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INTEGRATION OF RENEWABLE ENERGY SOURCES IN SMART GRID: A REVIEW

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The increasing complexity of the existing power grid due to rapid population growth, development in technology, infrastructure and computational tools are the factors that contribute to the need of deployment of smart grid for secure and efficient use of electrical energy.The modernization of electric grids toward a smart grid is being carried out to improve reliability, facilitate integration of renewable energies, and improve power consumption management.Due to continuous depletion of primary fuel resources and global concern about the environmental pollution, the development of smart grids based on renewable energy resources has gained huge strategic significance now a days to resolve the energy crisis. However the intermittent and fluctuating nature of these sources makes the integration a difficult task that needs to be effectively addressed. Firstly this paper briefly discuss the emerging renewable energy resources (RERs) and Energy storage systems (EES).Secondly this work comprehensively reviews the potential challenges in integration of these sources in smart grid along with the applied control strategies for their facilitation and some practical case studies.

Keywords: Smart Grid (SG), Renewable energy resources,Energy storage systems, Integration, Power electronics

1. Introduction

A smart grid (SG), also called next generation power grid, is generally defined as the "aggregation of emerging technologies, hardware, software and practices that make the existing infrastructure of power grid more reliable, accommodating, secure, resilient and ultimately more beneficial for consumers" [1]. In conventional power grids a large number of customers are generally fed from a few central generators while in the smart grid bi-directional transfer of power and information occurs that makes the delivery network distributed and automated. The recent developments in the power system allow the seamless integration of alternate form of energy production sources into the existing power grid [2]. However, the fluctuating and intermitting characteristics of these sources are the major barriers in integration to the smart grids that can be handled by the deployment and effective use of control techniques. This causes not only the improvement in performance but also the operational hours of these sources will be increased [3].

The most exploited renewable energy sources are hydel energy, wind and photovoltaic sources. The share of renewable energy production to global electricity demand is increasing continuously and it was about 20% at the end of 2011. However, these sources vary in requirements for their incorporation in main streamline. Issues such as efficiency, reliability and security in power system forces the operators to exploit widely distributed renewable energy sources and deploy them rapidly into grid. These sources are beneficial to environment and also to human health due to less pollution generated. Risks associated with others plants such as disruptions in fuel supply due to international conflicts, problems in transportation and unavailability of crew can also be overcome by the onsite small scale renewable generations. Renewable energy resources can be used for power generation as standalone or isolated system but their benefits are significantly enhanced when they are integrated into electric utility system. With greater use of smart grid enabling technologies, higher degrees and rates of penetration can be accommodated.

Integration of variable nature renewable energy resources require a huge modification in existing network operation which may eventually lead to increase in electricity cost. In ref.[4] four problems are mentioned related to intermittent nature of RER and these problems are clearly demonstrated in ref. [5]. Cameron W. Potter [6] also describes the variation aspects of RERs in the integrated power system that are named as daily, monthly and yearly variability. For the efficiency and stability of modern grid, the understanding of this variability is vital. In this article long term and short term forecasting of RERs are widely discussed through

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the assessment of weather patterns. Significant penetration of renewable energies creates challenges to maintain grid balance. Certain regions have more flexible generator fleets which can more easily balance the intermittent and variable nature of most renewable energies. The concept of flexibility can be described as the capacity of a grid to rapidly modify generation or demand in response to evolving uncertain conditions. Hydroelectric complexes with reservoirs are capable of storing some energy and offering balancing services. Internal combustion turbines can be stopped or started at short intervals (i.e. 10 to 20 minutes) and contribute to grid balancing. This is not the case for nuclear power plants, which take longer time to increase or reduce production and to start/stop. Interconnections to other grids, market approaches and demand side management also provide the potential for increased grid flexibility [7]. Numerous studies have shown that strong penetration of fluctuating renewable energy is possible, but involves constant changes in planning and operation of transmission and distribution networks [8].

The scope of this review work is to give overview of emerging renewable energy sources, energy storage technologies and the brief description of newly evolved smart grid paradigms. Next the comprehensive review of work done so far on the deployment of these sources in smart grid environment is presented which are segmented into three sections. First sections discusses the potential challenges and barriers in the full scale deployment of these sources in modern grid, second section briefs about the employed control strategies for efficient operation of integrated power system and last one summarizes some practical case studies, micro grid prototype models and Test beds developed by researchers for simulation purposes.

2. Renewable Energies Classification

Renewable energies also called green power sources include the wind, hydro, solar, biomass, ocean and tidal energy sources. These resources have a promising future due to their environment friendly nature and wide availability.

2.1 Wind Power

Wind energy is considered as one of the most effective and potential alternate energy resource due to its renewable and clean nature. The kinetic energy of wind molecules is converted into mechanical energy with the help of wind turbine that is connected with the rotor blades. The rotor is further coupled to the generator (usually doubly fed induction generator) for the conversion of mechanical energy into electrical energy. The power derived from the wind turbine at specific location generally depends upon the wind velocity, at tower height and turbine speed characteristics. Power law equation is used to calculate the wind velocity at hub height [9]:

$$V_h = V_i \left[\frac{h}{h_i}\right]^x \quad (1)$$

Here

V_h = Wind Velocity at hub height *h,*

V_i= Wind Velocity at reference height $h_{i,}$

x=Power law exponent

The real power quantification obtained from wind turbines is given by the following relation [10]:

$$P_m = 0.5\rho\pi R^2 V^3 C_p \quad (2)$$

Here

R= Wind turbine radius (m)

C_p = Turbine power conversion coefficient

The electrical power output can be further derived as:

$$P_e = n_o P_m \quad (3)$$

Here

n_o Collective efficiency of turbine and generator

Although having no harmful effect and power production at affordable cost from wind energy there are also certain drawbacks such as uncertainty of availability, uncontrolled power output etc. Due to its randomness and stochastic behavior, probability based modeling techniques are required and its optimum allocation can be sought out by the use of evolutionary algorithms.

