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Transmission Network Enhancement with Renewable Energy

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Abstract

Wind and solar energy play an important role in the de – carbonization of electricity generation. However, high shares of these Variable Renewable Energies (VREs) challenge the power system considerably due to their temporal fluctuations and geographical dispersion. This paper systematically reviews and analyzes transmission grid extensions as an integration measure for VREs. Effects of grid extensions for fundamental properties of the power system as a function of the penetration and mix of wind coupled with solar energy were revealed in the study. The paper also provides an overview of the system implication of wind and solar PV energy and investigates a way to partly overcome transmission grid extensions.

Keywords: Renewable energy; Transmission network; Integration; Electric power; Grid

Introduction

Access to modern energy is considered one of the foremost factors contributing to the socio-economic and technological development of every nation. Energy use is a prerequisite for physical and socio-economic development in both rural and urban communities. There is a need to promote and guarantee energy security, availability and reliability to preserve any existing level of development and further new developmental strides for human comfort [1].

However, at the same time, energy production can contribute to local environment degradation, such as air pollution and global environmental problems, principally climate change. As a result of this, most developing nations of the world are looking towards renewable energy sources as a sustainable option [2]. Sustainable development has been at the center of recent policies and development plans of many developing countries. This is a pattern of development that delivers basic environmental, social and economic services without threatening the viability of natural, built and social systems upon which these services depend.

Today, the primary energy source all over the world is non-renewable fossil fuels that have been and will continue to be a major cause of pollution and climate change [3]. Moreover, fossil fuels-based conventional grid extension in developing countries from centralized power systems in urban centers to rural areas is usually capital intensive and in most cases not economically realistic. From a global perspective, more than a quarter of the human population experiences an energy crisis, especially those living in the rural areas of developing countries.

Because of these problems and dwindling supply of primary energy source such as petroleum, natural gas etc finding sustainable alternatives is becoming increasingly urgent.

With increasing energy demand and growing concerns for environmental impacts, renewable energy sources are receiving increased attention for their inherent low pollutant and greenhouse gas emissions. However, the intermittent and uncontrollable nature of renewable energy sources introduces new technical challenges for integration into electric power systems, especially as the market share of renewable energy becomes large [4].

The objectives of harnessing renewable energy (RE) as primary energy source are to focus on provision of sustainable energy to the economically subjugated fraction of the society, combat energy shortage, encourage the development of rural infrastructure and provide clean energy from the perspective of the Kyoto directive towards global decarbonization. This concept of RE has become a fast growing idea in the global power sector. The popularity of RE development can be directly allied to the growing trend of environmental concern and the rapidly depleting reserves of conventional energy resources due to the aggressive utilization. These emergent concerns call for a viable alternative solution to the contemporary environmental challenges and the energy crisis scenario through sustainable means [3]. Perhaps the greatest challenge in realizing a sustainable future is to develop technology for integration and control of renewable energy sources in smart grid distributed generation. The smart power grid distributed energy system provides the platform for the use of renewable sources as adequate emergency power for major metropolitan load centers and the ability to break up the interconnected power systems into the cluster smaller regions.

Among the available literatures on the potential of integrating renewable energy on grid include:

The concept based on an appropriate combination of solar, wind and biomass systems used by Jain [5] to prove that integrated renewable energy system (IRES) is reliable and viable concept from energy production and utilization point of view. Further, the small-scale decentralized IRES concepts were discussed in the paper by Ramakumar [6]. The study considered solar PV (SPV), solar thermal, wind, biomass and falling water as renewable resources. Another study by Ramakumar [7] showed that the concept of energization through resource-need matching has been found to be preferable as compared to straightforward rural electrification. Segurado et al. [8] used the hydrogen renewable energy source (H2RES) model to analyse different

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scenarios with the objective of increasing the penetration of renewable energy in the electric energy system of the São Vicente Island in Cape Verde. An integrated approach was used to analyse the electricity as well as the water supply systems. The results showed that it is possible to have more than 30% of the yearly penetration of renewable energy sources in the electricity supply system, and to desalinate more than 50% of the water supplied to the population by the use of wind power. Bernal-Agustin and Dufo-Lopez [9] performed economic analysis on the Grid Connected (GC) solar PV system connected to the Spanish grid. Using Net Present Value (NPV) and Payback Period (PP) parameters, the profitability of the system was studied. The system was evaluated for its economic as well as environmental benefits and the results clearly showed that the system is profitable enough to be invested in, but very long pay back periods were dissuading the investors. The Ministry of New and Renewable Energy (MNRE) annual report [10] discussed how attractive GC systems are in the context of Clean Development Mechanism (CDM). Life Cycle Analysis (LCA) was performed to assess environmental benefits of solar PV systems, the effects of application Kyoto protocol, and reduction in emissions.

Furthermore, studies on the introduction of flexibility to electric power system to allow the penetration of fluctuating renewable energy to be increased have been carried out. One technology which is ideally suited for increasing energy flexibility is energy storage. Benitez et al. [11] analysed the impacts of additional wind capacity on the Alberta electricity network in Canada and concluded that when Pumped Hydroelectric Energy Storage (PHES) is added in conjunction with wind power it can provide most of the peak-load requirements of the system and thus, peak-load gas generators are no longer required. Dursun and Alboyaci [12] carried out a detailed review of wind - PHES studies and outlined how this solution could be employed in Turkey, by utilizing the mountainous areas around the Black Sea and electrical infrastructure to other hydro facilities. Black and Strbac [13,14] examined the benefits of PHES on the British energy system for a wind penetration of 20%, which equates to an installed wind capacity of 26 GW. After paying particular attention to reserve requirements and systems costs, the authors concluded that the value of PHES is very dependent on the flexibility of the conventional generation also on the system. The results also indicated that energy storage could reduce system costs, wind curtailment, and the amount of energy required for conventional generation.

