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Smart Grid Analysis for the Caribbean Region

Daniel Sooknanan[a], Sanjay Bahadoorsingh[b, Ψ], Ajay Joshi[c] and Davinder Pal Sharma[d]

[a,b,c] Department of Electrical & Computer Engineering, The University of the West Indies, St Augustine Campus, Trinidad and Tobago, West Indies, West Indies; E-mails: Daniel.Sooknanan@sta.uwi.edu; Sanjay.Bahadoorsingh@sta.uwi.edu; Ajay.Joshi@sta.uwi.edu

[d]Department of Physics, The University of the West Indies, St Augustine, Trinidad and Tobago, West Indies, West Indies; E-mail: Davinder.Sharma@sta.uwi.edu

[Ψ] *Corresponding Author*

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Abstract: *This paper presents a gap analysis of smart grid technology for the Caribbean region, and outlines the opportunities for the potential widespread roll-out of this technology, the challenges posed and the exercises employed to assist legacy power systems transition to the smart grid. By exploring the evolution of the smart grid and smart grid statistics, this paper applies smart grid technology to regional and local contexts. The available technologies involved are also discussed, as well as economic and business strategies for the smart grid in a Caribbean context. For the region, the most important factor is the adoption of renewable energy sources and a distributed generation paradigm that is characteristic of the smart grid, as well as the widespread use of relevant communications and information technologies. Other recommendations include rigorous planning with cost versus benefits analyses being performed with respect to the applicable technologies and a strategic business plan. The paper concludes by describing the transition to the smart grid using micro-grids.*

Keywords: *Smart grid, Electricity, Power system, Caribbean, Renewable*

1. Introduction

In the Caribbean, the electrical network is considered to be antiquated as the current electrical infrastructure in most, if not all, Caribbean nations has remained unchanged for decades and is aging while electricity consumption is increasing. One means of enhancing the existing grid is the adoption of smart grid (SG) technology. The smart grid is a next generation electrical power system, typified by increased use of communications and information technology (ICT) in the generation, delivery and consumption of electrical energy (IEEE Smart Grid 2014). While the traditional grid has always been "smart" to some extent, there is a need for grids to get smarter. Utilities are developing and deploying standards and technologies to transform the traditional grid into a smart grid, leading to higher levels of resilience and reliability. The smart grid is, therefore, a modern electrical power grid infrastructure, boasting improved efficiency and sustainability, with smooth integration of renewable and alternative energy sources.

While most developed countries, European countries and the US for example, have embarked on enhancing their 20th century grids with SG technology, the Caribbean region is focusing on renewable energy (RE) research and deployment. According to the Caribbean Electric Utility Services Corporation (CARILEC), 85% of all electric power in the Caribbean is generated with fuel oil and most Caribbean countries are either fully or more than 90% dependent on oil, thus emphasising the need for energy diversification in the region (CARILEC 2008). On March 1, 2013, the Caribbean Community (CARICOM) countries embarked on the development of a Regional Energy Policy focused on the widespread deployment and integration of renewable energy sources, in an attempt to reduce dependence on fossil fuels and contribute to the fight against climate change (CARICOM 2013).

Smart grid technology is therefore promising for the Caribbean region: The emergence of the SG will lead to enhanced environmental sustainability, with more reliable power supply services. There is, then, the need to investigate the suitability of SG technology to the region and to determine the measures needed for full-scale roll-out. The University of the West Indies (UWI) is currently undertaking a research and capacity building initiative on how this technology will enhance the efficiency of present electrical power networks in the region.

This paper outlines the requirements to enable the evolution of the existing grid in the Caribbean to SG status. This gap analysis will also focus on the opportunities and challenges for the smart grid in the region. Some insights on regionally relevant technologies are shared. As an outcome, the UWI intends to construct and deploy a microgrid within a laboratory environment, which will be used to simulate the technology on a small scale.

2. Grid Evolution

The smart grid can be thought of as the outcome of the evolutionary development of existing networks towards an optimised and sustainable energy system (Hashmi, Hanninen, and Maki 2011). The International Energy Agency (IEA) defines a smart grid as an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids coordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability (International Energy Agency 2011).

This evolutionary development is centred on the mass infusion of Information and Communication Technology (ICT) and Computational Intelligence (CI) into the existing grid. The smart grid is emerging as a convergence of computing and communication technologies with power system engineering (Farhangi 2010). At the core of this transformation is the need to make use of current assets, incorporating new technologies gradually, thus following an evolutionary trajectory, rather than performing a complete overhaul. The evolution of the grid is illustrated in Figure 1.