2.2 Solar Power

Solar energy is widely distributed over the territory and it can be harnessed by the use of different ever evolving technologies i.e. solar thermal electricity, Solar photovoltaic (PV) that are classified on the basis of their mechanism of capturing the solar radiations and its conversion into electrical energy. Solar thermal power plant is an indirect method of transferring solar energy into electrical energy, in which thermal power is generated by aggregating the sunlight radiations and then steam is produced that drives the turbine generator as in case of conventional thermal power plants. The photovoltaic power plant, main form of solar energy, is a direct method of converting the solar radiations into electricity. Photodiodes are used in these plants for the efficient absorption of sunlight. This whole system is generally composed of rechargeable battery, controller, inverters, load bank etc. PV power plants can be used as standalone source of energy and it can also be connected to main power grid.

Less environmental pollution, inexhaustibility, no geographical restrictions, and flexible plant scale are the major advantages of the use of solar energy; however there are certain drawbacks in it such as high cost of installation of PV plants, power losses in converter switching mechanisms and these problems are continually addressed by the researchers to overcome them. Probability distribution functions and mathematical models are sources to predict the PV behavior and their penetration into smart grid due to variability in their behavior. Solar radiations are the input source of energy to the PV system and it is estimated on an inclined surface as [11]:

$$I_T = I_b R_b + I_d + (I_b + I_d) R_r \tag{4}$$

Where I_d and I_b are diffuse and direct normal solar radiations, R_r and R_d are the tilt factors for the reflected and diffuse part of the solar radiations. The hourly output derived from PV system when total solar radiation I_T (kW h/m^2) is incident on a photovoltaic surface with covered area A_{pv} (m^2) and efficiency η [12]

$$P_{si} = I_{Ti} \eta A_{pv} \tag{5}$$

2.3 Hydel Power

Hydro power is the largest renewable energy resource so far and it is harnessed from the gravitational force of the moving water. Hydro power is widely used worldwide and it contributes about 16% of the global electricity production. The potential energy from the falling water is converted into mechanical by hydel turbines that govern the alternators to produce electricity. Hydel power plants are operated at high efficiency due to less energy losses during the conversion process. Hydro power plants are generally classified on the basis of capacity such as large scale, small scale and micro hydel power systems. The generating methods also vary depending upon the availability of water sources and required power demands that include the conventional water dams, pumped storage technology and run off river plants. Small and micro-scale hydel plants are widely used due to their quick response to the variety of operating conditions, fewer impacts on ecological environment and less investment required. The power extracted from the moving water is determined by the relation as follows[13]:

$$P(t) = \rho g Q h \tag{6}$$

Where ρ is the density of water in kilograms per cubic meter, Q is the discharge in cubic meters per second, g is the acceleration due to gravity, h is the height difference between inlet and outlet.

2.4 Geothermal Power

Geothermal power is produced by using the geothermal energy that is the heat harnessed from the depth of earth. The heat extraction process requires the circulation of fluid down in the earth through the reservoir that brings heat to the surface where it is used for the electricity generation or in direct heating applications. Geothermal power system works similar to conventional thermal plants except here steam is produced from geothermal energy that is result of chemical and ecological processes deep in the earth. However, the efficiency of these plants are comparatively low than thermal plants due to the low temperature of the generated stream. Geothermal energy production can be estimated through the following relation [14];

$$P(MW) \approx (C_p * F * \Delta T * \eta) - p \tag{7}$$

Where

P(MW)	Output Power Obtained in mega watts
C_p	Specific heat of the working fluid
F	Flow rate from the production well
ΔT	Extracted sensible heat ($T_{Reservoir} - T_{Extracted}$)
η	Efficiency with which the heat energy is used
P	Parasitic losses

2.5 Tidal Power

Having inexhaustible and no environmental effects, tidal power is also classified as a renewable energy resource. Though tidal potential has not been fully realized yet but it has a substantial source of energy in future. Gravitational force of attraction between the earth and moon, and also between the earth and sun produce tides in the oceans. Through the rise and fall of generated tides kinetic energy is extracted that is used to drive the hydel turbines coupled with generators to produce electricity. Tidal power generation is categorized into outflow generation, flood generation, two way generation, and two basin schemes depending upon the location of the plant and available tides potential [15].Instead of lot of beneficiaries of tidal power, their high installation costs and sea life impacts are the still major barriers in the developments of tidal plants. The theoretical power available from tidal plants is calculated by the following relation [16]:

$$P_t = 0.5\eta\rho AV^3 \quad (8)$$

Where,

P_t Turbine Power (KW)

ρ Mass water density

A Total Effective area swept out by Turbine (m^2)

η Turbine Efficiency

V Tidal Current Velocity (ms^{-1})

2.6 Biomass Generation

Biomass is another widely used form of renewable energy resulted from the organic matter. As a result of different chemical and biological processes in trees and agricultural products, gaseous fuel is produced that is used to produce electricity through gasification process. A number of technologies are available for the production of gaseous fuel from biomass depending upon the specific requirements. Instead of electricity generation it also has chemical feedstock, transportation fuel, direct heating and cooking applications. Biomass plants are most suitable at locations where vast sources of waste products from forestry and agriculture industry lie. The four main types of biomass are characterized by the researchers, namely woody plants, herbaceous plants, aquatic plants and manures [17]. For all plant species, the energy content of biomass is same and lies in the range of 17–21 MJ/kg. The primary selection criteria for biomass species are their harvesting and intrinsic material properties, ease of management and growth rate etc.

3. Energy Storage Technologies

For the facilitation of fast growing production of intermittent renewable energy sources a concept of distributed energy storage (DES) and Energy storage technology has gained a huge significance. Electrical energy storage systems (EES) and Smart grid technologies (SGT) can play a pivotal, flexible and multifunctional role in electrical power systems.They reduce the need for reserve power plant, manage the transmission and distribution grid in a more efficient manner and decrease the cost and number of power failures. Further, they smoothen out fluctuations in power supply and enable more RES by improving capacity factors (i.e. by changing the demand curve using either load shifting or through energy conservation incentives by intelligently linking all market participants). As can be seen from the literature review there is a wealth of experience, knowledge and research in the area of EES and SGT [18]. Figure 1 classifies the various EES technologies. In general terms EES are categorized as magnetic, mechanical, kinetic, electrical, and chemical technologies that are further categorized as Super Capacitors (SC), super conducting Magnetic storage (SMES), Battery Storage System (BSS), Hydrogen Fuel Cell (HFC), Compressed Air Energy Storage (CAES) and Pumped Hydro Energy Storage (PHES). However, battery storage systems are widely used for energy storage purposes in many “off-the-grid” domestic systems due to its ease of use. A brief description about their modeling is described below.