The literature reveals that no comprehensive review has been reported on transmission network enhancement with renewable energy. The prime objectives of this study therefore are: (i) to review availability of renewable energy for electricity generation (ii) to review grid interface technology with renewable energy (iii) to assess possible ways of strengthening integration of renewable energy into electrical power systems and (iv) to proffer remedial actions aimed at addressing problems related to transmission network with renewable energy sources.

Renewable Energy Sources Availability

Energy demand in both developed and developing countries is growing rapidly. As global energy demand increases, RE provides one means among many of adding energy assets to the system alongside growth of other resources [15–17].

In 2008, it was estimated that RE accounted for 12.9% of the total 492 EJ of primary energy supply globally. Among which, Biomass contributed the largest share of 10.2%, while Hydropower represented 2.3%, whereas other RE sources accounted for 0.4%. From global electricity supply point of view, RE contributed approximately 19% (i.e 16% hydropower and 3% other RE). The global road transport fuel supply in 2008, biofuels contributed 2% and traditional biomass (17%). Considering the total demand for heat in 2008, modern biomass contributed 8%, solar thermal and geothermal energy together contributed 27% [18,19].

In 2009, renewable electricity generation already accounted for 62% (17 GW) of all newly constructed power-generating capacity in Europe. In particular, wind energy installation, increasingly larger in size, accounted for 38% (10.2 GW) of all renewable energy growth [20]. Recently, the world's fastest energy source is wind power [21]. The decentralized and locally available nature of wind energy makes it particularly attractive to grid electrification. Wind power is growing at the rate of 30 per cent annually, with a worldwide installed capacity of 198 gigawatts (GW) in 2010, and is widely used in Europe, Asia, and the United States. Wind power accounts for approximately 19 per cent of electricity use in Denmark, 9 per cent in Spain and Portugal, and 6 per cent in Germany and the Republic of Ireland. The United States is an important growth area and installed US wind power capacity reached 25,170 MW at the end of 2008.

Research has shown that the available solar energy resources are 3.8 YJ/year (1, 20,000 TW) [19]. Less than 0.02 per cent of available resources are sufficient to entirely replace fossil fuels and nuclear power as an energy source. Solar PV uses and applications have been justified and strongly recommended for grid electrification [22]. In 2007 grid-connected photovoltaic electricity was the fastest growing energy source, with installations of all photovoltaic increasing by 83 per cent in 2009 to bring the total installed capacity to 15 GW. Nearly half of the increase was in Germany, which is now the world's largest consumer of photovoltaic electricity (followed by Japan). Solar cell production increased by 50 per cent in 2007, to 3800 MW, and has been doubling every two years.

Power generation through the use of biomass offers a viable and long-term solution to grid electrification; however it is inefficient use, biomass resources presently supply only about 20% of what they could if converted by modern, more efficient, available technologies [17]. In recent years, interest in biomass as a modern energy source, especially for electricity generation has been growing worldwide. Electricity produced from biomass sources was estimated at 44 GW for 2005. Biomass electricity generation increased by over 100 per cent in Germany, Hungary, the Netherlands, Poland, and Spain. A further 220 GW was used for heating (in 2006), bringing the total energy consumed from biomass to around 264 GW. The use of biomass fires for cooking is excluded.

World production of bio-ethanol increased by 8 per cent in 2007 to reach 33 billion liters (8.72 billion US gallons), with most of the increase in the United States, bringing it level to the levels of consumption in Brazil. Biodiesel increased by 85 per cent to 3.9 billion liters (1.03 billion US gallons), making it the fastest growing renewable energy source in 2007. Over 50 per cent is produced in Germany.

The total shares of all renewable for electricity production make up for about 19%, a vast majority (83%) of it being from hydroelectric power [23]. Worldwide hydroelectricity installed capacity reached 816 GW in 2005, consisting of 750 GW of large plants, and 66 GW of small hydro installations. In 2005, China, Brazil and India added large hydro capacity totaling 10.9 GW. There was a much faster growth (8 per cent) small hydro, with 5 GW added, mostly in China where some 58 per cent of the world's small hydro plants are now located. China is the largest

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hydropower producer in the world, and continues to add capacity.

The growth rate of renewable energy has been keeping at a double-digit for the recent 5 years. EIA (Energy Information Administration) estimated that there would be a 3.1% annually increase in the share of electricity generated from renewable energy during the period from 2008 to 2035 all around the world [24]. It means 45% of global electricity will be generated from renewable energy by the year 2035 [9,15].

Features and Structures of Electrical Power Systems

The main elements in an electric power network are generators, transformers, switchgear and power factor correction components interconnected by a web of transmission lines of various voltage and current ratings and a considerable number of electrical joints [25].

The electricity generation (or power station) equipment has the capacity to convert a primary energy flux into an electrical energy flux and (in some cases) to maintain a voltage waveform at its point of connection. End - use equipment has the capacity to convert an electrical energy flux into an end-use energy flux, in the process providing an end-use energy service. However, neither generation nor end-use equipment can operate in isolation, particularly as they are usually at different geographical locations [26-28].

Electricity transmission and distribution networks provide current paths so that electrical energy can flow between the generation and end-use equipment to complete the energy conversion chain. The electrical transmission and distribution system is an essential part of every developed nation and failures within the system have the potential to cause immediate and unexpected power loss over a large geographical area with wide ranging implications [29,30].

Electrical power systems are operating under heavily loaded conditions due to various economic, environmental and regulatory changes. So with the increased loading and exploitation of the power transmission system, the problem of voltage stability and voltage collapse has been reoccurrence situation and this has attracts more attention recently. Hence, maintaining voltage stability has become a growing concern for electric power utilities [31-33].

