IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 6, June 2021

DOI: 10.17148/IARJSET.2021.86129

Applications of Energy Storage Systems in Power Systems with high penetration of RERs

Aditya Kumar Dixit[1] , Awadhesh Kumar[2]

Department of Electrical Engineering,

Madan Mohan Malaviya University of Technology, Gorakhpur, India

***Abstract*—** Many countries have provided new power regulations that encourage renewable energy resources as a result of public awareness of the need to reduce pollution and, as a result, a significant increase in the costs of conventional electricity resources. Wind, solar, and hydro mainly based energy, examples of renewable electricity resources. These are eco-friendly and can be used more widely. In comparison to single-use of such structures, combining these renewable power assets with backup devices to build a hybrid system can provide a more cost-effective, environmentally friendly and reliable energy distribution in all load demand conditions. Energy storage systems (ESS) provide lots of benefits, including controlling production and consumption, as well as improving electricity quality smoothing the intermittency of renewable resources, and allowing supplementary services like frequency and voltage management in micro grid (MG) operation. Hybrid energy storage (HESSs), which are characterized by the coupling of two or more different storage methods, have developed as a solution for achieving the desired performance by implementing the acceptable capabilities of several technologies. Because of its restricted functionality and potency in terms of lifespan, cost, electricity and energy density, and dynamic reaction, a single ESS technology cannot do the necessary operation. As a result, unique HESS configurations based on storage type, interface, control technique, and thus the provided service have been offered in the literature. This study examines the state of the art of HESSs device for MG in detail and provides a popular perspective on the growing HESS market. The capability sizing methodologies, a topology of the power converter for the HESS interface, architecture, control, and electricity regulation of HESS in MGs are described, all evaluated and classed as important features of HESS utilization in MGs. A financial analysis is also included, as well as a design approach, to help investors and distribution system engineers understand the HESS. Based on the research analysis and observed limitations, major developments in HESS in MGs are suggested.

Keywords— Scalability, Hybrid technology, Optimization, Renewable energy

1. INTRODUCTION

Nowadays, the globe faces a major challenge in order to fulfill one of society's most basic needs: Energy. Coal, natural gas, and petroleum products are currently the most common sources of energy, and others supply a large share of the world's energy needs [1], [2]. Furthermore, energy requirements are growing at an exponential rate, resulting in a significant increase in the demand for traditional fossil fuels [3]. By 2050, the International Energy Agency estimates a 125 to 130 percent increase in CO2 emissions and a seventy percent rise in oil consumption if no changes in energy policy are made, resulting in a 6°C increase in global average temperature[1]. Renewable energy sources (RESs) they most effective way to overcome these issues. Wind and solar power technology are commonly used to generate electricity. The cumulative wind and photovoltaic (PV) developed capacity around the world shows in Figure 1. In 2017, the total production world of wind was 539 GW and PV 401 GW in the world [2].

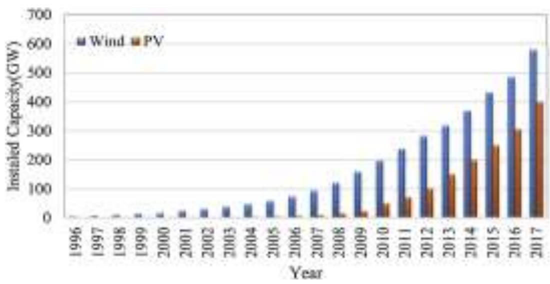

Figure1. PV and wind installed capacities.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 6, June 2021

