Smart Grid Technology and Distributed Generation

C. N.Karue, D. K. Murage, C. M. Muriithi

Abstract - As the energy demand grows, combined with the quest to achieve Sustainable Energy for All (SE4ALL) objective of doubling the share of renewable energy (RE) in the global energy mix by 2030, there is a significant increase in penetration of distributed generation (DG) to cater for this demand. This increase is further explained by factors such as environmental concerns, restructuring of electricity businesses, and development of technologies for small-scale power generation. For effective integration of DG into an existing traditional power system, there is need for intelligent monitoring and control of the interconnected systems. Smart grid technologies can carry out this role. Smart grids are essential to avoid lock-in of outdated energy infrastructure, attract new investment streams, and create efficient and flexible grid system. Further, application of smart grid technologies at bulk power generation and transmission levels by use of for example Flexibles AC Transmission systems (FACTs) , Direct current links like high – voltage DC (HVDC) , bulk storage , dynamic line ratings and synchro phasors (Phasor Measurement Units PMUs), have been identified to achieve reliability and quality power systems.

Smart grid technologies and renewable energy integration are already making significant contributions to electricity grid operation in several countries such as Denmark, Jamaica, Netherlands, Singapore, and United States (New Mexico and Puerto Rico).

This paper provides a literature review on smart grids technologies and renewable DG for bulk power generation/ transmission levels. It then identifies areas of research to develop knowledge required for appropriate placing and sizing of renewable DG units to enhance voltage stability margins while considering the probabilistic nature of the load and the DG unit's resources in developing countries.

Keywords *-Distributed Generation, Smart Grid Technologies, Sustainable Energy, Stability*

I. INTRODUCTION

Traditionally, electromechanical grids are based on a vertical integrated utility structure to control and generate power. These power grids suffer operational challenges such as generation reserves, scheduling, increased penetration of renewable systems and increased power transfers over long distances. These challenges lead to unpredictable events such as voltage instability and power loss because of limited awareness of management staff and physical damages[1]..At the National grid level, and based on the zonal requirement, the energy management is implemented to mitigate between supply and demand from an aggregate of multiple networks and multiple power generation companies with multiple operators employing varying levels of communication and coordination, most of which is manually controlled. This contrasts with 60 percent efficiency for grids based on smart grid technologies where a smart system balances the requirements of the zones and the availability of energy from the different sources in the zones without human interference. Smart grids solution increases the connectivity, automation and coordination between suppliers, consumers, and networks. It provides protecting and automatic monitoring for interconnected elements from generators via transmission network and distribution system for industries and home users with their thermostats and other intelligent appliances [1].

A smart grid is a canopy term that covers modernization and the concept of "digital upgrade" of both the transmission and distribution grids to both optimize current operations by reducing the losses and allowing alternative energy production[1]. Other benefits of smart grids include the ability to reduce power consumption; enabling grid connection of distributed generation power; incorporating grid energy storage for distributed generation load balancing; reduction in CO_2 emissions and eliminating failures such as widespread power grid cascading failures.

II. CURRENT TRENDS

A. *Smart Grids*

Previous advancement in communication and information technologies opened the way of operations in power grids [2]. Smart grid concept provides grid observability; creates control of assets, enhancement of security and performance with cost-effective operations, maintenance and system planning. Smart grid technology further provides self-corrective reconfiguration and restoration capabilities. The earliest and still largest commercial smart grid is the Telegestore project done in Italy in 2005 by Enel S. P. A. The company designed and manufactured their own meters, acted as their own system integrator, and developed their own system software [3]. According to DOE (Department of Energy) USA, modern grids initiative is sensing technologies, control methods and integrated communication into current electricity grid on distribution and transmission level whose main objectives as identified by DOE are as in Table 1. Some of the developed countries that have adopted this effective and advanced power system technique includes North America, China, Europe, Denmark, Jamaica, Netherlands, Singapore, Italy and United States (New Mexico and Puerto Rico) with reported effective technical solutions, cost and income benefits[4]. The main technologies adopted by smart grid are such as sensor networks, wireless mesh networks, intelligent and other interconnected technologies. According to National Institute of Standards and Technology (NIST), seven domains of different conceptual model of smart grid system and devices used as a reference for many parts of electric systems are presented [5]. Each domain includes with different smart grid actors with Figure 1 showing the smart grid conceptual model presented by NIST. The smart grid infrastructure is

