Electricity Integration Efficiency Measures in The Conventional Grids

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Abstract

Integrating energy efficiency (EE) measures into conventional power systems is required to reduce the overall energy demand, increase grid reliability, and reduce greenhouse gas emissions through modification of power generation processes, grid upgrading, and management of end-use consumption to ensure that conventional power plants operate closer to their peak. Integration of distributed energy resources in the electricity grids presents significant opportunities and challenges. This is because renewable energy sources like solar and wind, are huge and offer sustainable and low-emission energy, but are inherently variable intermittent and unpredictable which can cause serious strain to grid infrastructures. Additionally, the amount of energy accessible is affected by technical losses during conversion, transmission and distribution to consumers. Decentralization of generation has become a trend in electricity generation driven by the need to develop alternate energy sources for growing demand and global emissions and climate targets. The global drive for decarbonization, digitalization and decentralization, has caused need for a significant overhaul of electricity distribution networks to integrate distributed energy resources (DERs) into sustainable power systems in a way that maintains operational stability and system reliability. This study evaluates current DER integration techniques, the methodological constraints, and innovative integration methods. 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. Smart grids improve efficiency of power systems and hence the integration of renewable energy (RE) systems whose use reduces greenhouse gas emissions, increase energy security, provides diversity in the generation mix, and dependence on fossil fuels. The integration of decentralized and distributed energy resources most of which are renewable and sustainable encounters various integration and utilization challenges. This study examines and synthesizes the various energy resources, conversion technologies, integration techniques, and scalability factors associated DER integration in smart grid and micro grids as well as the traditional grid. Electricity produced in power stations is transmitted to the points of use with the aid of the grids which are interconnected networks for electricity transmission and distribution to consumers from electricity producers. The grid is classified into the smart grid and conventional grid on basis of the energy devices and their functionality. As a result of many challenges facing the conventional grids in meeting varying demand and supply of electricity, the smart grids were proposed and developed as a conventional grid infused with the intelligent sensors and controllers, with automated switches and substations, having two-way communication and other technologies

Key words: power generation; electricity grids; grid integration

I. Introduction

The variable energy sources like wind and solar poses challenges for conventional grid operations as many countries seek affordable fossil fuel substitution to reduce greenhouse gas emissions and improve the energy security with 183 countries having adopted targets for generation of renewable energy. As the cost of solar photovoltaic (PV) and wind technologies, reduces because of technology advances and

economies of scale their share in the energy mix is expected to substantially increase, but high levels of variables into the introduces operational and reliability [1]. Transmission lines electricity generated to final users in a process that losses up to 35.655% of energy produced, actual loss varying with type of power transported, distance, network properties, and meteorological factors[2, 3]. Additionally, fossil fuels which account for over 60% total electricity in many countries globally getting depleted and are becoming increasingly costly while at the same time accounting close to 68% of greenhouse gas emissions globally. As result of these factors, renewable energy, with 2024 installed capacity estimated at 4,448,051 MW and energy storage technologies continue to be deployed as response. The pursuit for resilient power grids, higher energy efficiency, and lower greenhouse gas emissions have generated interest in Distributed Energy Resources (DER), particularly renewable sources like wind, solar, hydroelectricity, geothermal, bioenergy, geothermal, marine energy, and energy storage technologies, are [4, 5].

The electric power distribution sector provides a base for economic and social development as an enabler of modern infrastructure construction and enables the energy transition. There is a need for an efficient, sustainable energy distribution systems s a result of growing demand, growing share of distributed and decentralized energy sources and environmental shifts[6]. Distribution networks perform their role as fundamental technological frameworks for sustainable development through strategic deployment, to meet requirements for energy access, stability, reliability and equity, as well as for carbon reduction[7].The electricity grid is expected to continuously and consistently progress so that it can meet the growing needs in electricity sector and to replace old-pattern power generation with renewable generation often characterized by high degree of intermittence and variability[8-10].

DERs have an important role in the new governance of the energy system by enabling providing the needed resilience and support to exploit enormous generation potential and flexibility. The DERs offer multiple solutions for to microgrids within satisfactory models and control strategies and also offer relevant environmental, economic and social benefits. Incorporation DERs enables diversification of energy asset ownership and empowers users and contributes to the global and local objectives of decarbonization, energy security and market price efficiency[5, 11].

The smart grid is modernizing power systems towards high consistency, higher efficiency, reduction in costs and power losses while incorporating variable renewable energy sources to the grid. The electricity market is characterized by changing consumer needs and trends, new industrial invention and growing demand for renewable energy resources for power generation. These changes and advances in the electricity and general energy markets calls for modernization of the electricity to cope with the changing markets. The. Smart grid has emerged as an ultimate answer to the ongoing technological and electricity market reforms occurring in power generation, the transmission and distribution that requires increased application of sensors, advanced two-way communication computers [8, 12].

The integration or interconnection of decentralized energy resources is an evolving power sector scenario globally as a result significant issue, like fossil fuel scarcity, widespread deployment of advanced Distributed Energy Resources (DERs) technologies, as a result of ongoing deregulation in power sector, and growing awareness on environmental impact of traditional electric power generation[13, 14]. Decentralized generation has opened up new opportunities as well as challenges in power generation and distribution markets, as small-scale non-conventional systems become attractive in the generation of electricity with limited environmental impacts, highly efficient and easy to install, and operate with increased power system reliability [15, 16]. With increasing awareness on environmental impacts like global warming and impacts, the renewable energy sources have become important in modern power systems. The different political, social, geographical, financial and environmental, factors in different countries create opportunities for renewable and sustainable energy resources like solar, wind, geothermal, and biomass resources[10, 17]. Additionally, low power generation capacity of DER generate incentives for integration of multiples sources which leads to creation of micro grid for better power generation capacity, reliability and marketability of the micro sources aimed at reducing the load

congestion on the conventional power system or utility grid and enable localized generation close to point of use by customers[18],[19].

