# Approaches in Smart Grid Integration of Renewable Energy Resources

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**Abstract**
The integration of energy sources especially the decentralized and distributed energy resources (DERs) most of which are renewable and sustainable encounters various integration and utilization challenges. The DERs constitute technologies like diesel engines, micro turbines, fuel cells, photovoltaic, small wind turbines, among others using local energy resources, most of which are both sustainable and renewable. The main challenge with variable renewable energy sources is that they are associated with intermittence and are stochastic in nature, which requires optimal energy management strategies to attain a high level of system reliability and operational efficiency. The grid integration is a significant challenge associated with the global expansion of distributed energy systems that should be addressed. This study examines and synthesizes the various energy resources, conversion technologies, integration techniques, and scalability factors associated DER integration in smart grid and microgrids as well as the traditional grid. The integration of distributed and decentralized energy resources (DERs) in the grids is very important for the energy transition because it reduces greenhouse gas emissions and helps in mitigating global climate change while at the same time it advances critical components and deliverables of the sustainable development goals with additional socio-economic benefits derived from the renewable energy systems. The growing global concerns about greenhouse gas emissions and climate change as well as the resource depletion have led to increased interest in renewable energy alternatives and decentralization of generation to exploit the massive renewable sources which are sustainable, and environmentally sound, and offering a cost-efficient solution for electricity access.

**Key words**

**Highlights**

## I. INTRODUCTION

The integration of distributed energy resources (DERs) into smart grids presents immense opportunities and challenges for the improvement of power system efficiency, reliability, and sustainability. The intermittence and variability, of variable renewable sources, is the main challenge to grid stability, while enhancing grid resilience, increased uptake of renewables and reduction of transmission and distribution losses, as well as creation of new business models are the opportunities presented by decentralized generation. These innovations are key if the world has to achieve a sustainable, low-carbon energy through pathways and technologies like green hydrogen and Power-to-X technologies while global energy interconnections will enhance energy security and grid stability on a global scale.

### A. Problem Definition

The DERs constitute technologies like diesel engines, micro turbines, fuel cells, photovoltaic, small wind turbines, among others using local energy resources, most of which are both sustainable and renewable[1, 2]. The main challenge with variable renewable energy sources is that they are associated with intermittence and are stochastic in nature, which requires optimal energy management strategies to attain a high level of system reliability and operational efficiency. The grid integration is a significant challenge associated with the global expansion of distributed energy systems that should be addressed. The integration is associated with multiple technical challenges in terms of grid stability, quality of power, and the need for robust control and communication system[3-5].

Deployment of Decentralized Energy Systems (DES) signals a new frontier in power system design, and planning of local energy systems. As decentralization of power systems

grows, cities and urban centers are transforming into venues, of both energy consumption and distribution, which calls for systemic and paradigmatic change in existing energy infrastructure[6]. For variable renewables, integration costs increase as the share increases in the mix. As an example, integration of large amounts of wind energy is technically and economically viable or feasible up to 30% of total generation, at integration costs generally being less than 10% of the cost per MWh of wind and often significantly less [7-9].As investments in electricity increase globally, there is need for grids to be robust and technologically sophisticated to cope with the growth. It is projected that Smart grids and digital infrastructure will get significant investment by 2030, based on the net-zero emissions by 2050 scenario. Growth of global electricity demand growth together with high need to identify sustainable energy sources, leading to a paradigm change in how power networks are planned and run. Decentralized and distributed energy resources (DERs) pose a significant threat to traditional centralized power generating and distribution models[10-12]. Global electricity demand increased by 3% year-on-year in 2025 after realizing 4.4% in 2024, on account of intense heat waves and strong industrial activity. The annual demand, annual demand growth over the next five years is projected to be 50% higher on average compared with the average across the previous decade[13, 14]. To meet this demand growth calls for strategies to exploits local energy resources most of which are renewable like wind, solar, and other environmental sources through energy harvesting technologies[15-17].

### B. Rationale

The integration of distributed and decentralized energy resources (DERs) in the grids is very important for the energy transition because it reduces greenhouse gas emissions and helps in mitigating global climate change while at the same time it advances critical components and deliverables of the sustainable development goals with additional socio-economic benefits derived from the renewable energy systems. The integration of energy sources especially the decentralized and distributed energy resources (DERs) most of which are renewable and sustainable encounters various integration and utilization challenges. To overcome the technical challenges and realize the full potential of decentralized generation requires careful planning, advanced control strategies, and robust communication system.

Successful grid integration of DERs comes with multiple benefits. Denmark's integration of wind power is typical example that stands as a successful example, demonstrating how a high share of wind energy can be managed effectively by addressing the various technical and economic challenges by employing strategic investments in grid infrastructure, regulatory adjustments, and the establishing supportive market conditions for renewable energy development. In another case, California's, smart grid technologies were deployed to manage integration of solar energy in the state by use of advanced metering infrastructure for monitoring and control of energy use and production and promoting energy efficiency and converting consumers to prosumers[18].

#### i.) Reliability

Smart grids significantly improve grid reliability by means of real-time monitoring, fault detection, and self-healing capabilities to maintain an uninterrupted power supply by identifying and addressing faults on real time basis leading to higher customer satisfaction, reduced economic losses, and greater economic productivity[18].

#### ii.) Sustainability

Smart grids enhance sustainability through optimized energy use and reduced environmental impacts with more efficient renewable energy integration which helps reduce carbon emissions and encourages cleaner power generation. The smart grids play a key role in in reducing the overall carbon footprint through facilitation of services and new product offerings like electric vehicles and decentralized energy generation, which are crucial for decreasing dependence on fossil fuels[18]

#### iii.) Reduced Prices

Smart grids facilitate operations and Management Costs reductions which helps utilities cut operations and management expenses, which benefits consumers through lower electricity costs through optimization of resource use, remote monitoring and control, and supporting predictive maintenance whose benefits outweigh high upfront costs, in the long-term through higher system efficiency, reliability, and renewable energy integration [18].

