Smart Grid – Implementation, Challenges, and Strategies related to Energy Efficiency and Informatics

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Abstract
Smart grid (SG) has contributed much to enhance energy efficiency as well as the energy sector utilizing energy informatics (EI). There have been many smart tasks and services implemented to perform energy related operations. Energy-optimized solutions for smart buildings, demand response, and energy-use prediction are some examples that efficiently exploited SG conception. In this line, EI has been exploited to enhance the performance of such energy related operations. However, there are lots of challenges so as a result, performances can be then affected. Many obstacles need to be discovered and corresponding solutions proposed in order to solve the majority of them. As a result, this study attempts to explain a number of issues that are encountered throughout the implementation of SG and provide critical ways to overcome them. In this paper, a case study of Malaysia is provided and discussed in terms of implementation of SG and key strategies proposed.

I. INTRODUCTION

The Smart Grid (SG) concept came abroad when the electric generation units start to multiply and increase the production capacity to meet the electricity demands. There was a need to monitor the generation, grid distribution & transmission, consumer consumption, maintenance, price, and services. SG was introduced to incorporate the integrated aspect of information and communication technology in electricity generation, transmission, distribution, and retails. SG warrants an opportunity to develop from a conventional type of system to a new paradigm digitalized network system to ensure reliability, availability and efficiency of electricity supply that will contributes to the nation growth, economy, environment and well-being of people [4]. Promoting efficiency in fossil fuel power plants would reduce the fuel consumption and eventually contribute to a lower greenhouse gas emission.

The organization of this paper is provided as follows: in Section 2, a definition of SG is in detail presented. Section 3 discusses the conception of energy informatic (EI) framework of SG. Section IV is dedicated to discusses the implementation of SG around the World previewing several EI-related examples. Section V discusses the implementation of SG in Malaysia. The challenges in implementation of SG and key strategies to overcome barriers in Malaysia case are presented in Section VI and Section VII, respectively. Section VIII draws the Conclusion.

II. SMART GRID (SG): DEFINITION

SG originated from US in 2007, through Energy Independences and Security Act 2007. The SG works as a two-way communication between the supplier and consumer and allows a flexible information to the generators and consumer in an effective and efficient way. To maintain grid efficiency, the SG provides a variety of smart solutions for planning the resources, reducing energy waste, and cutting costs. It is achievable with advance technology available such as Internet of Things (IOT), Cloud, Big Data, mobile and range of connection online networks. An integrated network of sensing, control and communication into the power chain of network is shown to be an advancement in technology.

In this transition period of SG and during the implementation phases, it critical to ensure, digital advance technology upgrading is in place, consumer education and acceptance, regulatory regulation is in line, networks and device is being established in that particular country to ensure the SG comes into reality and achievable, further information is provided in Figure 1.

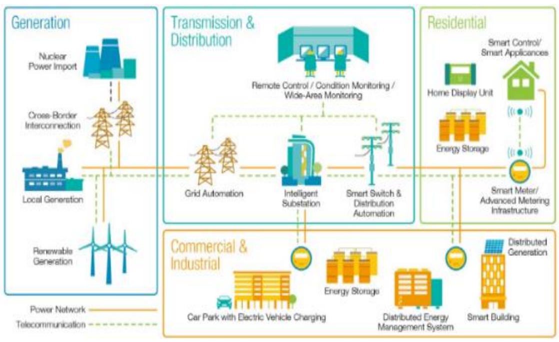

Figure 1: How SG connects between Generations, Transmission and Residential

A. SG Objectives

SG was introduced with the objective mainly to:

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a) Optimize the operation and manage the available and reliability. With the limitation in generation, SG could improvise the amount of intermittent in system. It leverages between the non-renewable energy generation and the fossil fuel energy generation to support the whole system. The grid's connection might optimize the mix generation idea and enable the dispatch of additional clean energy sources, such as solar, wind, and photovoltaic systems [12].
b) Manage the increasingly energy cyber-security. SG helps utilities preserve energy, decrease costs, increase reliability and ensure process extra efficient through digitalization and internet network. Utilities company remain exposes to cyber security. They must consider SG security, including vulnerable areas, strategic issues, the layered security approach, data management and privacy concerns, and scenario planning and threat profiling.
c) To rationalize the cost of supply and transparency. SG would help the generator to plan the production and manage the source of energy. The planning would help the generator to run the plant efficiently based on the demand requirement, which eventually leads to the managing of the fuel for generation. Lower fuel consumption will reduce the operating cost and the lower could be translated to elasticity tariff and pass to the consumer.
d) To reduce the high dependent on fossil fuel and move to nonrenewable resources.
   This is to ensure the country is moving towards more on renewable energy supply for electricity generations. To foster and promote green energy, more electricity to be anchored on renewable energy such as wind, solar, wave tide, hydro and biogas. This is in line with the countries sustainable development and addressing the environmental impact in reducing the Greenhouse Gas (GHG).
e) To meet consumer's demand and expectations, through technology, network, products and equipment's.
   By introducing smart appliance, advanced metering infrastructure and consumer home device, customer is able to monitor their consumption, billing, time of use and payments. It empowers customer to be more efficient, adapt to the digital energy network and able to communicate with the utilities.

