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Generation of Hybrid Energy System (Solar-Wind) Supported with Battery Energy Storage

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Abstract: The utilization of renewable energy is significantly important for the world because global energy consumption is increasing, while conventional energy sources are no longer sufficient to meet the energy demand, triggering energy crises. In recent years, the increasing prices of fossil fuels and concerns about the environmental consequences of greenhouse gas emissions have renewed the interest in the development of alternative energy resources. Renewable energy is now considered a more desirable source of fuel than nuclear power due to the absence of risk and disasters [1]. Considering that the major component of greenhouse gases is carbon dioxide, there is a global concern about reducing carbon emissions. In this regard, different policies could be applied to reducing carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations. There are various of renewable energy sources such as Solar, biomass, wind, hydrogen, fuel cell, nanocomposite, and supercapacitor. Each of the energy sources are suitable for specific geographical locations and can suits from region to region. However, variation in solar radiation and wind speed caused by climate and weather conditions restricts the stable operation of renewable energy systems, therefore, causing the output to fluctuate. A hybrid renewable energy generation system can be highly efficient by combining multiple renewable energy sources and is regarded as a promising solution to overcome from this issue. Hybrid solar systems are the systems combining two renewable sources of energy, like solar and wind. Then, energy is generated through solar on sunny days and when there is limited sunshine but there is wind, energy can be generated through it. The study aims to focus on generation of hybrid solar-wind power plant with the optimal contribution of renewable energy resources supported by battery energy storage technology. The motivating factor behind the hybrid solar–wind power system design is the fact that both solar and wind power exhibit complementary power profiles. Advantageous combination of solar and wind with optimal ratio will lead to clear benefits for hybrid solar-wind power plants such as smoothing of intermittent power, higher reliability, and availability. However, the potential challenges for its integration into power grids cannot be neglected. A potential solution is to utilise one of the energy storage technologies, though all of them are still very expensive for such applications, especially at large scale. Therefore, optimal capacity calculations for energy storage system are also vital to realise full benefits. Currently, battery energy storage technology is considered as one of the most promising choices for renewable power applications. However, solar-wind power technology are most suitable for off-grid services, serving the remote are without having to build or extend expensive and complicated grid infrastructure. Therefor standalone system using renewable energy sources have become a preferred option. Hence hybrid energy systems are an ideal solution since they can offer substantial improvements in performance and cost reduction and can be tailored to varying end user requirements.

Keywords: Hybrid Power generation system, Renewable energy, methodology, unit sizing, optimization, storage, energy management.

I. INTRODUCTION

In this modern era, the entire world is focusing on economic and viable energy resources for the generation of power. The demand for power is increasing all over the world, and mostly power generation is through conventional energy sources. But in future, one day all these sources get deplete. Then, further no one can utilize these sources, so there is a necessity for alternate energy sources and a greener way to generate power [2]. Presently, renewable energy sources have such potential to replace them, and every nation is looking forward for better approach to utilize these sources for generating power. There are various of renewable energy sources such as Solar, biomass, wind, hydrogen, fuel cell, nanocomposite, and supercapacitor. Each of the energy sources are suitable for specific geographical locations and can suits from region to region. However, the harvest of renewable energy on a large scale and achieving maximum permeation of renewable energy sources in power systems is considered a cumbersome task. Variation in solar radiation and wind speed caused by climate and weather conditions restricts the stable operation of renewable energy systems, therefore, causing the output to fluctuate.

Hybrid systems, as the name implies, combine two or more modes of power generation together, usually using renewable technologies such as solar photovoltaic (PV) and wind turbines. Hybrid systems provide a high level of energy security through the mix of generation methods, and often will incorporate a storage system (battery, fuel cell) or small fossil fueled generator to ensure maximum supply reliability and security [3]. Reducing emissions and moving towards decarbonizing energy are two fundamental objectives for safeguarding the planet. To achieve this, combining the most competitive renewable energies, as wind and solar energy, in hybrid installations — that can be complemented by storage systems — is proving to be an effective tool for delivering clean and efficient energy [4].

In recent years, the availability of solar panels at cheaper prices has contributed toward the emergence of solar photovoltaic (PV) power to be a leading incipient technology of renewable energy domain [5, 6]. However, the integration of PV power into local power grids poses several challenges due to its intermittent nature. The problems encountered due to the use of solar power include generation of unwanted harmonics in the voltage and current, deviations of voltages in distribution feeders, and flickers. Thus, it is necessary to study the effects of PV penetration and discuss solutions so as to deliver solar power in a substantial amount at the highest possible reliability and efficiency at an affordable cost. Similarly, the power obtainable from wind has also revealed a profligate growth rate [7]. However, the integration of wind power at local levels poses power quality, reliability, and protection issues which are required to be addressed in order to deliver efficient wind power at an affordable cost [8]. The operation of interconnected grids is also affected due to fluctuating power output of wind farms. Intermittent nature of wind power has limited its maximum penetration in power networks.