The Integration of distributed Energy Resources (DERs) into power grids provides several benefits, like enhanced reliability better power quality, and enhanced energy independence. However, this integration is associated with multiple technical challenges in terms of grid stability, quality of power, and the need for robust control and communication system[20]. Grids fueled by renewable energy sources and managed by smart grids offer higher reliability, cost effective and more efficient energy systems. 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 integration of distributed energy resources (DERs) into micro grids presents immense opportunities and challenges for the improvement of power system efficiency, reliability, and sustainability[21, 22].

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. Methods available for increased integration of renewable energy to grids and micro grids include the use of grid scale storage, integration of the cellular approach in the energy system planning and operation, use of virtual power plant concepts, use of V2G technologies and electrification of transport, application of demand side measures, use of smart grid features and infrastructure in micro grids (Smart micro grids) by upgrading the traditional grids and micro grids, the use of dc micro grids and application energy management and optimization tools and techniques and micro grid operation[23-25]. The future status of decentralized energy integration relies on the development of storage technologies, and the use of artificial integration and machine learning in optimization of the grid functions. These innovations are key in achieving 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.

1.1. Problem statement

There is growing reliance on renewable energy sources, particularly wind and photovoltaic (PV) and wind power, which present challenges in terms in the form of intermittent and variability of parameters like solar irradiance and wind speed leading to fluctuations in generation and hence a mismatch between supply and demand, which can cause serious power quality issues, like frequency and voltage instability that affect reliability of the power grid[26]. High penetration of Renewable Energy Sources (RES) with energy storage and microgrid control systems is critical future distribution grids for optimal utilization and management of Distributed Energy Resources (DERs) to ensure system operators adopt the right path to transform their traditional grids into smart grids. The continued expansion DERs, makes it necessary for current distribution grid to transition a carbon-free electricity system and greener energy-transportation applications calls for adoption of measures and strategies for efficient integration to existing grids besides modernizing them to smarter and more resilient grids [4, 27]. The challenges of the traditional grid infrastructure include

i.) The Traditional grids are designed for one-way power flow originating in centralized plants to consumers, yet the DERs cause power to flow backward, which complicates voltage regulation and protection schemes of the tadeonal grids.
ii.) Intermittency and Variability that characterize the renewable sources create rapid fluctuations in supply that is difficult for the traditional grids to balance.
iii.) Data and Communication Overload is a challenge cause by thousands of scattered, small-scale resources hence the need for a massive, secure, and low-latency communication networks to support communication.
iv.) Legacy Infrastructure of the traditional grids in terms of grid hardware consisting of transformers, switchgear and other critical devices lack the digital capability for intelligent to interface with modern inverters and smart grid components
v.) Variability and Unpredictability

Renewable energy sources (RES) create rapid fluctuations in power generation which makes balancing supply and demand challenging. The variability created demands advanced forecasting and real-time grid management to maintain stability.

vi.) Infrastructure Limitations

The transmission and distribution infrastructure I many countries is outdated and not cannot handle bidirectional power flows which is characteristic of renewable energy resources, hence the need to upgrade these infrastructures to accommodate increased
renewable capacity. These upgrading process is quite costly and time-consuming but very important.

vii.) Ancillary Services Deficiency

There is growing need for alternative sources of power as conventional power plants provided essential grid stability services like frequency regulation and voltage support are gradually. Adoption of new technologies and innovative strategies is curricula for grid reliability and maintenance of a stable power supply[21, 22].

1.2. Rational of the study

The net load must be managed by grid operations, for conventional and smart grids and microgrids. The main challenge with the renewable energy sources is they are more variable and less predictable. The integration of variable renewable energy resources (VRE) sources into a power system creates "net load" which is the difference between actual load and variable renewable generation [1]. Adding a variable resource like wind power increases;

(i) the ramping rate, which is the speed at which the load-following units should increase generation to balance demand and supply and hence grid stability
(ii) the ramping range, or which refers to the difference between minimum and maximum demand on a daily basis; and
(iii) the forecasting uncertainty[1]

The global shift towards decentralized generation is driven by the need to mitigate climate change, reduce greenhouse gas emissions, and shift to sustainable energy systems. Unfortunately, integration DERs into existing power grids poses unique challenges occasioned by their intermittence nature and changing demand of modern electricity consumption, which requires a multifaceted approach combining innovation, modernization of power systems infrastructures, and developing supportive policy frameworks[5, 26].

The energy transition requires a reliable distribution network to support services and products like electrification of transport, support growing share of variable renewables and load as well as modernization of electricity services and products which require a stable and reliable electricity supply[7]**.** Electricity availability shows a direct relationship with human development indicators, social inclusion, education levels, and economic status. It has been established through studies that renewable energy-based rural electrification systems results into positive impacts on human capital development and community participation, which is critical for sustainable development[1, 28]. The integration opportunities presented by the traditional grid include;

i.) Grid Resilience and Reliability can be attained by **s**trategically positioning the DERs to form microgrids with islanding capability during weather or outages, which enable critical infrastructure to continue operating during an outage [29]
ii.) Peak Load Reduction can be attained by discharging stored energy during peak demand to reduce strain on transmission lines which also reduces the need for deployment of expensive, traditional infrastructure upgrades
iii.) DERs can provide support for vital grid functions like frequency regulation, voltage support, and "black start" capabilities, in a way that is faster than faster than conventional generators
iv.) Integration of the DERs converts consumers to prosumers enabling them **to** actively participate in energy markets, which reduces their electricity bills and potentially earn revenue by selling excess power back to the grid
v.) Reliability improvement

Investment in integration of DERs improves grid reliability via real-time monitoring, fault detection, and self-healing functions e.g., when smart grids are adopted. Maintenance of uninterrupted power supply enhances reliability leading to higher customer satisfaction, reduced economic losses, and supports greater business productivity [18].

