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Computer Architecture and Multi Time-Scale Implementations for Smart Grid in a Room Simulator

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Abstract— **This paper describes how to utilize physics-based unified modeling of complex electric power systems in order to design a multi-layered interactive Smart Grid in a Room Simulator (SGRS). In this simulator, the dynamic response of a given interconnected grid is simulated and assessed as a family of interfaced sub-processes jointly evolving at different time-scales. Compared to state-of-the-art simulators, advantages of the SGRS are that it is scalable to large systems since it uses distributed computing and that it allows for privacy of different components since one object does not need to know the models or methods of another object. Standardized and transportable objects representing physical components at various degrees of temporal, spatial, and functional granularity are constructed by different users and added to the SGRS platform for future use by all. This allows users to simulate and assess the effect of the technology of interest to them, which makes the SGRS effective in supporting the deployment of new technologies with well-understood effects. Examples on the SRGS are described for simulating market-driven sub-processes and the fast dynamics sub-processes in response to market actions and/or to sudden hard-to-predict disturbances.**

Keywords-Cyber Physical Systems (CPS) for energy systems; computer platforms; distributed simulations; event-driven simulations ; simulations-based smart grid test beds.

I. INTRODUCTION

This paper is motivated by the need for simulation-based test beds which are scalable to large power systems and can assess the effects of new technologies on the power system's performance at different time-scales. For example, in today's changing electric power industry, decisions to commit or consume power are made interactively by both the system operator and the producers and consumers themselves. One simulation layer is the market, which requires sequential information processing over time in a feedforward way. The second simulation layer is the physical dynamic response of the interconnected power system to the changes in the equipment settings made by market participants. At present, there are no simulators which show the effects of changing power outputs on the dynamic system response, but such simulators are truly needed for implementing stable markets.

Another drawback with existing state-of-the-art power system simulators is that they use a centralized approach and hence are not scalable for large systems. For this reason, a novel computer platform, called the Smart Grid in a Room Simulator (SGRS), is developed. The computer platform utilizes Carnegie Mellon University's physics-based Dynamic Monitoring and Decision Systems (DyMonDS) framework for modeling, simulating and designing cyber components needed to enhance performance of the electric power grids [1]. The SGRS runs different power system objects (components) distributed over multiple processors and computers, which makes this approach scalable for large systems.

It should be emphasized that an object does not need to know the methods or models of other objects, which makes this approach very attractive for privacy reasons. Only selected data needs to be communicated between neighboring objects. There is no need to exchange data between all objects or with a centralized entity.

Using a physics-based unified modelling approach, standardized and transportable objects are constructed by different users and added to the SGRS library. This allows different users to simulate and assess the effect of the technology of interest to them. Therefore SRGS could become instrumental for the understanding of new technologies by allowing users to benchmark their effects relative to existing technologies.

Section II summarizes state-of-the-art power system simulators and discusses what improvements are critical in the future. A new unified modeling approach is summarized in Section III. Next, using this approach, an entirely data-driven computer platform is proposed in Section IV. Section IV.A illustrates how the market sub-process is simulated using this platform while Section IV.B describes the simulation of the fast power system dynamics, and further illustrates the basis for its parallelization. Finally, Section IV.C, shows how the market and fast transient sub-processes interact through well-defined data-driven models coordinated by the model-based communications protocol.

II. STATE-OF-THE-ART CYBER ARCHITECTURES OF ELECTRIC POWER SYSTEMS

This section summarizes state-of-the-art power system simulators and computer algorithms used in today's electric power industry. It should be noted that cyber entities for enabling performance of physical power grids have evolved over time as different needs have emerged as well as progress in computing has been made. Once it is understood

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what exists in terms of functional specifications required, numerical algorithms used and the resulting simulators, it becomes possible to propose the next generation SGRS needed to meet the emerging performance specifications.

