The Trends of Integrating Renewable Energy Sources: A Survey

Sardar Mehboob Hussain[1], Muhammad Hassan Rahim[1], Zunaira Nadeem[2], Iqra Fatima[1], Zafar Iqbal[3], Sikandar Asif[1], and Nadeem Javaid[1](✉)

[1] COMSATS Institute of Information Technology, Islamabad 44000, Pakistan
nadeemjavaidqau@gmail.com
[2] National University of Sciences and Technology (NUST), Islamabad 44000, Pakistan
[3] PMAS Arid Agriculture University, Rawalpindi 46000, Pakistan
http://www.njavaid.com

Abstract. Renewable energy sources (RESs) are considered as future replacement of traditional energy generation sources with zero carbon emission and low price electricity producers. RESs are intermittent, uncertain and random in nature, they do not produce fixed amount of energy and heavily depend upon weather, season and area. In this paper, new trends in the integration of photovoltaic and wind turbine are presented. This paper discusses the integration of RESs at three level i.e. consumer level, micro grid level and main grid level. A comprehensive review of the intermittent and stochastic nature of RESs is also provided. Additionally, fault protection concerns and the feasibility of RESs are discussed. Moreover, the usage of storage system to deal with the fluctuating behavior of RESs is presented.

1 Background

Fossil fuels dominate as a power generation source in traditional power generation systems, and are considered as one among the most greenhouse gas (GHG) produces. The limited natural resources are diminishing and also contributing in depletion of ozone with their excessive usage. The challenge is not only to reduce GHG emissions but also to increase electricity generation in view of socio-economic aspects of generation.

The clean and economical energy is directly harvested from the unlimited resources of sun and wind. No extra costs incurred except the first time capital investment for enabling technologies. Over the past decade, electricity sector, heating and cooling sectors and transport sector are sharply moving towards RE generating. Solar photovoltaics (PVs) and wind turbines (WTs) technologies further increased the confidence of RESs.

The current status and enabling architecture of RESs in the developing countries is assessed in [1]. The objective and goals achieved in terms of social, political and environmental concerns are categorically elaborated. The research ranges

L. Barolli et al. (eds.), *Advances on Broad-Band Wireless Computing, Communication and Applications*, Lecture Notes on Data Engineering and Communications Technologies 12,
https://doi.org/10.1007/978-3-319-69811-3_56

from small scale PV installation to large scale RE powered grids. The countries which share similar grid codes and constraints are placed into a group.

The long term planning of RESs require large complex linear and non-linear computing because the randomness involved in energy generation. [2] discusses the generation expansion planning in order to find an optimal long term energy generation plan. This plan must satisfy the enclosed constraints and provide the electricity to the required and committed sectors. Unlike traditional generation expansion planning, current generation expansion includes RESs which are economical and carbon free generation sources.

Integration of RESs lead to many electrical protection challenges due to random and stochastic behavior of energy generation. These protection issues compelled system operators to establish grid codes to ensure proper operation of PVs and WTs, particularly, in case of contingency situations. The current systems used to enhance the performance of grid under large share of RE are reviewed in [3]. RESs are majorally used to ride through low voltage faults and also to damp inter-area oscillations. The authors reviewed the methods and grid code used to avoid low voltages and inter-area oscillations. PVs are integrated to both low voltage and medium voltage networks.

The successful and failed projects of RESs installations are studied in [4]. The major objective is to provide a feasibility report of the successful penetration of RE to the investors and policy makers. The installed projects are studied in view of economical, environmental, social and political concerns. The authors also provide a guideline for future RESs installation through providing the past experience. Additionally, the analysis of the reasons that make the RESs feasible, successful and economical is provided in depth.

In [5], a review of incentive based RESs and other low carbon technologies integration is investigated. The authors study the state of the art tariffs for RESs for different countries. A comprehensive review and feasibility assessment of RESs and other enabling technologies for the different regions of the different countries of the world are presented. PVs and WTs are the special core of authors because of their wide range availability on earth.

2 Description of RESs

Sun is an unlimited source of energy with many social and economical benefits. PV panels, solar thermal systems and concentrating solar power (CSP) are different methods used to harness the clean and cheap energy from the sun. Wind is also a natural source which is available everywhere on the earth. From the past decade, these technologies have been the core focus for energy generation in all over the world.