3.1 Modeling of Battery System

As the renewable energy sources are not available all over the time so sometimes battery storage is sized to fulfill load requirements during the non availability of RES. Battery sizing depends upon many factors such as battery life, required battery capacity, temperature correction, and maximum depth of discharge. The required battery capacity is estimated by the following relation [24];

$$B_c = \frac{E_{c(Ah)}D_s}{D_{md}\eta_t} \quad (9)$$

Here

$E_{c\,(Ah)}$ load (Ampere hour)

D_s Battery Storage days

D_{md} Maximum battery depth of discharge

η_t Temperature correction factor

4. Newly Evolved Grid Paradigms

In this section some of new paradigms that promote the need of deployment of smart grid are briefly discussed. Along with the renewable energy sources, involvement of these paradigms is also necessary because without the concept of new and improved power grid is incomplete. It involves

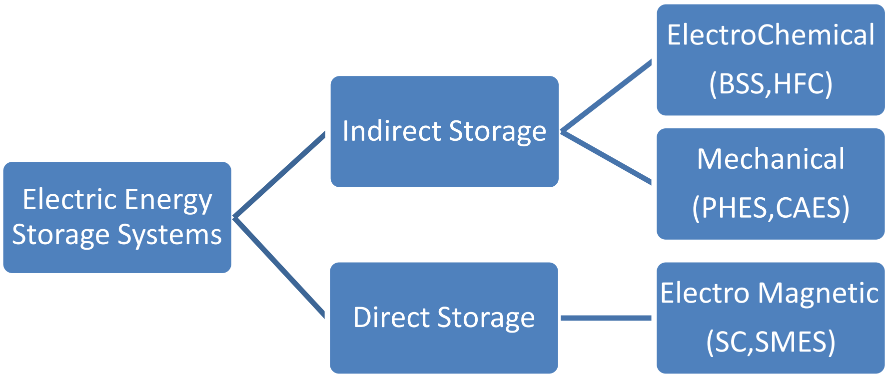

Figure 1. Energy storage systems classification.

generally the microgrid, electric vehicles and sources for generation other than renewable sources. Here we discussed briefly about fuel cells that now a day's widely deployed for power generation and more important the electric vehicle that is the most emerging grid paradigm.

4.1 Fuel Cells (FC)

These are another way of power production. Their advantages are more efficiency than other generation types and essentially no air pollution. However we cannot consider them as renewable resource unless they operate on a renewably generated fuel, for example wind power or hydrogen derived from PV or digester gas. Fuel cells utilize atmospheric oxygen to react with hydrogen from fuels (natural gas, oil, gas, etc.) with the aid of an electrolyte, and form the water along with electricity generation [19]. Among the existing Fuel Cell technologies, each type can be integrated in a system emphasizing on the market segments that fulfill its characteristics in most favorable manner. For portable, residential power transportation and applications FCs [alkaline FCs and polymer electrolyte FCs (PEFCs)] with quick start-up potential, low-temperature are being considered. For stationary power generation, higher temperatures FCs [molten carbonate FCs, solid oxide FCs (SOFCs) and phosphoric acid FCs] are often favored. In spite of the presence of their solid electrolyte, some car manufacturers and suppliers use SOFCs for their transportation applications. No doubt the gains in terms of both pollutant emissions and energy savings are dependent on design of the whole FC system and application of global optimization on these systems. In the similar manner, before introducing such competitive, reliable and efficient fuel cell power generators in the market, a large number of technical challenges are to be met [20]. The quantity of useful energy generated relative to the change in stored chemical energy that is liberated when a fuel is reacted with an oxidant is known as the thermal efficiency of an energy conversion device. Hence the efficiency may be defined as [21]:

$$\eta_e = \frac{Useful\ Amount\ of\ Energy}{\Delta H(Thermal\ Energy)} \quad (10)$$

4.2 Electric Vehicles (EV)

An electric vehicle is a vehicle employing one or more electric motors for the propulsion. Plug-in hybrid electric vehicles or fully electric vehicles will be popular in the upcoming era due to gradual decrease of availability and increase in prices of fossil fuels. In this article, we use EV for representing both plug-in hybrid electric vehicle and fully electric vehicle. The broad application and deployment of EVs leads to two concepts, named as Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V). One possible solution of minimizing the effect of EVs on grid is to optimize their charging profile. Otherwise stated, the desire is to keep the peak power demand to a minimum, considering the extra power utilization from the vehicle charging. Possible solution is to coordinate the charging operations of several EVs so that they are not charged at the same time. Organized EVs charging can improve voltage fluctuations and power losses by leveling peak power as described in ref. [22].

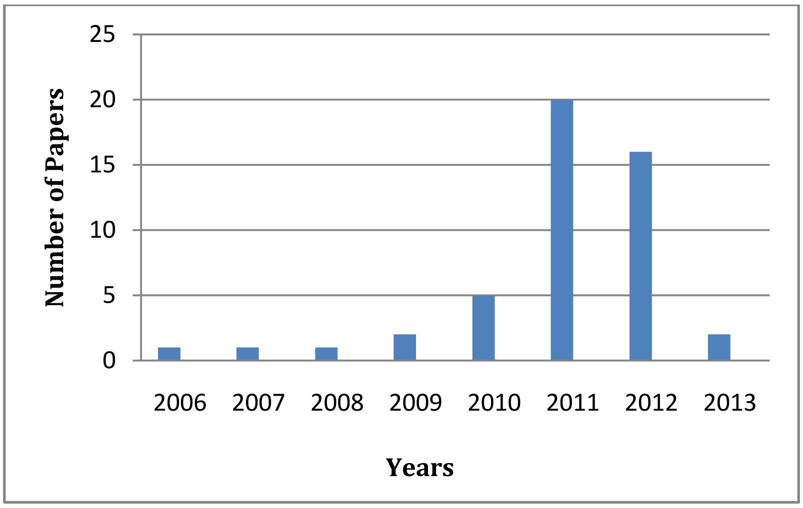

Figure 2. Comprehensive survey of literature on the integration of RERs in SG.