The stability and security of the supply of electricity are assured when consumers can rely on electricity of a defined quality at any time of the day. The consumption and production of electricity must be balanced to secure the stability of the grid [34]. Among the potential measures to compensate for more frequent imbalances between supply and demand is introduction RE into electricity industries. Higher RES penetration will result in a significantly reduced load factor for conventional generation, as the RES technologies will replace a growing section of the electricity supply curve [35,36]. Electric systems that can accept lower levels of overall reliability may be able to manage the integration of RE into electrical power systems at lower costs than systems that demand higher levels of reliability, creating a trade-off that must be evaluated on a case-by-case basis [37].

Renewable energy integration into competitive electricity industries

Electricity generated using renewable energy resources will, in the most part, be delivered to the point of end-use via large scale transmission and distribution systems [38]. Consequently, the successful integration of renewable energy generation into large power systems has become fundamental to successfully addressing climate change and energy security concerns [20,39].

Renewable energy technologies are suitable for off-grid services; they can serve remote areas of the world without expensive and complicated grid infrastructure.

The ability to integrate electricity generated from renewable into grid supplies is governed by several factors, including [40]:

- The variation with time of power generated
- The extent of the variation (availability)
- The predictability of the variation
- The capacity of each generator
- The dispersal of individual generators
- The reliability of plants
- The experience of operators
- The technology for integration
- The regulations and customs for embedded generation

Despite these difficulties, researches have shown that electricity from renewable can be integrated into grid supplies without significant financial penalty [39-41]. Several mature RE technologies, including wind turbines, small and large hydropower generators, geothermal systems, bio-energy cogeneration plants, bio-methane production, first generation liquid bio-fuels, and solar water heaters, have already been successfully integrated into the energy systems of some leading countries. Further integration could be encouraged by both national and local government initiatives. Over the longer term, integration of other less mature, pre-commercial technologies, including advanced bio-fuels, solar fuels, solar coolers, fuel cells, ocean energy technologies, distributed power generation, and electric vehicles, requires continuing investments in R &D, infrastructure, capacity building and other supporting measures.

The outstanding example of ever-increasing integration of renewable energy generation into the grid is Jutland, western Denmark [42]. In the early 1980s, the limit for wind power exported to the grid was considered to be 20% of total supply. However by 2003, about 40% of annual electricity supply was from wind, and at times, significant areas were supplied totally by wind power. The reason for the change was the willing application of new technologies and practices.

Successful integration of high shares of RE with energy systems in recent years has been achieved in both Organization for Economic Co-operation and Development (OECD) and non-OECD countries, including Brazil, China, Denmark, Spain, New Zealand and Iceland [43–48].

Access to some Renewable Energies (RE) resources is abundant in many parts of the world [49]. The characteristics of many of these resources distinguish them from fossil fuels and nuclear systems and have an impact on their integration [50]. Some resources, such as solar, are widely distributed, whereas others, such as large hydro, are constrained by geographic location and hence integration options are more centralized. Some RE resources are variable and have limited predictability. Others have lower energy densities and different technical specifications from solid, liquid and gaseous fossil fuels. Such RE resource characteristics can constrain their ease of integration and invoke additional system costs, particularly when reaching higher shares of RE [51].

Due to above fundamental limitations for any renewable energy generation technology and plant it is essential to integrate renewable energy generation options with control and storage such that they complement each other.

Integration of DG causes bi-directional power flow which reduces the capacity of feeder and transmission line. The other benefits of distributed generation include the reduction of power loss, better voltage support, peak shaving and the improvement of overall efficiency, stability and reliability [52].

In a Region where a majority of electricity generation is based on renewable sources is far beyond the horizon, it is clear that the confluence of government policy, utility planning and global demand growth has the potential to increase penetrations of RE substantially on electricity grids worldwide. This shift in generation portfolios will have profound effects on the operation of the grid, which will in turn affect the operation of RE resources themselves as well as the operation of other resources and equipment connected to the grid [53].

Different types of grid interfaces

Electricity generation using renewable energy resources is often taken place in small scale due to disperse nature of the resources. Good examples are small hydro, solar photovoltaic, biogas, biomass and small wind turbine based electricity generation systems. The size of these generators typically varies from a few hundreds of kilowatts to several megawatts. These small scale electricity generators are generally connected to the grid at the primary or secondary distribution level and are considered Distributed Generation (DG) or Distributed Resources (DR). Distributed resources include both renewable and non- renewable small scale generation as well as energy storage [54,55].

There are different options for producing electricity from renewable energy sources. Consequently, there are several ways of connecting the gained electricity with the existing grid. The potential renewable energy sources are wind, hydro, solar, biomass, photovoltaic cells, bio fuels and geothermic. The electricity generated from these sources is induced by asynchronous or synchronous generators except for photovoltaic cells. This operation creates co-current flows and gets through an inverted rectifier into the power grid [56].

Often, the small scale renewable generators are not directly connected to the grid. The generation technology or the operational characteristics requires the use of some interface between the generator and the utility distribution grid. For example, solar photovoltaic (PV) panels generate DC electricity and therefore, a power electronics based DC to AC converter is required between the grid and the generator. Some technologies such as induction generator based small hydro or wind can be directly connected to the AC grid (Figure 1). However, concerns such as starting transients, energy conversion efficiency and power quality issues make connecting them through a power electronics interface a better choice [57,58].

Table 1 summarizes some of the common types of generation and their preferred interfacing technologies. Figure 2 and Figure 3 present the block diagrams of interfacing technologies for grid integration of solar energy and wind energy respectively.

The Renewable energies option for climate change and energy security

Climate change is one of the most difficult challenges facing the world today and preventing will necessitate profound changes in the way we produce, distribute and consume energy. Burning fossil fuels such as coal, oil and gas provides about three-quarters of the world's energy. However, when these same fuels are burned, they emit Greenhouse Gases (GHGs) that are now recognized as being responsible for climate change [59]. These fuels are ubiquitous. Fossil energy has fuelled industrial development, and continues to fuel the global economy. The primary greenhouse gas emitted through fuel combustion is CO_2. Land-use and land-use changes, notably deforestation, also involve emissions of CO_2 [25].