A proficient solution for the integration of renewable energy sources into the power grid is the use of energy storage systems (ESSs) [9–14]. Several types of ESSs are available nowadays including battery energy storage system (BESS), fuel cells, super capacitors, and flywheel-based storage systems [15–17]. Nonetheless, the affordability of these ESSs is still an area of concern. Among the available technologies, battery ESS (BESS) is considered as one of the most promising choices for renewable energy systems. The working principle of a BESS is found on storing surplus energy in the periods of excess energy production as compared with the demand and feeding power back to the grid when needed. Thus, the renewable power system can be made more economical by optimizing the cost and size of BESS. This can be achieved by: (i) selection of less expensive storage type; (ii) minimization of storage size; (iii) and development of efficient dispatching procedures [18].

Determining optimal BESS capacity, however, is a challenging task due to the irregular nature of wind and solar powers. If the storage system is over dimensioned, it leads to an unnecessary elevation in the installation capacity cost as well as the operational cost. On the other hand, if the storage system is less than the required size, it will result in power outages, hence making the system less reliable. Therefore, there is a tradeoff between system reliability and costs, which can only be addressed by the development of efficient capacity estimation techniques for the BESS. Numerous research works have been carried out in this regard for optimal sizing of storage systems along with the generation units such as wind and solar PV plants [19–23]. The complementary nature of these resources is utilized for determining the optimal capacity of a BESS. However, there is a lot of room for novel research ideas in this field for minimizing the operational costs and maximizing profits.

II. CONFIGURATION OF HYBRID POWER GENERATION SYSTEM

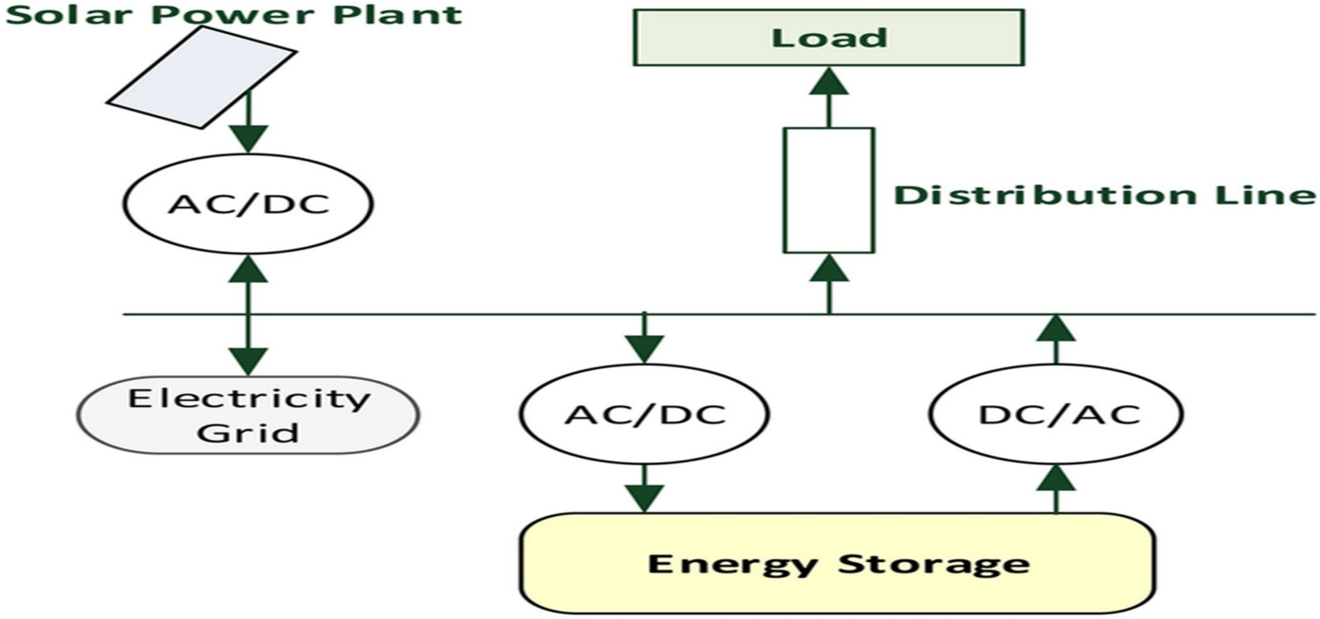
Hybrid power generation configurations involving wind and solar power sources have attracted much attention [24–26], recognized as an option of delivering power to remote locations. Complementary power production features of RE sources have contributed to the growth of hybrid generation systems [25]. It is a tedious task to integrate the un-controllable RE resource into an existing design of an electrical power grid [28–30]. These issues have utmost importance for the delivery of renewable power at an affordable cost such that the reliability and stability of the power grid are not affected adversely.