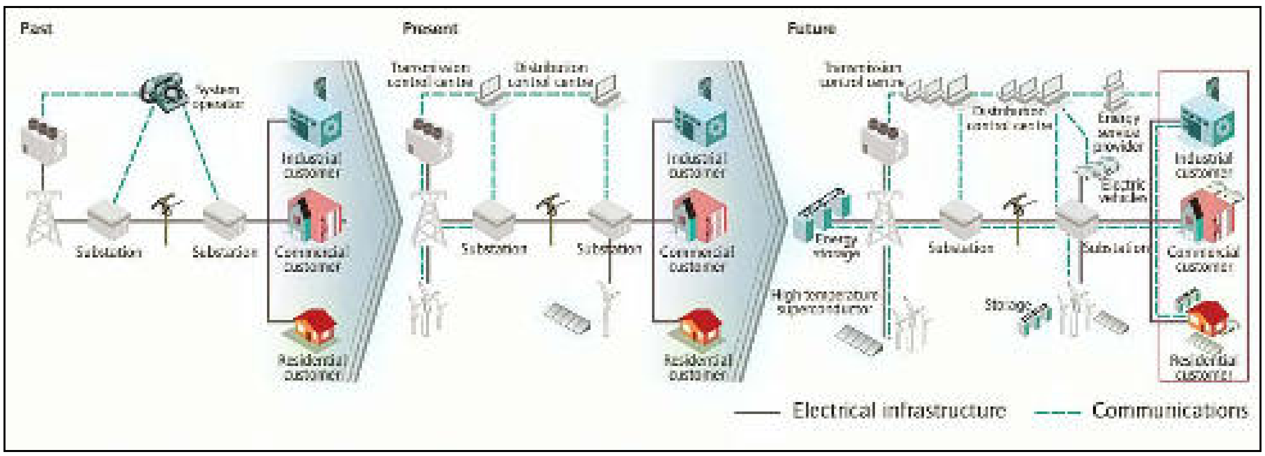

Figure 1. Grid Evolution
Source: International Energy Agency (2011)

Referring to the traditional grid as having always been “smart”, implies that traditional grids make use of ICTs. However, in a truly smart grid, there is heavy use of modern communication and high performance computing technologies. SG evolution can be segmented into distinct versions. For the sake of clear nomenclature, the terminology presented by Trilliant Inc. (2015) will be utilised. Smart Grid v0.0 is the base case – this cannot be classified as a “smart” network since each network used proprietary protocols to read meters on isolated networks. This phase is typically associated with automated metre reading (AMR). Smart Grid v1.0 saw the advent of advanced metering infrastructure (AMI), a smarter version of AMR. In AMI, metres are automatically read and standards-based solutions provide applications like demand response and time-of-use (TOU) billing. The next phase of the SG, Smart Grid v2.0, involves the consumer becoming directly involved with energy utilisation. It highlights the necessity for two-way communication and the advent of a consumer-oriented grid. Finally, Smart Grid v3.0 is the future of SG technology, where plug-in hybrid electric vehicles (PHEVs) and micro-grids of distributed generation interact with the grid to balance energy supply and demand (Trilliant Inc. 2015).

Communication and data management play an important role, placing a layer of intelligence over the existing and future infrastructure. It is worthy to note that in the future grid, communications and electrical infrastructure work in tandem from generation to consumption, which results in improved control, monitoring and automation, as well as stronger consumer involvement (Farhangi 2010).

The smart grid can therefore be realised through strategic implants of distributed control and monitoring systems within and alongside the existing electricity grid. This will facilitate the distributed generation and co-generation of energy and allow for the integration of alternative energy sources and the management of a system’s carbon footprint. It will also enable utilities to make more efficient use of their existing assets through demand response, peak shaving and service quality control (Farhangi 2010).

According to Farhangi (2010), 90% of all power outages and disturbances originate in the distribution network. Therefore, the move towards the smart grid should start in the distribution system. A proposed method to modernise the distribution network is the introduction of technologies that help with demand-side management and revenue protection. Utilities across the world are moving towards deploying advanced metering infrastructure (AMI), which provide utilities with two-way communication to the metre (Farhangi 2010).

The IEA lists some general characteristics of the smart grid which are applicable in any regional context. The SG enables informed dynamic participation by customers (usage data and pricing); integrates all generation and storage options; provides the power quality for the range of needs driven by market conditions; optimises asset utilisation and operating efficiency (automation and remote control); and provides resiliency to disturbances, attacks and natural disasters. The smart grid cannot and should not be a replacement for the existing electricity grid, but is a complement to it. It should coexist with the existing grid, adding to its capabilities, functionalities and capacities by means of an evolutionary path (Farhangi 2010).

Farhangi (2010) describes the smart grid as an ad hoc integration of complementary components, subsystems and functions. The evolution of the smart grid is facilitated by the integration and interconnection of smart microgrids. Smart microgrids are defined as distributed energy systems that can function either connected to or be independent of the electricity grid. These interconnected microgrids have dedicated paths for command, data and power exchange. The system of integrated smart microgrids operates in parallel with the existing grid, with functionality and load gradually being migrated from the existing grid to the smart grid. The topology of the emerging grid will therefore resemble a hybrid solution (Farhangi 2010).

