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# Integration of Distributed Energy Resources in Smart Grid System

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**Abstract- The increasing rise in world energy demands has raised concern on present energy sources sustainability as well as environmental pollution from fossil fuel energy use. This has generated interest and increase use of renewable energy for power generation as one of the major solutions to mitigate the depletion of world energy reserve. Major renewable energy sources, however, are intermittent and therefore, limit their usage. Smart Grid, an evolving concept, is aimed not only to allow maximum use of renewable energy but also to power future vehicles and efficiently economised use of energy. Smart Grid, a modernized power system, is intended to replace the conventional grid and it is a system that pools so many existing and emerging technologies together to manage power grid supplied by widespread, multiple energy resources for electrical energy sustainability, reliability, availability, stability, security and affordability. It is a power system that provides real time information on electric power equipment, grid's parameters and variables so that the action of electricity users and suppliers can be monitored and managed automatically. This work provides comprehensive review of technicalities of smart grid and its conceptual technologies in a way to take fullest advantages of massive renewable energy deployments and other distributed energy resources.**

**Keywords:** Controllable loads, Distributed generation, Energy storage, Smart grid, Renewable energy**.**

## 1.0 Introduction

The trend for use of distributed energy resources (DERs) particularly renewable energy (RE) for electric power generation has been on very high increase globallly. The growth is due to the need for decarbonisation of power generation, environmental friendliness, security and sustainability of energy sources as well as consistent improvement and falling cost of renewable technologies.

However, integration of REs to conventional electricity grid is very difficult to manage. This is due to serious frequency fluctuation as a result of frequent loss of generation occasioned by intermittent nature and variability of RE. In addition, it is further compounded by reverse power flow that may occur in the conventional grid designed to allow power flow only in one direction.

Conventional grids are centralised systems connecting output from many large power plants and transmit the power steadily from remote areas over a long distance to demand centres. This allows power flow only in one direction from high voltage to low voltage level for onward distribution to consumers. RE in most cases is localised and small in term megawatt production and generated voltage relative to conventional power plant. Therefore, its integration to large, highly centralised grid poses limitation to their use.

To maximised the use of RE, spur the need to develop alternative, next-generation grid system called smart grid (SG). Smart grid is perhaps one of the most important, most challenging and most ambitious venture of our time [1]. SG is a radical modification of the existing electric grid and it is a combination of many technologies pooled together to improve grid reliability, flexibility, resilience availability and energy efficiency. SG involves enhancement of every area of power systems (from a generation part to a consumer part) and it incorporates consumers' equipment and behaviour in grid design, operation and communication [2]

Smart grid technologies and concepts will significantly reduce barriers to the integration of renewable resources and allow power grids to support a greater percentage of variable and intermittent renewable resources [2]. SG as 'intelligent' grid is not only important for efficient use of DESs but provides management of demand and supply of electricity from RE and energy storage sources (ESS) by both users and suppliers of electricity.

One of the crucial aims of SG is to encourage active participation of consumers in energy supply, energy demand, in decision making and to provide the operational environment in which both electricity suppliers and users influence each other [3]. It provides for two-way flow of electricity and information to create automated distributed energy delivery system. Smartness of the grid will allow for time-shifting of electricity demand as influenced by intermittent nature of renewable and incorporation of ESS. This paper study integration, operation and planning of DESs with SG system as a future energy network as well as explicates its constitute technologies.

**2.0 Smart Grid System**

Presently, there is no generally acceptable SG definition. Its description and definition is not unique, it is still evolving, developing and the concept is becoming more and more mature [4, 5, 6]. However, many authors and reputable professional organisations have put forward definitions.

Ontario Smart Grid Forum [7] describes smart grid in the following words:

"A smart grid is a modern electric system. It uses communications, sensors, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system. It offers consumers increased choice by facilitating opportunities to control their electricity use and respond to electricity price changes by adjusting their consumption. A SG includes diverse and dispersed energy resources and accommodates electric vehicle charging. It facilitates connection and integrated operation. In short, it brings all elements of the electricity system production, delivery and consumption closer together to improve overall system operation for the benefit of consumers and the environment."

From the definitions above and many other research papers [3, 8.], SG is basically electric power delivery system similar to the existing grid but modernised with high level of system automation to coordinate generation, supplies, demands, and consumption. It consists of high level automation, control, sensors, computer, equipment, new and emerging technologies operating collectively on power grid to respond intelligently and digitally on time to the grid conditions based on energy demand, supply and occurrences on the system. SG system, is a combination of many related but basically different and diverse technologies working hand-in-hand to produce, deliver and utilise energy in the most efficient and reliable manner [6].