2.1 Photovoltaic

A PV panel consists of several small solar cells which absorb the solar radiations and produce electricity. These solar cells are semiconductor devices which have an ability to transform the solar energy directly into the DC electricity without any further processing. The PV cells collaboratively form a PV module with varying capacities. These modules are then coupled together to make a complete PV panel system. This PV system also comprises of different inverters, converters, batteries, and other required electrical devices to make the use of generated electricity. The PV modules can be further coupled to increase the capacity of PV system up to a required level.

PV panels are often formed with silicon technology, however, some non-silicon semiconductors are also increasing in the niche market. Although, the price of these non-silicon semiconductors are quite reasonable, they do not have high efficiency. In terms of efficiency, concentrating PV cells dominate with an efficiency ranges up to approximately 40%. Two main advantages to PV panel systems are: (1) PV modules are manufactured in large industrial plants which allow economic production, (2) PV panels generate energy even if the sky is partially sunny. Due to this feature, PVs are installed at large scale throughout the world.

PVs applications are categorized into two groups. (1) Off grid (isolation from grid) and (2) grid connected. In developing countries, the areas which are not yet electrified can be easily powered by off grid PV system.

2.2 Wind Energy

WTs are used to convert wind energy into useful form of electricity. WTs have blades, which run with wind speed and these blades produce electricity which is cheap and clean energy. The first WT was used back in 20th century. This technology has emerged and used at large scale in all over the world. Currently, wind energy is most sustainable and cheaper electricity with no harmful emissions. WTs are going be more promising in coming era.

The technical working of a WT can be explained as: the moving air has kinetic energy which is transformed into mechanical energy. This mechanical energy is then transformed into electrical energy. The three step conversion is challenging task for wind industry in terms of cost. A WT captures only a fraction of kinetic energy available in air. A WT is typically designed in a way so that it can increase the energy capture from the available air density. WTs are also designed to use less materials so the fan can move with more velocity.

Wind generation is strongly coupled with wind speed. We consider three wind speed levels for WTs to work. A rated wind speed, cut-in wind speed and cut-out wind speed. Cut-in wind speed is defined as the speed at which the blades of WT start to move. It is the initial speed at which a WT starts generating energy. Rated wind speed is defined as the level of wind speed at which the WT generates maximum energy of its designed capacity. Cut-out speed is upper limit of wind speed where the blades are closed and WTs are brought to rest. No energy can be generated as it is the highest speed which can cause a breakout of WT. The values for cut-in, rated and cut-out wind speed depend upon the size and capacity of installed WT.

3 RESs Integration

Renewable energy integration is one of the key underpinning of SG. In literature, RESs are installed at three different premises, i.e. consumer level (roof top PVs and WTs), MG level and SG level. In spite of social and environmental benefits, these intermittent and random sources have some economical concerns with respect to the installment capacities and sites. RESs integration at different levels is categorically discussed in the subsections inscribed below.

3.1 Consumer Level

Some RESs i.e. PVs and WTs are integrated at consumer level in order to produce economical and environmental friendly electricity. This integration architecture is also called behind the meter integration. These sources require only one time investment, however, their power output is not always constant and varies with area, season and weather.

In [6], load scheduling and power trading problems under large share of RESs come under the focus in residential sector. Authors consider several smart homes with roof top PV panels as local generation units. The excess power is shared among different homes with energy deficit. Results prove the economical feasibility of small scale RESs installation. When a consumer actively participates in local energy generation, it becomes prosumer.

Similarly, a stochastic optimization approach is adopted in [7] to optimally schedule home appliances. The smart home is also connected to the main power house (i.e. SG or MG) to satisfy the load when power output form RESs is limited or unavailable due to certain reasons. Local RE is prioritized to utilize at the time of generation to avoid the frequent use of storage system. Integration of RESs at consumer level has been proved to be economical and sustainable at small scale to save electricity expense. Consequently, local RE generation also contributes in lowering the harmful emissions and reducing the burden on main power station.

3.2 MG Level

RESs integration at MG level is quite appealing and growing concept. Numerous architectures and techniques have been proposed to optimally schedule the operations of MG. Energy management and planning of MG system was rule based that imposes built-in or predefined operation techniques to follow, which itself is paradoxical to the optimal operation of RE. The analysis and sizing of RE with battery energy storage system is discussed in [8] and a hybrid model using MILP is proposed considering uncertainty and stochastic behavior of RE in residential MGs. One year available weather data is used to predict whether profile of next three years, and then is used to figure out, using MILP model, the optimal size of WTs, PVs and thermal load profile for residential buildings.