3. Smart Grid at the Global Level

Worldwide statistics ought to be considered when performing a gap analysis to determine the direction towards the full scale roll-out of a smart grid for the Caribbean. These statistics are drawn from projections as well as results from pilot implementations. The integration of (intermittent) renewable energy sources (RES) is a major benefit of the smart grid, because it reduces a country's carbon footprint. Electricity distribution within the smart grid paradigm would reduce carbon dioxide emissions by up to 25%. A 25% reduction in CO_2 emissions equates to 7.6 billion tons by 2030 (U.S. Department of Energy 2014). The reduction of Green House Gas (GHG) emissions via smart grid deployment would be as a result of removing 140 million cars from the road (by encouraging the use of PHEVs), lowering coal use by 18% and natural gas use by 50%, and avoiding the construction of 80,000 MW coal-fired generation plants (U.S. Department of Energy 2014).

Some of the requirements of smart grids include improved utilisation through the use of improved control and monitoring of networks, and reduced consumption via Demand Side Management (DSM) (Hashmi, Hanninen, and Maki 2011). From pilot implementations in the US, it has been found that smart grid enabled energy management systems have been able to reduce electricity usage by 10-15% and up to 43% of critical peak loads. A state of the art high capacity transmission line can conduct as much electricity as six standard lines, at one-third the cost, using 25% less land, and with one-tenth the line losses. Smart grid enabled distribution could reduce electrical energy consumption by 5-10%, carbon dioxide emissions by 13-25% and the cost of power related disturbances to business by 87% (Energy Future Coalition 2015.).

The global market for smart grid IT and management services will grow from $1.7 billion in 2014 to more than $11.1 billion in 2023. Services include home energy management, advanced metering infrastructure, distribution and substation automation communications, asset management and condition monitoring, demand response, software solutions, and analytics (Energy Future Coalition 2015).

4. Smart Grid: Regional and Local Context

This section of the paper will examine where the Caribbean stands currently in terms of its progress towards achieving smart grid status, and covers the goals in bridging the gap.

4.1 Renewable Energy

There is a disproportionate dependence on fossil fuels in the Caribbean region, particularly oil and natural gas, (CARILEC 2008, CARICOM 2013). This dependence on fossil resources is primarily for electricity generation and vehicular transport. According to GIZ and CARICOM (2014), over 95% of the commercial energy consumption is based on mineral oil products. This leads to high levels of national debt and high costs for electricity generation (GIZ and CARICOM 2014). As such, the Caribbean region is faced with several critical challenges with respect to the generation, distribution and use of energy (Auth et al. 2013). With the CARICOM countries focusing on the deployment of renewable and alternative energy, in an attempt to diversify energy sources and combat climate change as a regional body, it is important to examine the renewable energy plans of each country.

As an outcome of the CARICOM Regional Energy Policy, the first phase of the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS) was commissioned. C-SERMS Phase 1 is aimed at coordinating a regional approach to expedite the increased use of renewable energy and energy efficiency, while promoting climate-compatible development, minimising environmental damage and fostering economic growth and innovation (Auth et al. 2013). Another such outcome is the Renewable Energy and Energy Efficiency Technical Assistance (REETA) Project. The REETA project builds on the results and successful approaches of the Caribbean Renewable Energy Development Programme (CREDP) and other projects in the region (such as C-SERMS) (GIS and CARICOM 2014). The REETA project focuses on the development of a regional energy strategy, the establishment of regional know-how and the support of the regional networking of stakeholders. The overarching project goal is for regional and national players in the areas of RE and energy efficiency to increasingly comply with the political, organisational and technical demands of a growing market in the Caribbean (GIZ and CARICOM 2014).

One of the main characteristics of the smart grid is the deployment of renewable and distributed resources, thus leading to a reduction in GHG emissions. In particular, smart grids are characterised by distributed generation (DG), which refers to the introduction of small rating electricity sources, typically decentralised and located close to end-user locations on the distribution side of the grid. This gives rise to an on-demand power quality of supply, enhanced grid security (reduced susceptibility of a centralised power source) and reliability, and deferrals in the transmission investment (Simoes et al. 2012).

As such, the first step towards the regional deployment of a smart grid in each Caribbean nation, from a technological standpoint, is the adoption of the DG paradigm, which involves the deployment of distributed, renewable energy sources. For power generation there are no viable alternatives that could compete on price with oil, coal or natural gas. The Caribbean region therefore needs to explore the best possible and most economically feasible options in the field of renewables. The most obvious options in the Caribbean are wind power, biomass, geothermal, ocean thermal, hydropower and solar power (CARILEC 2008). Tremendous potential exists in many countries to meet most or all of current demand with renewables. Table 1 illustrates the technology potential measured with respect to its measured share of peak demand in each member state.

Table 2 compares the renewable energy target of each Caribbean nation, and also indicates whether or not these countries have already deployed RES in their grid supplies. Some countries already have provisions for widespread deployment of renewable energy sources. This underscores the need for larger countries such as Trinidad and Tobago and Belize to introduce renewable sources into their local energy mix and/or enforce time of use tariffs on non-renewable sources. The development and deployment of alternative and RE sources is therefore one of the major gaps between the region's SG roll-out when compared to already existing SG implementations. Apart from this, economic and business factors must be considered.