C.N. Karue1, Department of Electrical Engineering, JKUAT (corresponding author; phone: +254 722 647699; e-mail: karuenyaguthii@yahoo.com).

D. K. Murage, Department of Electrical Engineering, JKUAT (dkmurage25@gmail.com) and C. M. Muriithi, Department of Electrical Engineering, MUT (cmainamuriithi@gmail.com)

divided into smart energy subsystem, information subsystem and communication subsystem. Through communication infrastructure [6], the smart monitoring and metering approaches provide real-time energy consumption with advanced grid intelligent devices, dedicated software and control centers interaction. Existing electrical utility-wide area networks are based on hybrid communication technologies such as wired and fiber optics, power line communication, copper wire line and other wireless technologies. For data communication, technologies such as GSM, WiMAX and WLAN among others are used[7]. These technologies support smart grid applications in term of controlling and monitoring operations as SCADA (Supervisory Control and Data Acquisition), EMS (Energy Management Systems, DMS (Distribution Management Systems), ERP (Enterprise Resource Planning) systems, distribution feeder automation, generation plant automation and physical security.

Table 1: Smart grid objectives according to DOE, USA

Serial No.	Smart grid objectives
1	To accommodate all storage and power generation option
2	Scalable , enabling all new services, products and market
3	Cost effective and efficient in operating and assets utilization
4	Fulfil the 21st century needs in terms of power quality
5	Able to address disturbance by automated prevention, restoration and containment
6	Having operating capability to handle all types of hazards

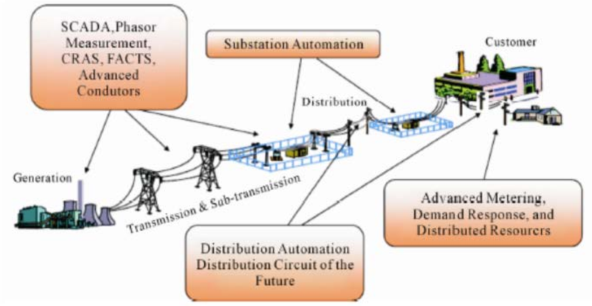

Figure 1: Smart grid components

B. Challenges of smart grids technologies

Some of the challenges of smart grids are;

- Achieving modern intelligent grid in generation and demand
- Developing decentralized architectures enabling smaller scale electricity supply systems to operate harmoniously with other utilities
- Upgrading communications infrastructure to allow potentially millions of stakeholders to operate and trade in the one market
- Strengthening the grid to ensure sufficient transmission capacity to interconnect energy resources including renewable resources
- Developing the most efficient connections for offshore wind farms and marine technologies
- Active demand side to enable all consumers play an active role in the operation of the system
- Integrating intermittent generation including residential microgeneration
- Preparing for electric vehicles due to their mobile and highly dispersed character and possible massive deployment in the next years [8].

C. Smart grid standards

Many standards have been implemented in different areas, countries and organizations. Table 3 shows the list of main smart grid standards. In order to promote the smart grid development, industries, governments, academia and industries have put an excessive deal of effort in pilot projects and programs

Table 2: Smart grid standards

Country of Origin	Standard
USA	NIST IOP [23]
Europe	CEN/CENELEC M/441[24]
Germany	BMWi E-energy program BDI initiative-internet der energie[25]
China	SGCC[26]
Japan	METI[27]
Korea	Smart Grid 2030[28]
IEEE	P2030[29]
Microsoft	SERA

III. MODEL SMART GRID

The model for smart grids include smart generation, smart transmission, smart storage and smart sensors to isolate faults is as shown in figure 2 [30].