The hybrid wind–solar structure offers several basic advantages due to the complementary power profiles of both wind and solar. Since the continuous supply from these intermittent power sources is not guaranteed; a BESS is used to support the renewable power plants or as backups as mentioned earlier; however, the size of BESS is always a concern due to high cost. Therefore, the main contribution of this work is to present a strategy for joint planning and optimization of the wind–solar mix for the hybrid power plant along with the optimal capacity of BESS to meet the load demand at the given location. Many recent research works can be found targeting the wind–solar complementarity assessment [13, 27] and optimal sizing of BESS separately [9, 18] but the simultaneous planning of a complete power system using both of these concepts is an innovative phenomenon that still has room for contribution. In summary, our research targets the following main points directly or indirectly:

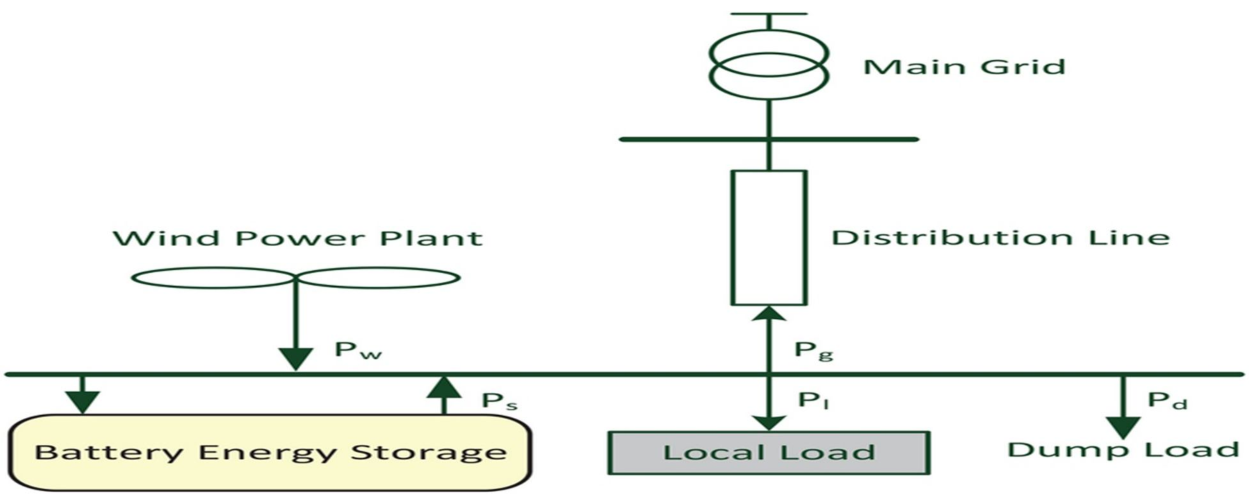
1) Renewable resource assessment for combined solar and wind.
2) Optimal allocation of the renewable power mix.

3) Optimal energy storage system.
4) Cost optimization.
5) Reliability enhancement.
6) Risk mitigation.

Nowadays, stand-alone systems with solar and wind resources are receiving full attention over the globe at larger scale comparatively [31]. However, such plants cannot produce reliable power independently owing to the seasonal characteristics of solar and wind power. For instance, the power generation from the stand-alone solar system is not available during non-sunny days. In the same manner, the power obtainable from a stand-alone wind system has significant fluctuations, and hence cannot meet constant load requirements. Additionally, there occur deviations in system frequency and power outages when the wind power integration is significant. To mitigate these issues, a BESS is attached to the system.