Observe that V2G and G2V are not fully separated concepts in SG vision. V2G-enabled EVs, for example, are frequently used to supply power to help balancing loads by “valley filling” (charging during low demand) and also “peak shaving” (when demand is high, sending power back to grid). Hence, a key question is the determination of the appropriate charging and discharging times throughout a day. Hutson,et al.in [23] studied the above mentioned problem and formulated a binary particle swarm optimization algorithm for finding optimal solutions to maximize profits to vehicle owners along with satisfaction of vehicle owner and system’s constraints.

5. Integration of RERs in Smart Grid

A global concern about the green earth is related to efficient and a better method of generation & transmission of electrical energy. Today’s there is need of an efficient and customer friendly power grid based on the renewable energy sources. Smart grid enables grid operators to provide most useful way of integrating RERs in main grid. Power inverters play a key role in a flexible interconnection of different players of power system (energy producers, EES, Flexible transmission & distribution). This survey covers the potential challenges and barriers in deployment of these sources and application of power electronics in a flexible integration of RERs and EES to power grid that are segmented into three sections. Figure 2 shows the trend of research work on the employment of these sources in Smart grid environment.

5.1 A Review on Potential Challenges in RER Integration

Integration of renewable sources in power system with their variable generation schedules introduces certain challenges in the systems. It will necessitate the changes in power system planning and operation while keeping reliability and economy constraints in considerations. Large-scale storages also need to be incorporated to meet peak loads demands. Several factors which need to be addressed during integration are power quality, reliability, energy conversion cost and power system efficiency. Research and development regarding these issues are underway and several methodologies and algorithms have been proposed in order to meet these challenges and making power grid transition towards smart one in an effective manner. The potential challenges and their possible solutions represented in different papers are given below. Figure 3 at the end of this section gives the brief classification of challenges faced in integration.

Storage systems alongwith power electronics need to be incorporated in energy system due to unreliable behavior. Distributed energy sources and their integration related issues are discussed [25]. Problem with these storage systems is that each storage component requires different control strategies for each case. This then results in planning a separate control technique for each individual case. It increases cost and is time consuming. The purpose is to design such methodologies that can be used for almost every type of storage devices. For present large power stations top-down technique is used. In distributed generations, initial limiting points and boundaries need to be defined for optimum and economic power flow. Hence these require bottom-top strategy. Electric storage systems support the main system in system voltage frequency, angular stability; load leveling, reliability, quality control and compensation for unbalanced load. The paper discussed the need of feasibility analysis for optimal integration of distributed energy storages in system.

In ref. [26] the challenges considered are power forecasting, orderly combination with grid, and storage systems at a larger level. Based on these important problems a framework is developed for smart grid with integrated renewable sources considering its scope in China. Types of renewable energy available in the country are first to be determined. Planning, power output predictions, power generation control and implementation, their detection and visualization, payments and response measures are major areas considered while designing the framework. Challenges of forecasting of renewable outputs, influence of renewable integration on system security and stability, use of large scale storages and their optimal placement, grid scheduling support system are discussed in the paper.

The reference [27] provides the application of research on a energy requirements in an intelligent building extracted from renewable sources (Wind Energy, PV cells and solar collectors). For a period of one year, daily values of wind speed and wind power are recorded measured at specific height. Voltage-current characteristics of a photovoltaic module are also taken under two different cases. The authors developed and simulated a computer program named as Soft Comfort v6.0 for adjustment of position of PV panels. Application of Crocodile-physics v6.05 program investigated the average energy consumption during the day in intelligent building along with the simulation results of energy consumption electric equipments. Concepts of decentralized automation for intelligent homes are also discussed in this article.

With the increasing penetration of renewable energy sources and deployment of more efficient base-load power plants, the utilities are forced to cycle the aging fossil fuel power plants. Demand response (DR), the energy product of smart grid enabling technologies has also improved due to increasing investments. Due to penetration of wind energy, the effect of increased operational and maintenance cost of conventional plants are mitigated by the use of Fast, Real time and day ahead demand responses. The article at [28] extensively explores the DR energy benefits in terms of reduction in fuel costs. Simulation results revealed that significant results can be achieved with demand response if it used to reduce cycling of fossil units and also system reliability increases by DR in variable generation scenarios by reducing on/off scheduling.

Ali Keyhani et al. [29] presented a methodology for the future cyber smart bulk power system comprises of many microgrid systems and small power grids. AC and DC architectures for the smart micro-grid systems are developed having plug and play capabilities. With the help of interchangeable converters, various RER and DES are connected to the AC or DC bus which makes the system to operate in two modes of operation either in standalone or synchronized with utility. The author also analyzed the control strategy of single phase inverter under various linear and non-linear conditions to achieve rapid transient response, low total harmonic distortion (THD) output voltage. The simulation results revealed that under linear loads PID controller works well but in nonlinear conditions the performance were unsatisfactory.

The integration of renewable energy resources at higher levels in distribution networks will introduce a new set of challenges. The reference at[30] is based on Solar Grid Stadtwerke Ulm / Neu-Ulm GmbH (SWU) project test area. The authors analyzed the possible settlement of network’s future operation which starts during planning phase. The initial analysis is related to second measurement values taken from first test area. Based on these analysis changes in performance and load could be made. Moreover, the results of this analysis were verified by test area. This analysis provides the base to develop a prognostic system for the network state parameters.