vi.) Sustainability

Increased integration of DERs helps in reducing carbon emissions and encourages cleaner power generation lowering overall carbon footprint by reducing dependence on fossil fuels. [18]

vii.) Reduced Operations and Management Costs hance cheaper power can be attained by optimizing resource use, effective remote monitoring and control, and ability to undertake predictive maintenance. Although upfront costs are incurred in modernizing or replacing the traditional grid infrastructure, long term benefits outweigh these costs due to higher efficiency, improved reliability, and greater renewable energy integration. [18].

viii.) Faster Electricity Restoration after Disturbances

With two-way communication, grids can automate power rerouting when during equipment outages which significantly reduces both the frequency and impact of outages. Automated monitoring, remote control, and predictive analytics further support rapid response and recovery. Upgrading traditional grids can effectively manage unplanned outages, fasten infrastructure restoration after major outbreaks and minimize disruptions [18].

ix.) More Efficient Electricity Transmission

Modernization of grids improve the efficiency by use of use of digital technologies, sensors, and software for real-time balancing supply and demand. To fully realize the benefits, utilities should adopt strategies like advanced analytics, strong cybersecurity and data privacy, energy storage, predictive maintenance, integration (DERs), grid resilience through microgrids, , and automation [30].

x.) Reduced Peak Demand

Enhanced adoption of demand side management and demand response which comes with grid modernization for enhanced integration of DERs reduces reducing electricity costs, empowers empower consumers to make smarter energy choices[23, 31]. By demand response programs which reduce peak time energy usage along with load shifting, energy storage, and grid optimization and automation further reduces stress on the system, enhances reliability and efficiency while reducing peak-related expenses and investments [18],[23]

2. THE TRADITIONAL GRIDS

The traditional electricity grid is an interconnection of various power systems elements like the synchronous generator, transformers, transmission and distribution lines, transmission substations, distribution substations, and different types of loads in a way that they are located far away from power consumption areas in a one-way flow direction[32]. The traditional grid supports two centralized generation of power and long-distance transmission at high voltage making the traditional grid system inefficient[33]. The traditional power grid is an interconnected network designed to produce, transmit, and distribute power from centralized power plants and deliver to consumers located far away. In local grids, once electricity is produced, it is transported through high-voltage transmission lines before being stepped down by substations and distributed locally through the distribution network to consumers[34].

The origin of the traditional power grid dates back to the late 19th century, that emerged after the innovations in electrical engineering. The early power systems were localized, and designed to serve individual buildings or neighborhoods. As electricity demand increased due to urbanization and industrial growth, the need for larger, interconnected systems emerged. The development of the modern, interconnected power grid, that allowed economies of scale was built on the pioneering work of Thomas Edison and George Westinghouse Edison's developed the direct current (DC) system, which was however

limited inn ability to transmit power over long distances. This challenge was solved by Westinghouse, who champion the Nikola Tesla's alternating current (AC) system, enabling more efficient transmission of high-voltage electricity across long distances[35].

The conventional grids make use of wired communication to monitor grids, however due to high costs and the maintenance of the links they are rarely used. On the other hand, a smart grid is independent fault components hence has a self-healing capability with faulty components being independent, and do not affect the grid. The conventional grid technology is unidirectional, with limited information sharing and lower efficiency and is generally used for data gathering from a limited number of sensors located at t critical distribution and transmission points, transmits limited control signals, and has limited fault detection. [32].

2.1. Features of the traditional grid

The conventional electrical grid defines the traditional structure of electric power systems, and an older model primarily consisting of three core elements: generation, transmission, and distribution networks. However, the power sector is shifting away from this conventional setup towards a more modern, efficient, and sustainable power systems which prioritize operational reliability and use of greener energy which has seen the electricity undergo substantial growth for reliable grid operation and for more efficient and sustainable energy use[36].

The conventional grid also referred traditional electricity grid is an interconnection of various power system elements like alternators, transformers, transmission lines and different types of and loads for transmission of electric power from production point to electricity use[37].

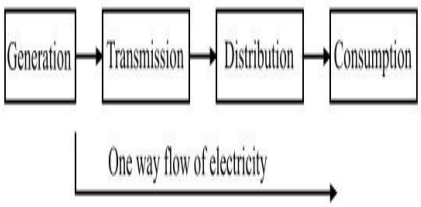

Figure 1 - Conventional Power Grid

From figure 1, it is noted that the main elements of the traditional or conventional electricity grid are the use devices or consumers, power plants or generators, transmission and distribution systems. Wit power flowing in one-way flow of electricity from the power plant generators to the consumer.

i.) The traditional grid is a centralized system for power production, transmission and distribution.
ii.) The traditional grid relies on large-scale power plants powered by conventional power plants using fossil fuels, nuclear, or hydroelectric sources.
iii.) There is a unidirectional flow of power the traditional grid towards consumers.
iv.) Faces challenges in managing grid reliability and balancing load changes
v.) The infrastructure of many traditional is aging and requires massive infrastructure investment to maintain and upgrade[38, 39]

2.2. Interpreting the Traditional Power Grid

The objective in operation of a traditional electricity grid is to balance supply and demand in real time basis and generators have to produce exactly what consumers need at the given moment to maintain grid stability which requires constant monitoring and adjustments operators with the health status being interpreted based on frequency stability i.e. 60 Hz or 50 Hz and voltage levels, which should remain within acceptable tight tolerances. Deviations may cause equipment damage or widespread outages, called blackout. The efficiency of a traditional grid is measured from factors like transmission losses, power lost as heat in transmission, and capacity to meet prevailing demand without interruption[37, 39].

