Optimization of Smart Grids in a Cyber-Physical System Approach

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***Abstract*: The electric network that deliver reliable and secure energy supply thereby enhancing the operation efficiency for generators and distributors are formed as smart grids. These networks employ advanced monitoring, control and communication technology providing flexibility of choice to consumers. The paper presents a glance of technical challenges that are faced by smart grids. Grids which are a fusion of complex physical network system and cyber systems, following this overview of potential contributors that cyber-physical system can make to smart grids and the challenges faced by cyber-physical system due to smart grids will be laid. Closing shall involve outcome of present technological advances to smart grids.**

***Key word*: Smart Grid, CPS, Data analytics**

I. INTRODUCTION

The contribution of electricity to human civilization has immense since its discovery in the 19th century. It is the backbone to our social and economic activities like it is easy to transmit over long distance than any other form of energy. Electric grids interconnected by physical networks are heavy and form the base of supply and use of energy in present times [1].

The increase in demand by cleaner energy in recent years has led to environmental concern for efficient utilization of energy. Limited availability of non renewable energy sources such as coal, gas and oil have added to the same. The global energy demand is to grow by 37% by 2040 according to the 2014 world energy outlook report [2]. Efficiency thus is crucial to lesser pressure as energy supply while accommodating soaring demands without depreciating the environment. Harnessing hydro, biomass, solar, geothermal and wind is different although these being renewable energy (RE) sources are abundant by available. Application of advanced technology is needed so as to make these energy supplies more reliable and secure. Newer energy policies are being adopted by the government of many countries and extensive scale deployments of smart technologies are now in place. For instance president Obama of the United States has lunched the above mentioned energy strategies.

Since 2008 the renewable energy (RE) generation from wind, solar and geothermal sources have doubled. A target of 20% RE has been set. Chinese government has set an exponential ambitious target of 86% RE by 2050 followed by 15% range of its own which to be achieved by 2020. European commission has also set 20% RE target by 2020 [4]. This requires a revolutionary revisit of thoughts for deciding how to supply and use electric energy in a more efficient, effective, economically and environmentally sustainable manner.

Smart grids are models of excellence that fulfilled the above mentioned energy requirement and overcome challenges laid. Their target is to bind all the players in the energy supply chain by integrating their behaviors and actions. This would foster delivery of sustainable, economic and safe electric energy and ensure economical and environmentally prudent use. The pauseters integration and interaction of the power network infrastructure is the key to success of SGs. This includes physical systems and information sensing, processing, intelligence and control as the cyber systems. In addition the emergence of new technology platform called cyber physical systems, answers to address the very integration and issues in SGs. Emphasizing effective and efficient interaction and integration between physical system and cyber systems. CPS furthermore would make SGs more efficient in operations, more responsive to pro systems, more economically feasible and environmentally sustainable. The exceptional nature of SGs will bolster new challenges to the development of CPSs.

The paper at first is aimed to lay an overview of these challenges in the context of CPSs. Following an outline of potential contributions that CPSs can make to SGs, As usual the challenges that SGs before CPSs will be made finally, the outcome of present technological advances to SGs will be outlined.

II. SMART GRIDS

Varied definitions and meanings have been called for the term smart grids (SGs). Manager of enabling ICT and other advanced technologies with large scale power networks to enable electric energy generation, transmission, distribution and usage to be more efficient, economically sustainable is essential smart grids (SG) definitions. The U.S. National Institute of Standards and Technology provides a conceptual model which defines seven important domains: bulk generation, transmission, distribution, customers, service provider, operations and markets.. The meaning of SGS is broad in the United States that refers to the transformations of the electricity industry from a centralized, producer controlled network to the one that is more customers interactive. SGs in Europe refer to broad society participation and integration of all European countries [8]. SGs in the china on the other hand refers to a more physical network based approach to ensure energy supply that is reliable, more responsive and economic in an environmentally sustainable manner[9]. Chinese government has recently paid a noteworthy attention to leverage the infrastructure to generate more socioeconomic benefits and thereby introducing a market-driven national demand-side management framework and system [10].