The use of renewable energy sources and energy efficiency (EE) technologies in each country would lead to reduced dependency on mineral oil imports. According to GIZ and CARICOM (2014), "increased investments in EE and RE will mitigate some of the uncertainties in the future costs of energy".

Table 1. Technology potential measured with respect to measured share of peak demand in CARICOM member states

	Hydro	Wind	Geo-thermal	Solar	Biomass/ Other
Antigua and Barbuda	None/Low	Extremely High	None/Low	High	Unknown
The Bahamas	None/Low	High	None/Low	Medium	Medium
Barbados	Unknown	Medium	None/Low	Medium	Medium
Belize	Very High	Unknown	None/Low	High	Very High
Dominica	Very High	Extremely High	Extremely High	Extremely High	Unknown
Grenada	Unknown	High	Extremely High	Very High	Unknown
Guyana	Extremely High	Unknown	None/Low	Extremely High	Unknown
Haiti	Medium	Medium	None/Low	Unknown	Medium
Jamaica	Medium	Medium	Unknown	Unknown	Medium
Montserrat	Unknown	Unknown	Extremely High	Unknown	Unknown
St. Kitts and Nevis	None/Low	Medium	Extremely High	Unknown	Medium
St. Lucia	Medium	High	Extremely High	Unknown	Medium
St. Vincent and the Grenadines	High	High	Extremely High	Very High	Medium
Suriname	Extremely High	Unknown	Unknown	Unknown	High
Trinidad and Tobago	Unknown	High	Unknown	Medium	Unknown

Extremely High (>100%)	Very High (50-100%)	High (20 – 50%)	Medium (0 – 20%)	None/Low	Unknown

Source: adopted from Auth et al. (2013)

Table 2. Renewable energy targets of each Caribbean country and whether or not RE exists in the grid supply

Country	Renewable Energy Target	Renewable Energy in Grid Supply
The Bahamas	NYA	No
Barbados	40% by 2010	Yes
Belize	NYA	Yes (HEP)
Dominica	25% by 2010	Yes (22% HEP in 2007)
Grenada	10% by 2013; 20% by 2017	No
Guyana	70-80% by 2012 (HEP)	No
Jamaica	15% by 2020	Yes (Wind, HEP)
St. Kitts	100% by 2012	No
St. Lucia	30% by 2012	No
*Trinidad and Tobago	NYA	No
St. Vincent	NYA	Yes (20% HEP)

Remarks: *5% target of 60 MW in 2022; NYA = Not Yet Available; HEP = Hydro Electric Power
Source: Ministry of Energy and Energy Affairs (2011)

Reducing electricity tariffs in countries that do not have their own energy sources would effectively lower the bills of domestic consumers. Figure 2 illustrates the typical bills of domestic consumers at 100 kWh/month for September 2012. Countries, like Trinidad and Tobago, which produce its own fossil fuels and hydrocarbons from abundant sources within the nation's territory, have lower bills: the commodity is more expensive for those countries which import resources.

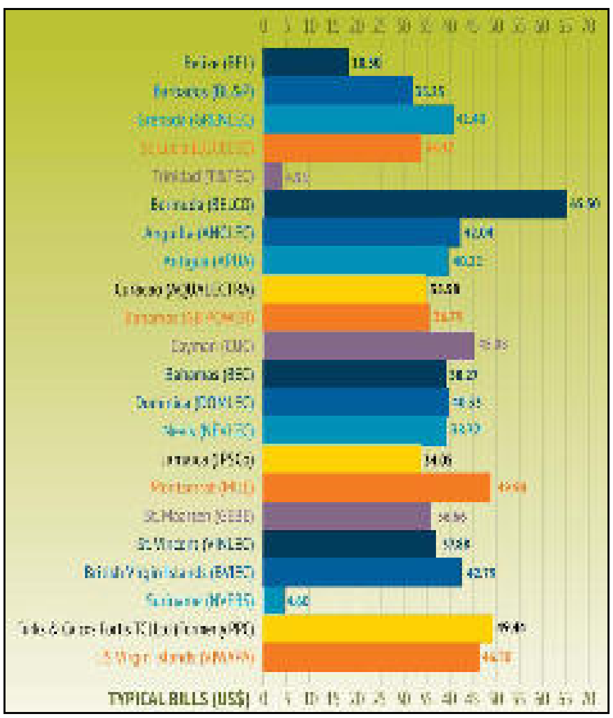

Figure 2. Typical Bills for 100kWh/month Domestic Consumers for 2012
Source: CARILEC (2012)

4.2 Smart Grid Business Plan for the Caribbean

Before the deployment of SG technologies can occur, utilities and researchers alike must examine how implementation of the smart grid can be done in a cost effective and efficient manner. A number of economic factors affect the roll-out of new technologies. Any utility which wishes to implement a smart grid on a macroscopic level must first determine and select various business objectives to suit their needs, i.e. implementation needs and the needs of consumers. This is especially important in the Caribbean region since most countries are developing nations and each has a different economy, budget, developmental priorities, and supply and demand factors. Due to the diversity of operational challenges that each utility will face, SG implementation will differ from one utility to the next. However, one thing remains common: the driving objective of every smart grid is ultimately a business objective (Barbosa 2012).