Zhang Shuan et al. [31] discusses the impacts of large scale wind energy penetration in context of smart grid environment. Dispatch targeted load of the system are reduced with the superposition of the fluctuated wind power into power grid. This article points out the integrated wind farm ranges and probability of shut-down of all wind plants. Large scale wind power connected to the power grid without the need for dedicated equipment, generator or the accumulator system, and that the results of the study show that grid to accept the wind power penetration rate of around 25 per cent.

Compared to conventional grid, the future smart grid is advantageous in terms of large-scale integrated wind power and emission reduction and energy conversion. In ref. [32] a detailed survey is carried out which includes SG technologies with integrated wind power facilities. Also an effort is carried out for identifying progress of future trends. The paper is also useful for owners to realize present SG technologies and their suitability towards future trends. SG can prominently increase ability to allocate available resources optimally.

Photovoltaic and wind resources do not have consistent output. This is highly unacceptable for low voltage systems. Therefore renewable energy integration does not require any pre-set supply behavior. Also improvement of communication protocols among regulators and operators need to be emphasized as discussed [33]. Therefore, compliance of IEC 61850 will be necessary for systems with integrated RER. The paper discusses need and requirement of existing equipment to meet integration developments.

In ref. [34] various potential challenges encountered during integration of renewable to smart grid are discussed. Moreover an output forecasting model is suggested for smart grid. The challenges include renewable power generator designs, their expected types of run, their interaction with each other, and their optimal placement in the system and grid characteristics. These challenges result in voltage fluctuations, harmonic distortion, reactive power compensation, synchronization, storage systems, load forecasting and scheduling and load management. These problems are discussed in the paper in detail. The paper presented a forecasting approach for solar irradiation and wind data prediction on daily and hourly basis respectively. Several models were developed and their efficiency was checked. For wind data Bagging and RBFN techniques were found to be very accurate and efficient. For solar irradiation data Bagging and RSS were found suitable techniques. Future trend to be discussed are also mentioned.

In order to meet increasing loads and make the power system more environments friendly, renewable are to be incorporated in the electric power system. The paper at[35] discussed some major issues like economy, quality, system security, reliability etc. and their possible solutions to make electric power system environment friendly and self-healing. The issues highlighted in paper are substation automation, responses and distributed generations. Self-healing features of smart grid are also discussed. The strategies for conversion of present grid to green grid by integrating distributed resources are also given. Finally micro-grid and demand responses are discussed. Case studies were also taken. Power system re-designing leads to several pricing schemes, hence it plays a very prominent role in system development. It is considered to be the backbone for future grid which is a two-way communication system. But it is expected that entry of communication protocols will lead to cyber-attacks. Privacy of data and its security are hence major concerns for future grid.

The authors in ref. [36] proposed that prospect of industrialization is a complete circle i.e. from energy system to communications and services. Also trends in renewable sources integration are discussed. The issues related to renewable energy integration including efficient energy storage, development of advanced control and monitoring algorithms, sources' networking and capability of managing micro-grids etc. are reviewed in the paper. Various renewable energy technologies utilized worldwide are also discussed. Also cooperation between control, communication and power electronics fields are reviewed.

Newly developed smart grid applications although make system more reliable, they are yet a cause of uncertainties and security issues due to insecure products and designs. These uncertainties may arise from products not meeting desired standards, communications system failures, access technology and problems in operating systems. In ref. [37] security problems for smart grid are discussed and also measures to be taken to cancel or mitigate their effects. The vulnerabilities may result due to poor network protocol implementations, information leakage, and design problems and component configuration issues. Communication systems to be implemented and network security measures to be taken to make future grid more secure are also discussed in the paper. Data networks need to be segmented in order to secure the power system. The measures and safety steps taken during implementation as well as operation phases, most of these possible threats can be removed or mitigated. Network designs allowing expansions possible also make the power system more secure.

The paper at [38] discusses several aspects regarding renewable integration to the smart grid. PVs and Wind Energy Conversion System (WECS) are most popular types of renewable under consideration. Variable DC output of PV requires a Power Conditioning Unit (PCU) for integrating its output to the main grid. AC output of wind power units has voltage and frequency stability issues; therefore a rectifier and a DC-DC convertor are required. Also energy storage system needs convertors. The paper discusses these various types of convertors in terms of design and control. Also an AC-DC micro grid, hybrid in nature was also formulated and implemented. Convertors using power electronics which can be used as interfaces between main grid and DGs i.e. both PVs and WECS were checked and their design implementations were validated. Experiments were carried out to check the effectiveness of these designs and results verified their usefulness.

In ref. [39] authors explored various renewable energy resources components vital for controlling carbon dioxide emissions. Various challenges to be faced during transition from present grid to future smart grid in context of renewable resources are also discussed. The attributes of renewable energy resources to be considered while looking for its implementation are efficiency, reliability and its integration.

Problems of system planning and difficulties due to varying weather conditions can be overcome by implementing HVDC and Flexible AC transmission system (FACTS). In ref. [40] the problems faced during integration of renewable are discussed. Solar and wind sources are taken into account. Advantages of use of HVDC and FACTS devices incorporating power electronics technologies are also discussed. These applications are having an important part to enable present grid to integrate renewable resources.

In ref. [41] authors suggested a hybrid structure for conversion of present grid into smart one. Wind and photovoltaic resources along with storage devices are used with AC system. Data for wind speed and changes in irradiation were collected from meteorological department. Neural networks for forecasting purpose and constraint function are used to help in multi-agent system for smart grid environment. The design was implemented in UADY Faculty of Engineering.

In ref. [42] authors proposed the use of a generalized evolutionary algorithms approach for optimum placement of renewable sources for reactive power management. These sources can be well integrated to the more flexible smart grid taking into account certain reliability and security constraints. Genetic algorithms are used for managing reactive power for multi-objective functions. Both optimal placements of distributed generations and reactive power control help in stabilizing system voltage and improvement in distributed generations' integration level. For algorithm both controlled and uncontrolled distributed generations are considered separately. The paper gives complete outline of evolutionary programming by applying it on four bus system. Then the algorithm is applied on a 34-bus system using both single and multi-objective functions. The algorithm proved to be very efficient and effective for optimal placement of distributed generations and reactive power control. The papers gave the methodology of effectively using evolutionary algorithms to construct power systems with increased level of DG integrations.