#### iv.) Faster Electricity Restoration after Disturbances

Smart grids facilitate automatic power rerouting in case of equipment failure or outages which significantly reduce both the frequency and impact of outages. Rapid healing and rapid response are supported by automated monitoring, remote control, and predictive analytics. Smart grids effectively handle unplanned outages and speed up the restoration after extreme weather events, to minimize disruptions to normal live and activities [18].

### v.) More Efficient Electricity Transmission

Smart grid improves the efficiency of electricity transmission by use of digital technologies, sensors, and software for real time balancing supply and demand. To fully realize benefits, utilities should adopt strategies like integration of distributed energy resources (DERs), advanced analytics, predictive maintenance, cybersecurity and data privacy, microgrids, energy storage, and automation[18].

### vi.) Reduced Peak Demand

Smart grids help reduce the peak energy demand which effectively reduces energy costs which contributes to reducing electricity costs. The smart grids empower the consumers to make smarter energy choices through use of demand response programs which help shift demand and usage away from the peak times. This along with along with load shifting, energy storage, and grid optimization and automation, help in easing stress on the power system to enhance reliability and efficiency to cut peak-related expenses including delayed new investments [18]

## II. GRID INTEGRATION OF MEASURES

Distributed energy systems (DES) can enhance sustainability of electric power systems. Distributed systems are generally small-scale power technologies ranging between 3 kW–300 MW that are located close to consumers to provide an alternative or enhancement to the conventional power system [19, 20]. They are directly connected to distribution system or on the customer side of the meter, which effectively reduces the transmission and distribution costs. The high consumption of fossil fuels and growing commitments to reduce anthropogenic greenhouse gas emissions has created significant interest in renewable energy sources for power generation[2, 21]. This has in effect created demand for distributed generation systems. However, electrical power grids face a number of new challenges on the road to 100% renewable energy system as big centralized power plants get replaced by small distributed generators that heavily rely on renewable energy sources particularly wind and solar[5]. This adds a layer of uncertainties in grid power generation because of these challenges like reverse power flow.

There are multiple benefits realized by the integrating Distributed Energy Resources (DERs) into micro grids. The opportunities include increased energy sufficiency, reliability, and sustainability. Others are enhanced grid resilience, new business opportunities and models, reduced transmission losses and greater uptake of renewable energy sources by grids. The limitations include dealing with resource variability and intermittency of renewable sources, which are the main sources of energy used [22, 23].

Decentralized generation can significantly reduce transmission and distribution losses with negligible footprints. This makes decentralized generation a preferred alternative as a sustainable solution to growing future energy needs. The decentralized energy systems can be solo operated but may be affected by variable resource availability [24-29]. Different distributed energy resources can be used for electrification purposes as grid connected or standalone or hybrid systems [30]. Distributed energy systems have established themselves as viable substitutes to the grid where generators are located closer to load centers to mitigate transmission and distribution losses [31, 32].

There are diverse sources of energy that can be used in decentralized heat and power production by applying different conversion technologies. Both renewable and nonrenewable energy sources have an important role in decentralized generation and in the energy sustainability e.g., although oil and coal are nonrenewable fossil fuels, they are dispatchable, cheap and easily accessible sources of energy for power generation. Sustainable and renewable energy sources like wind and solar and hydro have the greatest potential but are significantly affected by reliability of supply due to intermittence and variability in resource supply. The main solution to these challenges is investment in storage, smart grids and micro grid technology infrastructure, which effectively increases the cost of investment [26, 33].

Variable renewables provide a significant risk to energy security and the grid stability hence power/energy system, reliability for the traditional grid because they are unpredictable and intermittent hence unreliable in energy supply. This, which increases the demand for smarter and resilient grids for distributed power systems [34, 35]. The use of smart grids and micro grids increase the ability to absorb small producers and variable supplies especially for wind and solar and small hydro sources and which have a significant role in the global energy transition[35, 36].

Power systems can achieve enhanced efficiency and reliability by leveraging on the state-of-the-art technologies like block chain, data analytics, and sophisticated control algorithms, which require commitment to innovation and optimization in energy management. The transition to cleaner energy sources is required to reduce emissions. Other than variable sources, variable loads like electric vehicles, which have an important role in the transition, are another source of challenge to the grid stability. Scheduling of electric vehicles (EVs) and flexible asset a key aspect of demand side management (DSM) strategies, needed for enhanced energy efficiency and cost savings that requires active monitoring and control of energy consumption. The use of smart grid technology can potentially increase the overall system performance while at the same time promoting grid absorption of renewable energy sources. Therefore policymakers, investors , and scholars should guide the energy sector to a more sustainable future through deployment of technology [10].