The major problem in implementation of RE powered MG is unavailability of a protection and control mechanism in both, grid connected and islanded mode.

In [9], authors highlight the malfunctioning in traditional protection schemes and propose a novel protection model for islanded mode of a MG. Different relays in combination with static switch are used to figure out the faults with time coordination features to ensure maximum selectivity. Line-to-line, line-to-ground and upstream outages are captured using negative sequence current, differential current and over current relays respectively, whereas, symmetrical faults, the worst types of faults that may cause breakdown of entire system, occur rarely and hence are triggered by under voltage relays. Another key concern is, if an additional feeder or line at any stage or location is added in MG, the pre-set time for all available relays will have to be adapted. Relays in proposed scheme are time coordinated; there is always a chance for faults to travel in MG within coordinated time, because fault currents travel very sharp in MG due to the small area of MG.

Integration of heating/cooling system into smart MG considering RESs is an open question in research for many years. An active controller is proposed in [10], which is responsible for merging the heating/cooling systems with RESs to reduce GHG emissions and energy expense. A parallel version of PSO is used as optimization technique to figure out optimal size of generation units of MG. This research improves reliability of MG and minimizes the aggregative cost of MG, size of RE resources and energy import from central power grid.

Real time energy storage management for RE integration in MG is considered in [11]. The authors used off-line algorithm for optimization and proposed a novel sliding window based on-line algorithm. The main objectives of research are to minimize the cost of power purchased from grid and maximize the penetration of intermittent RESs in MG. A model of RE offset with respect to load and time, named as net energy profile, conceived as limited errors prediction. Cost function was formulated by strictly convex function and optimization problem was solved using dynamic programming.

When large scale RESs are integrated into MG, it becomes necessary to monitor the system status for reliable and consistent operation of MG. An appropriate and suitable way of accurate state estimation is proposed in [12] with the hybrid combination of weighted least square (WLS) and firefly algorithm (FA). The algorithm reads the input data, converts constrained problem in adjacent unconstrained problem, generates random population, calculates objective function, improves population and checks the termination criteria to finish.

Large scale integration of RE into the power system requires optimality of involved sources to enhance and expand the power distribution capability of distribution networks. A dynamic energy management strategy is proposed in [13] where a cooperative interaction between distribution systems (connected to multiple grids) and generation systems is formulated. Twofold optimization of problem is expressed in distribution networks, where the first interaction is between MG and active distribution networks, whereas, other is among different MGs. On one hand, upper level provides benefits to prevent power fluctuations, voltage swell and sags and energy losses, whereas, on the other hand, lower level optimization deals with power losses and operational cost. Bi-level programming is used to explain the former and later is described by interactive energy game matrix (IEGM), newly proposed in this work.

3.3 SG Level

Cellular networks, SGs and RESs are assimilated into a new integration architecture in [14]. The motivation behind the idea is that the cellular communication industry is one of the dominant consumers of electricity with 0.5% of global energy consumption. The inevitably growing cellular companies and their users also contribute in carbon emissions, global energy cost, peaks at grid and many more. The proposed model is decomposed into two sub-domains 1) SG and 2) cellular networks. Cellular networks are integrated into the SG using smart meters

Table 1. Summarized results of papers surveyed.