DOI: 10.17148/IARJSET.2021.86129

With an expanding trend, to transmit electrical power consumption and decreased greenhouse gas emissions, renewable energy sources have been widely used. The intermittent nature of clean energy sources has a negative impact on power generation, posing a difficulty for ensuring an uninterrupted moreover, consistent supply of power to consumers, endangering grid several operational and technical problems in operations. Micro grid (MG) is proposed as a cluster of loads and distributed generating (DGs) that may operate in both island mode and grid-connected modes to maximize the benefits of RES. An ESS could help with RES integration into the MG by smoothing RES variations, improving power quality, and providing to frequency and other ancillary services. [3].To store electrical energy, the ESS structure employs a variety of storage technologies [[4], [5], [6]]. The most essential storage methods in power systems and MGs are illustrated in Figure 2. In this paper, the classification of various electrical energy storages, as well as their energy conversion process and efficiency, has been analyzed [7]. Batteries are widely accepted as one of the most significant and effective strategies to keep electrical networks stable [8]. They are appealing they are cost-effective, compact, and simple to deploy. A battery is made up of many different cells are linked in parallel and series and converts chemical energy into electrical energy and vice versa using a chemical process. For MG applications, a variety of battery technologies can be used. Figure 2 depicts the possibilities of various battery technologies both in terms of power and energy density Air compressor and pumped hydro energy storage are two ESSs that can serve large-scale energy storage uses [9]. Pumped hydro energy storage is highly dependent on certain geographic and environmental factors, making its development extremely difficult [10]. Electromechanical energy storage is provided by a flywheel energy storage system [[11], [12], [13]] A back-to-back converter, an electric generator, and a massive disc, and a DC bus capacitor combine up this system. However, mechanical components in this form of the storage system can impair efficiency and stability. A superconducting thrust It is proposed to include a systems for flywheel energy storage with minimum loss and maintenance costs in order to overcome various difficulties with the flywheel [14], The levitation force is provided by one made completely of permanent magnets, while the stabilizing is provided by the other, which is made up of a permanent magnet and a superconductor. Supercapacitors (SCs) are electrostatic storage devices that have a high durability ratio and a high power density [15]. One of the few technologies for storing direct electric energy is superconducting magnetic energy storage (SMES). A cooling system, a superconducting coil, and an electrical and control system cover the SMES that allows for current adaptability and process optimization [16].

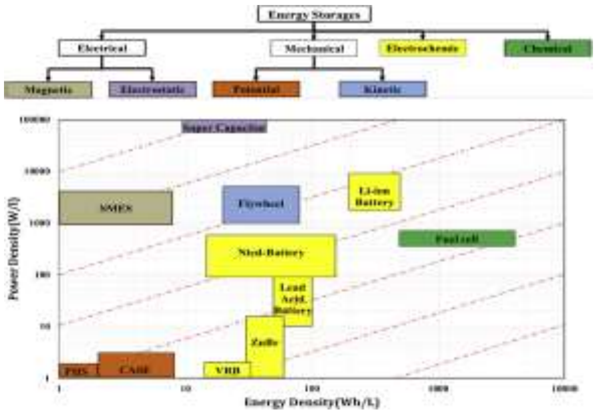

Figure 2. Energy storages classification.

Energy storage solutions have two key characteristics: power density and energy density. Figure 2 compares and shows the power and energy density of several energy storages. Because the dynamic response of ESS technologies with low power density but high energy density, such as batteries and fuel cells (FCs), poses power control problems. In contrast, technologies such as SCs and flywheels can provide a high power requirement, reducing the storage system's lifespan [17]. None of the available storage solutions can simultaneously meet both power and energy density. Due to technological limits in storage, it is frequently important to optimize the transient and steady state capabilities of a hybrid energy storage system (HESS) [18, 19]. For secure and optimal operation of the MG, appropriate technologies and control approaches should be coupled. In MG, the overall design of a HESS is determined by four interdependent factors: storage technology and rated capacity, power converter topology, energy management, and control approach, all of which must be carefully considered. The HESS has been used to deliver a number of review papers. The majority of review studies in the literature focus on HESSs in electric vehicles [6,[19], [20], [21], [22]] and some of the concentrate on HESS in the renewable energy sector [3,23,24] and MGs [17,25]. Most of the review papers look at converter topologies, control approaches, and applications. However, none of them goes into great length on the hybrid MGs and RESs are two types of storage. In addition, novel control strategies for HESS control have been developed in recent studies. The classification and analysis of HESS ability sizing methods has not been done in prior studies, and this work addresses and classifies them comprehensively. The following are the paper's major benefits:

- In the MGs field, it examines many operational and technical elements of hybrid storage areas and gives a general and comprehensive viewpoint on state-of-the-art developments.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 6, June 2021

DOI: 10.17148/IARJSET.2021.86129

- HESS sizes, HESS applications in MGs, HESS setups and connections, and HESS control methods are all covered in this comprehensive study of HESS for MGs applications.
- Control techniques, design capacity methodologies, and power converter designs are analyzed.
- A conceptual flowchart for correlating the various portions of HESS for use in MGs.
- Based on the literature and existing problems, future trends in HESS and research needs technologies are presented.