Policies to increase both energy efficiency and the share of renewable energy resources have been adopted by many countries as means to mitigate climate change and reduce dependence on external energy supplies [60]. With a high share of both wind power and CHP Denmark is one of the frontrunners in the implementation of such policies, and thus serves as valuable national case study of large-scale integration of new energy technologies.

Gas flaring by the oil companies operating in developing countries like Nigeria has raised temperatures and rendered large areas uninhabitable [30]. The use of renewable energy sources will reduce over dependency on the burning of fossil fuel. Moreover, instead of flaring gas, the gases can be converted to methanol and used as fuel for both domestic and industrial use. With good energy efficiency practices and products, the burning of fossil fuel for energy will be greatly minimized.

RE provides a number of opportunities and not only to address climate change mitigation but also addresses sustainable and equitable economic development, energy access, secure energy supply and local environmental and health impacts [31]. Market failures, up-front costs, financial risk, lack of data as well as capacities and public and institutional awareness, perceived social norms and value structures, present infrastructure and current energy market regulation, inappropriate intellectual property laws, trade regulations, lack of amenable policies and programs, lower power of RE and land use

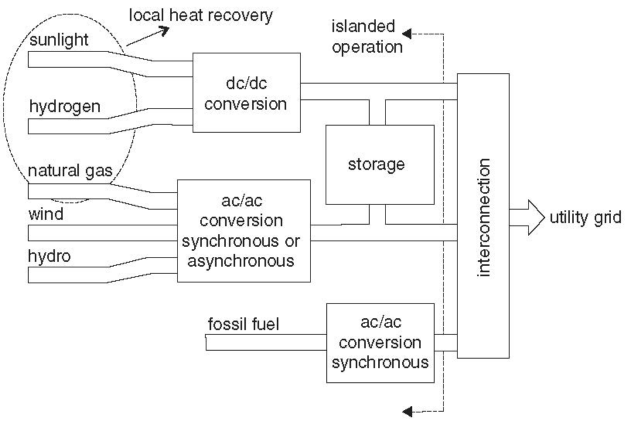

Figure 1: Alternative energy conversion technologies for injection of alternative energy power to the grid (Source- [34]).

Renewable Energy Type	Interfacing Technology
Wind Energy	Induction generator/power electronic converter
Photovoltaics	Power electronic converter
Small hydro power	Synchronous or induction generator, power electronic converter
Fuel cells	Power electronic converter

Table 1: Interfacing Technologies (Source [54]).

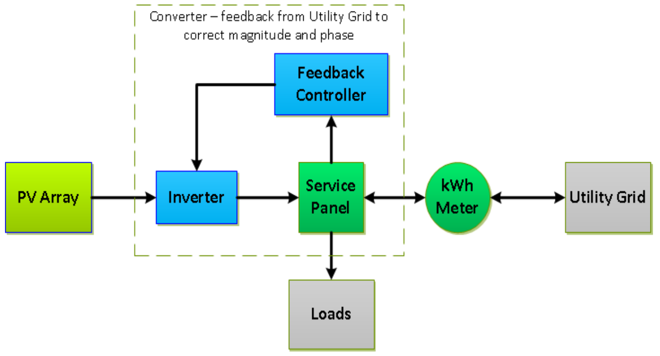

Figure 2: Block diagram for grid interface with PV array (Source- [56]).

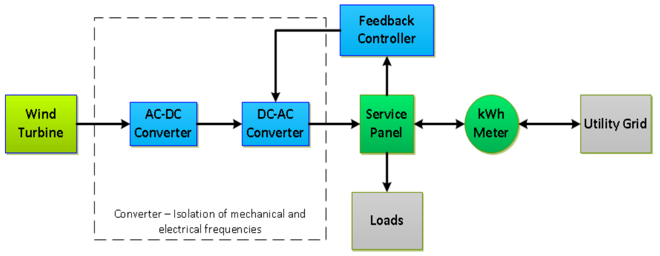

Figure 3: Block diagram for grid interface with wind turbine (Source- [56]).

conflicts are amongst existing barriers and issues to expanding the use of RE.

The deployment of renewable energy would result in significant energy security and economic benefits [33]. For example, renewable energy resources have a significant potential for energy efficiency, this would reduce energy import dependency to bring both energy security and economic benefits. For small-sized distributed generators (especially prosumers) with renewable resources, such as PV panels and wind turbines due to their vicinity and integration to the end-users, along with the smart grids implementations, it would greatly decrease the scales and consequences of blackouts. Furthermore, the self-healing features of smart grids would also accelerate the recovery and restoration of the system.

Challenges for integrating renewable energy into electricity industries

The existing power system heavily relies on power plants that have a controllable power output. Natural gas plants, for example, can be turned on and off as needed, or their output can be increased or decreased to balance changes in power supply. Renewable energy sources, for example wind and solar power are not as controllable as conventional generation resources and they thus present some challenges to the operation of the power grid [60].

Introducing a significant number of renewable energy resources into electricity industries adds new challenges to restructuring in addition to the particular challenges associated with renewable energy resources themselves. The key challenges facing the increased use of wind and solar power are [61]:

- The variable, non-storable nature of renewable energy forms such as wind and solar energy, leads to a need for accurate forecasting and a need to define appropriate boundaries to autonomous decision-making by renewable energy generators for both operation and investment.

- The novel nature of some renewable energy generator technologies, such as wind turbines and photovoltaic systems, leads to uncertainties in their technical performance, particularly during abnormal power system operating conditions when power system security may be at risk.