The distribution network has opened a new window of a competitive electricity market due to deregulation aimed at enhancing efficiency, reduce cost of operation, and minimize financial losses by utilities. The restructured system is divided into two main sectors, i.e., the e generation side and the load aggregator or end-user side. This system provides a way to effectively balance supply and demand to keep power fluctuation within the threshold level, which may not be achieved quickly in the conventional way. Therefore, demand response (DR) has changed for a sustainable power system through modification of the consumer behavior in response to real-time price tariffs program or incentives offered and responding to maintain grid stability. Hence, demand response (DR) strategy is an effective and lower investment approach to maintain a reliable power system operation. High penetration of distributed generation resources needs a reliable design function of DR. The DR program offers adjustment to the demand side rather than generation side which ensures that the power c consumer is an active participant in power distribution network.[37]

The energy management system (EMS) when used in a micro grid monitor and controls the operational status of optimal power allocation coming from different sources of energy to the controllable and critical loads. Controllable loads may be dispatched to ensure system reliability and stability when necessary. The design of the EMS collects the load profiles, forecast the energy resource information, policy, consumer preference, and electricity prices to ensure optimal power flow (OPF), generation scheduling, competitive pricing, and load dispatching. A decentralized energy management system (EMS) is an autonomous intelligence controller that considers several local controllers. Since local controllers make decisions and communicate locally, the congestion of communication and computational burden is reduced in decentralized systems compared with centralized EMS system. Participants in the distribution networks with micro grid clusters are interconnected with different operational objectives and decision variables because of the impact of the local operating environment[2, 21]. These makes centralized energy management system undesirable option for the generation scheduling in distribution networks having micro grid cluster. The decentralized energy management system (EMS) is a solution to micro grid operation and local controllers should be designed to determine the optimal power output locally. With this, decentralized EMS will reduce the computational power requirement in the entire micro grid[37].

Generation scheduling remains a challenge in micro grid planning which can be addressed by use of optimal planning techniques to both renewable energy allocation and energy management systems [16]. Different optimization methods are adopted based on prevailing technical, environmental, and economic constraints and uncertainties. Optimal planning techniques are used in energy management systems for smart buildings, smart homes, and smart grids. With decision-making-based energy, modeling tools being used for sustainable design, operation planning and control. The need for balancing between demand and supply has increased uncertainties associated with renewable energy

generation and thus scheduling generation units in the micro grid planning stage to achieve balancing [37, 38]

Smart micro grids, are advanced electrical power systems that incorporate digital communication and control for the electricity infrastructure, enable real-time monitoring and management of energy flows within microgrids. They achieve these by use of sensors, automation, and control systems in optimization of energy generation, storage, and distribution; thus, they optimize the integration of renewable energy sources based on key features like enabling two-way communication, ability to self-heal after disturbance and use advanced metering infrastructure. Therefore, the smart micro grid is a powerful tool for enhanced integration renewable energy sources in micro grids [39-41].

Opportunities for decentralized generation in electricity generation have increased because of growing need to reduce fossil fuels and global commitments to reduction in energy related emissions hence greater interest in renewable energy resources in electricity generation. Renewable decentralized systems can be grid connected for the purpose of peak shaving or use as stand-alone energy system to serving a particular load or an area [10, 42]. The main benefits and threats of Integrating renewable DGs to the power system include high penetration of renewables that may lead to adverse effects such as voltage rise, reverse power flow, high line losses, creation of harmonics and reduced voltage quality**.** In order to maintain optimal quality of the power system, the decentralized power systems need to be designed and operated within limits hence the need for optimal sizing and location of renewable decentralized generation (DG) units in the system for technical and economic benefits.

## III. INTEGRATION TECHNOLOGIES AND STRATEGIES

The integrating measures for smart grids and micro grids are summarized in table 8

Table 1: Strategies for integration of DERs [21], [43],[44],[10],[45]

| | Strategy and technology | Description | Impact |
|---|---|---|---|
| 1 | V2G Technologies and Electrification of Transport | V2G(Vehicle-to-Grid) technology, combined and electrification of transport, offers a pathway for grid integration of decentralized, renewable energy resources by facilitating electric vehicles (EVs) to withdraw electricity from the grid and discharge power back into the grid | The V2G functions like distributed energy storage system used to balance balancing supply and demand which enhances grid stability, and wider adoption of renewable energy resources source Electrification of transport plays a crucial role in mitigating greenhouse gas (GHG) emissions and facilitating the power system decarbonization |
| 2 | Smart Grids | Smart grids have an important role in integrating decentralized renewable energy sources into the power grid, which leads to higher efficiency, reliability, and sustainability. They enable the efficient management and distribution of electricity generated from diverse, often intermittent, renewable sources like solar and wind, while also facilitating consumer participation in the energy market. Moreover, the configuration of smart grids incorporates smart meters, grid frequency measurement tools, and demand response algorithms, which enables autonomous regulation of power demand and supply. Smart grids optimize the flow of energy in the grid, they balance demand and supply cross the grids, which is critical for the handling the variable renewables sources of energy | The specific role and benefits of smart grids are enhanced reliability and stability of the grid enables decentralized generation and improves connectivity, they enable micro grids, which are localized grids that may be connected to the grid to further enhance the resilience and facilitate more efficient management of renewable energy resources. They facilitate consumer engagement and enable active participation of power consumers in the energy market, converting them to prosumers who produce and sell own power back to the grid. They also enable almost a seamless integration of energy Storage and the grids, which helps, mitigate the intermittency of renewable sources supply. overall, smart grids lead to reduced carbon emissions and cost reductions |