2. ADVANTAGES AND APPLICATIONS OF HYBRID ENERGY STORAGE SYSTEMS

As previously indicated, MGs and RESs have Intermittency, poor power quality, stability, frequency regulation, and an unbalanced load are all challenges. In a standard MG, the ESS is exposed to an unique and frequent discharging/charging cycle, reducing the ESS lifespan and greatly increasing the ESS replacement cost [26]. HESS is an appropriate technique for dealing with MGs and RESs. In recent years, numerous researches have been conducted with the purpose of establishing the beneficial benefits of HESS on RESs [[27], [28], [29]]. Various energy storages can be employed as a HESS depending on the hybridization's target. The HESS is made up of two components: high-power storage (HPS) and high-energy storage (HES), with the HPS absorbing or delivering long-term energy resources, transient and peak power, and the HES [30, 31]. MGs and RES advantage from HESSs in a variety of ways, including increased overall system efficiency, lower system costs, and longer ESS lifespan [32]. A wide range of energy storage hybrids can be developed due to the various types of energy storage technologies with varied properties. Figure 3 shows a combination of storage technologies that can be utilized for a variety of purposes [6]. A wide range of energy storage hybrids can be developed due to the various types of energy storage technologies with varied properties. Figure 3 shows a mixture of storage systems that can be utilized for a range of applications. [4, 9, 11,33]. The best HESS combinations are determined by a number of factors, including storage hybridization goals, storage prices, geo-location, and storage space availability.

3. APPLICATIONS OF ESSs

This review examines the ESSs can be used in existing RER-DG power systems, both grid-connected and off-grid, that are equipped. The fundamental flexibility of ESSs allows them to cover a wide range of power system applications, including grid, generating, end-user/load, and RER integration. Any typical ESS's applicability is determined by its capacity and application requirements; however, no ESS is appropriate for all applications. As shown in Table 8 and Figure 3Such applications are usually divided into three categories based on discharge time and power rating: Short-term power quality, medium-term bridging power, and long-term energy management.

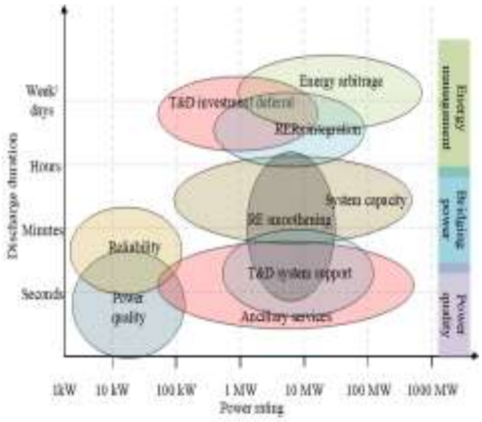

Figure 3 Uses of ESSs based on discharge time and storage capacity

3.1. Power quality applications

Because a delayed in response from the ESS could result in the entire power system collapsing, these applications have a short period of time period (less than a minute). These are both low-energy and high-power applications.

3.1.1. Voltage controller

One of the most important indicators of grid stability is voltage stability, and as the use of RERs in DG power systems increases, so does the importance of power systems. So do the issues of voltage management. The force that keeps the voltage stable at various levels in the power system is known as reactive power support. ESSs that are designed to mitigate voltage changes should have a quick reaction time and deliverability. The handful of batteries were an early example of ESSs providing voltage regulation services, but newer ESSs with fast reaction and long cycle life, FES, SMES, FBESS, and super capacitors, for examples, are recent technologies that have rapidly proven beneficial in power system.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 8, Issue 6, June 2021
DOI: 10.17148/IARJSET.2021.86129

3.1.2. Reactive power support

Squirrel cage induction generators (SCIG) are commonly used in DG power systems that use wind energy, Although they consume a lot of reactive power, they are reasonably priced and have excellent mechanical characteristics. High motive loads and uncompensated transmission/distribution lines consume reactive power, generating voltage instability. Support for reactive power is essential. Maintaining the desired voltage level in the power system necessitates the use of reactive power. As well as the sufficient ramp rate [11,75], short timeframe ESSs such BESS, FBESS, FES, super capacitors, and SMES are perfectly suited for such applications because of high reactivity of the ESSs to variations in voltage supply. The ESSs can continuously deliver four quadrant power converters provides reactive power to the system without impacting the real power saved in the ESSs.

3.1.3. Regulation of frequency

Frequency regulation acts as a stabilizing mechanism, ensure that the real powers of generation and consumption are equal. The frequency control problem is especially evident in DG power systems with RERs since generation does not match demand as closely as it does in traditional systems due to unpredictable weather conditions. ESSs can certainly be beneficial in frequency control services. Frequency regulation services, by definition, necessitate the charging and discharging of ESSs at a higher ramp rate across a large number of full charge and discharge cycles (500000+ cycles). FES systems are one of the best alternatives for frequency control services because of their long cycle life, deep discharge capabilities, and quick response time, and self-discharge, which is a fault of FES, is not a disadvantage in this service. Aside from SMES and supercapacitors, which have the desired qualities for frequency regulation applications, there are a variety of other materials that can be used, All varieties of batteries are suitable for this application.