Technique(s)	RESs	Feature(s)	Achievement(s)	Compromise(s)
[1] Dynamic programming and a game theoretic approach	Not mentioned	50 users 3 and 6 kW RE per user (2 cases)	Reduces electricity bill, better RESs utilization	User comfort and PAR, reverse power flow problem
[2] Certainty equivalent approximation technique	PV and WT	2 kW per hour (average)	Minimizes electricity payment and PAR	User comfort, computationally complex
[3] MILP	PV and WT	1250 kW PV 500 kW WT	Cost minimization, study effects of load flexibility	User comfort and PAR, computationally complex
[4] Newly proposed protection scheme	Not mentioned	Not mentioned	Fault protection, novel protection scheme	Time consuming, cannot be extended at large scale
[5] PSO	PV, WT and fuel cell	7.5, 1 and 1 kW	Cost minimization, optimal sizing	PAR, user comfort
[6] Sliding window based algorithm	WT	600 MW	Cost reduction, RESs integration to serve demand	User comfort, computationally complex
[7] Firefly algorithm and weighted least square method	PV and WT	120 kW	Reliable and accurate state estimation of MG to protect from faults	Increased cost, user comfort neglected
[8] NSGA-II and bi-level programming	PV and WT	Not mentioned	Cost minimization, MG quality enhancement	Complex architecture, compromised comfort
[9] Novel integration architecture	PV and WT	Not mentioned	Lower electricity cost, decrease peak consumption	Complex architecture, huge investment cost
[10] 100% RE powered SG	PV, WT, solar thermal, boiler, biogas, wave power, geo thermal	Not mentioned	Integration of RE in different sectors, minimized cost and fuel usage	Redesigning of all involved components at industry level

and inverters to allow bidirectional communication in order to reduce electrical bills and increase grid support. To ensure the aforementioned key benefits, local and mobile network operator (MNO) controllers are used in association with configuration controllers.

The feasibility of a 100% RE powered SG is discussed in [15], where the electricity, heating/cooling and transport sectors are merged in the SG. A storage system is also used to deal with the fluctuating behaviour of RESs. Authors present the design of a feasible, reliable and persistent smart energy system with integration of intermittent and uncertain RESs. Multidisciplinary synergies are formed for integration of RESs and different sectors are merged with each other for coherent operation of SG. Combined heat and power plants and district heating and cooling system are introduced which are responsible for providing heating and cooling loads to houses and other required places. Table 1 comprises of summarized results of the papers surveyed.

4 Variability of RESs

RESs are variable in power generation due to the couple of reasons. Plenty of work has been done to deal with the legacy stochastic nature of these economical power generation sources. The major causes of fluctuations in power output are described hereunder.

4.1 Area

Power production from RESs (i.e. PVs and WTs) heavily depends on the area where RESs are installed. RE generation from PVs and WTs is directly proportional to the solar radiations and wind speed. The earth has different levels of temperature and air density on its surface at different locations. So, RE generation from a similar size of PV or WT varies with respect to the area and location.

4.2 Season

The other thing which effects the RE harvesting is the season in that particular region. It has either positive or negative impact on power production. Typically, in summer, the sun results in massive solar radiations and the temperature becomes high through out the day. Consequently, PVs tend to generate maximum of their installed capacities. Moreover, the winter season is not positively correlated with PVs generation, however, WTs work more better in winter season than summer depending upon the installed capacities and area. WTs are usually preferred to locate near the corridors of oceans, deserts and rivers where wind speed has higher density.

4.3 Weather

The weather has its three common faces i.e. sunny, cloudy and rainy. These weather conditions severely impact on PVs and WTs generation. On a typical sunny day, PV panels generate more energy as compare to cloudy day. The rainy day may have no or very minimal power output due to no solar radiations. Whilst, sunny days usually do not cooperate well with WT generation, however, cloudy and rainy days propel wind speed which ultimately contributes in maximizing the output of WT. On the way around, when the wind speed crosses the rated wind speed limit it may result in breakdown of wind farm. WTs are brought to the rest and no more energy can be harvested because of excessive wind speed.

5 Economical and Environmental Aspects of RESs

Currently, transport sector is almost completely and electricity sector is partially but dominantly based on fossil fuels. These finite fossil fuels are decreasing and their prices are increasing day-to-day. This alarming situation demands considerable focus of energy policy makers to meet the inevitably growing needs of coming world. Alternatively, RESs have socio-economic benefits over traditional power generation sources. Energy generation using RESs has numerous economic benefits, some of which are inscribed below.

5.1 Economical Benefits

In developing countries like Pakistan, unemployment is one of the major concerns. RESs offer job creation and actively participate in growing the healthy economy. More people work in industry and the money circulates which in result strengthens the market as well. When we exchange this money among multiple hands, a multiplier effect comes into existence which contributes in local economy. People spend earnings to meet their daily life demands, this process also creates jobs at other sectors like restaurants, hotels, grocery, garments, as a few to mention.

In addition to the above, the increase of RE has a great impact on fuel usage. Fuels are the sources which are decreasing with time. RESs mitigate the use of fuels which not only save the fuels but also save cost.