- The small size of some renewable energy generator installations, such as photovoltaic systems, leads to a rapid increase in the number of supply-side decision-makers and a need to develop appropriate commercial contracts and technical requirements for generator connection to distribution networks, in contrast to the more mature arrangement for generators connected to transmission networks.

- While still in the development phase, renewable energy technologies will continue to require policy support. The challenge exists to provide financial support in a way that encourages the most cost efficient development of the technologies.

- The use of renewable energy in the context of autonomous single-users or small rural communities may raise community social, technical and financial resource questions, as well technical challenges associated with remote locations and long equipment supply chains.

- There are several aspects to be considered in order to integrate RES into traditional networks. However, there are two parameters that have high impact on the integration of RES plants in the network: the selection of the size (rated capacity) and the installation's location of such plants.

For these reasons, the regulatory framework and market rules for a restructured electricity industry may have to evolve to accommodate high levels of renewable energy penetration. To achieve effective outcomes, these issues must be addressed in a consistent manner, at all levels of decision making from the high-level, long time-scale governance level to the technically specific, short term power system operating level.

Technical issues for grid integration in the light of renewable energy technologies

The technical issues associated with renewable energy compatibility relate to the ability of renewable energy equipment to function effectively as part of the electricity industry as it exists today. Equipment must meet engineering requirements with respect to voltage, frequency, waveform purity, ability to rapidly isolate faulty equipment from the rest of the industry and reasonable ability to withstand abnormal operating conditions (fault ride through) [40].

The technical assessments expressed about concerns for utilization of PV- DG integration into the grid in some countries leading in utilization of PV electricity are as follow [62]:

- Harmonic emission by inverters was considered a present and future concern for high penetration of PV.

- Voltage regulation was considered a big concern for weak grids with high PV penetration. Different regulations allowed overvoltage limits of 5% to 6% by PV plants.

- Network protection was considered a big concern as there is lack of direct control on DGs by the DNSP.

- Unintentional islanding due to high penetration of PV-DG was considered a matter of concern.

The properties of wind turbine generators may increase the power quality (PQ) related problems such as voltage fluctuation, harmonics, voltage unbalance. By integrating wind turbine into the grid can introduce PQ disturbances such as [63]:

- Flickers which are commonly due to rapid changes in the load or the switching operations in the system.
- Steady-state voltage level influence.
- Response to grid disturbances/faults (Stability).
- Wind power may affect the power flow direction in the network and can cause transmission capacity problem.

Smart grid system

Smart Grid Network is an intelligent, managed, controlled and ultimately self-healing electric distribution network capable of closely matching supply with demand while improving efficiency and reliability. Sensors and control devices on the grid, combined with integrated high speed communications and advanced analytic software, provide utilities with actionable intelligence reports and information [64]. A Smart Electric Grid can identify where electricity is lost or where the system is not in balance or optimized. Such optimization can save 3% or more of overall electric demand without requiring any change in consumer behavior [65].

Smart technologies comprise of the following components: (i) Smart meters to quantify the energy consumption and the power quality of each electrical equipment connected to it and allow the user to take a decision on the best way to consume power and what equipment to consider as regard to power quality, (ii) Artificial intelligent monitoring equipment that has the ability to pre-detect fault and monitor power quality on the network (iii) Real- time transmission power flow monitoring equipment and power electronics that can limit the waveform distortion either from the generator or the load and correct the waveform deformity. Figure 4 shows a pictorial view of Smart Grid structure, from Generation to the Consumers.

Today's electric grid system was designed to operate as a vertical structure consisting of generation, transmission, and distribution and supported with controls and devices to maintain reliability, stability, and efficiency. However, the grid system is facing new challenges including the penetration of renewable energy resources (RER) in the legacy system, rapid technological change and different types of market players and end users [42]. Several factors that contribute to the inability of today's grid to efficiently meet the demand for reliable power supply can be overcome by smart grid system.

The potential promise of the smart grid includes improved reliability and power quality, reduction in peak demand, reduction in transmission congestion costs, potential for increased energy efficiency, environmental benefits gained by increased asset utilization, increased security, ability to accommodate more renewable energy, and increased durability and ease of repair in response to malicious attacks or adverse natural events.

It is now obvious that there is an urgent need to transform the current electricity system to meet future energy demand and reduce Greenhouse Gas Emissions. So we need a modern, smart and intelligent grid which can respond to all the challenges presented by today's grid system.

Managing Renewable Energy in a Grid

The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or even to improve the power-supply reliability and quality. The renewable energy sources such as solar, wind, small hydro power etc. has accelerated the transition towards greener energy sources. Keeping in view the aforementioned challenges of integrating renewable energy sources to the grid, some of the possible ways for renewable energy utilization in a grid are [65]:

- The power balance using RES can be carried out by integrating RES with energy storage unit. The benefits of battery energy storage system (BESS) are classified based on end – users as: Transmission level uses, System level uses, ISO Market uses.
- The power-electronic technology plays an important role in distributed generation and in integration of renewable energy sources into the electrical grid, and rapidly expanding as these applications become more integrated with the grid- based systems. During the last few years, power electronics has undergone a fast evolution, due to two factors, the development of fast semiconductor switches that are capable of switching quickly and handling high powers and introduction of real- time computer controllers that can implement advanced and complex control algorithms. These factors have led to the development of cost- effective and grid-friendly converters. The performance of power electronic systems, especially in terms of efficiency and power density, has been continuously improved by the intensive research and advancements in circuit topologies, control schemes, semiconductors, passive components, digital signal processors, and system integration technologies.
- Intermittence of power generation from the RES can be controlled by generating the power from distributing RES to larger geographical area in small units instead of large unit concentrating in one area.
- In case of irrigation load, the load is fed during the night time or off peak load time and this is fed by conventional grid. On other hand power generated by RES like solar PV is generated during day time so we can use this power for irrigation purposes instead of storing the energy for later time which increases the cost of the overall system. Using the solar water pumping for irrigation gives very high efficiency approximate 80% to 90% and the cost of solar water pumping is much lesser than the induction motor pumping type.
- In large solar PV plant output power is fluctuating during the whole day and this power is fed to the grid, continuously fluctuating power gives rise to the security concern to the grid for making stable grid. Solar PV plant owner have to install the different type of storage system which gives additional cost to the plant owner. Once the storage system is fully charged then this storage elements gives no profit to