| | | | |
|---|---|---|---|
| 3 | Demand Side Management | The DSM technologies can be employed to balance output and provide energy arbitrage opportunities accruing as benefits to the portfolio owner or to intermittent producers using this resource. This also enables more efficient use of the power system network capacity, and curtail need for reinforcements and expansions to benefit other crucial network activities and investments. | Demand responsive measures balance supply and demand by providing incentives to users to modify their energy usage away from the peak hours. This improves grid efficiency and reliability. Enhance the capacity of decentralized power systems to operate off the main grid which is advantageous for isolated or rural areas |
| 4 | Cellular Approach in generation and consumption | The "cellular approach" in grid integration is a strategy of managing distributed energy resources (DERs) by dividing the grid into smaller, self-sufficient "cells" or micro grids aimed at achieving grid stability, resilience, and efficient integration of renewable energy sources. By leveraging on communication and control, technologies to achieve optimal energy flow in each cell and enable coordinated operation the cells. | The cellular approach provides an optimal course of action for the distribution system operators to keep power flowing by enhancing the resilience of smart distribution grids in the event of a disaster that affects distribution grids. It enhances reliability in the supply of power while minimizing energy costs. |
| 5 | Virtual power plants | Virtual Power Plants (VPPs) are power systems integrating different distributed energy resources, like solar, batteries, wind to operate as a single, controllable power plant. Virtual power plants improve grid stability, maximize renewable energy uptake and utilization, and providing flexibility to the energy market. | VPPs help in integration of in decentralized, diverse, and distributed energy resources into a dynamic, and unified which provides an innovative solution to the intermittency challenges that come with the variable renewables energy source (RESs) by helping resources that are too small for the grid to be connected and managed through smart software. |
| 6 | Energy Storage | Energy storage is important in integrating DERs into the grid through provision of flexibility and reliability Electricity cannot be stored and hence should only be generated as needed based on prevailing demand. Therefore, more sources of decentralized generation new difficulties in controlling supply for it to match demand. Storage is critical for intermit-tent renewable sources, which often generate the highest capacities during off-peak hours. Just as the generation, storage should be decentralized to for maximum efficiency | It helps to manage the variability of renewables and create a more stable and reliable power supply. Storage systems store excess energy during periods of high generation for later release when demand is high or generation is low, which help smoothen out supply fluctuations As a solution, storage techniques like batteries, pumped storage hydro and compressed air assets the grid by storing excess energy and feeding it back into the grid during hours of peak demand |
| 7 | DC micro grids | In DC micro grids, a common DC bus is employed to connect the DERs to the grid via an AC/DC converter. The construction of a DC micro grid is composed of different generation sources, both dispatchable and non-dispatchable as well as energy buffers, like fuel cells and ultra-capacitors, which provide a steady-state and transient power for the micro grids. Different configurations of power electronic converters are proposed to interface these generation resources to a common DC bus bar. A unidirectional DC–DC converter is used for a fuel cell but an ultra-capacitor requires a bidirectional DC– | Direct current (A DC) micro grids are localized energy systems operating on direct current (DC), in a way that offers benefits in terms of higher efficiency and compatibility with renewable energy sources when compared with the traditional alternating current (AC) grids. The DC and Ac micro grids have common operation principle, but the DC micro grid reduces the power conversion losses since it only requires one power conversion to connect DC bus making it more efficient, cheaper and smaller. A cost-effective micro grid or grid solution requires a |

| | | | |
|---|---|---|---|
| | | DC converter to maintain the charge of the ultra-capacitor, the overall efficiency depends on the efficiency of these converters. | converter that are affordable and have a high efficiency. |
| 8 | Energy management and optimization Tools and Techniques | The intermittence and randomness of renewable energy supply and generation creates issues with reliability and stability for power systems hence the integration into smart grids. To address this downside of micro grids, measures like application of the battery management system and a proper forecasting algorithm is necessary | Different optimization techniques can be employed to address this issue by enhanced scheduling or energy storage to maintain stability and optimum dispatch of power produced for more economic benefit. This study provided an insight into the different optimization techniques for micro grid energy management. |

From table 1, it is noted that the main strategies for optimal integration of decentralized and distributed energy sources are V2V, use of smart grids integrated with artificial intelligence, demand side management, cellular approaches, virtual power plants, energy storage options, use of DC micro grids and energy management and optimization techniques.

The growth in the interconnection of DERs to the grid i and decarbonization of power systems globally show that DGs, particularly those based on renewables-can play a significant role in the global energy transition to a sustainable energy system. However, in as much as the integration of DG into the power grid has benefits, like line loss reduction, greater grid flexibility, cost-effective generation and curtailment of capacity investment, several issues may arise when DERs are connected to the network[46]. Among these issues are the point where the distributed renewables should be injected into the grid. The study has also discussed the impacts of DG location on the system voltage. Nonetheless, the constraints of power system stability remains paramount in the integration particularly for the variable renewables, which calls for innovative integration tools before deployment to mitigate any possible disturbance in the network[47].

## IV. MERITS OF DG INTEGRATION INTO THE GRID

The DG connection to the grid comes with numerous benefits hence the growing interest by countries to increase their DG interconnection into the grid. These benefits even increase when the DGs are from renewable sources, e.g. emission reduction and capital costs for deployment compared to the conventional fossil fuel-based centralized power systems. The injection of electricity from DGs based on both renewable and non-renewable provides numerous benefits, like minimizing real power losses, grid stability, reduction in harmonic, pollution reduction voltage stabilization, system reliability, and peak demand curtailment, support of reactive power, frequency control and reduction in generation cost. The merits are hereby discussed;

### i. Peak Demand Curtailment

With most distributed generators (DGs) located near end users, they can offset the electricity demand during peak periods and decongest the grid thus avoiding situations instabilities and improve the reliability of the grid. The amount of offset peak demand varies with the on the capacity of DG, operation pattern and the feeder demand profile. Operating a DG in a way that curtails peak demand on a substation, limits the need for routine maintenance, which increases the lifespan of the components' while at the same time deferring transmission and generation capacity expansion. [47].

### ii. Reduction of Power Losses in the Network

The DGs are installed close to load centers and power produced does not have to be conveyed through long transmission lines hence less power losses. The power is easily delivered to the point of use without need for evacuated from the main grid with high power losses.