As a result, utilities must undertake strategic planning, selecting business objectives according to their priorities. Typical SG business objectives are similar, however priority will differ from one utility to the next (Barbosa 2012). According to Barbosa (2012), typical business objectives for the planning of the smart grid include:

- Enabling informed participation by consumers
- Reducing operational costs through better voltage control
- Improving power quality delivered to customer
- Enabling DG and storage options throughout the network and better management of those assets which are owned by both utility and customer
- Strengthening the network's resiliency in the face of cybersecurity attacks and natural disasters
- Introducing new products and services to the consumer
- Optimising existing and new asset utilisation

Barbados Light & Power (BL&P) suggests a phased approach, i.e. implementing the SG in several phases, driven by various business objectives (Barbosa 2012). BL&P's phased approach allows control of: budget, technology deployment, application of key technologies in the highest priority areas, technology evaluation, change management, maintenance and implementation phases within a realistic plan (Barbosa 2012). This shows that Barbados is one of the few Caribbean countries which has made progress to bridge the economic/business gap of SG deployment. Their business model as mentioned above, is sound, and avoids common pitfalls to which some utilities succumb. This approach and model is useful to other Caribbean nations as they move towards SG implementation.

After determining and selecting the most suitable business objectives, the utility must then select the SG technology that meets these business goals. There should be a thorough evaluation of potential technologies before selection; utilities must conduct cost-benefit analyses and investigate integration issues when selecting technologies (Ockwell 2012). According to Ockwell (2012), the evaluation of a well-designed and integrated pilot program may reveal the need to invest in primary infrastructure before proceeding with technology deployment. The rationale behind this is that the smart grid is not a single technology proposition. A true smart grid involves integrated architecture that can adopt new technologies as new business objectives emerge and change (Barbosa 2012; Ockwell 2012).

5. Smart Grid Opportunities in the Caribbean

This section highlights the range of opportunities available for smart grid implementation and deployment in the region. With a focus on the development of Trinidad and Tobago's smart grid, an attempt will be made to present opportunities which may be applicable to other Caribbean countries, mainly from a technological standpoint, while also performing a gap analysis on SG technologies.

The instrumental role of ICT based applications in the SG revolves around real-time control and monitoring. There is the need for automated control, modern communications infrastructure and sensing technologies. Smart grids generally feature increased digital information, in particular the bi-directional flow of information, which requires sophisticated control, sensing and computer-oriented monitoring devices. This is achieved through the use of Advanced Metering Infrastructure (AMI), which facilitates two-way communication and the transmission of delivered and generated energy data, along with actionable commands to customers, thus affording consumers better control over energy usage (Simoes et al. 2012). Data from sources (metres, sensors) must be relayed to appropriate controllers in the grid to make smart decisions. In 2006, the Trinidad and Tobago Electricity Commission (T&TEC) developed a plan to install over 40, 000 metres across its customer base. As of 2008, sixteen thousand metres were installed (CARICOM 2013).

Smart grid advancements have the potential to manage demand by shifting loads to off-peak hours and better utilising domestic renewable energy resources (Auth et al. 2013). This is referred to as the peak shaving of load demand and in the case of Trinidad and Tobago, can result in a 13-24% peak reduction. At the household level, the deployment of smart meters (AMI), combined with appropriate policy provisions, would allow customers to generate their own power and sell excess electricity back to grid (Auth et al. 2013). This gives rise to another highly desired feature of the smart grid, the bi-directional flow of power. This is facilitated by the DG paradigm mentioned previously, as well as efficient electricity storage. The use of smart meters also facilitates real time pricing, which can potentially result in energy consumption behaviour modification.

As stated, the SG is also characterised by the embedding of Computation Intelligence (CI) in the grid. This implies that computing technologies play a major role in the implementation and deployment of smart grids, making it a truly cyber-physical system. This can potentially translate to a technological revolution for the region, with the infusion of high performance computing technologies to facilitate processing of data in ensuring efficient control, monitoring and automation processes. In particular, it ensures that these processes can be carried out in real-time, and allows for data mining/storage, intelligent coordination, security, simulation, visualisation and control (Green II, Wang, and Alam 2013). This therefore opens opportunities in the Caribbean for high performance computing solutions. Such technologies include cluster, multi-core, many-core (GPU), grid and cloud computing.

Cloud computing opportunities are vast due to the one to many relationships between data and devices over the Internet. This translates to extensible and secure computing data centres and enables cost effective incremental development. It leverages Software as a Service (SaaS), effectively minimising capital and implementation time. This also gives rise to the opportunity for creating a thriving smart grid IT market within the region, providing jobs for professionals, and reducing the need for outsourced labour.