2.3. Operation of traditional grids and applications

In cases where demand increases triggered by events like need to cool in hot summer when temperatures soar in an area served by the traditional grid leading to a rapid surge in electricity consumption and hence peak demand will place huge strain on the traditional power grid. To manage this e.g. put to load large fossil fuel-powered plants to increase their power generation to cope with new load. However, if the demand continues to rise unexpectedly or a major source or major transmission is load, the grid operators may implement a rolling blackout in which power is cut to certain areas to prevent a complete system

collapse, which is a major limitation of the. unidirectional nature and the challenges of dynamic load balancing in the traditional grid[40].

2.4. Practical Applications

Traditional electricity grid is the backbone of modern economies, which enables delivery of power to consumers like industries, homes and other essential services in modern society. Economically, the traditional grids represent massive capital expenditure incurred in the construction and maintenance by mostly public utility companies subject to extensive utility regulation. As governments prioritize energy security and reliability of grids, huge public and private sector investment is incurred in their upkeep and modernization e.g. the Bipartisan Infrastructure Law in the US includes historic investments in America's power grid, which reflects the critical need to enhance resilience and capacity of the grids[40].

2.5. Limitations and Criticisms

The traditional power grids face several significant limitations and criticisms e.g., the centralized architecture makes vulnerable to single points of failure, like loss of a large power plant or a critical transmission lines, leads to widespread power outages e.g., in 2003 Northeast Blackout, prompted renewed focus on grid resilience and modernization efforts. The conventional grids employ wired communication for grid monitoring but are not preferred because of high expenses in the development and maintenance of these links. With self-healing features and ability, the smart grid is preferred. Being unidirectional, and with limited information sharing, the traditional grid has lower efficiency compared to smart grids. In the traditional system of grid communication data is gathered from a limited number of sensors located at limited critical distribution and transmission points, hence limited transmission of control signals, and fault detection [32]. All these characteristic features lower the performance effectiveness and efficiency of the traditional grid.

The traditional grids are not accommodated for bidirectional flow of power from decentralized renewable energy sources and does not efficiently integrate intermittent like wind and solar, except with significant upgrades. Overreliance on dispatchable fossil fuels power plants also contribute to greenhouse gas emissions. The traditional grid also has substantial age in many developed nations leading to higher maintenance costs and increased susceptibility to severe weather events[18, 39].

1. CONVENTIONAL VERSUS TRADITIONAL GRID

The traditional or conventional grid is s designed to just meet basic electricity needs like the production, control, and supply of electricity, but has no forecasting ability which is a crucial step in grid performances today to avoid wastage and manage stability and reliability challenges associated with DERs. With rapid increase in non-conventional energy generation and usage has increased has created challenges for grid management like grid stability and power quality. The smart grid was introduced to mitigate the limitations of the conventional grids which do not have forecasting ability for demands[41, 42].

The smart grid and traditional grid represent two different approaches to electricity supply, with the traditional grid being characterized by its largely one-way power flow from centralized generation to consumers, while the smart grid employs two-way digital communication.

The key differences between the Traditional Power Gird and the Smart Grid can be discussed on the basis of technology, generation and distribution, monitoring and sensors, equipment uses, sensors, monitoring, healing, equipment, and customer choices as follows. The differences between the smart grids and traditional grids are summarized in table 1

Characteristics	Traditional Power grid	Smart Grid

Technology	The traditional grid is an Electromechanical system i.e., a mechanical device operated electrically operated. The technology is considered to be "dumb" and has no means of communication between devices and little internal regulation.	The smart grid employs digital technology which facilitate better communication between devices and enable remote control, self-regulation and self-healing
Distribution	The distribution in traditional grids is One-Way Distribution:	The distribution in smart grids is Two-Way Distribution and power in a smart grid system, allows power to go back up the lines to the main plant from a secondary provider.
Generation	In traditional grids the infrastructure, is centralized making incorporation of alternative energy sources into the grid difficulty.	The smart grids can distribute power from multiple plants and substations for balancing, reduce peak time strains, and limit power outages.
Sensors	The central grid infrastructure is not does not support many sensors on the lines which makes it hard to pin point area with problems.	The smart grid infrastructure system is equipped with multiple sensors placed on the lines which can pinpoint the problem and can help reroute power to points of need and reduce downtime.
Monitoring	The monitoring in traditional grids is manual which limits monitoring capability	The smart grid can monitor itself using digital technology which enables balancing power loads, mange distribution and troubleshoot outages
Restoration/Repairs	Repairs on traditional energy infrastructure, are manually or physically done at the point of failure which is expensive and time consuming	In smart grids, the sensors can detect problems and do simple troubleshooting and repairs without physical intervention. Where infrastructure is damaged, the smart grid can immediately report to technicians at control centers to undertake necessary repairs.
Equipment	traditional grid infrastructure is prone to failures which can lead to blackouts, which aging infrastructure for most traditional grids	In smart grid system, the electricity can be which limits the area impacted by power outages.
Control	The traditional power infrastructure, is difficult to control and companies have no control when power leaves the power plant or substation	With more sensors, their smart infrastructure, utilities have more control than ever over power distribution, while electricity consumption can be monitored from the moment it leaves the power plant to the consumer.
Customer Choices	The traditional grid system infrastructure cannot give customers a choice in the way they receive their electricity. Alternative energy sources,	smart technologies, infrastructure may be shared by allowing more companies and forms of alternative energy to use the grid

	have to be separated from power plants and traditional grid infrastructure. a public utility.	and enable consumers to have more choice in how they receive energy.

It is noted from table 1 that the traditional grid relies on a "dumb" infrastructure having minimal flow of information, unlike the smart grid which employs advanced sensors, computing, and digital controls for optimization of energy functions, quickly and effectively detect and integrate a wider array of energy sources. Therefore, difference in communication and control fundamentally define and distinguishes operational abilities and limitations for future energy management.