Unlike conventional transmission and distribution system, SG could be supplied by numerous very low-carbon power generating plants located very close to load centres. It entails active participation of consumers particularly in adjusting their demand to meet supply and also encourage consumers to be power producers. It also has ability to automatically locate fault, isolate it and also restore services once the fault is cleared as well records its activities on the grid. This helps the grid to reduce the number, impact and duration of outages and interruptions.

SG allows free flow of information among suppliers, consumers, equipment and systems. Its purpose is to increase energy efficiency, security and sustainability of energy sources, improve power system reliability, reduce cost and decarbonise environment. The modernised grid will be designed to automatically detect fault and be self-healing. That is, SG operations will swiftly sense and respond appropriately to disturbances on the grid with very minimal or no effect on the consumers.

## 2.1 Smart Grid Technologies

Smart grid technology is a collection of existing and emerging technologies working together for proper monitoring and management of power grid. When properly coordinated, these technologies will enhance grid reliability and economic operation of electric energy system. Essential components of SG technology include advanced sensing and measurement, automatic monitoring and control systems, weather forecasting and monitoring, information and communication technology.

*i) Advanced sensing and measurement*

Smart grid involves smart metering which provides customers and utilities with data on electricity price and consumption, including the time and amount of electricity consumed. It evaluates the health of equipment, the integrity of the grid, and support advanced protective relaying. It enables consumer choice and demand response, and helps relieve congestion on the grid. Advance sensing and measurement improves the reliability of the grid by detecting faults early, allowing for isolation of operative system, and the prevention of power outages.

*ii) Automatic monitoring and control*

Smart grid has real-time monitoring and display of power system components conditions and performance, across interconnections and over large geographic areas, helps system operators and consumers to understand and optimize power system components, behaviour and performance [9]. SG's monitoring and control technologies produce data and provide visual representation of system status to help makes inform decision, mitigate wide area disturbances, and improve distribution capacity and reliability.

*iii) Renewable Resources Forecasting*

The challenges of intermittent nature of renewable particularly wind and solar call for accurate forecast. Advance accurate forecast of wind and solar energy availability can alleviate negative impacts on the required spinning reserves for reliable operation of the grid [1]. Advanced forecasting will provide prior information of resources, load and grid conditions. This would help in effective scheduling and dispatch; which assist in proper planning according to consumers' load requirement from analysed data. Forecast would bring about a dynamic nature in all levels of the power system while helping to balance variable generation, keeping the grid stable [10].

*iv) Information and Communication Technology ICT*

The present power system infrastructure involves connections of all major power system operational facilities (generating, transmission and primary distribution substation) to the system control centre which is part of conventional power system [11]. However, this communication is extended throughout distribution networks and offer high-speed two-ways communication flows that makes the SG dynamic, interactive for real time information exchange. SG employs ICT technology at each level of power system right from generation down to consumer appliances in order to improve electric power services, grid reliability and efficiency, cost reduction and improved environmental friendliness [12].

*v) Distribution Automation*

Distribution automation (DA) is techniques for automated control that maximize the performance of electricity distribution networks to make the grid more reliable and efficient. DA is an important component of SG. It helps to readjust the distribution topology to incorporate renewable variability, power ramping and bi-directional power flows [12] DA provides for sensing and monitoring of voltage and power factor at different points on distribution circuit. If it senses deviation from expected range, it trigger automatic control of voltage regulating devices. This allows injection of reactive power and voltage to be regulated to the pre-set value. When fault or outage occurs, with DA the fault can at the real time of occurrence be identified and located faster and accurately by operators even at remote location. Therefore, there will not be need for time wastage on manual fault tracing and consumers will not need to report to the distribution company.

## 3.0 Distributed Energy Resources

Distributed Energy Resources are small to medium-scale decentralised power and energy sources that are usually located close to load centres. DERs provide an alternative or enhancement to conventional power grid and are capable of feeding entire distribution systems [13]. DER is a faster, less expensive option to the construction of large, central power plants and high-voltage transmission lines. DERs reduce load on transmission lines and offer consumers the potential for lower cost, higher service reliability, high power quality, increased energy efficiency, and energy independence. When DERs use any of the renewable technology, it has good contribution to power generation mix and as well be a part of green solution for sustainable environment. Government all over the world, particularly in Nigeria, are encouraging incorporation of DERs especially renewable sources into power distribution systems.