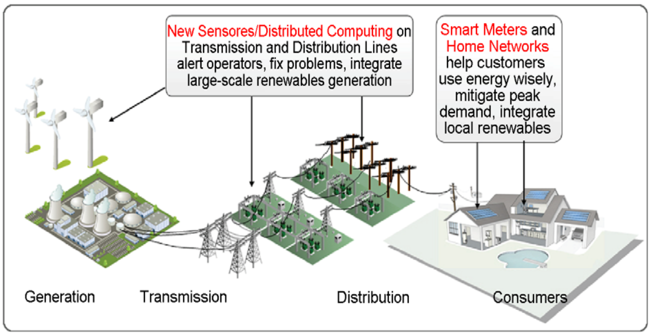

Figure 4: A concept of smart grid (Source-[40]).

the system owner. Therefore solar based water pumping system may be installed instead of storage system.

Strengthening integration of renewable energy into electrical power systems

Partially dispatch able renewable sources pose greater challenges to electric power system operators. In essence these sources of generation cannot be fully controlled (dispatched) since they reflect the time-varying nature of the resource. The main way in which they can be controlled is through reduction of the output. This is in contrast to dispatch able generation that can be controlled by increasing or reducing fuel supply [64].

Solar PV penetration levels remain quite limited despite high growth rates of installed capacity in certain countries. For example, in Germany where active programs of PV installation have been successful, about 10 GW of PV were installed by the end of 2009, producing 1.1% (6.6 TWh or 23.76 PJ) of German electrical energy in 2009 [66]. There is concern that severe grid disturbances with strong frequency deviations can be worsened by large amounts of PV systems [63]. Due to this, the German guideline for the connection to medium-voltage networks requires a defined frequency/ power drop for frequencies above 50.2 Hz [65]. Protection systems in distribution grids also have to be adapted to ensure safety [61]. In general, these adaptations and guidelines indicate that it is important that solar PV become a more active participant in electrical networks [63].

Challenging situations for system balancing caused by high ramp rates for wind power production during storms when individual wind power plant production levels can drop from rated power to zero over a short time span, due to wind turbines cutting out have been reported.

The presence of wind and sunlight are both temporally and spatially outside human control, integrating wind and solar generation resources into the electricity grid involves managing other controllable operations that may affect many other parts of the grid, including conventional generation. These operations and activities occur along a multitude of time scales, from seconds to years, and include new dispatch strategies for ramp able generation resources, load management, provision of ancillary services for frequency and voltage control, expansion of transmission capacity, utilization of energy storage technologies, and linking of grid operator dispatch planning with weather and resource forecasting [66].

Application of new transmission technologies: The following transmission technologies can be applied to overcome the challenges of integration of RE into power grid.

- Higher voltage level AC transmission (UHVAC): Ultra high voltage AC transmission (UHVAC) is suitable for transmitting power from on-shore RE plants using overhead lines. Research and application of 1000 kV UHVAC transmission as a desirable technology to meet the need for large scale, long distance power transmission from the large coal, hydro, wind and solar energy bases are embarked upon in China to connect the northern and western regions to the central and eastern regions with huge and still fast growing electricity demand.

- More flexible AC transmissions (FACTS): Based on advanced power electronic technologies and innovative designs, FACTS equipment can be applied to improve the capacity, stability and flexibility of AC transmission, making it more capable of transmitting large-capacity RE. For example, thyristor controlled series compensators (TCSCs) can be installed in transmission lines to reduce electrical distance, increase damping and mitigate system oscillation; SVC, STATCOM and controllable shunt reactors (CSRs) can be shunt installed on substation buses to solve the reactive power compensation and voltage control problems which are common in RE integration due to their output fluctuation. SVCs or STATCOMs may also be used to improve the performance of RE power plants to meet integration requirements on reactive power and voltage control, while keeping the design of RE generators relatively simple.

- Higher voltage level DC transmission (UHVDC): Ultra high voltage DC (UHVDC) transmission is a conventional HVDC transmission technology that is relatively mature and has long been used for long-distance, large-capacity power transmission without midway drop points, as well as for the interconnection of asynchronous power networks. Compared to AC transmission, it has advantages such as lower loss, lower line cost, narrower corridor and rapid power control capabilities [67]. Like AC transmission, DC transmission is also progressing in the direction of ultra-high voltage levels for larger capacity and longer distance power delivery. Again, China is leading in the application of ultra-high voltage DC (UHVDC) transmission.

However, there are still some problems in the use of CSC-HVDC or UHVDC to transmit RE. For example, when HVDC lines are used to transmit only wind power to load centers (Figure 5), not only the low utilization rate problem occurred, but also the minimum start up power of the HVDC lines and problems in frequency stability and voltage stability are encountered and these require advanced technology.

With voltage support from the local AC grid (Figure 6), the stability problems can be mitigated.

- More flexible DC transmission: From VSC-HVDC to MTDC and DC grids the major advantages of VSC-HVDC as compared to conventional CSC-HVDC make it not only suitable for application in RE integration, but also more convenient to form multi-terminal DC (MTDC). Three or more converter stations are linked to each other with DC lines, each interacting with an AC grid, which facilitates flexible multi-grid interconnection and even DC grids. These will be useful in future RE integration where multiple resource sites and multiple receiving ends are involved.

In order to connect remote offshore wind power plants to a grid, VSC-HVDC technology is preferred. In order to tap large quantities of offshore wind power from the North Sea, a transnational offshore grid based on multi-terminal VSC- HVDC has been proposed [60] (Figure 7).