3.1.4. Powerquality

The combination between RERs and load can result in increased harmonics, low power factor, and phase imbalance, in addition to voltage and frequency changes. The power converters connected to the ESSs can resolve these power quality issues. In voltage stability applications, performance and cycle life are less important than the supply of full power at a rapid rate. On average, power quality systems must minimize 100 accidents per year. Li-ion, NaS, and LA batteries have technical properties that make them suitable for power quality applications. Because of their quick response and high DoD, FES, SMES, and supercapacitors can also provide power quality services.

3.1.5 Low voltage ride-through (LVRT)

LVRT is the ability to maintain the generating system connected to the grid in the case of a problem, a large load change, or a steep drop in the generating system's output power. This can result in a significant drop in voltage as well as a reduction in the amount of power collected from the devices. In addition, certain grid standards mandate that DG power systems create the most reactive current. By integrating itself at the point of grid connection, ESS can avoid this situation, lowering the risk of a total power system failure. For LVRT applications, batteries, flow batteries, SMES, and super capacitors, as well as other ESSs with high power capability and fast reaction, are suited.

3.1.6. Fluctuation suppression

RERs are the primary producing sources in DG power systems, particularly during islanding actions. Variations in generation can induce system instability RERs have a reduced power inertia than traditional systems due to their intermittent nature. ESSs with a fast response time and a high reliability, as well as continuous operation and quick power modulation, are suitable for reducing variations. Individually and in hybrid combinations, FES, SMES, supercapacitor, and BESS (except LA battery) have the capacity to reduce fluctuations.

3.1.7. Oscillation damping

The flexibility of existing sources allows for RER penetration in DG power systems to some extent. However, the penetration level of RERs rises, the system may experience oscillations and stability concerns. ESSs can be used to moderate these oscillations by injecting or absorbing actual power at a frequency of 0.5 Hz-1 Hz. The time it takes for ESSs to input or receive real power ranges from seconds to minutes. As a result, ESSs that have a quick response time and a rapid ramp rate are preferred. The simplest ideas for this application are FES, SMES, batteries, flow batteries, and supercapacitors.

3.2. Applications for bridging power

Bridging power applications required ESSs capable of providing services in the mins to hours range, bridging the gap between limited RER generation and highly variable electrical demands, and seamless switching between various RERs.

3.2.1. 3.2.1. Transmission support

By adjusting for disturbances and irregularities such as sub synchronous resonance, voltage sag or swell, and unstable voltage, ESSs can help improve the transmission system's performance and load carrying capacity. Transmission support ESSs must be reliable and capable of providing both active and reactive power. Because ESSs are subjected to repeated charge and discharge cycles, a long cycle life is another important feature, Short of short to medium length Transmission support uses ESSs such as BESSs, FBESSs, SMES, and super capacitors.

3.2.2. Congestion relief in the transmission system

Transmission congestion occurs when demand for transmit power exceeds transmission line capacity in a transmission system. A high level of RER saturation in the electrical system might reduce delays in the transmission and distribution systems. The temperature, voltage, and angular stability of the system are all impacted by this environment. Large-scale ESSs have a lot of promise for reducing grid congestion by injecting and absorbing a specific amount of electricity into and out of the system. The technology employed in these applications, on the other hand, should be prepared for these conditions ahead of time. The methods PHES, CAES, and TES are suitable for decreasing road congestion and avoiding costly congestion costs.

3.2.3. Black start capability

In the event of a catastrophic failure, it is the potential of the generating units to restart operation after being shut down without the support of the grid. Black start system is possible with ESSs that have a suitable grid interface. The methods PHES, CAES, and TES are suitable for decreasing road congestion and avoiding costly congestion charges. When needed, the storage technology must be completely charged. The technologies that should be used in these services are CAES, BESS, and FBESS.

3.2.4. Contingency reserve

To prevent insecure as well as unstable performance due to a quick loss as a result of producing units or power stations, service providers including independent system operators (ISO) keep an estimated cost at various levels (s). Contingency reserve could be divided into spin and non-spinning resources depending on the response time required. The first line of protection is the spin reserve, which has a capacity equivalent to the area's largest unit. If a necessity arises, these resources will be able to supply service quickly. Non-spinning reserves are a specific type of unit that is utilized as a second line of response may be put into duty in as little as 10 minutes. This application is well-suited for ESSs like CAES, PHES, HESS, BESS, and FBESS.

3.2.5. Uninterrupted power supply (UPS)

UPS systems are used to provide essential loads including medical facilities, safety equipment, computer databases, and security systems with continuous, reliable, and high-quality power. It essentially significant benefit loads from power failures and also unusual voltage, oscillation, and harmonic distortion. The ESSs utilized in this application must respond instantly in order to provide backup during power outages. In UPS facilities, FES and BESS (mostly LA batteries) have been widely deployed. HESSs and super capacitors, in addition to such technologies, have potential uses in UPS.