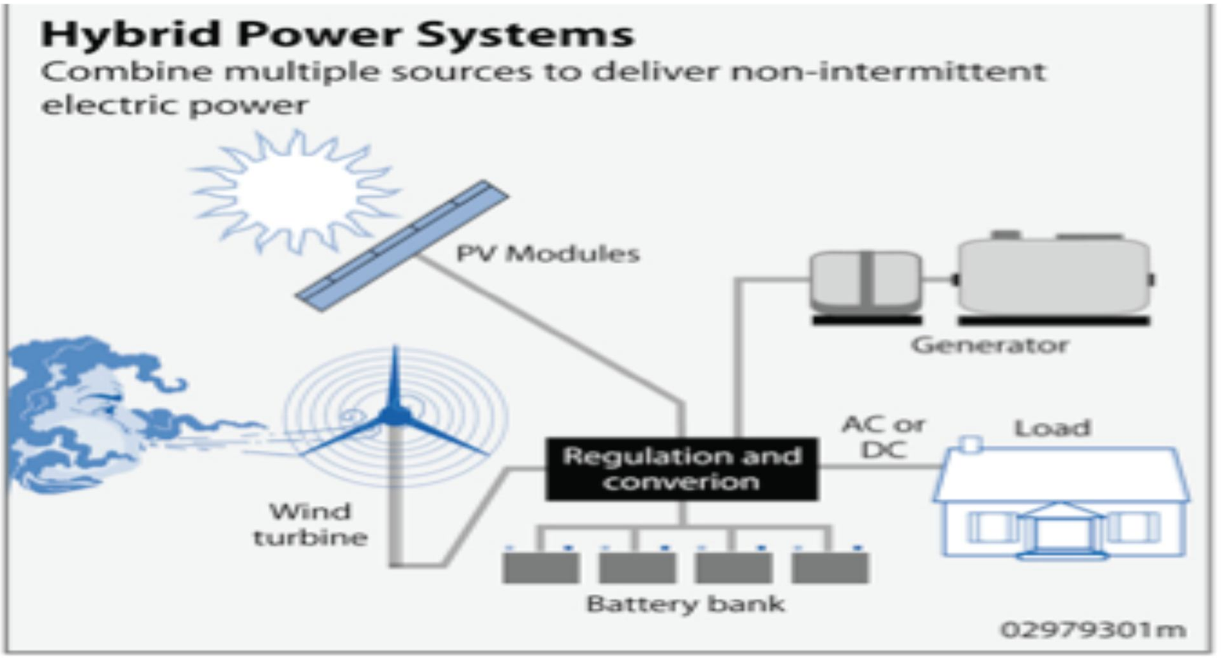


Stand-alone solar systems employing energy storage in Figs. 1 [32]



Stand-alone wind systems employing energy storage in Figs 2 [32]

However, the benefits of ESS come at a price, and the cost efficiency of hybrid renewable systems depends largely on the cost of storage system because the storage technologies are generally expensive. Therefore, the solution is to use hybrid RE systems and employ a common optimal BESS capacity, i.e. minimum energy storage requirements to supply the demand reliably at all times along with given RE resources.



Schematic diagram of hybrid PV/wind system with battery storage Figs. 3 [33]

III. APPLICATIONS OF HYBRID POWER GENERATION SYSTEM

The characteristics and components of a hybrid system depend greatly on the application. The most important consideration is whether the system is isolated or connected to a central utility grid [34-36].

A. Central Grid Connected Hybrid Generation System

If the hybrid system is connected to a central utility grid, as in a DG application, then the design is simplified to a certain degree and the number of components may be reduced. This is because the voltage and frequency are set by the utility system and need not be controlled by the hybrid system. In addition, the grid normally provides the reactive power. When more energy is required than supplied by the hybrid system the deficit can be in general be provided by the utility. Similarly, any excess produced by the hybrid system can be absorbed by the utility. In some cases, the grid does not act as an infinite bus, however. It is then said to be ‘‘weak.’’ Additional components and control may need to be added. The grid connected hybrid system will then come to more closely resemble an isolated one.

B. Isolated Grid Hybrid Generation Systems

Isolated grid hybrid systems differ in many ways from most of those connected to a central grid. First, they must be able to provide for all the energy that is required at any time on the grid or find a graceful way to shed load when they cannot. They must be able to set the grid frequency and control the voltage. The latter requirement implies that they must be able to provide reactive power as needed. Under certain conditions, renewable generators may produce energy in excess of what is needed. This energy must ben dissipated in some way so as not to introduce instabilities into the system. There are basically two types of isolated grid hybrid systems which include a renewable energy generator among their components. These are known as low penetration or high penetration. In this context, ‘‘penetration’’ is defined as the instantaneous power from the renewable generator divided by the total electrical load being served. Low penetration, which is on the order of 20% or less, signifies that the impact of the renewable generator on the grid is minor, and little or no special equipment or control is required. High penetration, which is typically over 50% and may exceed 100%, signifies that the impact of the renewable generator on the grid is significant and special equipment or control is almost certainly required. High-penetration systems may incorporate supervisory control, so-called dump loads, short term storage, and load management systems. Two important considerations in an isolated system are whether the system can at times run totally on the renewable source (without any diesel generator on) and whether the renewable source can run in parallel with (i.e., at the same time as) the diesel generator. It is most common for one or the other to be possible (and normal). It is less common that both modes of operation are possible. This latter system offers the greatest fuel savings but is more complicated [35].