2. GRID INTEGRATION OF DISTRIBUTED AND DECENTRALIZED ENERGY RESOURCES

Electricity generating from renewable energy which dominate the decentralized and distributed energy resources (DERs) rather than fossil fuels (reduces greenhouse gas emissions from the power sector. On the basis of emissions load, the DERs are preferable to fossil fuel generators from an emissions standpoint, making them preferred choice, but they are much difficult to control by grid operators[11]. The intermittent nature and wider diversity in terms of size and distribution/spread makes it difficult to balance demand and supply, which becomes more and more complicated as the share grows [11]

The integration or interconnection of decentralized energy resources is an evolving power sector scenario globally as a result significant issue, like fossil fuel scarcity, widespread deployment of advanced Distributed Energy Resources (DERs) technologies, as a result of ongoing deregulation in power sector, and growing awareness on environmental impact of traditional electric power generation[13, 14]. Decentralized generation has opened up new opportunities as well as challenges in power generation and distribution markets, as small-scale non-conventional systems become attractive in the generation of electricity with limited environmental impacts, highly efficient and easy to install, and operate with increased power system reliability [15, 16]. With increasing awareness on environmental impacts like global warming and impacts, the renewable energy sources have become important in modern power systems. The different political, social, geographical, financial and environmental, factors in different countries create opportunities for renewable and sustainable energy resources like solar, wind, geothermal, and biomass resources[10, 17]. Additionally, low power generation capacity of DER generate incentives for integration of multiples sources which leads to creation of micro grid for better power generation capacity, reliability and marketability of the micro sources aimed at reducing the load congestion on the conventional power system or utility grid and enable localized generation close to point of use by customers[18],[19]. The various elements of the grid integration of decentralized energy resources are shown in figure 2.



Figure 2: The grid integration[15]

The structure of power systems is changing globally because of the adoption of decentralized generations because large-scale penetration of decentralized resources often interferes with the stability and operation of power systems at all voltage levels. To mitigate these challenges, and exploit the flexibility of decentralized systems, different concepts can be adopted to achieve grid integration like substation level voltage regulation, modification of grid configurations, use of the 'N Minus Zero' Regulation, control of reactive power, creation of Express Feeders in the MV Network [43, 44]. The grid integration of DGs into the distribution network benefits the utility companies, consumers and power system operators. However, the network performance will degrade if the connection point and DG capacity are not appropriately established leading to increase in in power losses and voltage fluctuation. Therefore, the coupling of DGs to the grid, particularly the distribution network,

requires optimal planning of components, determination establishment of optimum hosting capacity and the selection of an optimum connection point, which improves the security, and reliability of the power system while increasing the penetration level and reducing the generation costs. Additionally, the capacity of a DG unit should be sized properly to enhance the network efficiency [45, 46].

As a measure to bridge the gap between legacy grids and new energy resources, the grid operators apply different targeted strategies. Some practical options being used for to grid integration include;

3.1. Vigorous Voltage Regulation at the Level of Substations

At the level of the substation, HV/MV transformers adapted with voltage regulation functionality to adjust the voltages in the transition between the high voltages (HV)/medium voltage (MV) networks. Many utilities used voltage regulators as an intervention mechanism to compensate for voltage fluctuations on the HV net on high voltage work and stabilize the MV to a constant level. With growing share of renewable energy integration in the grid, grid operators have incorporated power electronics and software applications to adjust the MV levels with respect to the percentage of renewable energy penetration and the load flow conditions at substation to subdue the increasing voltage on the MV network upon renewable energy injection[46]. The challenges associated with the renewable energy injection include voltage variation, which affects consumers connected at the medium-voltage (MV) level, thus limiting widespread application of the dynamic voltage control. The possibility of reducing the voltage in a network depends on the physical spread of the renewable energy systems in the grid with energy systems located far from the substation presenting problems when reducing the voltage [45, 46]

3.2. Modified Grid Configuration

In this strategy, the grid is expanded by addition of distributed generators to optimize the structure of the existing grid. The expansion is done in a way that reduces power losses, enhances fault detection/correction, and enable physical access to switching stations[45]. The growing renewable penetration which is associated with and the necessity for grid expansion provokes system operators to set supplementary goals like avoiding the creation of new transmission lines or power substations as much as possible. This goal, of reducing the expansion of the power network is however in conflict with other optimization scheme [45], hence may not be desirable.

Actions aimed at reduction of grid impedance improve the hosting capacity of renewables in the power network. Grid operators can reduce grid impedance by developing a closed-loop in MV networks in which the radial MV grid configuration is modified to a closed ring in which the substation is connected to more to more than one energy supply line. The method connects previously autonomous transmission lines fed by a common distribution transformer to a switching station, to create a closed loop. The method however makes fault detection and fault recovery complicated and making the method controversial among power system operators. This called for other sustainable methods which evenly distribute injected renewable power into the entire grid for optimum utilization of the existing grid capacity[46, 47].

3.3. The Use of the 'N Minus Zero' Regulation

System operators can also increase the penetration level of renewables by establishing renewable energy generators to serve as a backup generator, when a fault occurs at one part of the grid. Renewable energy systems are the continuously added to the grid as required by the energy demand and grid stability requirements, but are detached any moment the stability of the network is compromised. A substation may be equipped with additional HV/MV transformer that supports the network during maintenance or other contingency events. This extra transformer could be used to host more renewable energy systems in thin MV network. This method improves the utilization of the available grid capacity, but renders the power system operation complicated [46]. Therefore, simpler methods must be is required with clear implementation guidelines and protection measures for convenient addition of renewable energy systems to the grid in an incremental manner[47].