System security in a smart grid context may refer to many things, which include, but are not limited to resilience, stability and reliability of the power supply. The smart grid solution provides the opportunity to improve system security in the region. Existing grid infrastructure is outdated and often insufficient to meet the population's current and growing energy needs; this is evidenced by the region's high technical losses and, in select member states, an unreliable electricity supply (Auth et al. 2013). System security manifests itself in the SG in real-time monitoring, fault anticipation, corrective action, expeditious (self) restoration and the reduction of outage frequency and spread.

Another sustainable opportunity of SG deployment in the Caribbean is electrification of the transport sector. This is linked to the reduction of GHG emissions since it includes eco-friendly and financially feasible transport. This may even be extended to include mass transportation systems, but will focus mainly on

Plugin Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). This will lessen the dependence on fossil fuels and could eventually lead to the gas station becoming obsolete.

6. Smart Grid Challenges in the Caribbean Region

Just as there are numerous opportunities within the region for Smart Grid deployment, there are also numerous challenges which arise due to several, usually unavoidable, factors, as well as poor planning in the initial stages. These challenges manifest themselves in economic and business setbacks, poor technology deployment, vulnerabilities in the grid and shortfalls in the technologies used.

Often, within the utility, the corporate business objective is not well known; engineering, operations and IT may not agree on the direction in which they are taking the utility (Barbosa 2012). Utility executives often do not clearly identify the strategic business objective of the utility (Ockwell 2012). According to Barbosa (2012), the utility executive must provide clarity in leading the organisation in their strategic business objectives and the organisation must cooperatively create a multi-department tactical plan that is able to meet those objectives.

The unclear business objectives result in another challenge in the SG setting, i.e. the selection of SG technology. It is common for a utility to invest early in a single technology under a system wide roll-out without performing some critical analysis on cost vs benefit. Often, the technology is selected first without a sound business objective. This can be seen in the case of AMI. AMI has the potential to consume multi-year budgets using time and resources that may be spent on the deployment of other integrated SG solutions (Barbosa 2012). The business objectives drive the technologies and the technologies will specify the deployment plan. To overcome this, BL&P suggests the phased roll-out in a minimal area of the network (Barbosa 2012). This reflects the microgrid approach, discussed further on. A phased roll-out affords the utility the opportunity to evaluate the technology from many aspects, in terms of meeting technical requirements and deployment costs (Barbosa 2012).

Existing grid infrastructure poses a major challenge. The smart grid is susceptible to all threats which the existing grid faces, such as natural disasters and intentional attack. As the existing grid evolves, there is the increased interdependence among the fields of energy, telecommunications, transportation and financial infrastructures, which poses increased risk (Amin and Giacomoni 2012). This interconnectivity makes the grid vulnerable to a spectrum of threats – cascading outages brought on by material failure, natural disasters, sabotage or human error, and failure in one part of an infrastructure network can have adverse effects in other areas (Amin and Giacomoni 2012).

The energy aspect of the smart grid also faces numerous challenges. Generation sources, particularly RES, are intermittent; this affects the output characteristic of generator and convertor sets (Simoes et al. 2012), as well as the transient stability of supply. Interconnection standards must be developed and adhered to when considering diverse generation sources. There are also potential problems in the transmission and distribution systems due to new power flow patterns and quality concerns. Protection, automation and control upgrades may also prove challenging. The introduction of the electric vehicle also poses some challenges in terms of distribution system loading and quality of supply concerns.

A common hidden challenge which obstructs deployment is the lack of data or data quality (Barbosa 2012). Before specific SG technologies are deployed, primary infrastructure should be developed to ensure data quality. On a similar note, there may be integration issues with data infrastructure. The framework of communications, data, computing platforms, sensors, switching devices, active devices and software may not support integration of other solutions (Barbosa 2012).

The infusion of ICTs and upgrade of control systems in the smart grid can introduce vulnerability in terms of cyber-security. Digitisation increases the threat of remote attacks by hackers, who capitalise on known vulnerabilities and misconfigured operating systems, servers and network devices (Amin and Giacomoni 2012). Existing control systems which were initially intended for use with proprietary, stand-alone communication networks are now being connected to the Internet without adding the technology necessary for security. Furthermore, in the communication and control of power systems, various forms of communication media and protocols are used. This diversity and lack of interoperability causes problems when attempting to establish secure communication to and from a substation (Amin and Giacomoni 2012). Increased automation which entails a complex system of sensors and automated controls, tied together through communication systems, also presents a threat. Activities that compromise the operation of sensors, communications and control systems could disrupt the system, cause blackouts and even result in physical damage to key system components (Amin and Giacomoni 2012). To counteract these challenges, Amin and Giacomoni (2012) suggest a layered security approach to minimise disruptions. Multiple security technologies should be combined and deployed at each layer of a computing system (personnel, networks, operating systems, applications, databases) to reduce the risk of unauthorised access (Amin and Giacomoni 2012). Security features include examination, detection, prevention and encryption (Amin and Giacomoni 2012).

The implementation and deployment of AMI, which is typically one of the first steps in the digitisation of the grid, also introduces potential security breaches.