Energy storage and its applications in electricity grid: Power schedule and dispatch can be made possible with the adoption of energy storage. It allows intermittent power to be harvested at the time of excess and redistributed during scarcity. With this technology, degree of intermittency can be reduced and integration flexibility is enhanced, therefore the contribution from REs can be increased.

Energy storage, due to its tremendous range of uses and configurations, may assist RE integration in number of ways. These uses include, inter alia, matching generation to loads through time shifting; balancing the grid through ancillary services, load following, and load levelling; managing uncertainty in RE generation through reserves; and smoothing output from individual RE plants [65].

Possible energy storage technologies for RE integration include: Mechanical (e.g Pumped hydro, compressed air, fly - wheel), Electromagnetic (e.g Super-capacitors), Chemical (e.g Fossil fuel, biomass), Thermal (e.g Heat pump), and Electrochemical (e.g

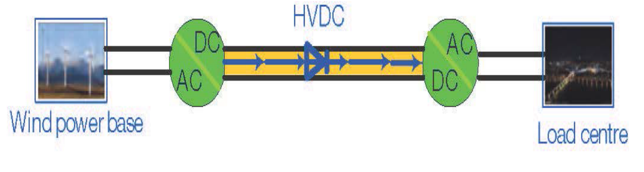

Figure 5: Design for transmitting wind power only with HVDC (Source- [65]).

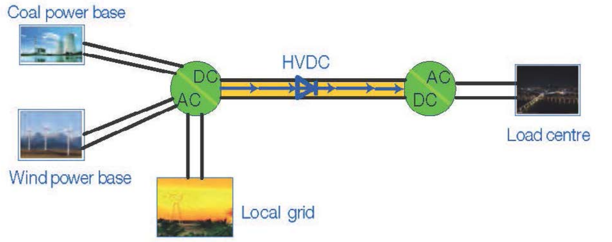

Figure 6: Wind-fire bundling design with HVDC transmission and local grid (Source- [65]).

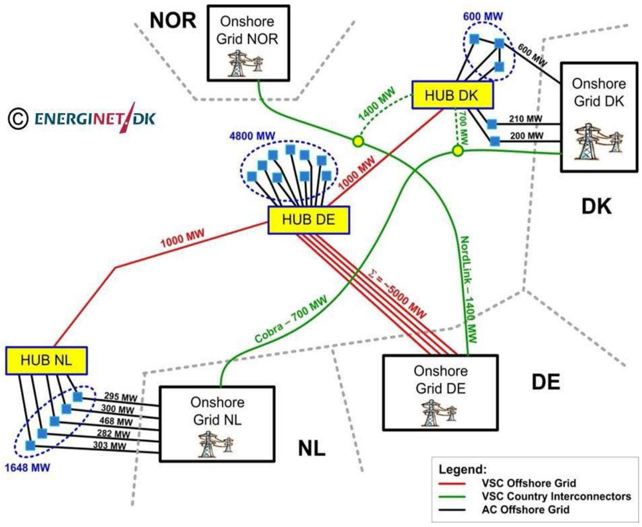

Figure 7: Transnational Offshore Grid Based on Multi-terminal VSC- HVDC (Source- [60]).

Batteries). The tremendous application range of storage is shown in Figure 8.

The suitability of electrical energy storage (EES) resource for a particular discharge time-frame is determined by its power density and energy density. Power density refers to the energy storage technology's ability to provide instantaneous power. A higher power density indicates that the technology can discharge large amounts of power on demand. Energy density refers to the ability of the technology to provide continuous energy over a period of time. A high energy density indicates that the technology can discharge energy for long periods. Generally, energy storage technologies with the highest power densities tend to have the lower energy densities; they can discharge enormous amounts of power, but only for a short time. Likewise, technologies with the highest energy densities tend to have lower power densities; they can discharge energy for a long time, but cannot provide massive amounts of power immediately. This quality gives rise to a division of electrical energy storage technologies into categories based on discharge times. These classifications are useful in conceptualizing how many roles energy storage device can play with respect to renewable integration [67].

Short discharge time resources discharge for seconds or minutes, and have energy-to power ratio (kWh/kW) of less than 1. Examples include double layer capacitors (DLCs), superconducting magnetic energy storage (SMES), and flywheels (FES). These resources can provide instantaneous frequency regulation services to the grid that mitigate the impact of RE's uncontrollable variability.

Medium discharge time resources discharge for minutes to hours, and have energy-to power ratio of between 1 and 10. This category is dominated by batteries, namely lead acid (LA), lithium ion (Li-ion), and sodium sulphur (NaS), though flywheels may also be used. Medium discharge time resources are useful for power quality and reliability, power balancing and load following, reserves, consumer-side time-shifting, and generation-side output smoothing. .

Medium-to-long discharge time resources discharge for hours to days, and have energy-to power ratios of between 5 and 30. They include pumped hydro storage (PHS), compressed air energy storage (CAES), and redox flow batteries (RFBs). RFBs are particularly flexible in their design, as designers may independently scale the battery's power density and energy density by adjusting the size of the cell stacks or the volume of electrolytes, respectively. Technologies in this category are useful primarily for load-following and time-shifting, and can assist RE integration by hedging against weather uncertainties and solving diurnal mismatch of wind generation and peak loads.

Long discharge time resources may discharge for days to months, and have energy-to-power ratios of over 10. They include hydrogen and synthetic natural gas (SNG). Technologies in this category are thought to be useful for seasonal time shifting and due to their expense and inefficiency will likely cause deployment only when RE penetrations are very large. For example, large amounts of solar power on the grid will produce large amounts of energy in the summer months, but significantly less in the winter. Storing excess generation in the summer as hydrogen or SNG and converting it back to electricity in the winter would allow a time-shift of generation from one season to the next. Such technologies can assist RE integration in the long term by deferring the need for transmission expansion and interconnection that arises due to the location dependency of renewable resources.