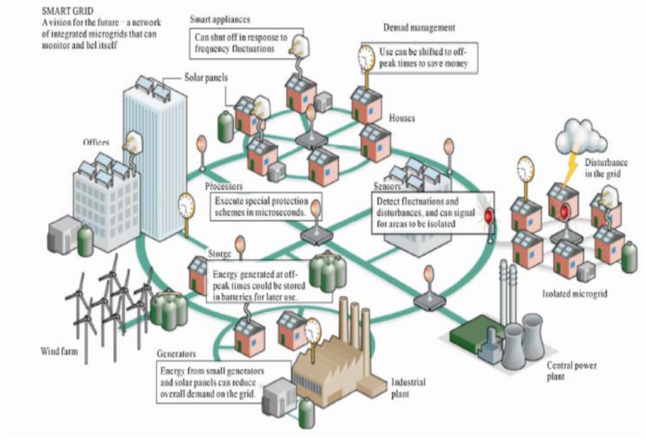

Figure 2: A model set up of smart grid network

A. Starting Point

For smart grid to become a reality technical, regulatory and environmental and cultural issues should be addressed in a research and development results integrated with existing infrastructure and technology to realize immediate benefits while maintaining steady and evolution towards better power supply [8].

I. Optimizing Grid Operation and Use

In order to manage the ever increasing demands for energy trading and security of supply, the existing transmission and distribution networks require improved integration and coordination. Available tools should be deployed to manage the complex interaction of operational security and trading and to provide active prevention and remedy of disturbances.

Such elements and priority components include;

- Wide Area Monitoring (WAM) and Wide Area Control (WAC) systems with regulation of static VAR compensators, optionally in a closed loop, to maximize the use of available transmission capacity while reducing the likelihood of disturbances
- Distributed state estimators for large synchronous areas with real-time power system security assessment and optimized dispatching with dynamic constraints
- System operators' staff training covering traditional issues (e.g. power system control) and emerging issues (e.g. electricity market and regulation)
- Coordinated ancillary services, including integration of balancing markets and coordination of reserves throughout the grids/control areas - the integration of balancing markets is of particular importance both, for enhanced power system security and for improved market liquidity;
- Steady state and dynamic (transient) simulators with modelling of Renewable Energy Sources and nonlinear devices.
- Coordinated operation of power flow control systems (FACTS, phase shifters, etc.) with devices for automatic counter measures/system defence.

II. Optimization of grid infrastructure

Transmission and distribution grids infrastructure require efficient asset management solutions for better planning and coordination. Rather than being only deterministic, coordinated planning should be based on scenarios and include the necessary elements of risk management in order to cope with the increased volatility and uncertainty in location and size of generation and growing intermittent generation.

Such elements and priority components include;

- Expanding the transmission grids with new infrastructure such as HVDC.
- Designing new overhead line with increased capacity and reduced electromagnetic fields.
- Reinforcing existing high voltage lines using innovative network assets including superconductivity technology and Development of systems and components to maintain power quality while integrating new generations

III. Integrating large scale intermittent generation

Renewable power generations such as wind and solar and geothermal generation require networks balancing, either by energy storage, conventional generation or by demand side participation [5]. Further, off-shore wind energy needs marine power collection networks and reinforcement of the terrestrial networks which promotes and fosters large-scale integration of renewable energy resources in a manner that meets the requirements of grid security while considering economic efficiency.

Such elements and priority components include;

- Technically viable and commercially affordable solutions for wind offshore power networks offer security, quality of supply, economy and environmental sustainability
- Transnational and cross-border grid reinforcements with short affordable licensing procedure
- Development of efficient and secure future grids systems with significant intermittent generation, heavy bulk power which are easily dispatchable.