Antonello Gaviano et al. [43] presented a migration concept of existing electronic devices and communication standards for integration of wind and solar energy in smart grid environment to ensure reliability, safety and security of future network. With the application of smart grid technologies, an efficient use of RER and distributed energy storage systems can be optimized. The authors concluded that the IEC 61850 is a global standard for utility communication requirement that provides a high level of interaction of distributed entities and reliable and smooth activity of the network.

LV Chun-quan et al. [44] presented an operation mechanisms for the integration of renewable energy sources in smart grid. The off grid renewable energy incorporation in a system opens a new territory for research and developments and makes the power delivery structure more reliable and secure. This article provides a basic framework and detailed transport mechanism for grid connection of RER. The basic framework for the renewable incorporation is segmented into various sections named as; operational planning of renewable power generation, renewable energy forecast model, operation and control mechanism, process monitoring, response mechanism, RER incorporation price and settlement.

Integration of renewable energy sources to the system in order to meet increasing demand is found to be a reliable, efficient, secure and most

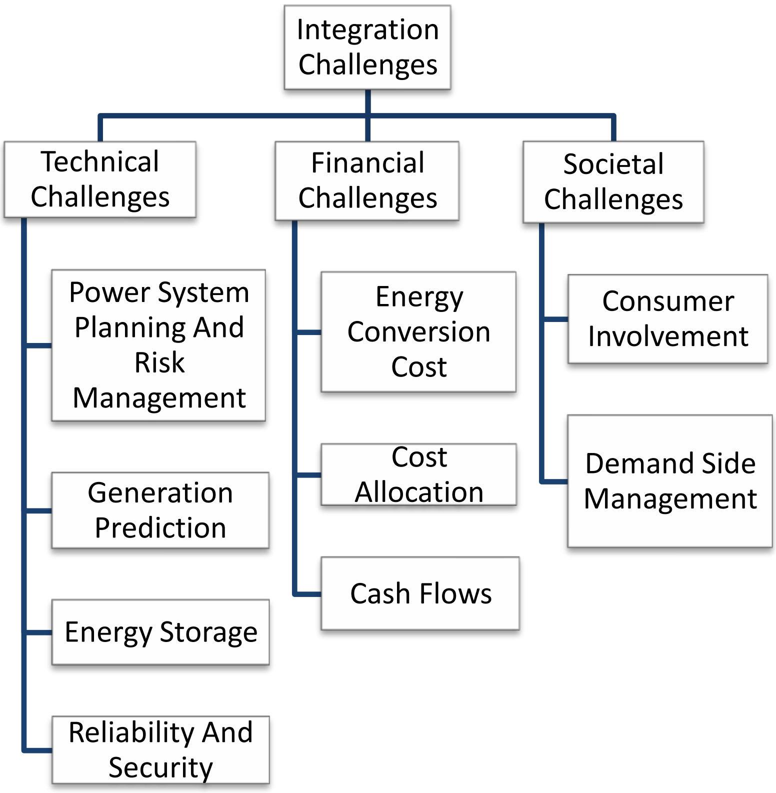

Figure 3. Classification of potential challenges in integration of renewable energy resources.

accepted solution without affecting environment. However there is insufficient knowledge regarding cost and economic benefits of research and developments about distributed generations. In [45] a methodology is suggested for cost effective and technical assessment of application of distributed generations including a dynamic line rating tool and automatic voltage control. The technique is implemented on a case study to see its efficiency for economic expediency of systems.

5.2 A Survey on Control Strategies for Integration of RER's

Control technologies are implemented to improve the reliability, security, interoperability, and efficiency of the electrical grid, while reducing environmental impacts with improved economic growth. A vast number of smart devices and systems need to be implemented in order to effectively utilize the Renewable Energy Resources, potential. This section summarizes several control strategies, their architectures and their effectiveness presented in literature.

Rapid increasing electricity demands are causing unbalances in the existing system which results in various issues such as power quality, unbalanced voltage and load curtailment which ultimately affects the customers. Now a day's generations by the conventional sources are insufficient to meet the demand requirements due to continuous depletion of fuel sources, therefore the integration of renewable energy sources to system is necessary to overcome these issues. The ref at [46] gives us an introductory view of smart grid emerging technologies and integration of RER in smart grid environment through advanced power electronics. Integration of RER in smart power system is considered as the most promising way to resolve the issues like power quality, environmental pollution etc. This work gives us the brief overview of energy storage technologies, application of FACTS devices for integration purposes, modeling of Wind/PV hybrid energy system and the smart grid developing trends in Japan. The purpose of this work is to facilitate the researchers by exploring the potential research opportunities in the subjected area of work.

Juan Manuel Carrasco et al. [47] reviews the new trends in power electronic technology for the integration of wind and photovoltaic (PV) power generation to centralized Power system. The authors also reviewed the appropriate storage-system technology used for the integration of intermittent renewable energy sources. The current technology and future trends in variable speed wind turbines and PV sources are widely discussed along with the development trends in Energy storage systems used for the grid integration.

The research work in ref. [48] describes the main inverter topologies intended to connect the renewable energy resources to the grid utility. This shows the circuit configuration of the full bridge three-phase inverter, fly back inverter, Z-Source inverter and neutral point clamped inverter, and it also discusses their advantages and disadvantages for each application. At the end of the article the authors also pointed out some peculiarities of renewable resources that can be handled better by some specific or multi-function converters referred in the text.

The paper at ref. [49] describes the use of control methodologies in integrating renewable resources is essential for their better performance. The use of these control strategies will enhance system performances and also operational daily hours for these resources can be increased. Control is the key enabling technology for the integration of renewable energy systems. Solar and wind power resources require advanced control techniques for better performance and reliable operation. The paper proposes that application of control technologies will reduce costs to affordable levels.