Table 2 describes various grid-side roles of energy storage and their relevance to large capacity RE integration challenges, along with some examples of EES technologies currently in use. These examples are

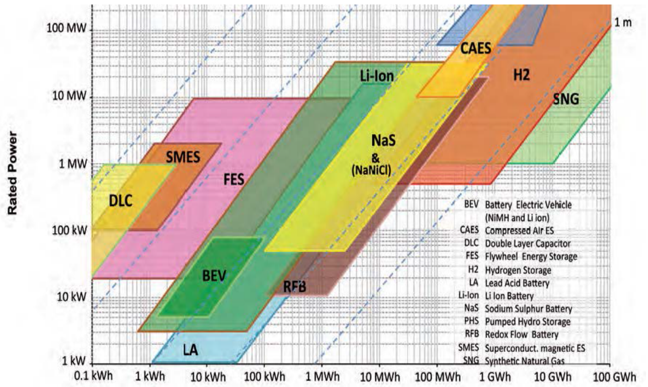

Figure 8: Comparison of rated power, energy content and discharge time of different EES technologies (Source- [65]).

Role	Time Scale(s)	Description	Benefits to RE integration	Examples of EES technologies
Time-shifting/ Arbitrage/ Load-leveling	Hours to days	EES allows storage of off peak energy & release during high demand period.	A solution to diurnal generation cycles that do not match load cycles	NAS batteries, CAES, PHS, RFB
Seasonal Shifting	Months	EES stores energy for months at a time, releasing it at times of the year when RE output is typically lower	Allows use of Renewably – generated energy year-round, reducing reliance on traditional generation in seasons with e.g low sunlight	Hydrogen, SNG
Loading following/ Ramping	Minutes to hours	EES follows hourly changes in demand throughout the day	May mitigate partial unpredictability in RE output during critical load times	Batteries, Flywheels, PHS, CAES, RFB
Power quality& Stability	< 1 second	Provision of reactive power to the grid to handle voltage spikes, sags and harmonics	Mitigates voltage instability and harmonies caused or exacerbated by uncontrollable variability of RE generation.	LA batteries, NAS, batteries, flywheels, RFB
Frequency regulation	Seconds to minutes	A fast response increase or decrease in energy output to stabilize frequency.	Mitigates uncontrollable moment – to moment variability in RE generation output.	Li – ion batteries, NAS batteries, flywheels, PHS
Spinning Reserves	~ 10 minutes	A fast response increase or decrease in energy output to cover a contingency e.g generator failure	Mitigates partial unpredictability of RE generation output, providing (or removing) energy when the RE resource does not perform as expected	PHS, flywheels, batteries
Supplemented Reserves	Minutes to hours	A slower response resource that comes online to replace a spinning reserve.	Provides firm power in the event of a severe and long lasting drop in RE output. Use for RE integration is expected to be in frequent and low value	PHS
Efficient use of Transmission Network	Minutes to hours	EES can help grid operator defer transmission system upgrades through time – shifting and more efficient operating reserves.	Reduced transmission costs, mitigates location dependency challenges of RE generation	Li - ion
Isolated grid Support	Seconds to hours	EES can assist in the integration of RE on small power grids.	Time shifting and power quality applications to mitigate variability and Unpredictability of RE generation	LA batteries
Emergency Power Supply/ Black Start	Minutes to hours	EES may be used to re-start the power system in the event of catastrophic failure	No specific benefit accrues to RE integration, but storage resources may nonetheless provide black start capability to the grid	LA batteries

Table 2: Grid-Side Roles of Electric Energy Storage (EES) System (Source [68]).

impressionistic: the suitability of an EES technology for a particular use is highly context-dependent and will vary according to the needs of the grid operator and the specific design of the EES.

Conclusion

In this paper, renewable energy resources availability, utilization and grid integration of RES have been presented.

The study shows that, integrating more large capacity RE into the grid brings variability and uncertainty. At the same time, there will continue to be unexpected disturbances stemming from load variation, grid faults and conventional generation outages. Worldwide studies and experience in recent years have shown that new technical solutions are needed to address this conjunction of difficulties. The new solutions will include new technologies, methods and practices, applied in order to provide more flexibility and improve the efficiency of power systems, constantly balancing generation and load. Only this will make the power systems reliable and maintain security of supply, i.e. avoid any interruption in the supply of power.

Furthermore, in order to address the increased variability and uncertainty brought about by integrating higher levels of large-capacity RE, the power system must become more flexible so as to maintain a constant balance between generation and load.

Power system flexibility can be achieved from the generation side (both RE generation and conventional generation), from the load side, and through electric energy storage (EES) acting as either generation or load. It can be better exploited if system operating technologies and practices are improved, and based on control shared over wider geographic areas with the support of transmission expansion.

The technologies to store the excess electricity and control the different processes in the grid with adequate communication ports is one of the basic requirements for a better integration of alternative energy sources. If these conditions are achieved, the integration of alternative energy sources can help to stabilize the current grid in perturbations and do not aggravate the situation.

RE generation can be made more predictable, controllable and dispatch able, or in other words more grid-friendly, by improving the design, operation and modeling technology at the generating unit, plant and plant cluster level. Higher-voltage level transmission, the power electronics based FACTS and DC transmission technologies are paving the way for the transmission expansion needed for accommodating more large capacity RE generation. Based on these technologies, development of probabilistic transmission planning methods is possible for power security and stability.

Demand response, supported by new smart grid, smart building and smart home technologies, is a promising source of power system flexibility in the future, but it is still in its infancy. The rate at which it will mature and be widely applied depends heavily on an understanding of customer behaviour underlying the load demand, as well as on institutional and commercial innovations.

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