3.4. Reactive Power Control

The injection of active power in the grid causes a voltage rise therefore the ability of distributed renewable energy to produce reactive power is employed by system operators for voltage quality control. The reactive power supplied neutralizes the voltage rise, which improves the ability of the network to host or absorb renewable energy system with high reactive power. At high voltage level, the system operators use advanced methods like automatic supervisory control systems for regulation of reactive power injection. Reactive power control

is also used to smoothen the reactive power imbalance in medium voltage network, supplied by generators[46, 47].

3.5. Creation of Express Feeders in the MV Network

The express feeders are transmission systems with huge cross-sections (500–800 mm^2) having to transport large amounts of electricity to consumers at lower voltage drop because of the large cross-section. System operators can also enhance the uptake of renewables or DERS by creating express feeders to connect HV/MV substations to distributed generators to evacuate power at a higher current carrying capacity. The lower voltage drop significantly increases hosting capacity of the MV network. This method is economical in areas where voltage complications caused by high renewable penetration are experienced [46, 47].

3.6. Storage

Energy Storage Systems (ESS) are employed to store excess energy for later release during peak demand periods. These offers benefits like reducing variability of renewable energy output, grid stability, peak load shaving and enabling peak load shifting, providing ancillary services, and increasing integration, while at the same time it lowers peak demand and associated costs[19]. Other benefits of incorporating storage in traditional grids include reduced carbon emissions, deferred investment in transmission and distribution infrastructure and facilitating energy arbitrage. Common systems and devices used for energy storage include battery storage, pumped hydro, and compressed air storage. ESS stores energy during high availability and generation for release it during low generation, which helps in balancing demand and supply [15, 26]. Storage can enhance grid operations by enabling quick response times and good cycling efficiency of many storage technologies. Storage technologies vary in terms of rated power and discharge time. Examples of grid scale or connected storage like compressed air energy storage and pumped hydro can be used to capture high winds at night when demand is low for release during peak hours which shows that storage can be employed to reduce variability of VRE output[1, 48, 49].

3.7. Smarten the traditional grids (Smart grids)

Transforming the traditional grid to Smart grid which rely on two-way communication, control systems, and advanced computing with Phasor Measurement Units (PMUs) helps in monitoring grid stability, smart meters that provide consumers with real-time data and report outages automatically, enabling quick fault detection and response for rerouting power during disruptions[26]. Smart grids employ advanced technologies for control of grid components and to enlist customers to manage demand which increases the efficiency, flexibility, and intelligence of a power system and contribute to enhanced integration of renewable energy resource integration by the following ways

i.) Smart grids adopt codes and standards that promote manufacturing of reliable equipment that ensures safe and nondisruptive flow to the network while supporting system operations like data/information provision/supply

ii.) Smart grids enhance supply flexibility through by controlling the generation from small-scale distributed PV units making it possible to reduce the output of individual units (or even disconnect them entirely) to avoid violating ramping limits set by utilities using ramp rate control systems.

iii.) Demand-response programs facilitate control and consumption or through voluntary load reduction. A smart grid using direct load controls regulates consumers' thermostats or switch from one power source to another based on availability or nonavailability of energy resources e.g., when cold and windy, the smart grid may use the spike in wind power to provide more heat for consumers which maintains balance between supply and demand

iv.) Smart grids can reduce the operational impacts of variable renewables by taking advantage of short-term solar and wind forecasts. Smart wind turbines can incorporate millisecond wind forecasting ("nowcasting") for optimization of power output by dynamic adjustment of the pitch of turbine blades. Short-term solar forecasting like ground-based sky imaging can be employed to measure cloud speed and short-term output. Hence an increase in grid's forecasting capabilities leads to more

responsive energy markets and more flexible day-ahead and real-time dispatch[49]

3.8. **Advanced Distribution Management Systems (ADMS)**

In this approach, centralized software platforms are deployed to provide real-time monitoring and automated control of the entire distribution network

3.9. **Distributed Energy Resource Management Systems (DERMS)**

This employs a specialized software for aggregation of thousands of small DERs, to allow them act as a single, dispatchable "virtual power plant." Virtual Power Plants (VPPs) are used to aggregate DERs into a single, coordinated network leading to benefits like reduced household energy costs, higher grid stability, and less the environmental impacts as a result of reduced reliance fossil fuel sources. The concept of virtual power plant (VPP) has been extensively developed and expanded and today, a VIP refers to an intelligent and dynamic cyber-physical system that orchestrates a heterogeneous portfolio of DERs, that incorporate distributed generation, energy storage, and dispatchable loads to operate as cohesive and flexible entity [50, 51].

3.10. Smart Inverters

Smart inverters are grid-interactive with ability to actively respond to grid frequency and voltage deviations, instead of just disconnecting during disturbances.

3.11. Time-of-Use (TOU) Pricing

This approach involves the implementation of dynamic rate structures which incentivize consumers to shift consumption or discharge batteries during off-peak.

3.12. Modernized Communication Protocols

It important to upgrade communication protocols to high-speed, secure communication standards like IEEE 2030.5 for seamless interoperability between utility servers and consumer-owned device[27, 52]

3.13. Advanced Forecasting and Control System

These systems which t employ machine learning algorithms and weather models are used to improve accuracy of renewable generation forecasts by allowing better planning and response strategies. Inverters can provide synthetic inertia, which aid in frequency control [26].

3.14. Use of Advanced Power Electronics

i.) Energy Conversion and Control

Power electronics play have an important role in transforming energy from renewable sources into forms suitable for grid use e.g., DC power from solar panels must be converted to alternating current (AC) by inverters before it can be supplied to the grid or users, while wind turbines produce variable-frequency AC which should be converted to fixed-frequency AC. Advanced power electronic converters have control over current , voltage, and frequency, necessary for renewable energy to remain stable and compatible with grid demands standards[26]

ii.) Grid Stability and Flexibility

Variabilities which threaten grid stability are managed by power electronics to address grid stability and flexibility and facilitate dynamic control of power flow by use of technologies like flexible AC transmission systems (FACTS) and high-voltage direct current (HVDC) transmission which enables the power system to withstand fluctuations and maintain resilience[26].