Integration of DERs into conventional grid at distribution level, however, poses a number of technical challenges such as islanding, reverse power flow, grid stability, frequency variation, power quality issues. These challenges can be adequately taken care of in SG system. DER can be categorised as controllable loads such as distributed generation, energy storage and Demand Side Management (DSM).

### 3.1 Distributed Generation

Distributed Generations (DG) are small scale power plants that feed micro grid or small distribution unit and are usually located very close to the load it power. In G, diverse energy resources can be integrated to form electrical energy systems that can provide the power need of the locality. It can either be renewable or non-renewable generation. Non-renewable DG includes fossil fuel generation (coal, diesel, gas). Renewable DG can be dispatchable in which case the output power generated can be control by amount of 'fuel' injected into the system. Examples are hydro, biomass. Non-dispatchable are solar photovoltaic, wind in which the generation output cannot be control but dependent on weather condition. Technologies for DG include solar photovoltaic, wind, geothermal, biomass, combined heat and power, hydroelectric.

*(i) Solar Photovoltaic*

Solar photovoltaic is direct conversion of sunlight to electricity through electronic process that occurs in certain types of materials called semiconductors [14]. Photovoltaic is perhaps the most flexible of all the power generating technologies. It is easy to install with very little running cost, its operation is silent and environmental friendly. The technology is mature but it is still growing [15]. Its major disadvantage is that its output is zero at night and can vary considerably during the day depending on weather condition.

*(ii) Wind Energy*

Wind power plant operates by using kinetic energy of the wind to rotate wind turbine which in turn spin generator rotor to produce electricity. Wind turbines are mounted at good height to capture the most energy and take advantage of high speed but less turbulent wind. It is important to cite wind farm in areas of high wind speed which is often away from habitation [16]. A single wind turbine can produce up few kW to 5MW of electricity. Like photovoltaic, its power output is also intermittent depending on wind availability.

*(iii) Combine Heat and Power*

Combined heat and power (CHP) is simultaneous production of electricity and usable heat in one single, very efficient plant. CHP generates electricity for use within a facility and export the excess to the grid. The heat can be for industrial processes, for space heating inside the host premises and for transport to the local area for district heating [17]. CHP can reduce carbon emissions by up to 30% compared to the separate means of conventional generation via a boiler and power station [18]. CHP are fuelled by natural gas, oil, or a combination of fuels.

*(iv) Small-scale hydroelectric generation*

Hydroelectric plant works by using the power of falling water (usually in dam) to turns water turbine connected to generator which then produce electricity. Hydroelectric is considered to be RE because water cycle is endless and can be reuse for power generation and as well serve other purposes. The hydro system is neat, produces no waste, with very low emission figures [17]. The amount of electricity produce can be easily increased or reduced quickly and it is capable of meeting high peak demand.

3.2 Electric Energy Storage

Energy Storage System can provide stability and enhance reliability for SG with heavy penetration of RE. In other words, it can compensate for RE intermittency. Electric energy storage facilities would allow energy that would have been unused to be captured and retained in one form or the other and then later converted to electrical for use during peak periods or when there is no generation from renewable. Energy storage is being developed in many ways and can be in form of pumped hydro, compressed air, flywheel, batteries, and electromagnetic (super capacitor). Storage plant can also assist in ancillary services like voltage support, frequency stability and black start capability [7, 19].

3.3 Demand Side Management/Controllable loads

Demand Side Management (DSM) can be defined as a set of initiative taken on the consumer side of the meter to achieve a desired change in demand profile. DSM should result in conservation of electricity or its efficient utilization which could be either reduction of kWh consumption or load (kW Demand) or combination of both [4]. The aim of DSM is to balance the available supply at real time with the demand and to manage cost. Controllable loads are load that can be shut down for a period of time based on the grid condition without affecting the comfort or convenience of the users. In other words, they are load whose consumption can be postponed to a more convenient time for the grid. Some of the controllable loads can be automatically interrupted or postpone by the load's utilities monitors. Controllable load management offers the advantage of peak shaving, load balance, frequency control, and voltage stability. It is also effective at providing fast balancing services to the renewable energy grid in the distributed energy resources power system [20].

## 4.0 Microgrid Distributed Energy Resources

Microgrid is a segment of main power grid that can be disconnected or isolated from the central grid and operate independently. Microgrid has its own autonomous power generating source which may also include ESS and are sited close to the load centre. The microgrid can integrate multiple DERs to form energy and power system. During operation, the power system can choose any of the DERs and this may be selected automatically, depending on the load demand and availability of each source per time so as to balance the load with supply. The sources may be renewable like wind, solar, biomass or non-renewable or energy storage like pump hydro, batteries flywheel etc.