5.2 Environmental Benefits

Fossil fuels dominate as a power generation sources in traditional power generation systems, and are considered one among the most greenhouse gas produces in society. The challenge is not only to reduce the greenhouse gas emissions but also to increase electricity generation in view of socio-economic aspects of generation, as the demand increases day-by-day. RESs are considered as future replacement with zero carbon emission and low price electricity producers. RESs are intermittent, uncertain and random in nature, they do not produce fixed amount of energy. RESs are zero GHG emissions electricity producers, however, a very minimal anthropogenic carbon dioxide emits from some RESs like biomass, etc.

6 Conclusion

RESs play a very important role in reducing the energy expense at consumer level and balancing the demand and supply at electricity grid level. Besides this, RESs also have environmental, social and geopolitical benefits. RESs are the future replacements to the conventional fossil fuel based energy generation sources. In this paper, we survey the trends of integrating RESs into the grid and consumer level. We figure out the feasibility of RESs installation at different premises and provide a comprehensive review of successful projects initiated across the globe. The variability of RESs is also inscribed based on literature discussed. Also different technologies used to deal with the fluctuating behavior of RESs are presented. Some new concepts of RESs and their fault protection concerns are unveiled. WTs are the dominating source used to harvest RE followed by the PVs. PVs are the future of power generation industry. Storage system is necessary to achieve maximum benefits from RESs.

References

1. Khoury, J., et al.: Review on the integration of photovoltaic renewable energy in developing countriesSpecial attention to the Lebanese case. Renew. Sustain. Energy Rev. **57**, 562–575 (2016)
2. Oree, V., Hassen, S.Z.S., Fleming, P.J.: Generation expansion planning optimisation with renewable energy integration: a review. Renew. Sustain. Energy Rev. **69**, 790–803 (2017)
3. Eltigani, D., Masri, S.: Challenges of integrating renewable energy sources to smart grids: a review. Renew. Sustain. Energy Rev. **52**, 770–780 (2015)
4. Abdmouleh, Z., Alammari, R.A.M., Gastli, A.: Review of policies encouraging renewable energy integration & best practices. Renew. Sustain. Energy Rev. **45**, 249–262 (2015)
5. Punda, L., et al.: Integration of renewable energy sources in southeast Europe: a review of incentive mechanisms and feasibility of investments. Renew. Sustain. Energy Rev. **71**, 77–88 (2017)
6. Samadi, P., Wong, V.W.S., Schober, R.: Load scheduling and power trading in systems with high penetration of renewable energy resources. IEEE Trans. Smart Grid **7**(4), 1802–1812 (2016)
7. Samadi, P., et al.: Utilizing renewable energy resources by adopting DSM techniques and storage facilities. In: IEEE International Conference on Communications (ICC), 2014. IEEE (2014)
8. Atia, R., Yamada, N.: Sizing and analysis of renewable energy and battery systems in residential microgrids. IEEE Trans. Smart Grid **7**(3), 1204–1213 (2016)
9. Akhtar, Z., Saqib, M.A.: Microgrids formed by renewable energy integration into power grids pose electrical protection challenges. Renewable Energy **99**, 148–157 (2016)

10. Hakimi, S.M., Moghaddas-Tafreshi, S.M.: Optimal planning of a smart microgrid including demand response and intermittent renewable energy resources. IEEE Trans. Smart Grid **5**(6), 2889–2900 (2014)
11. Rahbar, K., Jie, X., Zhang, R.: Real-time energy storage management for renewable integration in microgrid: an off-line optimization approach. IEEE Trans. Smart Grid **6**(1), 124–134 (2015)
12. Khorshidi, R., Shabaninia, F., Niknam, T.: A new smart approach for state estimation of distribution grids considering renewable energy sources. Energy **94**, 29–37 (2016)
13. Lv, T., Ai, Q.: Interactive energy management of networked microgrids-based active distribution system considering large-scale integration of renewable energy resources. Appl. Energy **163**, 408–422 (2016)
14. Hassan, H.A., Haj, A.P., Nuaymi, L.: Integrating cellular networks, smart grid, and renewable energy: Analysis, architecture, and challenges. IEEE Access **3**, 2755–2770 (2015)
15. Mathiesen, B.V., et al.: Smart Energy Systems for coherent 100% renewable energy and transport solutions. Appl. Energy **145**, 139–154 (2015)