3.15. Building More/Expanding Transmission Lines

As a strategy to connect more areas endowed with renewable resources (e.g. sandy and windy areas high electricity demand increases value of renewable resources and reduce uncertainties of their electricity generation hence measures like building more solar plants in deserts in sunny areas and wind mills in windy areas can reduce weather-dependent uncertainty [11]. Sites are often geographically dispersed and far from load enters are rich in renewables like solar and wind. However, transporting variable renewable sources greatly affects the quality of the resource because many of the resources are site-constrained. These requires building of transmission networks to reach them. [1, 48]

3.16: Use of Dispatchable Sources

The electricity generation mix for power systems should include flexible units like diesel generators whose output can be deliberately varied to account for load variability and be ready to meet peak demand [1]. The ability of a power system to change output to match fluctuations in demand is determined by how generators alter power output, in a process referred to as ramping

up (or down). An optimal generation mix should incorporate fast-ramping generators like gas turbines or hydropower turbines which n quickly increase or decrease output. Both types gas turbines and hydropower plants are ideal for balancing net load, and supply of ancillary services and hence their deployment on grids enhances grid flexibility[1].

3.17: Combining/Diversifying Resources to Reduce Variability

Renewables e.g., Solar and wind resources are often negatively correlated e.g., when solar peaks in summer, wind tends to peak in the winter. Additionally, solar power peaks during the day as winds tend to be stronger in the afternoon and at night. These characteristics correlations yield mix wind and solar resources whose combined output mimics the demand curve, which is a phenomenon called natural balancing[1]

3.18 Ancillary Services

Use of ancillary services enable the system operator to balance instantaneous generation and demand while maintaining voltage and frequency at acceptable levels even after a generator or transmission line fails. Any mismatch, however small it is between the actual and forecasted load disturbs the frequency of the electricity in the system, which should be kept as constant as possible to avoid mechanical damage to generators and transformers in the power system. Frequency regulation is done by a set of fast-responding oil and gas units which increase or reduce output best on central signaling to balance real-time mismatches that are not handles by energy operations. Load following sources ensure that production matches the varying demand, with balancing occurring through automated generator control system. Frequency regulation and load following manage forecasting errors but their difference is based on operation timeframe with former responding more rapidly to load fluctuations within minute or less, but load following responds to changes on the order of 5 to 30 minutes[49].

In case of a contingency like loss of a large generator, specific set of generation units should immediately respond hence one set of contingency reserves i.e. "Spinning reserves") is synchronized with the grid and kept ready to respond in few minutes or seconds of a contingency. Additionally, another set of fast-responding units may not be synchronized (non-spinning) but are tuned to urgently respond within few minutes of a contingency. Other ancillary service operations like voltage control and "black start." Voltage control equipment are employed to deliver reactive power in case a source is cutoff or fails. Black start services are delivered by y generators of quick start without an external electricity source and are often used to restart the power system during a major blackout[49].

3. SUMMARY AND DISCUSSION

The transition to renewable and sustainable energy is critical for a sustainable and low-carbon future. However, this transformation comes with complex challenges for grid integration. The issues that must be addressed in the transformation are the intermittency, lower system inertia, concerns over power quality concerns, and the geographic dispersion to maintain a stable and reliable electricity grid. These barriers can be overcome by enhanced grid infrastructure and capabilities, technological innovation, advanced system controls, and supportive policy frameworks. Through proactively investment in solutions and fostering collaboration among stakeholders, the distributed and decentralized energy systems can be intergraded without compromising grid reliability, laying ground for a cleaner and more resilient energy future[26, 28].

3.1. Summary of findings

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 prosumer[53-55].

The advances in renewable technologies, have led to considerable drop in systems cost within the last 10 years. The electricity costs from

solar PV reduced by about 75% between 2009 and 2018, while electricity from onshore wind farms reduced by about 25% over the same period. These cost reductions have created a favorable business opportunity for distributed renewables and henceforth, attention will shift to the reduction of integration cost for the DERs equipment. Besides cost improvement, managing large quantities of variable renewables requires high flexibility of the entire energy value chain, from power generation to power transmission/distribution, storage and, and demand management [19].

Decentralization has been having been with us for some time and has proved quite successful in some countries like German. The lessons from the successful cases are essential and offer a realistic analysis that could help guide other countries to in creating more resilient renewable integration systems and spearhead a swift and sustainable renewable energy transition with high system reliability and stable electricity tariffs. However, the diverse nature of nations imply that countries have different challenges and hence appropriate associated measures may vary [39, 56]. Therefore, the global renewable energy transition ought to be tacked using multidimensional approaches. Wears no two countries may be identical, and thus take different pathways, successful measures previously used may be a good match for countries having similar energy market characteristics[45, 57].

It was observed in this study that solutions to distributed and decentralized energy issues are available, but the drawback may be economic rather than technical. Therefore, highest ideal penetration level for DERs is one where any additional cost are more than the benefits of an extra DG unit hence a point where additional DG capacity may not be economically sustainable. This study recommends future research aimed at minimizing the cost of integrating the DERs and appropriate optimization strategies[58, 59].