In short, we could summarize SG is to integrate and enhance the distributions of electricity and managing the fossil fuel resources to achieve a more efficient and reliable grid. It also encourages consumers to actively participate in sustaining the environment and reducing the green houses gases. It also encourages the generation to be more efficient and lowering the cost of operating. In the context of Malaysia, the implementation of SG would enable the electricity provider and power producer to enhance their digital and technology capabilities and maximize the efficiency of the national power grid system.

B. SG Comparison

The SG is equipped with advance digital and numeric technology with having a pervasive smart control system. It has a link to the distributed power generating system. The meter and sensors communicate with each other via two-way digital communication through a number of linked networks. The system itself is self-organised and could be self-monitored. SG can be tailored to accommodate during blackout and island mode. SG gives an opportunity to the users to leverage the services and reduce their power consumptions.
The differences between SG and Conventional Grid can be summarized in Table 1:

Table 1: Differences between SG and Conventional Grid

SG	Conventional Grid
Demand follows Supply	Supply Follows Demand.
Bi-directional flow- to and from consumers	Unidirectional flow of power from producer to consumer
Completely digital	Electromechanical sensors and relays
Multiple opportunities & cost savings to customers	Limited choice to customers
Distributed generation	Centralized generation
Intermittent generation sources	Dispatchable generation sources

C. SG Components

The components of SG could be summarized into 3 main layers such as devices which consists smart meters and sensors, communication network and infrastructure/technology and operation management which are consist customers billing, consumption monitoring, services and applications. A graphical representation of SG components can be found in Figure 2.

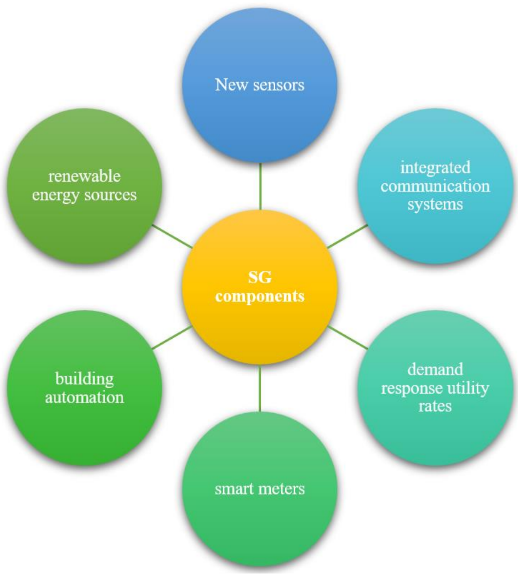

Figure 2: SG Components

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SG improvise the operation efficiency through the distribution automation such as:

a) Scada system
b) Tripping indication Faulty Isolation process
c) Remote switching
d) Motorized ring main unit
e) Reclosure relays

The above automation will enable the network to automatically sectionalize and restore the connectivity and the supply which lead to reliability, a better visibility and transparent of network, could reduce losses in term of down time and inefficiency and improve the grid utilization and managing the resources. In addition, the automation would keep tabs on, record, and detect any system disruptions, and then attempt a restoration automatically back to normal operation. The system could track any faulty and dispatch the maintenance team to the sit promptly.