In ref. [50] a high step-up DC-DC converter with three-winding coupled inductor and clamp capacitor is proposed. Three-winding coupled inductor and voltage doublers increase the voltage transformation ratio. A clamp capacitor is also used to reduce voltage stress. The convertor is verified using simulations. The reverse recovery problem has been overcome.

The authors in ref. [51] proposed a distributed cyber-physical control architecture for matching supply with demand. The model is of hierarchical control structure type. It comprises of primary, secondary and tertiary levels with operating time ranges of milliseconds to minutes. It was proved satisfactory for accommodating perturbations in RER. It results in increased social welfare as well as desired frequency control.

Employment of renewable and distributed energy sources into smart grid through power inverters is the new frontier for smart grid developments. Qing-Chang Zhong and Tomas Hornik [52] presented a systematic overview of power inverter control technologies to provide facilitation in the integration of RERs in smart grid. This work is segmented into four parts; part I discusses the various control strategies for the quality improvement of inverted voltage, Part II presented the topologies to maintain a stable neutral line for facilitation of phases independent operation, in Part III voltage and current controlled strategies are discussed for power flow control between inverter and grid and last one deals with the conventional synchronization methods. This research work is very useful for scientists, engineers and researchers working in the area of smart grid and RERs to learn how control strategies works and improves system performance.

In ref. [53] a scheme for demand side management is proposed. It allows customers in proactively controlling their very demands. It also allows load shifting from peak loads to low demands. It is also proposed how to utilize available energy by using EVs. The results indicate the potential of the scheme to achieve energy savings and release capacity to accommodate renewable energy and electrical vehicle technologies.

The paper at ref. [54] presents a general overview of present power electronics technologies to be used in renewable energy resources for integration in smart grid. A network of this type is essential in order to deploy electric vehicles. These are applicable where utility companies and consumers are working together to attain sustainable energy consumption, by increased use of renewable energy sources, bringing generation closer to customers and making a commitment to rational and efficient consumption.

In ref. [55] an energy management system (EMS) is suggested to optimize operation of smart grid. It behaves as a sort of aggregator of distributed energy resources allowing the SG to participate in the open market. Integration of demand side management (DSM) and active management schemes (AMS) gives a better exploitation of renewable energy sources. The effectiveness of the proposed EMS was verified on a 23-bus 11-kV distribution network. Results proved that the combined operations of RES and Price Responsive Demand mitigate network constraints while satisfying higher demand levels and reducing the energy costs.

Increasing significant penetration of renewable energy sources especially wind energy to system causes a great concern to smart grid security due to their uncertainty of generation and intermittent nature. This also causes a huge stress on system generation operational planning and system ramp management along with the transmission line congestion. Kwok W. Cheung in [56] proposed a new dispatch framework named as generation control application to fix these challenges caused by the wind energy penetration. The proposed dispatch system composed of three main distinct elements named as Multi-stage Resource scheduling process, comprehensive operation plan, demand forecast. With robust dispatch algorithm, wind energy forecast, advance demand forecast along with the flexible system configuration, the proposed frame work will be able to cope with the intermittent sources with significant system ramping capability.

Xiao-fang et al. [57] comprehensively analyzed the flexibility of modern grid scheduling technical support system under various aspects with effects of large scale wind energy penetration. The framework of this system consist of basic working plate form integrated with other modules such as Real-time monitoring and early-warning class applications, Operation plan class application, Security verification type of application adaptation assessment, Schedule Management application adaptation assessment. The authors concluded that the aspects such as wind farm modeling, control strategy, policies and regulation are needed to further improve for efficient operation and wind power admission ability sharpness.

In ref. [58] systems and control opportunities in the integration of renewable energy into the smart grid are described. Integration of renewable energy resources offers a rich set of research problems, many of which will critically require systems and control methods in their solution. Authors have collated a partial list of specific problems driven by the variability and uncertainty of renewable resources. The problems associated with renewable integration include their variable, non-dispatch-able nature; they are periodic in operation and also uncertainty. The challenges to be faced during integration of renewables cover a wide range of research. Of these, some problems need systems and control strategies for solution. The paper includes some of these problems. These are cyber security, best possible placements for phase measurement units, controlling wind turbines, DEG, grid control, best PV operations employing power electronics and reactive power compensation.

In ref. [59] the authors studied the power management problem in the smart grid network with multiple energy resources, including both the conventional thermal power plants and the renewable energy resources. The integration of Plug in Hybrid Electric Vehicles(PHEV's) has been proposed in this article as an energy efficient solution to address the problem, and stochastic programming frameworks have been formulated to obtain the power management solutions for both the case without and with the integration of the PHEV fleet. The numerical results revealed that the energy generation of the conventional thermal power plants can be apparently reduced using the integration of PHEVs, and the overall energy generation cost to satisfy the load can be effectively reduced.

5.3 A Survey on Case Studies & Test Beds

Smart Grid is a concept of two way power flow with integrated RER and various control and communication options. Technologies to verify its effectiveness and make it a secure and reliable system are still underway. In order to check viability of these developments, representative models, known as test beds in SG context and simulations are carried out. This section reviews these case studies and test beds developed by researchers for the facilitation of RERs in Smart Grid environment.

R. W. Wies et al. [60] describes a educational project that involves the design of an energy-efficient standalone distributed generation system integrating existing fossil fuel based energy sources with RER and smart grid technologies for off grid communities. This developed project by authors addresses many facets of engineering design and development including system component design, system integration including smart grid technology, environmental impacts, and economic and cultural concerns. This research work contributes in the development of stand-alone electric power sources for Native American villages in rural Alaska.

In ref. [60, 61] authors reviews the Hybrid Energy Storage Systems(HESS) for Renewable Energy Sources Integration in Microgrids.In this paper the different topologies and energy management algorithms that have been applied in the RES and microgrid contexts have been analyzed and compared. A review of the latest papers related to the use of HESS to facilitate the integration of the RES in the microgrid context is carried out. The researcher also presents the different energy management strategies for coordinating the two storage devices that have been used in different literature works so far.