The integration approached to the traditional grids can be summarized as follows

	Integration approach	Description
1	Vigorous Voltage Regulation at the Level of Substations	Many utilities used voltage regulators as an intervention mechanism to compensate for voltage fluctuations on the HV net on high voltage work and stabilize the MV to a constant level.
2	Modified Grid Configuration	In this strategy, the grid is expanded by addition of distributed generators to optimize the structure of the existing grid. The expansion is done in a way that reduces power losses, enhances fault detection/correction, and enable physical access to switching station
3	The Use of the 'N Minus Zero' Regulation	Renewable energy systems are the continuously added to the grid as required by the energy demand and grid stability requirements, but are detached any moment the stability of the network is compromised. A substation may be equipped with additional HV/MV transformer that supports the network during maintenance or other contingency events.
4	Reactive Power Control	Reactive power control is also used to smoothen the reactive power imbalance in medium voltage network, supplied by generators
5	Creation of Express Feeders in the MV Network	The express feeders are transmission systems having huge cross-sections (500–800 mm^2) to evacuate large amounts of electricity to consumers at lower voltage drop because of the large cross-section
6	**Storage**	Energy Storage Systems (ESS) are employed to store excess energy for later release during peak demand periods. These offers benefits like reducing variability of renewable energy output, grid stability, peak load shaving and enabling peak load shifting, providing ancillary services, and increasing integration
7	Smarten the traditional grid	Transforming the traditional grid to Smart grid which rely on two-way communication, control systems, and advanced computing
8	Advanced Distribution Management Systems (ADMS	In this approach, centralized software platforms are deployed to provide real-time monitoring and automated control of the entire distribution network
9	Distributed Energy Resource Management Systems (DERMS)	This employs a specialized software for aggregation of thousands of small DERs, to allow them act as a single, dispatchable "virtual power plant
10	Smart Inverters	Smart inverters are grid-interactive with ability to actively respond to grid frequency and voltage deviations, instead of just disconnecting during disturbances

11	Time-of-Use (TOU) Pricing	This approach involves the implementation of dynamic rate structures which incentivize consumers to shift consumption or discharge batteries during off-peak
12	Modernized Communication Protocols	It important to upgrade communication protocols to high-speed, secure communication standards like IEEE 2030.5 for seamless interoperability between utility servers and consumer-owned device
13	Advanced Forecasting and Control System	These systems employ machine learning algorithms and weather models are used to improve accuracy of renewable generation forecasts by allowing better planning and response strategies.
14	Use of Advanced Power Electronics	Power electronics play have an important role in transforming energy from renewable sources into forms suitable for grid use e.g., DC power from solar panels must be converted to alternating current (AC) by inverters before it can be supplied to the grid or users. Additionally, variabilities are managed by power electronics to facilitate dynamic control of power flow by use of technologies like flexible AC transmission systems (FACTS) and high-voltage direct current (HVDC) transmission.
15	Building more transmission lines	As a strategy to connect more areas endowed with renewable resources (e.g. sandy and windy areas high electricity demand increases value of renewable resources and reduce uncertainties of their electricity generation hence measures like building more solar plants in deserts in sunny areas and wind mills in windy areas can reduce weather-dependent uncertainty
16	Incorporating dispatchable sources in the generation mix	The generation mix for power systems should include flexible units like diesel generators whose output can be deliberately varied to account for load variability and be ready to meet peak demand

Electricity produced in power stations is transmitted to the points of use with the aid of the **grids** which are interconnected networks for electricity transmission and distribution to consumers from electricity producers. The grid is classified into the smart grid and conventional grid on basis of the energy devices and their functionality. As a result of many challenges facing the conventional grids in meeting varying demand and supply of electricity, the smart grids were proposed and developed as a conventional grid infused with the intelligent sensors and controllers, with automated switches and substations, having two-way communication and other technologies

3.2. Implications for the Grid of the Future

The falling costs and favorable policies are expected to drive the transition from centralized to decentralized power systems with the share of renewable energy expected to grow significantly. As an example, some US states like New York, California, and Illinois require that most of their power should come from renewables within the next few decades While Hawaii, has plans to produce 100% of its electricity from renewable energy sources by 2045. To accommodate a high penetration of variable renewable energy This transformation requires the modern grid to improve on flexibility on both the electricity supply and demand sides[11]. Operational measures that can increase grid flexibility and integration of renewable resources:

i.) Combining different renewable sources can balance out variability in generation e.g., grid integrating many types of renewable like solar, wind, hydro, and geothermal simultaneously faces less volatility than one that relies exclusively on one energy resource.

ii.) Apply demand-side management measures to strategically optimize the times when electricity is used to be in line with resource availability. Demand-side management can be used to shift flexible demand to off-peak hours to reduce demand during peak hours, to lessen the slope of the ramp[11].

iii.) Placing value on generator flexibility in the energy markets to encourage grid flexibility e.g. California manages its “duck curve” by development of a flexible ramping product that compensates generators for their ability to ramp quickly. This allows the market to decide how to best enable flexibility, rather than prescribing a set solution[11].

4. CONCLUSION

Integration energy efficiency measures into conventional power systems and grid is required to reduce the overall energy demand, increase grid reliability, and reduce greenhouse gas emissions through modification of power generation processes, grid upgrading, and management of end-use consumption to ensure that conventional power plants operate closer to their peak Decentralized and distributed generation usually employ small power systems located very close to the point of electricity use to provide enhanced or alternative power source for the conventional or central power system. The decentralized units are connected either directly to the distribution system or to customer side of the meter, which reduces the transmission and distribution costs and losses. The integration of distributed energy resources (DERs) into smart grids micro grids involves the use small-scale energy sources, conversion technologies, and storage systems to form a controllable power system. Micro grids either operate independently, or are connected to the main grid, which improves the reliability and grid resilience. Important determinants of the integration of distributed energy resources into micro grid systems are the innovative technologies, efficiency and reliability enhancement measures, energy resource supply variability and intermittency, energy storage options, grid stability, and system optimization.

This study identifies various methods of grid integration of Distributed and decentralized energy systems to both the traditional grid and the smart grid and microgrids. The research explored various techniques used to integrate RE into smart grids. Successful of the traditional grid to the smart grid, implementing advanced control and protection systems, and developing smart energy management systems is important to achieve maximum and optimal integration. Use of predictive models have a significant role in optimizing smart grids operations by forecasting DERs production and consumption patterns.

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