C. Isolated Or Special Purpose Hybrid Generation System

Some hybrid systems are used for a dedicated purpose, without use of real distribution network. These special purposes could include water pumping, aerating, heating, desalination, or running grinders or other machinery. Design of these systems is usually such that system frequency and voltage control are not major issues, nor is excess power production. In those cases, were energy may be required even when renewable source be temporarily unavailable, a more conventional generator may be provided. Renewable generators in small isolated systems typically do not run in parallel with a fossil fuel generator.

IV. CONTROL OF HYBRID POWER GENERATION SYSTEM

Hybrid energy system has complex control system due to integration of two or more different power sources. The dynamic interaction between the power electronic interface of renewable energy sources leads to problems of stability and power quality in the system, which makes the control difficult and complex. Because of the nonlinear power characteristics, wind and PV system require special techniques to extract maximum power. Hence, the complexity of HES control system increases with maximum power point tracking (MPPT) techniques employed in their subsystems. MPPT tracking has to be done for individual subsystems. The performance analysis of HES can only be evaluated after performance analysis of individual system. A HES can be standalone, or grid connected. Standalone systems, besides the generation capacity, need to have additional storage capacity large enough to handle the load. In a grid connected system, the storage device can be relatively smaller as deficient power can be obtained from the grid. A grid connected HE Scan supply power to both load and the utility grid. However, when connected to grid, proper power electronic controllers are required to control voltage, frequency and harmonic regulations, and load sharing. During operation hybrid wind-solar system is subjected to fluctuating wind speeds and solar insolation as well as to varying load demand. Hence a controller is essential to determine how much energy is available from each component and how much to use of it. The operation policy for standalone wind-solar hybrid system should employ the available energy from the wind turbine and solar panel in each sub-period to use first and excess energy to be stored in batteries. If the renewable energy is not sufficient to supply the load in a given sub-period, then energy is drawn from battery storage first and then through diesel generator (if available). In case of systems where diesel generator is available, batteries act as fuel saver, and they are used prior to diesel engine. The operation policy in case of grid connected hybrid system should exploit renewable energy first and excess energy if available should be stored in batteries. However, if excess energy is still available, then it should be sold to the grid. If renewable energy is not sufficient to supply the load in a given sub-period, then batteries should be employed first and grid power should be used if deficiency still exists. The battery in grid connected system store the surplus power from power generation system, so only small power from the grid is needed [37-39]

V. MODELLING OF THE SOLAR-WIND GENERATION SYSTEM COMPONENTS

A solar wind hybrid system consists of PV array, Wind turbine, battery bank, inverter, controller and other devices and cable. To satisfy the load demand PV array and wind turbine works together. The maximum available power can be extracted from the PV and Wind power sources depending on battery charger technology. In case of low wind speed or irradiation condition battery bank is use to store the energy surplus and to supply. For a wind solar hybrid system, as shown in Fig.3, three principal subsystems are included, the PV generator, the wind turbine and the battery storage.

A. Modelling of PV Generator

Weather data play as important role in PV module performance, especially solar radiation and PV module temperature. The models describing the PV module's maximum power output behaviors are more practical for PV system assessment, as the operation and the performance of PV generator is interested to its maximum power.

A mathematical model for estimating the power output of PV modules is used. Using the solar radiation available on the tilted surfaces, the ambient temperature and the data from manufact- urers for the PV modules as model inputs, the power output of the PV generator, P_{PV} , can be calculated with the following equations [40].

$P_{PV} = \eta_g NA_m G_t$

Where ηg - Instantaneous PV generator efficiency, A_m - Area of a single module used in a system (m2), G_t - Global irradiance incident on the titled plane (W/m2) ,

N- Number of modules.

Whereas all the energy losses in a PV generator, including connection losses, wiring losses and other losses, are assumed to be zero.