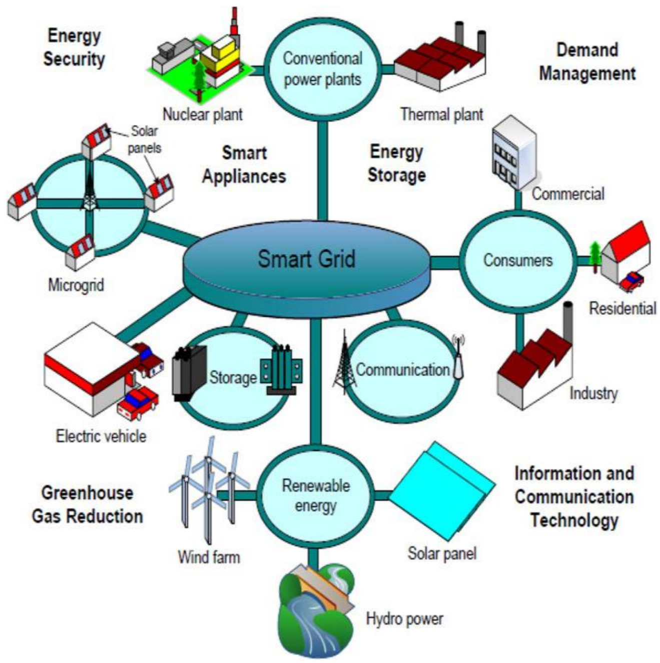

Fig-1 presents the structure of SGs, in which stakeholders and players are seen in a highly networked and large scale system [1]. The SGs are expected to have broad operations and control spread to the entire power systems taking into account. All the present and future technologies to enable bidirectional power flows, as in IEEE grid vision 2050 [1]. A rethinking or revisit of how to interact between the power networks, the cyber systems and users is needed to assess the future requirements of greater flexibility, portability, safety and security of energy supply and usage. A high level interaction and co-operation between physical systems (power network infrastructure) and cyber systems is a must.

A number of technical challenges need to be addressed compulsorily; these include large scale networks of small distributed generation mechanisms, such as photovoltaic (PV) panels, batteries, wind and solar, plug-in hybrid electric vehicles (PHEVs), and uncertainties incurred due to introduction of energy market mechanism.

The noteworthy difference between the peak and average demands of electricity is a key characteristic of power usage. The ratio of peak and average demands in Australia reached around just less than 50% between 2013 and 2014 [12], for instance the capacity of the energy supply would increase with more new power generation plants due to reduction in peak usage. There is one more way to reduce the unnecessary waste accounts for a substantial portion of energy generated. This supports the argument of embedded generation and sitting generators close to the point of consumption (a concept usually called "distributed generation").

Another issue is how to

Utilization of ICT and other advanced technologies to enhance efficiency of energy use, such as smart meters, telecommunication technologies for sensing, transmission, and processing information relating to grid conditions is one more important issue.

In order to correspond to the issues laid above several key technological advances are needed such as:

1) Distribution of control mechanisms to enable lower communication needs if grid components such as source, loads, and storage units can be controlled locally or can make some decisions by themselves.
2) A relatively accurate prediction of demand at the distribution level is needed estimating demand in any part of the grid a few hours or days in advance.
3) There should also be a relatively accurate estimation of energy generation from RE sources such as solar panels and wind turbines. This requires linkage with weather forecasting, so intermittent energy sources can be smoothly integrated with the grid.

III. INFORMATION SCIENCE AND ENGINEERING

A demand for information sensing, processing, intelligence, and control to be delivered fast and in real time arises if flawless integration and interaction between cyber and physical systems is to be achieved.

The traditional centralized paradigms for computation, information intelligence acquisition, and control are not suitable for delivering fast real-time actions. The proliferation of cost-effective sensors such as smart meters results in very large volumes of data streams which must be processed fast and efficiently in order to be useful for decision making and control, especially for the transient processes in SGs. information intelligence, Distributed computation and control mechanisms, subject to network-based uncertainties, must be adopted in order for distributed decision making, which is especially critical for the SGs. Information sensing, processing, intelligence, and control are at the heart of all the operations.

Many stakeholders are involved in SGs, be it generator to distributor and prosumer in an interconnected world of social, economic, and technological environments. A rethinking of how to analyze and design the CPS aspects of the SG is required due to the increasing complexity of and connectivity between components such as smart meters, solar panels, wind turbines and their sheer numbers. The applications involve components that interact through complex, highly interconnected physical environments. The discussion hereafter shall involve the SG developments from a CPS viewpoint.

III. SMART GRIDS FROM A CYBER PHYSICAL SYSTEM POINT OF VIEW

SGs integrate the physical systems (power network infrastructure) and cyber systems (sensors, ICT, and advanced technologies). The core issue is how much integration between the cyber systems and the physical systems there should be, a lot of calibration

and patching fixtures are usually required to allow them to function together to meet the stringent SG safety and security requirements.

A seamless integration between these two (cyber and physical) systems will bring enormous benefits to SGs, just like what mechatronics brought to the car manufacturing industries where a blend of electrical, mechanical, control, telecommunications, and computer engineering delivers much simplified mechanical design, rapid development trials, rapid machine setup, optimized performance, productivity, reliability, and affordability.