### iii. Frequency Regulation

There are set standard by countries and professional bodies, like IEEE, on acceptable frequency ranges for DG connection to distribution system. DGs are expected to strictly operate within a range of bounded frequency outside the DG unit will be automatically disconnect from the network. Some DG technologies provide frequency regulation functionality to grids through frequency adjustment based on the situation. This is very common to systems like those that the turbines whose speed can be controlled regulated to match the desired frequency, and in the event of violation, of frequency limits, the system trips. Application of standard inverters like IEEE 1547, facilitate a wider range of frequency and voltage, which mitigates issues like accidental voltage and frequency trips. Additionally smart inverters may be used to lessen the impact of DGs on the frequency and offer frequency support and avoid DG tripping [47].

#### iv. Voltage Stabilization

Addition of real power or utilization of reactive power in the grid, tend to improve network voltage waveforms and the load factor. The DGs can supply real power and consuming reactive power that supports the network voltage profile and load factor, but the ability of a DG to perform these functions is dependent on the connection point and the capacity of the DG plant[47]. .

#### v. Less Risk of Terrorism

With DGs, the grid is connected to many plants that geographically scattered, unlike the centralized power plants, which are fewer, and big hence a large section of the network is disconnected if terrorists attach. The electricity grid is a critical infrastructure and DGs are recommended as sustainable ways of limiting susceptibility to grid to terrorism. This is because the DGs supply power to critical facilities during extensive power disruptions. There will be largescale outages if terrorists attack a major generator in a centralized grid, in the absence of DGs [47].

#### vi. Shelving of Network Upgrade

This is the postponement or delay of grid expansion investment needed to reinforce the transmission line, feeders and transformers and other capital infrastructure because of the integration of DGs [48]. This is because DGs are connected close to load centers, and power flow from the central grid required is low as the DG plant offsets the demand. This demand curtailment leads to deferment of upgrade on the the network and installation of additional conventional power plants. Therefore, the DGs could assist in deferring future transmission line expansion plans, which leads to reduced operation and maintenance costs [49, 50].

#### vii. Improved Reliability and Security of Supply in the Network

Decentralized generators help in supporting the main grid by reliably meeting the demand that is beneficial to critical loads like for powering telecommunication systems, which require electricity with high reliability. The DGs can help improve the security of supply since they coupled with intelligent systems, which reduces the dependence on conventional energy sources by developing alternative sources [47]. .

#### viii. Delivery of Ancillary Services

Ancillary services play a critical role in the operation of a reliable power system, with utility companies installing DGs to provide auxiliary services like s reactive power support, back-up power supply, and provision of spinning reserves. Therefore, DGs may provide standby power to the main grid during emergencies or power outage. DGs could economically be employ to contribute to the delivery of auxiliary services [47].

#### ix. Economic Viability of DG Projects

Distributed generation can reduce electricity bills and deliver power more efficiently and reliably. Electricity tariffs account for inefficiencies in the transmission and distribution network, hence power losses in long transmission distance increases tariffs. Distributed generation reduces tariffs making power more affordable because energy produced near load centers, requires less transportation. Where investors are allowed to install own DGs, more power is made available as investors respond to favorable market forces which enhances power system

flexibility and competition leading to significant price reduction. Additionally, less cost and time is required for installation of DG plants compared to large power plants in the main grid, while the modular nature of DGs makes the assembly very easy. The DGs are also not interdependent and hence their operation does not depend on other generators, as failure of one may not necessary affect the other. Deferrals in capital investments due construction of DGs reduces capital costs per unit power. In jurisdictions with penalties for environmental pollution, DERs with small emissions help in lowering environmental penalties and hence generation and price of power[47]. .

## V. ISSUES RESULTING FROM DG TO GRID INTEGRATION

Power systems incorporating DGs around load centers with varying load demands present significant challenges in terms of the system operation and control ranging from under-voltage, harmonics and over-voltage to transient stability. In the traditional system, power generation, transmission and distribution were managed as autonomous processes. However, with growth in the integration of distributed generators (DGs) in the grid, this traditional management and control system is having been challenged and is changing. A modern power grid has DERs and DGs as important and significant components with positive and negative effects on the grid that should be mitigated. The impacts of DGs on the distribution network are more than other levels because they are mostly connected at the distribution network. As DERs become prevalent on the power grid, the grid design and operation must change to handle bidirectional power flows, which pose significant challenges to be addressed at both design and operations level. These issues are discussed as follows[12, 50].

### i. Voltage Level Fluctuations

A stable power system voltage is important for proper functioning of the system components of the grid. Since most DGs are situated close to load centers supplying power to consumers, and any substantial change in power flow has effects on the feeder voltage because power flow and voltage are influenced by change in demand and generation. The flow of power to loads in networks with radial configuration is prone to a positive voltage drop as you move down the network, causing fluctuations in voltage amplitude at network nodes. Likewise, the addition of DERs in the electricity network has similar effects to power quality as disturbing loads because they may also emit such disturbances in terms of short-term and long-term voltage variations, harmonic distortions and voltage flickers. Voltage variations can be observed in DERs depending on scenarios in question. The non-dispatchable nature of DERs i.e., inability to change supply to match demand is in itself a potential source of voltage fluctuations. A network should be designed in a way system voltage can be restored by some voltage regulatory circuitry[8, 9].

When DGs inject power to the grid, there is an effect on the voltage regulation because it significantly depends on the power flow in the network. There won't be a violation of voltage limits if they are located close to loads in a distribution feeder and the power factor of DGs is in unison with that of the load. The main grid supplies less energy with a reduced feeder current and, thus the voltage drop is minimized. The generation of DGs goes beyond the feeder load, or at an extreme power factor, voltage increases due to a reverse power flow depending on DG capacity, grid impedance and power factor[51, 52]. Voltage increase at a connection point of a DG comes from power supplied to the network, while for radial feeders; the change in voltage is determined by the following equation:

$$\Delta V = (PS - PL) + (QS - QL)\,XV$$

Where $P_S$ and $Q_S$ are real and reactive power, and $P_L$ line load real power, and $Q_L$ reactive power of the line load. R is resistance of the line linking DG to substation and X reactance of the line linking the DG to the substation. V stands for line voltage at connection to DG. This scenario is illustrated in figure 19.