B. Modelling Of Wind Generator

It is very important for wind solar hybrid system to choose a suitable wind turbine. There are three main factors that determine the power output of a wind turbine, ie, the power output curve (determined by aerodynamics power efficiency, mechanical transmission and converting power efficiency) of a chosen WG, the wind speed distribution of a selected site where the wind turbine is installed, and the tower height [41-43] taken on that the turbine power curve has a linear, quadratic or cubic form approximate the power curve with a piecewise linear function with a few nodes. As the installation height of the wind turbine has a large effect on the energy available from the system, the process of adopting of the wind profile for height can be taken into account by using an equation of height adjustment. In this study, the power law is applied for the vertical wind speed profile, as shown in equation below [41].

$V/Vr = V_r\,(H/Hr)^{\alpha 1}$

Where, V Wind speed at hub height H , Vr Wind speed measured at the reference height Hr and $\alpha 1$ Wind speed power law exponent.

Wind speed power law expansion which varies from (> 0.10) for very flat land, water or ice to more than 0.25 for heavily forested landscape. The oneseventh power low (0.14) is a good reference number for relatively flat surfaces such as open terrain of grasslands away from tall trees or building [44].

C. Modelling of Battery Storage

To regulate system voltage and to supply power to load in case of low wind speed or low solar radiation, a battery bank is used which is usually made of the leadacid type to store surplus electrical energy. During the charging process, when the total output of PV and wind generators is greater than the load demand, i.e. when power generation cannot satisfy load demand requirement, the available battery bank capacity at hour t can be described by [45]:

$Cbat(t) = Cbat\,(t-1).(1- \sigma) + [Epv\,(t) + EWG\,(t) – \{EL\,(t)/\ \eta iNV\}]\eta bat$

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as:

$Cbat(t) = Cbat\,(t-1).(1- \sigma) - [EL\,(t)/\ \eta iNV – \{EPV\,(t) – \{EWG\,(t)\}\}]$

Where, Cbat (t) and Cbat (t-1) are available battery bank capacity (Wh) at hour t and t1, respectively;

ηbat = the battery efficiency (during discharging process, the battery discharging efficiency was set equal to 1 and while charging, the efficiency is 0.65 to 0.85 depending on the charging current) ,σ = selfdischarge rate of the battery bank.

VI. SYSTEM SIZE OPTIMIZATION

The required number of Wind generators, PV modules and batteries for a given load demand are calculated as follows: Calculate the hourly energy output from individual wind generator and PV module for a typical year using wind speed and solar insolation of the site In order to match the generation with the given hourly load of a year, different combination of wind generator and PV module is used. There will be energy deficit during several consecutive hours in between the hours of excess energy generation for each of the combination. This cluster of energy deficit cannot be supplies by renewable sources. The combination of wind generator and PV module is selected which minimizes the maximum deficit. The amount of maximum deficit is used to determine the storage size ie. the size of the battery. Loss of power supply probability (LPSP) and 10-years total cost of the hybrid renewable power system are calculated for each of these combinations. Optimal combination is selected based on desired LPSP and minimum total cost of the system [46,47].

VII. CONCLUSION

The use of solar-wind hybrid renewable energy system is ever-increasing day by day and has shown incredible development in last few decades for electricity production all over the world. The solar-wind hybrid renewable energy is attracting more attention because they can become more economical, environmentally cleaner, and can be installed in a distributed fashion. A challenge with solar and wind resources is their intermittency and not constantly available; usually they are complemented by storage batteries. The proper sizing of system elements results in the efficient utilization of the power from the renewable sources and the battery bank. Various significant aspects of system, such as configuration, application, control, modeling, unit sizing and optimization of system are specifically focused on generation of hybrid solar-wind power plant. Future trends include cutting edge technology development to increase the efficiency of such hybrid systems and encouragement in terms of its implementation.

Hybrid renewable energy system has an immense potential to meet the load demand of remote, isolated sites and can contribute significantly to both rural as well as urban development. This in turn reduces the central generation capacity and increases overall system reliability. Hybrid energy system units can supply uninterrupted power at zero emission level, which is the major advantage of such systems. The widespread use of hybrid renewable energy systems will not only solve the energy issues but also ensure a green and sustainable planet.