To improve cyber–physical relationship in SGs, six key functionalities are required [13] such as 1) whenever a fault occurs the system has to be repaired in a simple and timely manner so that maintaining accessibility even the fault occurs is possible while at the same time not causing any harm when some part is malfunctioning; 2) without fundamental changes to its original configuration it's maintaining high reliability in open, evolving, and uncertain environments, so that the system can continue to operate even in the presence of failures; 3) high predictability which guarantees the specified outcomes within the time span it is required to operate accurately; 4) high sustainability embedded with self-healing and adjusting mechanisms and adapting to changing environments; 5) high security so that the system has adequate means to protect itself from unauthorized access and attack; and 6) high interoperability which enables the system to provide or accept services conducive to effective communication and interoperation among system components.

There have already been some attempts to address.

IV. CONSTRUCTION METHODS OF CPS

For the smooth functioning of the CPS, we generally concentrate on how to develop design methodologies based on CPS principles and to construct the fundamental CPS infrastructure. It demands high security and reliability as it is different from the general purpose computing facility [22]. The smooth control, communication and computing there should be CPS architectures that are designed especially for interfaces between power networks and network systems.

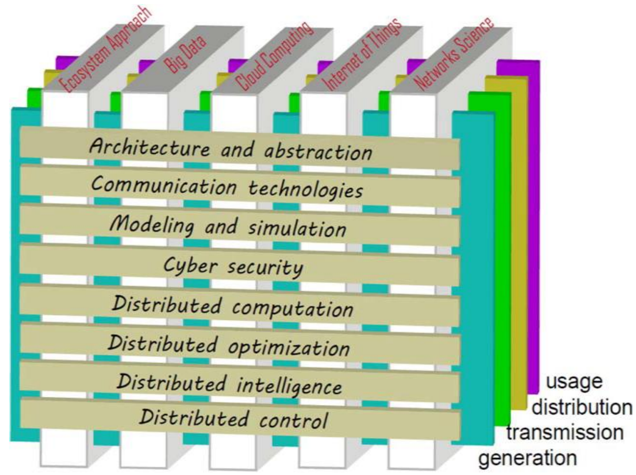

Fig. 2. SG from a CPS viewpoint.

CPS requires a unified standard framework under which the physical systems, communication protocols, computing languages, and software and hardware interfaces, which are all subject to standards in their own fields, can work together [21]. To support system and network specifications, interoperability, hybrid and heterogeneous modeling and operations, and modeling and simulation tools are critical to ensure that the large-scale network CPSs of SGs can operate seamlessly and components can cooperate with each other which require multidisciplinary work involving uncertainty analysis, risk management, system security, and economic coordination [21]. A new generation framework is needed for modeling and simulation of future SGs. The development of a trustworthy SG requires better understanding of the cyber–physical relationships in order to detect, prevent, and mitigate the cyber attacks. In computer networks, intrusion detection systems (IDSs) are the main security tools to capture, monitor, and detect various types of attacks. There are two main types of detection, the host-based IDSs and the network based IDSs,

V. UPCOMING CHALLENGES

SG developments cannot be done without considering environmental, social, and economic environments, as for solar panels, the costs and impact for their manufacturing from raw materials mined should also be considered. All these can be considered in a framework of "ecosystem," which is commonly defined as an ecological community interacting with the environment as a function unit [46]. The tighter integration of global optimization and local control where global optimization deals with multiple objectives such as minimum costs of energy production, maximum efficiency of electricity use, lest power network loss, and minimum carbon dioxide generation effects the success of SG.

SG is extremely complex with large numbers of diverse components connected through a vast and geographically extended network like distributed network hence there is a need of distributed global control mechanism which can provide a metaview to coordinate local controllers [39]. For a high level Control strategies for SGs can be divided in three layers [41], the economic and planning layer, the cyber layer, and the physical and operations layer, each of which requires different time scales to impose controls.

Data analytics for those big data issues associated with SGs require developments of effective architecture and design, time-critical information science and engineering technologies with specialized semantics, computation platforms, and smart algorithms [49]. As SG becomes an increasingly important development across the globe, legislators and regulators in various countries are considering possible implementation barriers based on numerous analyses done, which are different from country to country and have different focuses but there are outstanding legal and regulatory issues concerning data access, data provision, data privacy, software/hardware liabilities, and automated decision making. They are expected to be treated differently within the legislative and regulatory frameworks of individual countries.

VI. CONCLUSION

In this paper we focused on many challenges faced by SGs in the CPS point of view. Here we have given several potential contributions that a CPS can make to SGs as well as the challenges faced by CPS due to SGs. Also we have focused on the effect of several technologies on SGs such as Big Data, IOT, Cloud computing, legislation and regulations.

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