According to Amin and Giacomoni (2012), possible threats include: fabricating generated energy metre readings; manipulating energy costs; disrupting the load balance of local systems by increasing or decreasing the demand for power; gaining control of millions of metres and simultaneously shutting them down; sending false control signals; disabling grid control centre computer systems and monitors; and disabling protective relays. AMI also introduces privacy concerns, as customer energy usage information will be stored at the meter. Unauthorised access and malicious use of this data could expose customer habits and behaviours, opening up avenues for personal profiling, identity theft and home invasions (Amin and Giacomoni 2012). AMI systems also need to be defended against traditional cyber-threats, like malicious code, denial-of-service attacks, accidental faults due to human error and problems associated with aging hardware and software (Amin and Giacomoni 2012).

These threats and challenges bring to the fore further economic setbacks. There are price distortions in the region, for example where there is a fuel subsidy favouring fossil fuel and a lower tax burden compared to renewable energy. With intermittent sources being used for generation, there is the need for advanced storage technology. The energy storage market is estimated to reach $50 billion by the year 2020 (Jacques 2014), leading to increased expenditures on the part of the region. Other challenges posed are legislative in nature. Financial, technical and administrative legislation must be put in place and be on par with the rest of the world. Legislation must also be developed for the use of electric vehicles treating with issues related to charging, billing and dynamic tariffs.

Finally, there are the socio-cultural and human capital challenges of SG deployment. The Caribbean region generally does not have an energy conservative culture. This must be fostered throughout the region to ensure sustainability of energy resources. Additionally, on the utility side, there must be certain training requirements for operational and maintenance personnel (Barbosa 2012). The utility must possess the core competencies necessary to achieve full deployment.

7. Discussion

Smart grid growth is now a necessity; factors such as aging infrastructure, retiring personnel and abundant DG resources are creating a situation where traditional generation technology will be incapable of ensuring grid safety and stability (Elberg 2014; Gipling 2014).

In order to facilitate the full-scale roll-out of a smart grid, The University of the West Indies, St. Augustine Campus has embarked on a project/initiative entitled “Capacity Building and Research on Smart Grid Technology in the Caribbean Region”, with the intent of pioneering the enhancement of electrical power networks in the Caribbean Region by adopting smart grid technology. Research is being conducted on each of the technological aspects of the SG (Power, Communications and High Performance Computing), and implementation will be done on the microgrid level. A microgrid is a small-scale, localised version of the smart grid, achieving specific local goals (The Galvin Project Inc. 2014). It is envisioned that The UWI microgrid will foster the modernisation of the campus power grid.

Until there exists policy to support the integration of smart grid technology into the nationwide power system, yielding financial benefit to the consumer as a net producer, increased savings and efficiencies must occur at the micro level. This will result in localised facilities employing suitable technologies to address the specific concerns while hopefully improving some aspect of their power system.

8. Conclusion

The smart grid is essential to improved energy efficiency, economic development and climate change mitigation. Participation by government, the private sector, consumers and environmental advocacy groups is imperative to successful deployment. Caribbean member states must ensure that the necessary regulations are in place and market models are developed accordingly. System investment, prices and customer participation must evolve in the same manner as SG technologies for incremental smart grid deployment/implementation.

The gaps which exist in the Caribbean must be closed before full-scale deployment can occur within the region. These gaps would generally be similar across nation states. However, there would be minor variations among countries. In summary, utilities must determine and select relevant business objectives; select the appropriate SG technologies to match these objectives, while avoiding total investment in any one technology without proper evaluation; invest in and deploy renewable and alternative energy sources; find and promote local and regional smart grid markets; implement legislation and regulation frameworks, while adhering to worldwide standards; and foster and promote an energy conservative, eco-friendly culture.

References:

Amin, S. M., and Giacomoni, A. M. (2012), "Smart Grid: Safe, secure, self-Healing", *Power and Energy Magazine*, IEEE, Vol.10, No.1, pp.33-40. doi: 10.1109/MPE.2011.943112.

Auth, K., Konold, M., Musolino, E., and Ochs, A. (2013), *Caribbean Sustainable Energy Roadmap (C-SERMS) Phase 1 - Summary and Recommendations for Policymakers*, Worldwatch Institute, CARICOM

Barbosa, Jose (2012), "Barbados Light and Power's practical approach to the smart grid", *CARILEC Industry Journal*, Vol.11, pp.2-7.

CARICOM (2013), “CARICOM Energy Policy”, Paper read at the Forty-First Special Meeting of the COTED on Energy, at Trinidad and Tobago, The Caribbean Community/The Council for Trade and Economic Development, Accessed from http://www.caricom.org/jsp/community_organs/energy_progra mme/CARICOM_energy_policy_march_2013.pdf .

CARILEC (2008), *CARILEC Position Paper on Energy Policy*. edited by DNV KEMA, The Caribbean Electric Utility Services Corporation

CARILEC (2012), *CARILEC Annual Report 2012*, CARILEC.