IV. Active distribution networks

Transmission networks have always provided a balancing and management role in the electric power supply chain, whereas distribution networks have been designed to be passive ("fit-and forget") in operation. The challenge is now to provide many of the services found in transmission grids, such as power flow and constraint management, contingency analysis and balancing in distribution networks [7]. This is required because of emerging intelligent building services in both residential and commercial premises, the need for utilizing local generation to support the local network at times of stress on the main grid and anticipated future wide usage of electrical transportation vehicles. Distribution networks will need to be able to respond or adapt in real-time to the complex interactions of all of these challenges and provide enhanced information to various actors to enable the real-time trading of the various services.

Such elements and priority components include;

- An active network requires effective and coherent visibility of the various devices connected to it to allow timely decision making and information flow.
- Centralized manual control should be replaced by a coordinated and intelligent distributed control architecture that will enhance the networks of the future.
- Ensuring compatibility of all functions and devices from the present to the future active distribution grids.
- An active distribution network will introduce new functionalities, enabled by new tools and solutions relying on dynamic and multifaceted optimization [8]. Modelling of uncertainties in planning and operation required to achieve efficiency will build upon standardization of data models, communication protocols and communication systems capable of coping with the needs in terms of capacity, reliability and costs.

V. Intelligent information and communication technology

This involves defining tasks and implementing necessary Information and Communication Technology (ICT) standards for solutions in future Smart Grids. ICT is a pre-requisite for data exchange between the different market players in the electricity supply chain and for the secure, economic and environmentally benign operation of Smart

Grids [6]. Research of the most suitable technologies should be done and tested on site, with the goal of introducing ICT into the distribution level relying on existing communication infrastructure (radio, power line, copper or fibre optics). The challenge will be to coordinate all databases through one overlaying data warehouse based on common information models (CIM) which interconnects to all other databases hence ensuring data consistency.

Such elements and priority components include;

- Simple, robust, secure and flexible ICT infrastructure to allow monitoring, management, control and dispatching operations at all levels down to the distribution and customers with common information and data models for all information building blocks. Well-functioning, competitive and well-defined ICT solutions are essential for maintaining the security of supply and for the efficient interaction of the market players.

VI. Application of new market places, users and energy management

With smart grid concept, “democratization” and “decentralization” requires strengthened enhanced control and management. Application of new and emerging concepts successfully and effectively such as the Virtual Power Plants (VPP), micro grids and end-user energy management concepts is also required. In order to meet future customer needs, a range of new market participants will evolve transparent and non-discriminatory grid access and connection for all grid users (generation and demand).Micro grids and VPPs are two approaches to aggregating grid resources to achieve particular goals. Because a VPP or micro grid can be large enough to access the wholesale electricity market, it can pass real-time wholesale pricing signals to its internal sources, loads and storage, leading to more efficient price signal response. Other requirements are coordinated activity between the network, the smart meter, the user and the manufacturer of the goods.

Key elements and priority components

- Innovative Customer Interface Devices as bidirectional smart communicators between the customers and the market.
- Give the customer choice in energy supply, develop solutions to increase and optimize information related to energy consumption, improving the interaction between customers and market players.
- Provide the relevant energy information stored in digital or electronic meters to stimulate the consciousness and generate a virtuous new behaviour toward energy savings, increasing end-users energy efficiency.
- Use of “energy data providers” for all the smart appliances installed in house, in order to enable load management services.

B. Bulk power technologies

Some of the few renewable-friendly smart grid technologies applied at bulk power generation and transmission level are;