Microgrid can automatically isolate itself from the main grid as a result of power quality problems or outage on the main grid; and continue to power its loads. When this occurs, it is known as islanding. The microgrid in islanded mode enables it to maintain high reliability to the supplied territory. The switch that performs islanding and connecting operation usually has intelligent controller that monitors the conditions on the central grid and respond appropriately either to disconnect from or reconnect to the main grid.

The electric power can flow in either direction, that is from microgrid to grid and vice versa depending on which that is most technically and economically favourable to it. In other words, microgrid can inject into the main grid its excess generated power and can also take supply from the conventional grid if its sources are not available or available but the price of the central grid is cheaper. Conventional grids are not designed to accommodate DERs at distribution level. Therefore, incorporating DERs to grid directly at distribution pose a lot of technical challenges. Hence, it is absolutely necessary to follow certain technical procedures and standards in integrating DERs into microgrid. Microgrid is considered to be the building block of SG with numerous and diverse DERs [5].

### 5.0 Power Electronic in Smart Grid System

Power electronics in SG system performs the essential function of coupling the DERs to the power grid. It also boosts, regulates and does conversion of DC to DC or DC to AC electricity particularly in grid integration of RE. Unregulated voltage output of distributed energy and intermittency of RE sources requires power electronic for their interface to the grid [12] The DER’s voltage output could be in DC or AC form with variable frequency. Power electronics like HVDC, inverter and boost converter provides ancillary services for the grids in form of power quality improvement, reactive power support, electric grid stability control.

Of crucial importance among power electronics is inverter. Inverter integrate most renewable and ESS to the grid. Smart inverter can serve a number of different advantages in helping electric power system to operate with better stability, reliability and efficiency [12].

*i. Volt-VAR Control*

The injection of reactive power to control voltage is known as Volt-VAR control. Smart inverters are capable of providing reactive power at the point of connections to the grid to regulate the grid voltage. Thus preventing the serious stability challenges of grid voltage fluctuations occasioned by variability of renewable particular solar photovoltaic even during sunny hours of the day. The inverter is designed and programmed in such a way that its reactive power output at any time is dependent on the grid voltage at that time. Another way is to employ communication link to enable the power converter to inject its reactive power by the command of the grid operator.

*ii. Monitoring of the Grid*

Inverter, in their control functions at the point of interfacing with grid can monitor current, voltage, frequency and phase angle and as well communicate this data to the grid operator in real time. This information can further be process for appropriate action or decision.

*iii. Ramp-rate Control*

Non dispatchable RE production output like PV and wind goes up and down swiftly several times even within a couple of minute which may create complication for the operators. Smart inverter with built in small amount of supercapacitor can limit or reduce the rate of up and down output power ramping.

*iv. Frequency and Voltage Event Ride-Through*

As requirement, inverter is not supposed to release their output into the grid when the output parameters like voltage and frequency from the renewable are not within acceptable range for grid characteristics. Nonetheless there may be very brief momentary period of low and high voltage or low and high frequency on the grid. At this period further loss from renewable sources might aggravate this grid conditions. Frequency and voltage event ride through is a technology or technique that permit inverter to remain online and assist the grid during this momentary period of voltage and frequency deviation [12].

## 6.0 Smart Grid and Electric Vehicles

Electric Vehicles (EV) is emerging technology that can be an important component of smart grid system. SG and electric vehicle will both have impact on each other. Massive adoption of EV will have substantial increase demand on power grid but this can be effectively managed through demand response (DR) and load scheduling. On the other hand, EV can provide support for the grid through its battery ESS. Electric vehicle can capture excess non-dispatchable RE and use it to enable and support SG. Thereby balancing electric power demand with supply on the grid. The EV is part of green solution for world environmental and energy source sustainability. If the EV technology is deployed widely, it will provide large distributed energy storage capacity for the grid. The EV batteries are charged by SG at a time of excess generation, described as grid to vehicle G2V, and be use as energy storage backup for the grid.

This will enable the vehicle to discharge their battery electrical energy into the grid (V2G) when demand is very high. This serves to mitigate the intermittent nature of RE and provide the needed stability for the SG. The consistent continuous price falls of solar photovoltaic and battery for EV and development of electric grid capable of absorbing large amount of intermittent renewable is expected to enhance EV massive widespread adoption. The EV technology can even be extended to serve as electrical source or sink with bi-directional charging ability in which it can be charged and discharged between vehicle and home (V2H), between vehicle and building (V2B) thereby providing electric power for home, building and to grid and from home, building charging point to electric vehicles. The full benefit of EV being a part of SG system will definitely lead to new energy business model and provide new value for energy customers.