R. Al-Ali et al. [62] developed an intelligent system that integrates renewable energy resources and energy storage technologies to conventional power grid for managing the power consumption. This intelligent system has ability to supply smart homes with its required power by multiplexing the three power resources with single chip microcontroller. A two way communication system has been developed also for sharing valuable information between utility and consumers. By using utility server and home gateway billing system hardware and software system, demand response, energy flow and communication protocol were developed. A prototype model of designed system was implemented and tested at laboratory by using controlled load bank and different pricing intervals to reflect the real time consumption behavior of smart homes. To make the system user friendly and secure a cyber-security system was also implemented. The simulation results revealed that with the integration of RER and EST to traditional grid and application of efficient communication system gives 33% savings in home energy bill.

O. Lavrova et al. [63] identified New Mexico University campus as a potential candidate for the implementation of demand response strategies integrated with modern grid energy management and control system due to already installed and operational significant capacity of RER at campus. This efficient energy management system makes possible for the university campus to respond to modern grid signals in a more controlled manner. This paper addresses the required information technology and infrastructure improvements at campus that results in increased level of interoperability and conformance with the outside world and makes possible for its quick response on external requests.

Stavros Lazarou et al. [64] discusses the research facilities available at the European commission Joint research center (EUJRC), smart grid simulation center. This center is intended to combine the simulation tools with electrical power components and communication framework to evaluate different scenarios under various operating conditions and for the real time simulation of electric power system. This paper briefly discusses the multi terminal DC grid topologies and application of Voltage source converters for the integration of offshore wind power. This paper also provides explanation of North Sea Transnational Grid (NSTG) project performed jointly by Technical University of Delft, JRC and the Energy Research Centre of the Netherlands (ECN) for the investigation of best mechanism for the integration of large scale wind farms in terms of transactional grid.

The article at ref. [65] presents the design of an intelligent micro-grid with high percentage of clean and renewable energy resources on Pulau Ubin Island to meet existing and future electricity demand. The proposed system design has considered all possible energy sources, energy conversion efficiency, power demand, as well as environmental and economic concerns. Photovoltaic (PV), bio-diesel powered doubly fed induction generators are utilized to generate electricity. The authors predicted that upon successful implementation of this system, customers on island will be able to have cleaner electricity supply with high quality at lower cost. By integrating green energy, including PV and biodiesel, the smart grid on Pulau Ubin will become a model of sustainable development without losing its rustic charm, and it has great potential to be applied to other remote areas.

In ref. [66] a case study is carried out to analyze integration problems in renewable energy resources and their solutions in context of Singapore. The paper presented three domains of test beds to increase energy efficiency. Initially Energy Market Authority (EMA) presented Intelligent Energy System (IES), and then it presents clean and renewable energy deployment in the power system. Finally Agency for Sciences, Technology and Research gave a test facility of 1MW power grid.

The authors in ref. [67] present a residential SG incorporating decentralized renewable resource. The model was aimed with quantifying the optimal exploitation of renewable energy that trades off between the system-wide benefit from using the RERs.Moreover an algorithm is suggested for optimal use of renewable potential and energy scheduling.

The authors in [68] focused on significance of smart gird and micro grid models with integrated energy resources. The models are provided with all essential components for development of smart grid with renewable resources. Case studies were also performed to check efficiency of renewable resources during different hours of the day. In the end it is suggested that further enhancements in the models can be made depending on developments in future technologies and future trends.

In ref. [69, 70] a real-time, online and multi-time simulation is suggested for developing a common smart grid scope. Simulation, which is at large scale, includes roles of reliability coordinators, transmission operators, distribution operators, power plant operators, and substation operators. Also reliability impacts of some prominent smart grid resources are also discussed. A smart meter is also developed. Clear benefits about resource utilization, energy conservation and cost reduction to users are major benefits of these developments as stated in the paper.

The paper at ref. [71] discusses issues regarding hybrid renewable energy system (HRES) and an algorithm is also suggested to counter these problems. The purpose is to minimize operating costs while keeping system reliability in limits. The proposed solution procedure focuses on reducing solution time due to the complex structure of the network. Results showed that as the number of nodes gets large, the solving time increases. Also the algorithm finds the shortest paths in a very short time period.

6. Future Recommendations

1. Renewable energy resources being environmental friendly and enhance system reliability and stability, are widely deployed in power grid. RERs pose many problems at modeling, planning, integration and control level. The key issue is how to model the renewable energy resource. The fuel resource such as wind and solar radiations being highly unpredictable require probabilistic model, forecasting and scheduling methods.
2. Since Wind and solar are highly unpredictable therefore both can be available during off peak load hours. During this time period the installed potential can be wasted. To undo this wastage energy storage systems have to be installed. The extra power will be stored in these systems and will be provided to the load during peak hours. So storage systems need to be improved.
3. Effective electronic interface improves the performance of RERs. An effort is required to develop electronic interfaces controlled by intelligent controllers to integrate RERs in power grid.
4. When solar energy resources are included in power system, the cumulative inertia of power system reduces, thereby reducing the system stability. Effective controllers need to be designed to save the power system stability.
5. Solar cells have energy conversion and heating problems. Therefore research work has to be carried out to upgrade existing solar cell technology.

7. Conclusion

Due to potential significance of Renewable Energy Resources in smart grid environment, this survey paper comprehensively covers major aspects of RER integration to the main streamline. The survey has been further subdivided into three sections. First section includes literature review based on potential challenges and barriers to be faced in integration. Solutions to these problems as stated in corresponding papers are also presented. Second section is based on control technologies to be implemented for RER integration. Several control methodologies proposed so far are given in this section. Finally papers based on test beds, case studies and test models developments are presented. This section summarizes some practical case studies, micro grid and smart grid prototype models for simulation and analysis purposes.

Hence integration of RER to smart grid system, keeping in mind all challenges and best possible solutions to mitigate them, will help in meeting ever-increasing electric energy demands effectively. So it is derived from this research work that we need to explore not only how to improve this powerful hammer, but also the nails it can be used on.

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