- Flexible AC Transmission Systems
- Direct Current Links
- Bulk Storage
- Dynamic Line Ratings
- Synchrophasors

i. Flexible AC Transmission Systems

Flexible AC transmission systems (FACTS) are a family of devices that use power transistor devices to regulate grid voltage or power factor, improving dynamic grid stability and power quality[31]. Two more commonly used members of the FACTS family are static VAR compensators (SVCs) and static synchronous compensators (STATCOMs)[32]. SVCs use thyristor switches to shunt grid current through capacitors (or sometimes inductors), supplying (or consuming) reactive power to adjust the grid voltage and power factor [33]. SVC technology has been available since the 1950s and has gradually been replacing synchronous condensers, which are rotating machines previously used to provide reactive power. STATCOMs serve the same purpose, but use voltage sourced inverters to shunt current. STATCOM technology is newer, faster and more expensive than SVC technology. Both devices have the effect of increasing transmission line capacity by providing reactive power locally and are widely available commercially. FACTS are sometimes used in conjunction with large wind plants, especially with older turbine technologies. As noted in a previous section, smart inverters can also provide reactive power to control voltage and power factor. In fact, a STATCOM is a smart inverter without a power source (so it can only supply reactive power). Where smart inverters are used, wind and solar plants will not require utilities to install FACTS (although FACTS may still be needed for other non-RE-related reasons).

ii. Direct Current Links

Electric power is typically transmitted as alternating current (AC). Modern power electronics allow AC to be efficiently converted into direct current (DC). Utilities are beginning to use some high-voltage DC (HVDC) transmission. HVDC lines themselves are less expensive and have lower losses, but the AC-DC converters at each end are costly, so conversion to HVDC only makes economic sense in specific scenarios. Primarily these:

a) Long distances: For very long point-to-point transmission applications (more than 500 kilometres to 1,000 kilometres), HVDC lines are more economical because the high cost of the converter stations at each end is outweighed by decreased transmission losses and the lower cost of conductors though electricity cannot be accessed midway along an HVDC line without adding another costly conversion station.
b) Underwater: AC electric lines experience more losses when run underwater due to capacitance between the lines and the water and protective metal enclosures. DC transmission lines do not have this disadvantage.
c) Connection of separate AC grids: Two separate AC grids cannot share AC power even if they have the same nominal frequency, due to differences in phase and minor differences in frequency. DC ties allow power to pass between unsynchronised AC electric grids. The DC tie also helps prevent instability in one grid from affecting the other grid. The direction and amount of power flowing through a DC line can be controlled precisely.

iii. Bulk Storage

Bulk (long-term) energy storage, when available, is extremely useful for storing renewable electricity during off peak for use at on peak times sometimes called energy arbitrage. Stored power is used for ancillary services including frequency regulation, load following, and voltage regulation. The operational flexibility afforded by storage also facilitates optimization of grid asset utilization and deferral of upgrades to transmission and distribution infrastructure. Pumped stored hydropower accounts for more than 99% of currently installed storage capacity worldwide (Economist, 2012). Water is pumped uphill to store energy and released through a turbine to generate electric power. It is a well-proven technology, although capital costs are still significant. The need to store vast amounts of water in two reservoirs close together, with one reservoir hundreds of metres above the other, limits pumped stored hydropower to areas with convenient geography. Another form of bulk storage that also takes advantage of geography is compressed air energy storage. This involves pumping into an enclosure (often underground) and releasing it to spin a turbine. This technology is not new, but only a small number of installations exist worldwide. Several newer forms of bulk energy storage are being piloted. These include sodium sulphur batteries, flow batteries (including zinc bromide and vanadium redox) and molten salt thermal energy storage, which is convenient for use with concentrated solar thermal power. All of these are in the pilot project stage. Lithium-ion batteries are also beginning to target long-term storage in demonstration projects. These technologies are capital-intensive and are not yet cost-effective without subsidy, although the technologies are improving and prices are approaching levels that will make storage cost-effective. Bulk storage will first become cost effective in areas with expensive electricity and large differentials between maximum and minimum electricity prices. Storage may also be beneficial in remote or island locations where expensive diesel generators can be made to run more efficiently (IRENA, 2012). As with distributed storage, bulk storage is at a disadvantage in most areas because markets and regulations are not configured to value some of its benefits, such as ancillary services and deferment of generation and transmission upgrades.