III. Energy Informatic (EI) Framework of SG

The followings are several examples of SG frameworks applied for SG:

A. EI Framework for Distribution Automation System

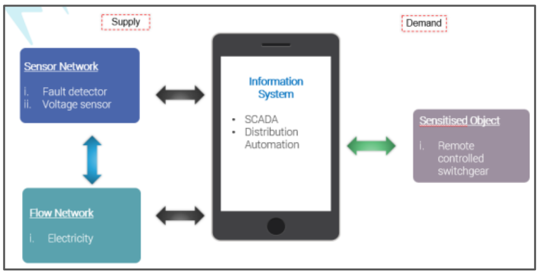

Figure 3: EI Framework for Distribution Automation system

Distribution automation system (shown in Figure 3) is one of components for SG. It is a system whereby sensors, processors, information and communication networks, and switches, through which a utility can collect, automate, analyze, and optimize data to improve the operational efficiency of its distribution power system.

a) **Sensor network**: It consists of fault detector and voltage sensor, which utilizes the voltmeter and relay.
b) **Flow network**: Flow network is electricity
c) **Information systems**: Information system includes SCADA, which is supervisory control and data acquisition that can monitors the flow network performance and remotely controls the circuit breaker switching from control room. Distribution automation system is synonymous to SCADA, but with enhancement of voltage monitoring and control. It integrates the sensor network and provides the information to the customers.
d) **Sensitized objects**: Sensitized object is the remote-controlled switchgears, which will be automatically switched on/off during fault current to isolate the fault and re-route the flow into another section of overhead/ underground line.

B. EI Framework for Smart Home

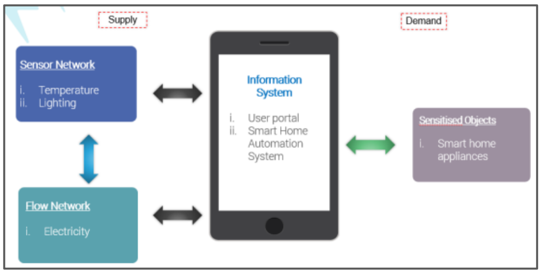

Figure 4: EI Framework for Smart Home

Smart home system (shown in Figure 4) is also another component for SG. It consists of system sensors, monitors, interfaces appliances and devices that is integrated that enables automation to manage and control the electrical equipment such as lighting, air conditioning remotely using internet connection [16].

a) **Sensor network**: Motion sensor that uses passive infrared to sense the motion of people, thermostat that monitors temperature and humidity inside the house, Light sensor that uses photocells and resistor to sense the light
b) **Flow network**: Flow network is the electricity
c) **Information system**: Information system that connects the sensor network, flow network and sensitized object to provide the info to the customers includes user portal which allows user to check and manage the equipment energy usage. Second is smart home automation system that allows the customer to remotely control the electrical equipment in the house.
d) **Sensitized objects**: Sensitized objects are the smart home appliances, which include lighting, air conditioning, washing machine, electrical plugs that can be remotely controlled by the users.

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C. EI Framework for Advanced Metering Infrastructure System

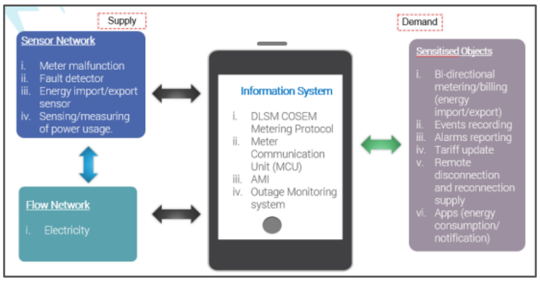

Figure 5: EI Framework for Advanced Metering Infrastructure System

Advanced structure metering system (shown in Figure 5) is a system to measure, collect, and analyze utilities distribution and consumption, and communicate with metering devices. Smart meter enables two-way communication between supply provider and customers [10].

a) **Sensor network**: Sensor for smart meter includes metering sensor such as SigFox, NB-IOT and radio frequency. Additionally, fault detector is also present to detect any fault current that occurs.
b) **Flow network**: Flow network is the electricity
c) **Information system**: Information system that connects the sensor network, flow network and sensitized object in order to provide the info to the customers and utility include outage monitoring system to monitor imminent outage, and meter communication unit that provides two-way communication between utility and customers.
d) **Sensitized objects**: Sensitized objects are customer billing that available offline and online, theft detection notice, remote meter connect and disconnect as well as alarm reporting to give alert the customers on mishap and accidents.

IV. Implementation Around the World

SG is not a grid that comes out a box. It is made of component systems from every business chain namely distribution, transmission as well as customer side. A benchmarking study was carried out on more than 50 utilities around the world to determine rating for the star rating system on the smartness of grid system from one to five stars [7]. In addition, it also lists out the best practices of utilities on implementation of SG. Below is a table listing best practices of SG around the world provided in Table 2.