REFERENCES

[1] Shahrouz Abolhosseini, TEMEP, Seoul National University Almas Heshmati, Sogang University, Jönköping University and IZA Jörn Altmann; TEMEP, Seoul National University- Renewable Energy Supply and Energy Efficiency Technologies, IZA DP No. 8145 April 2014
[2] Singh J (2016) Identifying an economic power production system based; Renew Sustain Energy Rev 60:1140–1155 Received: 11 June 2020 / Accepted: 12 August 2020 / Published online: 7 September 2020
[3] Kamal, Mohasinina Binte; Mendis, Gihan J.; Wei, Jin (2018). "Intelligent Soft Computing-Based Security Control for Energy Management Architecture of Hybrid Emergency Power System for More- Electric Aircrafts [sic]". IEEE Journal of Selected Topics in Signal Processing. 12 (4): 806. Bibcode:2018ISTSP..12..806K.
[4] https://www.iberdrola.com/innovation/hybrid-energy
[5] Mason, N.B.: 'Solar PV yield and electricity generation in the UK', IET Renew. Power Gener. 2016, 10, (4), pp. 456–459
[6] Dincer, F.: 'The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy', Renew. Sustain. Energy Rev., 2011, 15, (1), pp. 713–720
[7] Dincer, I., Acar, C.: 'A review on clean energy solutions better sustainability', Int. J. Energy Res., 2015, 39, (5), pp. 585–606
[8] Dunbar, A., Wallace, A.R., Harrison, G.P.: 'Energy storage and wind power: sensitivity of revenue to future market uncertainties', IET Renew. Power Gener., 2016, 10, (10), pp. 1535– 1542
[9] Lai, C.S., McCulloch, M.D.: 'Sizing of stand-alone solar PV and storage system with anaerobic digestion biogas power plants', IEEE Trans. Ind. Electron., 2017, 64, (3), pp. 2112–2121
[10] Kim, I.: 'Markov chain Monte Carlo and acceptance–rejection algorithms for synthesising short-term variations in the generation output of the photovoltaic system', IET Renew. Power Gener., 2017, 11, (6), pp. 878–888
[11] Baker, K., Guo, J., Hug, G., et al.: 'Distributed MPC for efficient coordination of storage and Renewable energy sources across control areas', IEEE Trans. Smart Grid, 2016, 7, (2), pp. 992–1001
[12] Khalid, M., Savkin, A.V: 'A method for short-term wind power prediction with multiple observation points', IEEE Trans. Power Syst., 2012, 27, (2), pp. 579–586
[13] Solomon, A.A., Kammen, D.M., Callaway, D.: 'Investigating the impact of wind–solar complementarities on energy storage requirement and the corresponding supply reliability criteria', Appl. Energy, 2016, 168, pp. 130–
[14] Zhao, H., Wu, Q., Hu, S., et al.: 'Review of energy storage system for wind power integration support', Appl. Energy, 2015, 137, pp. 545–553
[15] Dragičević, T., Lu, X., Vasquez, J.C., et al.: 'DC microgrids – part II: a review of power architectures, applications, and standardization issues', IEEE Trans. Power Electron., 2016, 31, (5), pp. 3528–3549
[16] Hannan, M.A., Hoque, M.M., Mohamed, A., et al.: 'Review of energy storage systems for electric vehicle applications: issues and challenges', Renew. Sustain. Energy Rev., 2017, 69, pp. 771–789
[17] Cabrane, Z., Ouassaid, M., Maaroufi, M.: 'Battery and supercapacitor for photovoltaic energy storage: a fuzzy logic management', IET Renew. Power Gener., 2017, 11, (8), pp. 1157–1165
[18] Harsha, P., Dahleh, M.: 'Optimal management and sizing of energy storage under dynamic pricing for the efficient integration of renewable energy', IEEE Trans. Power Syst., 2015, 30, (3), pp. 1164–1181
[19] Energy storage for remote area renewable energy systems', Appl. Energy, 2015, 153, pp. 56–62
[20] Zhang, X., Yuan, Y., Hua, L., et al.: 'On generation schedule tracking of wind farms with battery energy storage systems', IEEE Trans. Sustain. Energy, 2017, 8, (1), pp. 341–353
[21] Lakshmanan, M., Rao, S., Sivakumaran, N., et al.: 'A control strategy to enhance the life time of the battery in a stand-alone PV system with DC loads', IET Power Electron., 2017, 10, (9), pp. 1087–1094
[22] Savkin, A.V, Khalid, M., Agelidis, V.G.: 'A constrained monotonic charging/ discharging strategy for optimal capacity of battery energy storage supporting wind farms', IEEE Trans. Sustain. Energy, 2016, 7, (3), pp. 1224–1231
[23] Liu, F., Giulietti, M., Chen, B.: 'Joint optimisation of generation and storage in the presence of wind', IET Renew. Power Gener., 2016, 10, (10), pp. 1477–1487
[24] Kotra, S., Mishra, M.K.: 'A supervisory power management system for a hybrid microgrid with HESS', IEEE Trans. Ind. Electron., 2017, 64, (5), pp. 3640–3649
[25] Wang, S., Tang, Y., Shi, J., et al.: 'Design and advanced control strategies of a hybrid energy storage system for the grid integration of wind power generations', IET Renew. Power Gener., 2014, 9, (2), pp. 89–98
[26] Nguyen, C.-L., Lee, H.-H.: 'Effective power dispatch capability decision method for a wind- battery hybrid power system', IET Gener. Transm. Distrib., 2016, 10, (3), pp. 661–668
[27] Monforti, F., Huld, T., Bódis, K., et al.: 'Assessing complementarity of wind and solar resources for energy production in Italy. A Monte Carlo approach', Renew. Energy, 2014,
[28] Perera, A.T.D., Nik, V.M., Mauree, D., et al.: 'Electrical hubs: An effective way to integratenon-dispatchable renewable energy sources with minimum impact to the grid', Appl. Energy, 2017, 190, pp. 232–248