Elberg, Richelle (2014), *Smart Grid Technologies*, Navigant Research Navigant Research.

Energy Future Coalition (2015), *Smart Grid Facts*, Accessed February 19 2015, from http://www.energyfuturecoalition.org/files/webfmuploads/Transmission%20Smart%20Grid%20Fact%20Sheet%2002.20.09.pdf.

Farhangi, Hassan (2010), "The path of the smart grid", *Power and Energy Magazine*, IEEE, Vol.8, No.1, pp.18-28. doi: 10.1109/MPE.2009.934876.

Gipling, Lyndsey (2014), "10 facts about the Smart Grid: IT's role in unlocking clean energy", *TechRepublic*, Accessed December 30 2014, from http://www.techrepublic.com/article/10-facts-about-the-smart-grid-its-role-in-unlocking-clean-energy/.

GIZ and CARICOM (2014), *Renewable Energy and Energy Efficiency Technical Assistance (REETA) Project*, German International Cooperation & The Caribbean Community, Accessed from https://www.giz.de/en/worldwide/29362.html

Green II, R.C., Wang, L-F. and Alam, M. (2013), "Applications and trends of high performance computing for electric power systems: Focusing on Smart Grid", *IEEE Transactions on Smart Grid*, Vol.4, No.2, pp.922-931. doi: 10.1109/TSG.2012.2225646.

Hashmi, M., Hanninen, S. and Maki, K. (2011), "Survey of smart grid concepts, architectures and technological demonstrations worldwide", *Proceedings of the IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America)*, IEEE, Medellin

IEEE Smart Grid (2014), *IEEE and Smart Grid, IEEE 2014*, Accessed October 20 2014, from http://smartgrid.ieee.org/ieee-smart-grid.

International Energy Agency (2011), *Technology Roadmap Smart Grids*, IEA Publications Online, France, Accessed January 02 2015, from http://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

Jacques, Carole (2015), "Energy storage market rises to $50 billion in 2020, amid dramatic changes", Lux Research Inc., Accessed January 19, 2015, from http://www.luxresearchinc.com/news-and-events/press-releases/read/energy-storage-market-rises-50-billion-2020-amid-dramatic.

MEEF (2011), *Framework for Development of a Renewable Energy Policy for Trinidad and Tobago*, Ministry of Energy and Energy Affairs, Accessed from http://energy.gov.tt/wp-content/uploads/2013/11/266.pdf.

Ockwell, Gary (2012), "Do your Smart Grid technologies play well together?" *CARILEC Industry Journal*, Vol.12, pp.26-29.

Simoes, M.G., Kyriakides, E., Blunier, B., and Ribiero, P.F. (2012), "A comparison of Smart Grid technologies and progresses in Europe and the U.S.", *IEEE Transactions on Industry Applications*, Vol.48, No.4, pp.1154-1162. doi: 10.1109/TIA.2012.2199730.

The Galvin Project Inc. (2014), *What are Smart Microgrids 2014*, Accessed October 03 2014, from http://galvinpower.org/microgrids.

Trilliant Inc. (2015), *The Evolution of the Smart Grid 2015*, Accessed August 6 2015, from http://trilliantinc.com/blog/the-evolution-of-the-smart-grid.

U.S. Department of Energy (2014), *Smart Grid 2014*, Accessed December 29 2014, from http://energy.gov/oe/services/technology-development/smart-grid.

Authors' Biographical Notes:

Daniel Sooknanan *received his B.Sc. (Hons) in Electrical and Computer Engineering from The University of the West Indies in 2013 and is currently an M.Phil student at the university. His work is centred on programming and software. His M.Phil, research is in the field of High Performance Computing.*

Sanjay Bahadoorsingh *completed the B.Sc. degree at The University of The West Indies and the M.Sc. degree at UMIST. He completed the Ph.D. degree at The University of Manchester and is currently a lecturer in the Energy Systems Group at The University of the West Indies. He has published extensively in power systems operation and planning, renewable energy, smart grid, asset management and dielectric ageing.*

Ajay Joshi in 1996 earned *a Ph.D. in Advanced Computer Architecture from The University of Mumbai, India. He is currently with the Department of Electrical and Computer Engineering at The University of the West Indies, Trinidad and Tobago. Earlier, he was Head of Technology at IBM Advanced Training Centre at Nasik, India. His publications are in the field of embedded systems hardware related to memory and parallel processing. He is an IEEE member since 2004 and has chaired a session in IADAT Conference in Spain. Currently he is a Principal Investigator of NVIDIA CUDA center at the University.*

Davinder Pal Sharma *received Ph.D. in Communication Signal Processing from Guru Nanak Dev University, India in 2004. He has 16 years of University level teaching and research experience. Currently he is Lecturer in Electronics at The University of the West Indies, Trinidad and Tobago. His current research interests include Smart Grid Technology, Automatic Speech Recognition and Modelling of Fuel Cells. He is author of the book on Digital Signal Processing and has 38 publications in reputed journals and conferences. Dr. Sharma is an IEEE member since 2010.*

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