Table 2: A list of best practices of Smart Grid (SG) around the world

Company	System adopted
Enel, Italy	Predictive analytics and maintenance application to pre-empt asset failures
Enedis, France	Distribution automation system whereby it implements automated restore of supply without human interruption
Innogov, Germany	- Renewable energy penetration of more than 25% contribution - Time based EV charging
UK Power Network	Real time consumption data and pricing system to customers
Kansai Electric Power Company	Customers have access to real time information from Advanced Metering Infrastructure system
Ausgrid, Australia	Online network system which allows capacity visualization to guide Distributed Energy Resources investment
Tata Delhi, India	Advanced distribution management system integrated with SCADA and Online Monitoring System

V. SG Implementation

A. SG implementation in Malaysia

Smart Grid is not a foreign concept to Peninsular Malaysia. The planning for the smart grid was started way back in 2012 when the pilot studies was conducted. In 2015, the main power provider – Tenaga Nasional Berhad (TNB) has developed comprehensive program for smart grid under the Grid of The Future program. It is one of the pillars exists in Reimagining TNB initiative that has been established to prepare TNB for a better future in view of disruptions in the energy sector. Under Grid of The Future pillar, TNB has envisioned the following objectives:

a) Smart home: To track their use in real time, clients will have access to smart meters installed in their homes. Customers will be able to produce their own power and sell it back to the grid if they have any spare capacity after installing smart meters.
b) Local micro-grids: TNB has envisioned through Grid of The Future for local-microgrids, which operates mainly independent from backbone network and utilizes renewable energy sources
c) Transmission backbones: In the future, transmission backbones are envisioned to be robust and ultra-efficient whereby it is fully automated and digitalized.

For Distribution Network, the list of technology enablers that will help the success of SG is provide in Table 3 (Kumar, 2018):

Table 3: A list of technology enablers towards success of SG

Technology enablers	Descriptions
Advanced metering infrastructure	Integrated system that enables two-way communication between utilities and the smart meters. It is beneficial to the customers as well as enhances operational efficiencies
Distribution automation	Automated system that to improve reliability, operational efficiency, customer survey index and safety of the operation

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Volt-var optimization	Using a system to managing voltage level and reactive power optimally throughout the distribution network
Geospatial information system	Maintain, manage, analyze and publish intelligent network models, maps and related data with GIS solution for desktop, web and mobile devices
Demand response	Manage demand response through a single, integrated system
Smart streetlight	Manage, maintain, monitor the entire streetlight efficiently in a cost-effective and sustainable way
Electric vehicle charging	Provide free accessible charging station to electric vehicles to align with Green Technology Initiatives as part of National Transformation Program
Mobility solution	Advanced analytics using real time performance data and predictive algorithm which prevents asset failure, concentrate asset management efforts on critical assets, avoid excess maintenance works and premature asset replacement

B. SG implementation in Europe

Smart Grid Architecture Model (SGAM) shown in Figure 6, a method created in the past few years, offers a very excellent and organized framework for the design and development of new solutions and technologies.

M/490 mandated the European Commission (EC) to the European standardization bodies, ETSI (European Telecommunications Standards Institute) and CENELEC (European Committee for Electrotechnical Standardization) to find existing technical standards applicable to Smart Grids as well as to identify gaps in state-of-the-art and standardization of the Smart Grids. To get everyone on the same page, it was probably difficult because of the wide range of expertise and the sheer number of people involved [17, 18].

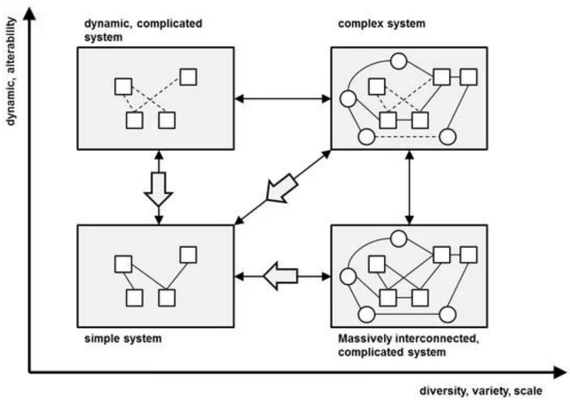

Figure 6: SG implementation in Europe [17, 18]

VI. Challenges in Implementation of SG

On the one hand, a higher demand for electricity and concerns for increasing existing transmission lines while still maintaining grid stability and reliability have been the primary motivations for moving toward Smart Grid. On the other hand, an increasing share of renewable energy resources, implementation of new technologies and data management methods in power system, development of communication systems.

