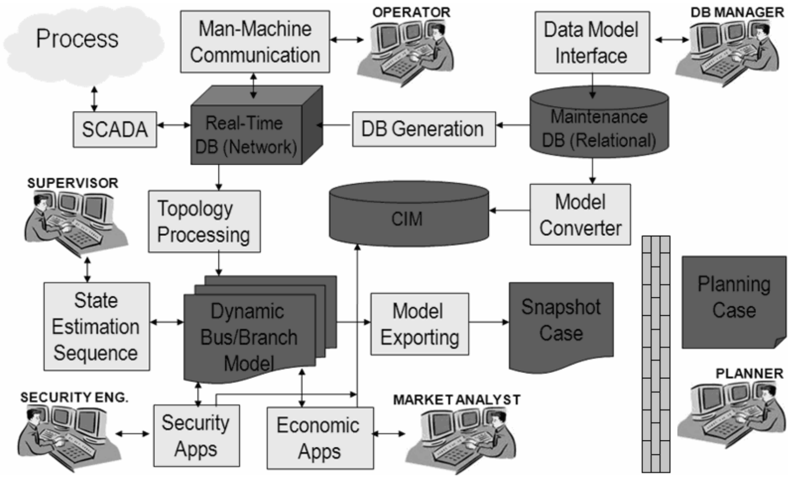

Fig. 2: Power System Models used in a Typical EMS System

Several efforts such as the Common Information Model (CIM) provide standardized definitions of power system data. Presently, however, the vast majority of applications represented in Fig. 1 continue to require converting CIM or other models to their native underlying format. Recently proposed solutions rely heavily on model conversion from an operations model to planning cases, a method that essentially "changes the data model to support legacy applications". Such methods do not support interoperability and will represent barriers in the long term.

Seamless EMS data modeling means that a common model is used across applications and across all relevant temporal and spatial scales. For instance, DMS data should seamlessly be propagated (either at data point or aggregated level) into the EMS database. If the ISO would like to "zoom in" into the utility model and have their applications take into consideration specific conditions of the distribution grid, that should be possible. (Today it is almost impossible to have applications or visualization that moves across control center boundaries.)

By the same token, PMU data must be integrated with SCADA primary data, model-based data, or application-generated data. Unified handling of the underlying new temporal scales represents a challenge. For instance, different ISOs use different temporal granularity for ancillary services optimization. Combined datasets must not only deal with synchronization, but also with non-unified granularity.

Support for Massive Data

The data architecture must support high volumes of data from PMU, substation automation, and smart meters. Models of these data must be compatible regarding geo-referencing, ID-ing, time-tagging, and verification for the various application scopes. Model data must be validated. Estimated data and parameters must be qualified.

The emerging power system will push the capabilities of existing historians and temporal databases, as well as of spatial databases. Power system domain-specific, on-the-fly processing of data for efficient storage and compression methods must be developed.

Machine learning and data mining applications are very promising tools that would provide powerful analytics and discovery. Such applications will allow exploiting the already significant amount of data being collected.

Support for Distributed Control

The electricity industry transformation may result in the deployment of massive amounts of distributed renewable energy. It is not sufficient to just connect the source devices to the grid. The local controls, the system controls and the market functions must also become more distributed and flexible. There is a rapid trend towards distributed control evidenced in various efforts towards enhanced DMS systems and microgrid, building and home energy management systems. Ultimately, grid control will span all the spatial scales from interconnections to appliances. The data model used by the industry must therefore support such distributed control.

At the same time distributed control can take place at the ISO, providing either intra-substation or inter-substation (PMU-based) control. The data model must hence address system modeling, local data collection, local data processing, local storage, data exchange and relying, synchronization protocols, etc. Beyond raw data, the information and the communication architectures associated with the EMS applications required for control will play a fundamental role in enabling distributed control use cases.

Computation

The first on-line analytical applications were introduced in the 60s with the first EMS and consisted of state estimation and contingency analysis, that is, steady state computation of the transmission grid. With increasing computation power and better algorithms, contingency analysis has been extended to dynamic analysis. In the 90s when next day markets were introduced, optimization methods were implemented to solve repeated optimal power flows. These are all computationally intensive applications and more sensitive to numerical convergence especially in the on-line environment using real-time data.

A market region usually covered many EMS territories and these markets encouraged higher levels of power transfers over longer distances. This required applications that covered regions encompassing many EMS jurisdictions thus requiring coordinating the same applications over several control centers. The results so far have been less than satisfactory because of data exchange limitations but even if the data exchange becomes seamless, the distributed computation needed to make the application seamless has to be developed. These techniques range from numerical computation advances (advanced matrix factorization, numerical integration, generalized robust estimation, etc.) to computation infrastructure such as cloud and GPU computing.

Visualization

Visualization of the real time condition of the power grid is the best monitoring tool the operator has. In addition, the voluminous outputs of the many control center applications are hard for the operator to digest without some easy forms of visualization and alarming. Visualization of the grid outside a control center boundary is unavailable (or very primitive) today. This is a major drawback in the operation of large interconnected systems – consider that it takes about 100 balancing authorities and 10 reliability coordinators to monitor the Eastern Interconnection with none of them having any idea of what is going on in most of the system. The limited ability of knowing what is going on in the neighboring system has been a consistent element among the causes of large blackouts.

Innovative visualization methods developed by in the late nineties by PowerWorld and others have made their way into mainstream EMS visualization. However, the static 2D visualization may not be sufficient for the emerging requirements. In particular mechanism for handling multi-dimensional and multi-scale data are highly needed. The feasibility of integrating the state-of-the-art visualization concepts into EMS platforms needs to be continued.

Integration

The core network EMS applications are proprietary and were originally written in FORTRAN or C. Complex EMS system applications have been incrementally built around the core code using other languages and better structure. Integration and interoperability efforts have been driven by XML and SOA. However, indiscriminate use of CIM wrappers for legacy applications has the risk of fossilizing core applications. The transformation of the electricity industry will be unprecedented and massaging models and application so they can fit the legacy code may not be the optimal approach. Integration must be balanced with innovation objectives. We will study innovative architectures for application integration, which provide such balance.

Summary of Issues

The present communications infrastructure is inadequate for handling the increasing real time data transfers imposed by the PMUs at the transmission level and the new measurements at the distribution level. The requirements are stretched by the data rates at the transmission level and by the data volumes at the distribution level.

The present proprietary data structures at each control center are a major impediment to data transfers between the distribution and transmission levels, as well as between EMS in the same interconnection. This issue impacts the ability to seamlessly monitor, operate and control the interconnected power system and is the crux of this paper.

The present communication architecture and data structure of control centers forces all the computation to be done at the control center. The ability to distribute the computation over several control centers would enhance the ability to seamlessly spread the applications horizontally over larger control regions (ultimately the whole interconnection) and vertically between transmission and distribution.

Visualization of the power grid is the most important tool available to the operators to monitor the grid but today is limited to the jurisdiction of the individual control center. The inability to seamlessly move data means that operators monitor their systems with blinders on, a condition that is flagged by every blackout report to be one of the root causes.

The seamless architecture and data management of control centers will allow the integration of applications across control centers. This can be across the interconnection (e.g. state estimation of the whole interconnection at PMU rate) or between transmission and distribution (e.g. coordinate distributed solar in one region with hydro or batteries in another region). Integration of applications over distributed computers will also impact the architecture.

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