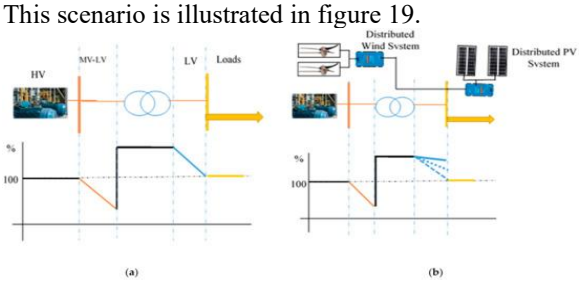


Figure 19: Voltage profile of network before and after RE integration: (**a**) Voltage profile at LV network with no distributed renewables; (**b**) Voltage profile at LV network with distributed renewables.

Voltage changes can lead to voltage violation, when the power system is subjected to voltages beyond the standard range specified by recommended by regulatory authorities. These fluctuations in voltage may lead to wear and tear in customer electrical appliances and

grid equipment, which increases the cost of operation and maintenance.

### ii. Effects on Power Line Losses

Electricity flow n conductors incurs power losses, evaluated with Ohm's law. These losses incurred by a current-carrying power line are analyzed using the following Equation:

$Ploss=1T\int T0(t)2R\ dt$

For a sinusoidal current, $(t)=Imaxsin\omega t$

, Therefore, $P_{Loss}$, for a cycle (T = 2π):

$Ploss=12\pi\int 2\pi 0(I2maxSin2\omega t)\times R\ d\omega t$

Which yields

$$Ploss=I^2R$$

Where:

$P_{Loss}$ = Average power loss in the line

I = root mean square (rms) of the line current;

R = line resistance.

From the power loss equation, it is noted that current is a function power flow in the lines and changes power flow affect the line losses. The power system loss incurred because of DG integration depends on the quantity of electricity injected and the connection point of the DG to the grid. When DGs are connected to loads in distribution feeders, the appliances will directly use electricity from the DG, which reduces the flow of power and related losses in the feeder. Additionally, power flow from the main grid (HV/MV network) to the load is reduced and the risk of grid overloading is reduced by the DG integration. When power delivered by the DGs into the distribution network is greater than the conductors were initially designed to accommodate, more power is lost in the network. The overall effect of power losses significantly affects network management cost and this cost is often shifted to consumers leading to higher tariffs.

### iii. Variability of Wind and Solar Resources

Electricity output from a solar/wind energy system depends on the availability of wind and the sun at a given place and instant as the solar radiation and wind speed continuously varies over time making the output constantly changing too. This may also apply to hydro without storage, which varies with recitation received [8, 9, 53]. The fluctuations in generation may lead to grid instability and low reliability as the generation fluctuates from these sources over time and location. Additionally, intermittent energy systems have a weaker correlation with the energy demand and hence they negatively affect grid losses energy demand at night is low and the wind generation, hence more energy will be lost, as it has to be exported to the main grid. The solution to this variability in generation is use of a local storage system to stabilize power flow and limit export of power. A typical variability of biomass, solar and wind is demonstrated in figure 20

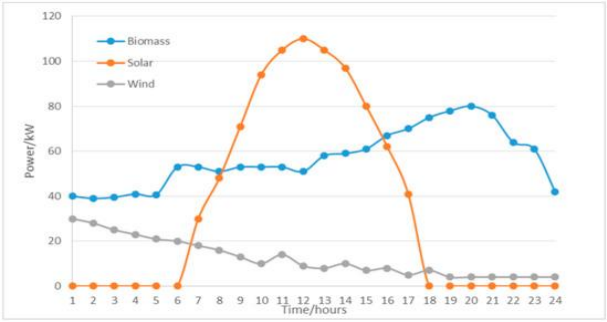


Figure 20: Example of renewable energy power generation patterns

From figure 20, it is noted that solar has the largest variation between minimum, which is zero at night, and maximum out at the day generally between 6 am and 6 pm depending on geographical location and seasons. Wind is variable too but generation tends to increase at night. Biomass sources tend to be steadier with minimum generation when solar and wind is at their best.

### iv. Issues from an Economic Perspective

Distributed generation is challenging when viewed from the perspective of managing conflicts existing between the utility and power consumers. The standard model for most utilities especially in developing countries is selling power and remain the sole actor in grid infrastructure management. If a customer installs rooftop PV, it means the customer will offset part of their electricity and maybe sell some to the grid operator. However, there are growing concerns about the economic sustainability of utility revenues as the share of distributed renewables increases. With no control in injection of power from DGs into the main grid may lead to thermal stress on grid components, hence reduced lifespan of the equipment. Injection of power from DG units beyond a certain penetration level may wear out transformers and conductors [before their which increases operation and maintenance costs and may affect the electricity tariffs. [47].

### v. Transient Voltage Changes

The grid may encounter some voltage changes when certain types of DG units to the are connected to the distribution grid caused by switching operations in the DG installation. This generally occurs during the equipment start/stop phase or a switch in a capacitor bank. Internationally, now, there is no particular designation of the transient voltage change and there are no limit values for this disturbance. The DG power plants can introduce transient voltage changes into the system when relatively large current variations are allowed during the DG grid connection and disconnection. The quantity of current transients is controlled at the design stage of the DG. The interconnection of synchronous generator-based DGs is associated with insignificant disturbance during synchronization if done the right way and anti-parallel soft-start components can reduce the magnetizing current of induction generators to below rated current value. Disconnecting a generator operating at full capacity may also cause substantial voltage drops in the system[54].