A. Functional specifications for today's cyber architectures

At present most modern power systems rely on supervisory control and data acquisition (SCADA) for sensing and processing system-wide on-line information about the system status and operating conditions. This information is processed to enable operators to make decisions about how to adjust different equipment in order to balance the system and deliver power to where it is required. SCADA relies on a tree-type communication architecture supporting extra-high voltage (EHV) transmission grid by sensing data and sending to the control center for processing the information. Here the control center serves as an information hub, and the root of the tree. At the same time, power plants, in particular, have had embedded constant gain automated controllers responding to the deviations of local outputs to the controllers set points which are changed by the system operators computing in anticipation of predictable system demand. All computer applications evolve around supporting analyses and decision making during normal operations (status of equipment as predicted) by the control centers as on-line information is provided by SCADA. In case of large equipment failures (contingencies), system operators use worst-case approaches based on time consuming off-line simulations to ensure that the predicted system demand is still supplied by rescheduling the stand-by generation reserves. On the other hand, the controllable equipment in local distribution grids has mainly been pre-programmed according to daily, weekly and seasonal demand patterns; it is not adjusted on-line. As a rule, distribution companies do not rely on data-driven automation at present. Much innovation is taking place right now in the local distribution grids by attempting to integrate distributed energy resources (DERs). Figure 1 shows a sketch of cyber architecture underlying future power system operations in smart local distribution grids.

B. Numerical algorithms using today's SCADA

Even the best simulators and computer algorithms used by today's utility industry were introduced for completely different purposes and under different assumptions than is currently required. It has been generally assumed that the power grid operator has full information about the grid and its users. It is moreover assumed that the operator and/or planner has full control over the grid and its users. As these assumptions turn out not to be true, we propose a distributed simulation approach, rather than a centralized one to take privacy issues of modelling into account. Most utility control centers use different stand-alone computer algorithms for different assessments, and, invariably under different assumptions. At times system operators have expressed the need for more computer-aided monitoring, assessment and decision making over wide ranges of conditions, but such software does not exist for reasons related to fundamental limits of the centralized simulation of large-scale complex network systems.

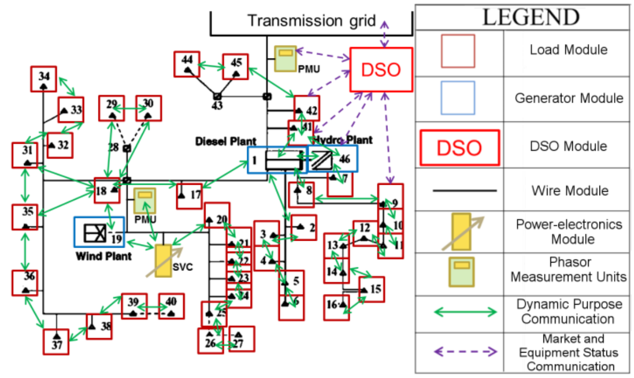

Figure 1:Cyber architecture for future distributed system operations [2].

C. State-of-the-art power grid simulators

To the best of the authors' knowledge, there is no single simulator capable of seamlessly emulating on-line physical response of a general large-scale electric power system as different exogenous inputs trigger changes away from equilibria. The closest simulator of this type is Eurostag [3]. However, Eurostag was designed assuming that one single entity knows all data and it is fundamentally supported by a centralized approach. This type of simulator does not lend itself well to assessing the effects of market-driven agents and distributed cyber technologies shown in Figure 1.

Perhaps the most advanced industry simulators used for purposes of monitoring physical response of their specific power grids have been hybrid hardware-software simulators in Hydro-Quebec [4] and Kansai Power [5] . Unfortunately, these simulators are not transportable to assessing other complex power grids. As such, they are truly dedicated to simulating time-domain response of specific large-scale power grids. Recently, a major consortium of software developers and users named iTesla was initiated with the objective to overcome these problems and to begin to provide near-real time simulators of complex power systems [6]. It is also important to mention recent efforts toward so-called real time dynamic simulators (RTDS) [7]. They are very detailed emulators of fast power system dynamics for small portions of power systems, sub-stations in particular, which are needed for protection and relay automation. They are too expensive to be scalable for applications such as assessing the interface between wholesale market effects and physical system response.

The above described industry simulators are all physics-based and were introduced by the power systems community. Most recently, there has been a major effort toward designing more general agent-based computer platforms by the computer science community. Examples are the Mosaik framework which uses the Python programming language to provide an agent based co-simulation platform for smart grids [8], GridSpice, which couples Gridlab-D and MATPOWER in a co-simulation environment [9], or the effort by Stifter et al. to couple GridLAB-D, PSAT, OpenModelica [10], and 4DIAC in a co-simulation to simulate components and controls of power systems [11].