iv. Dynamic Line Ratings

The capacity of power lines to carry current (in air) decreases with increased conductor temperature; in turn, conductor temperature increases with ambient temperature and solar radiation, and decreases with wind speed. Traditionally, power lines are given a single power rating based on the worst case weather scenario, meaning that they are almost always underutilised. Dynamic line rating (DLR) technology actively senses transmission line tension, which is directly related to the average temperature on the line. This allows real-time line rating values to be incorporated into transmission grid operations. The result is that line capacity increases by at least 10% over 90% of the time, and by up to 40% at some times. DLR is especially advantageous in conjunction with wind power, because wind cools lines, increasing their capacity. Line congestion, which frequently leads to unwanted wind curtailment in many regions, can be alleviated by DLR without the need for expensive and time-consuming line upgrades. DLR also gives grid operators valuable real-time knowledge of transmission line power flows, which are not always available. Though DLR technology is not new, it is only now being used in pilot projects. It is expected to be cost-effective on lines that are frequently congested.

v. Synchrophasors

Synchrophasors, also known as phasor measurement units (PMUs) are devices that measure the magnitude and phase of transmission line current and voltage 25 times per second to 120 times per second. A time reference provided by a global positioning system (GPS) is used to synchronise measurements from all the PMUs in a system to provide an accurate, near-real-time picture of an entire transmission system. PMU measurements are aggregated by a phasor data concentrator and relayed to the grid control system, facilitating advanced grid control and optimisation. Us are an improvement over current grid-monitoring technology, which gives a picture of the grid that is at least five minutes old (and sometimes much older) by the time it arrives at the control centre. PMU systems are expected be installed at wind plants in the future and the wide-area situational awareness provided by PMU systems is expected to facilitate integration of variable RE sources. Each PMU costs USD 2,000 to USD 3,000; communications and data processing systems make total projects much more expensive. Synchrophasor systems can enable higher RE penetrations without requiring transmission system upgrades. Brazil and Mexico were early adopters of PMU technology, and China may now be the world leader in installations. PMU communications systems and data models lack standardisation. Research and development of synchrophasor technology is rapidly ongoing.

C. A Smart port requires a smart grid

In line with European ports environmental priorities, which are namely ESPO environmental review ranking and IMO MEPC 70, port of Mombasa has to change from traditional to smart grid network as detailed on comparison Table 3.

Table 3: Smart ports: Traditional to smart grid

Traditional grid	Smart grid
Centralized power generation	Centralized and distributed generation
One-directional power flow	Multi-directional power flow
Generation follows load	Intermittent renewable generation
Top-down operations planning	Consumption integrated in system operation
Operation based on historical experience	Operation based on real time data

With new consumers entering ports, such as E-mobility markets, renewables power, shore power supply, hybrid and full electrical ferries, the solution is to provide state of the art port electrification infrastructure that can meet all our customer needs. This calls for smart ports, a lean power grid integration that reduces noise, emissions, provides high reliability of HV/MV switchgears, secure and powerful communication for better reliability, safety, performance and extended system life cycle.

In port power supply, further research will be on how to apply Synchrophasors/PMUs for real-time operations and off-line engineering analyses to improve grid reliability, efficiency and lower operating costs. PMU measurements record grid conditions with great accuracy and offer insight into grid stability or stress, and they are 100 times faster than SCADA [31]. Application of Direct Current Links on shore power supply will be done. This is because DC links allow power transmission between unsynchronized AC systems. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows transfer of power between grid systems running at different frequencies, such as 50 Hz and 60 Hz as is the case with shore power to ships. This improves the stability and economy of each grid, by allowing exchange of power between incompatible networks.

D. Conclusion

Some developed countries have already changed their traditional power systems into smart grids but still they have some major issues related to policies, standards and security. The less developed countries still lagging far behind in economic and technical aspect. Given the benefits of power system stability, customer's satisfaction, load distribution and all types of grid operations of smart grids, developing countries are taking strong initiatives to develop smart grid technology. This paper has dealt with literature review on Smart Grid Systems, which the power community is busy developing since it is longer a theme of future especially for developing green ports.

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