### vi. Voltage Flickers

The integration of some DERs such as wind energy systems introduces voltage flickers into grid because the output voltage varies as wind changes in speed and direction. According to the British Standards Institution, the voltage flicker assessment is required at power system design stage for wind energy systems connected to high voltage (HV) or medium-voltage (MV) networks. The Flicker indices $Pst$ and $Pst$ need to be evaluated by use of the equation:

$Pst=Pst=C(\varphi k,va)SnS''k$

Where: $C(\varphi k,va)$ refers to wind farm flicker coefficient established by a series of wind turbine tests; $\varphi k$: is network impedance phase angle; $va$: is annual average wind speed; $Sn$ : refers to wind farm rated power; while $S''k$: stands for is the short-circuit power at the point of common coupling (PCC) [55].

### vii. Harmonics Distortion

Distributed energy systems as wind turbines and solar have power electronic components like inverters, in the energy conversion process, may introduce current harmonics with some by voltage distortion at some points in the conversion process. The harmonics vary in order and magnitude depending on the type of converter, inverter characteristics and mode of operation. Most recent inverters that connect DGs to the power network can actively shape their current output to an acceptable limit, even though some of the injected harmonic currents may distort the voltage profiles that may be spread throughout the entire grid. Wind turbines with induction generators incorporated, may encounter an occurrence of harmonics within a short time interval especially at startup due to power electronic device. Some loads on the grid may also cause harmonics, where they introduce unwanted frequencies to the grid in multiples of 50 or 60 Hz that can cause the power system to malfunction. The presence of harmonics in a grid gives may cause diverse issues like equipment temperature rise and overheating, reduced system power factor of components, lower performance by devices, faulty responses by the protective system and devices, interference with communication signal, neighboring equipment may fail via resonance, undesired vibration and noise for devices like motors, etc.[56, 57].

### viii. Grid Instability

In the past, networks with unidirectional power flow were radial and grid operators simply interconnected DGs in a ‘fit and forget’ style. However, the increased penetration of DG has challenged this design as power injected power reached high and unacceptable levels. When DGs are connected to the grid, they displace substantial quantity of power from the main grid, which deteriorates the dynamics of power system operation. The grid is exposed to system instability, when DG power penetration exceeds 30%, in a situation where the DG unit replaces a major generator on the main grid leading to a drop in the existing inertia in the grid, but the penetration level significantly depends on the limits of the grid [55].

When a DG unit replaces a central generator in the main grid, an existing inertia drops which can increase the degree of imbalance existing demand and supply. If rotating inertia drops and a a large-capacity DG is withdrawn, the stability of the grid becomes fragile. The grid instabilities due to DG integration may be resolved using the ‘fault ride-through’ criteria, where standard time durations are defined for DGs to remain connected to the grid whenever voltage rises or falls (faults). This time or standard duration is generally set for large generators in the main

grid, and it may be important to set the same standards for DGs that are connected to the coupled to the grid at the distribution side. This will assist in frequency and voltage stabilization in case of faults; although it will depend on the capacity of the DG unit. With DGs being continuously coupled to the grid in case of a local fault, may interfere with operation of the local protective devices making fault recovery and identification complex. Therefore the DG grid interconnection needs synchronization among local protective devices and fault ride-through criteria, which calls for in-depth research in order to ensure a stable grid with DGs. [47].

### ix. Increase in the Fault Level and Fragile Protection System

The interconnection of DG into distribution grid influences fragility of the network because the DG could possibly contribute to the fault current. The way the DG plant is interfaced with the grid influences the e amount of fault current contribution, which may violate the ratings of the equipment. DGs connected to the grid via an inverter rarely add to fault current unlike those directly connection to the grid, where significant quantities of fault current are added. Large amount of fault current induced by DGs negatively affects the protective devices leading to improper operation of the protective system and challenges with fault detecting faults. Therefore, the DG to grid interconnection requires a protection management system having capability to support a bidirectional flow of power.

Thermal overload is a challenge to distribution network when power in the network exceeds the system components ratings. Any overloading on transformers which are some of the most expensive power system devices causes cause several collapse mechanisms and may lead to a complete damage The maximum current-carrying capacity of an overhead transmission line varies with total heat transfer to the cable and the resistance, and is expressed as

$I_L=\Delta HR$

Where $I_L$ is current in the overhead transmission line current (A),

R is resistance and ΔH is the heat transferred to the environment from the cable. There is need to upgrade equipment to higher ratting where components are subject to overloading. Therefore, injecting excess or huge amounts of renewable energy to the grid requires power system upgrade for it to support this electricity.

## VI. SUMMARY, DISCUSSIONS AND RECOMMENDATIONS

Grid integration of DERs requires a coordinated operation and control and use of controllable loads and storage devices, like batteries, flywheels, and capacitors being central to the concept of micro grid among other strategic, design and operational measures. The flexibility of local energy generation and energy use has increasingly become relevant for planning energy systems having high share of renewables, vehicle electrification, and decentralization

The challenges and issues associate with integration of DERs to the grid are summarized in table 1

Table 2: Summary of the challenges and issues associated with RE integration.