SG implementation is not an easy task. There are myriads of process, technology exploration, regulatory and policy governance as well as financial issue that the electricity supply provider needs to deal with. Below is the table listing among the challenges faced in SG implementation as sown in Table 4.

Table 4: Challenges and barriers in SG implementation approaches; according to strategy related concerns

Challenge	Remarks	Strategy
Inadequacies in grid infra structure	Accommodating renewable sources and distributed generators will pose challenges in design, erection, operation and maintenance. Low rating capacity	Technical concern
Cyber security	Cyber security is a major concern in an intensive web-connected system like SG. Any minor weakest link will pose threat or turn into disaster	Technical concern
Storage	Battery energy storage, although dubbed as the solution for intermittent renewable energy, it has short span of life. In addition, it requires large area for installation.	Technical concern
Data management	Massive data will be created with emergence of many systems integrated in SG. Smart meter, distribution automation system will need to deal with frequent and huge data transfer. Data management is a key challenge that supply provider needs to deal with	Technical concern
Communication issues	Bandwidth limitation can pose challenge in communication of data between systems	Technical concern
Stability concerns	Angular stability due to lower overall system inertia. Voltage stability due to lower power sharing support. Low-frequency power oscillation. Worsening of SG transients profile during micro-grid islanding. Inability to serve as system reserve.	Technical concern

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High capital investment	Financial health inadequacy of a country	Socio-Economic
Lack of awareness	Public awareness needs to be tackled which may create hurdle	Socio-Economic
Fear of electricity charge increase	Increase of electricity tariff might be experienced by the customers	Socio-Economic
New tariff	New tariff scheme like as real time use, time of use, critical time pricing – receive different response.	Socio-Economic
Regulation and policies	Under development - to facilitate SG along with amendment to the existing ones	Regulation and organization
Work force	Lack of expert working force	Other

VII. Key Strategies to Overcome Barriers for SG

SG features integrated parts and systems. From client to supply chain, systems use communication, information, and infrastructure technologies. These tips may help Malaysia create and implement an SG system [13].

1. Standardize the SG definitions and interfaces with the government, regulators, and utilities while setting product requirements and applications. While working with industry and other international stakeholders, the government, regulators, and utilities should adopt a plan and standards to assure system interoperability and limit the risk of technological obsolescence [11].
2. The government and regulators should collaborate with public and/ or private sector stakeholders to determine regulatory and market solutions that can mobilize private sector investment in the energy sector [14].
3. Regulators should create, promote, and adopt a real-time energy usage tariff – Generators, transmission system operators, and distribution companies should plan and operate the systems in a coordinated manner [14].
4. Transmission and distribution system operators should work in coordination to develop operational business models with government and regulators, which ensure that all stakeholders share risks, and are shown the benefits of system reliability, cost, environmental sustainability, and security [1].
5. Generators should be flexible on the methods used by the SG to meet demand growth and decrease emissions [9,15].
6. Create a mechanism for the utilities to invest in research, development, and demonstration.
7. The government should actively engage in developing system demonstrations and deployments to ensure consumer contribution to and benefit from future electricity systems and markets, while ensuring consumer protection [5].
8. Introduce feed-in tariffs for specific renewable technologies to encourage deployment.
9. Change policy to put energy saving at the forefront of the energy agenda and remove the barriers that limit Distributed Energy [2].

VIII. Conclusion

Across the globe, utilities are attempting to transform age old power grids into smart distributed power systems with great efforts to resolve the challenges that arise on the way. Major challenges in SG technology are renewable integration, data management, stability, cybersecurity, etc. Although there is no final solution found, multiple approaches from researches are under trial/implementation through several pilot projects. Socio-economic issues are prevailing but being resolved through joint efforts. Governments and organizations are sharing the high capital investment involved in these pilots and ensuring support and confidence to all stakeholders. Awareness programs are set across various platforms to bring a higher understanding and cooperation. Other concerns are being found and remedied, such as those relating to privacy, rules, policies, and the theft of electrical power. Further, several agencies are also working as a feedback network; they are analyzing the efforts to make SG a nearby success to reap its benefits. Reduced cost, enhanced reliability, improved power management, self-healing grid infrastructure, new jobs, satisfied consumer, green and clean power etc. are the major impacts that encourage SG and its global expansion. Despite several issues, consumers are willing to adopt smart distribution network. They are concerned and do have supporting role with utilities and government which is well revealed from the successful mini pilots SG project implemented in Malaysia.

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