[29] Koraki, D., Strunz, K.: 'Wind and solar power integration in electricity markets and distribution networks through service-centric virtual power plants', IEEE Trans. Power Syst., 2018, 33, (1), pp. 473–485

[30] Khatamianfar, A., Khalid, M., Savkin, A.V, et al.: 'Improving wind farm dispatch in the Australian electricity market with battery energy storage using model predictive control', IEEE Trans. Sustain. Energy, 2013, 4, (3), pp. 745– 755

[31] Renewables 2012 Global Status Report: 'Renewable Energy Policy Network for the 21st Century', 2012

[32] Mohammed AlMuhaini,Ricardo P. Aguilera,Andrey V. Savkin ; First published: 25 September 2018 https:// doi.org/ 10.1049/ iet-rpg.2018.5216

[33] US Department of Energy, Small "Hybrid" Solar and Wind Electric Systems (Washington,D.C., US Government, 2011).

[34] Manwell, J. F., Rogers, A. L., and McGowan, J. G. (2002). ''Wind Energy Explained: Theory,Design and Application.'' John Wiley & Sons, Chichester, United Kingdom.

[35] Hunter, R., and Elliot, G. (1994). ''Wind-Diesel Systems.'' Cambridge University Press, Cambridge, United Kingdom.

[36] Lundsager, P., Binder, H., Clausen, H-E., Frandsen, S. Hansen, L., and Hansen, J. (2001). ''Isolated Systems with Wind Power.'' Riso National Laboratory Report, Riso-R-1256 (EN),Roskilde, Denmark, www.risoe.dk/rispubl/VEA/veapdf/ris-r-1256.pdf.

[37] S. Nikolić and V. Katić, "Hybrid system of renewableenergy sources", Infoteh-Jahorina,Vol. 9, 210, pp.404 -408

[38] S. Diaf, G. Notton, M. Belhamel, M. Haddadi, and A.Louche, "Design and Techno-EconomicalOptimization for Hybrid PV/Wind System under Various Meteorological Conditions," Applied Energy, Vol. 85, pp. 968-987, 2008.

[39] T. Markvart, Solar Power, John Wiley & Sons,2000. [Control4] W. Shi, C. W. Kim, C. Chung, and H. Park, " DynamicModeling and Analysis of a Wind Turbine Drivetrain using the Torsional Dynamic Model," International journal of precision engineering and manufacturing,Vol. 14, No. 1, 2013, pp. 153-159

[40] Markvard T. 2000. Solar electricity, the second ed, USA. Willey.

[41] Ilinka, A., McCarthy, E., Chaumel, JL., Retiveau, JL. 2003. Wind potential assessment of Quebec Province. Renewable Energy 28(12),1881-1897.

[42] H. Yung el at. 2008. Optimal sizing method fro standalone hybrid solar-wind system with LPSP technology by using genetic algorithm.

[43] Chedid, R ., Rahman, S. 1998. A decision support technique for the design of hybrid solar wind power systems. IEEE Transactions on Energy Conv. 13(1), 76-83.

[44] Gipe, Paul, 1995. Wind energy comes of Age. John Wiley & sons,p.536.

[45] Bogdan, S. B. and Salameh, Z. M. 1996. Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. IEEE Transactions on Energy Conv. 11(2), 367-375.

[46] Nelson, D.B, Nehrir, M. H., Wang. C. 2005. Unit Sizing of Stand Alone Hybrid Wind /PV/Fuel Cell Power Generation Systems.IEEE Power Engineering Society General Meeting (3), 2116-

[47] Protogeropoulos C, Brinkworth BJ, Marshall RH. 1997. Sizing and techno-economical optimization for hybrid PV/wind power systems with battery storage. Int J. Energy Res. 21, 465-479.