| Issue (s) | Challenge (s) | Description |
|---|---|---|
| Empty Cell | Empty Cell | Empty Cell |
| Power Balance | Insufficient short-term ramping capability | As integration of DERs to the grid advances operation of the conventional synchronous generation is pertinent to maintain grid stability terms of reactive power and inertia support. The fluctuation of grid integrated DER may require the synchronous generation for rapid ramping capabilities, especially at higher penetration of renewables. If not systematic loss will be realized technically and economically in maintaining stability of the grid in terms of frequency. |
| | Inadequacy of power in long-term generation operation | As the share of variable renewables increases, in the grid, the operational aspects like seasonal and annual energy balancing will change and affect the scheduling of the synchronous generation system. This will make the system vulnerable to long-term system instability caused by inaccuracies from the unpredictable nature of |

| Issue (s) | Challenge (s) | Description |
|---|---|---|
| Empty Cell | Empty Cell | Empty Cell |
| | | renewable power output. The resulting systematic generation deviation is economically demanding. |
| | Insufficient forecasting of RE generators | The grid unscheduled operation realized due to forecasting inaccuracies output power generation may cause losses ranging from equipment damage, economic to technical, loss. |
| | Limited dispatchability of RE sources | As per the properties of most renewable sources of power the frequency stability of the grid may not be stabilized by operating the RE generators which can lead to foreseen outages caused by mismatch between power demand-and its supply/generation mismatch. |
| Power Quality | Voltage Flickering | The power electronics for locally integrated DERs increase flicker which reduces the life of electrical equipment |
| | Harmonics | The inverters for DERs can lead to higher harmonic distortions which reduces equipment lifetime, can cause trips, or damage of equipment for consumers. |
| | Low reliability during blackout | DGs that continue generating power within areas that are disconnected from the larger network are vulnerable to stability and power balance challenges hence face operational and safety concerns |
| | Voltage congestion at distribution level | Integration of DGs at low voltage level increases cases of voltage violation e.g. Over-voltage at peak generation and or during low load demand instances. |
| Optimal Power Flow | Increased overall voltage profile | Integration of DGs increases the overall voltage level particular in the case of radial distribution. |
| | Limitation of grid capacity | The existing grids may lack capacity to integrate the DG generators leading to power curtailment. Unplanned integration can lead to system vulnerability to faults and damage of equipment. |
| | Potential instability and uncontrollability at lower levels of the grid | Grid integration of DGs at high penetration, leads to higher unpredictability of power generation, which leads to higher curtailment of DER generators, stability requirement, and equipment damage. |
| | Grid Protection | The lower voltage levels often lack protection preparedness to resultant dynamics of the stochasticity introduced by integration of DGs. Lack of adequate protection planning at the lower voltage level leads to higher incidents of overloading and unplanned trips, which impacts on equipment lifetime. |
| | Higher short-circuit current | DG integrations leads to changes in the power flow and system dynamics particularly at lower voltage of the grid which leads to more cases of level of the short-circuit current during fault conditions. Hence system vulnerability and security are high based on the degree DER integration to the grid |
| | Reduced controllability over the REs | Hugh integration of multiple small unit capacity, which are not, planned collectively impact the power flow and system dynamics, which reduces the dependability of forecasting and planning leading to systematic instability of the grid. |
| | Low degree of observability of the REs | As a result, limited measurement devices to complement the variability associated with grid integration of DERs generation systems, unobserved power flow may occur at these voltage level leading to unscheduled grid operation which may be technically and economically harmful |
| | Low grid transmission | The integration of DGs to an existing grid may require |

| Issue (s) | Challenge (s) | Description |
|---|---|---|
| Empty Cell | Empty Cell | Empty Cell |
| | capacity | installation of additional transmission lines to avoid. Power curtailment and lower transmission capacity hence reduced regional power dispatch. |
| | Longer transmission line distances | DG integration is associated with unpredictability and some degree of uncontrollability. In cases of longer transmission, leads to increase in the overall transmission lines losses. |
| Grid Stability | Decreased reactive power support | Many DG technologies make negligible contribution to reactive power injection. However, the grid standards and dynamics require that transmission lines have reactive power support to maintain voltage standards. High penetration levels significantly limit this due to potential voltage violation occurrences. Missing reactive power support influences the power quality and stability which leads to curtailment or isolation of DGs. |
| | Reduced capability towards fault detection | Because of relatively lower value of short-circuit power of DG generation system detection of fault and voltage instability may be undetected which leads to complications towards stable grid operations and isolation of DGs |
| | Decrement in the grid inertia | Most DER technologies are dominated by electronics with lack or negligible inertia compared to the synchronous dominated grids. As a result, a rapid frequency excursion could lead to a highly unstable grid, which may necessitate generation curtailment or load shedding to maintain the system operational stability. |
| | Increased reserve for frequency control | DERs lack facility to provide reserves for grid operational aspects the short-term, and highly unpredictability fluctuating generation requires specialized and additional reserves for stable grids due to frequency deviations. Where we have unplanned DERs integration and operation, the solution could be to curtail generation, load shed, or need or other decisions to regulate for stability at critical conditions of the grids. |
| | Increased controllability and observability for inverter-dominated grid | DGs in line with the de-centralized transformation of the grid need inverters as interface that connects the DER to the grid. The resultant grid has power oscillations that are unobserved which may cause the grid to experience increased unexplained trips which creates a need for dedicated control algorithm for effective regulation under such circumstances |

From table 2, it is noted that there are numerous challenges associated with the grid integration of DERs that should be addressed to realize positive contribution of the decentralized and distributed energy resources.

## VII. CONCLUSIONS

Grid integration of DERs requires a coordinated operation and control and use of controllable loads and storage devices, like batteries, flywheels, and capacitors being central to the concept of micro grid among other strategic, design and operational measures. The flexibility of local energy generation and energy use has increasingly become relevant for planning energy systems having high share of renewables, vehicle electrification, and decentralization

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### b. Availability of data

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### c. Authors contribution

The first author (MJBK) developed the manuscript draft under with the e second author (OAO) providing administrative and technical support and guidance and review. The authors jointly agreed on content and

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### d. Declaration of competing interest

The authors declare that there are no known competing interests or personal relationships that could have appeared to influence the contents of this manuscript.

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