## 7.0 Communication in Smart Grid System

One of the key features of SG system is two-way flow of information and two-way flow electricity as well as real time communication among components in the system. Communication system is essentially important in grid integration of DERs and aid in the restructuring of the power system network topology based on the need for adjustment for efficient flow of electric power. Being a vast system, SG needs a range of networking and communication technologies that can enable timely and high speed two-way interactions among components, users and operators [5]. The medium of these communications can be wired (power line communication, fibre optics, copper cables) and/or wireless communication which include Wi-Fi, cellular, microwave etc.

In traditional approach, technicians go physically to power equipment/systems to collect data and consumer's terminal to take readings on a periodical basis for system monitoring and billing purposes. In smart grid systems, smart meters, sensors will not only provide real time information and remote monitoring but will also store all previous data. All these information is made available on communication platform to central location and to all concerned points through communication technologies using wired or wireless communication for all concerned to access.

This helps operators to be fully aware of the health of the power system and be able to predict and ascertain the system's condition ahead of time and thereby give appropriate notification to consumers. Examples are notification on possible outage with duration, energy price and amount of energy available at a given time. Consumers also can adjust their power usage pattern based on available information on their consumption rate and energy cost which they can easily accessed on communication platform even through their mobile phone in the comfort of their location.

**8.0 Cyber Security in Smart Grid System**

Cyber security in SG is very necessary as there is need to prevent abuse, malicious activities and unauthorised access to two-way flow of information on the grid system. Consumers' information need to be protected from hacking, theft and loss. Full implementation of SG system without adequate cyber security measures can open the system to sophisticated cyber-attack which can compromise the system and cause stability problem for the grid. Cyber-attack can also cause fraud like destruction of information and manipulation of energy consumption data. Cyber security should be aimed at integrity, confidentiality and timely availability of information [5]. The cyber security system should also be able to detect cyber-attack and information security violation and automatically sound alarm and respond to protect the integrity of the system.

**9.0 The Benefits and Cost of Smart Grid System**

The advantages of the SG system include:

1. Support greater percentage of RE integration, because SG is better designed to cope well with intermittent nature of wind and photovoltaic RE;
2. Foresee and respond to system disturbance to mitigate it, ease of repair, and faster restoration of supply in case outage;
3. Provide full information available to consumers concerning their energy use at any time, hour by hour or day by day;
4. Reducing the cost and peak demand of electricity by customers adjusting their consumption to a more convenient time for the grid based on cost and power production information available in advance;
5. Improved and enhanced grid efficiency, flexibility and reliability;
6. Encourage increasing use of EVs which will drastically reduce use of depleting fossil fuel and exhaust carbon emissions.

The cost of transiting from present power grid to sg system is massive but the benefits are very huge and will eventually result in reduction of cost of electricity. In the US, the cost is estimated to be an average of 17 to 24 billion dollar per year till 2030. Larger percentage of the amount will be spent on DA and upgrade of substation, lines, smart meter and grid communication system [21]

## 10.0 Implementation of Smart Grid System

For successful implementation of SG, each country need to develop and articulates its SG vision, strategies and means of achieving it. This help to motivate fervour and resources (technical and capital) toward modernising the current electric grid. SG vision and its full understanding is fundamental for smooth transition from conventional to SG system and deployment of existing and emerging technologies to achieve it [22]. Transition to smart grid can only be gradual and piecemeal until its full implementation is realised. It can start from the existing grid by introducing each of the SG technologies at a time. It can also begin with small pilot project in form of mini or micro grid in small geographical location and gradually improved upon and extended. Already, there are numbers of such SG pilot projects around the world in US, South Korea, Austria and Canada. In addition, most countries in advanced world are already gradually upgrading their existing grid to SG.

## 11.0 Conclusion

This paper has explicated the concept of SG in details and provided much information on its conceptual technologies as well as technicality involved in its implementation. The full implementation of SG system will lead to energy source security for all since the system can effectively sustain and absolve large percentage of locally available DERs most especially RE sources for stable, reliability and affordable electricity. SG system will also provide opportunity to effectively address climatic change occasioned by greenhouse emission through drastic reduction of dependence on fossil fuel as the most common world energy source. In addition, SG system can support and be supported by emerging EVs technology meant to further reduce dependence on oil. SG is the entire power system fully automated and intelligently monitored right from generation down to equipment it powers and also incorporate consumers' behaviours with the use of existing and emerging technologies for effective and reliable energy delivery system.

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