3.2.6. Electric service reliability

Electric service reliability, like power quality applications, helps in maintaining sensitive loads energized in the case of an outage on the electric grid. This function also provides for proper tools and process shutdown, with the aim of reducing equipment harm and damages. Power outages can be minimized by using ESSs with a quick response time and discharge duration of several minutes. BESSs, FBESSs, FES, and HESSs are advanced application for maintaining electric service reliability.

3.2.7. Reduction of forecast hedges

Climate changes in RERs must be fully cared for in terms of uncertainty and variation, offering major challenges in grid design and operation. Whereas weather forecasting, along with load prediction is one of the most important solutions for the optimal functioning of climate-dependent RERs, forecasting errors might cause more issues than solutions. ESSs can be used to mitigate forecast hedging and, as a result, balance demand and supply. This software [182,251] can use BESS, FBESS, HESS, CAES, and PHES.

3.2.8. Mitigating RERs integration issues

RER integration, in addition to the issues outlined earlier in this paper, creates additional technological issues such as islanding, equipment control, and protection, to name a few. Furthermore, The method of power system in the case of failure can result in unnecessarily long shortages, considering the DG power system unreliable. If the DG power system is capable of continuously supplying the islanding system, these a issue can be resolved, Which can be accomplished with the use of ESSs. BESS, FBESSs, HESS, and CAES are medium discharge duration ESSs that can help with RERS integration issues.

3.3. Applications for energy management

Energy management properties make use of ESS technologies to provide energy time-shifting on a time scale ranging from hours to days and even months. The following are a few examples of such applications:

3.3.1. Expenditure deferral in T&D

Although load growth was moderate and system investments are high, transmission and distribution (T&D) capital deferral occurs by utilizing smaller ESSs (4 percent to 5% of T&D equipment's load carrying capacity) and deferring expenditure in transmission and/or distribution system improvements. It should also be noted that the maximum load for most distribution systems occurs Because ESSs used in such applications are only used for some days per year and a short hours per day; they can also be used in other applications. PHES, CAES, TES, HESS, BESS, and FBESS are the technologies can bring important advantages for this application.

3.3.2. Changes in energy time (Arbitrage)

In the electrical market, power prices fluctuate, and energy time shift (arbitrage) requires buying low-cost electricity charging the ESSs during off-peak periods and then selling high-cost power during peak hours and discharging the ESSs, on the other hand, store excess energy from RERs that can be used later when necessary, rather than being reduced and wasted to compensate for energy time shift duty PHES, CAES, and TES are long-term ESSs with low self-discharge are well suited to accomplishing energy time shift (arbitrage).

3.3.3. Peak shaving/valley filling

Peak shaving/valley filling is closely related to power arbitrage within this ESSs are used to smooth the highest point and valley form of the peak load, so although electricity arbitrage has economic targets. Peak shaving with ESSs can effectively reduce the number of events of peak capacity operation of the utility system, extending its life.Valley filling improves the load factor of the generator, which improves overall efficiency. The ESSs PHES, CAES, TES, BESS, FBESS, and HESS are well suited for these applications.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 8, Issue 6, June 2021

DOI: 10.17148/IARJSET.2021.86129

3.3.4. Load following

The capacity to modify production in responsed to changes in end-user need is known as load following (load). When compared to other generation kinds, ESSs respond quickly to load fluctuations (both up and down). The ESS that will be used in this feature will have to operate on an hourly basis (mainly during morning pickup and evening drop-off). This service is mostly provided by CAES, PHES, BESS, FBESS, and HESS [1,83,2159] are examples of large-scale ESSs.

3.3.5. Management of demand charges

Demand charges can be decreased by limiting the amount of products obtained from the utility for a set period of time, referred to as the Period of consumption charge (usually during on-peak several min's). ESSs should be very beneficial in demand charge control. They store electricity when required charges are not applied and discharge when demand charges are apply. This application is best suited to ESSs with a discharge time of five to six hours.

3.3.6. RERs capacity firming

RER capacity firming's main purpose is to provide sufficient support for RER production by constructing power stations for energy, so that the mixed output of RERs and storage is fairly stable and firm. Amazingly, the ESS rating required for this application is relatively low, similar to RER output power fluctuations. ESSs used in capacity firming in RERs must have a short discharge period and a power rating in the MW range. The preferred techniques for RER capacity firming are PHES, CAES, BESS, and TES.

As can be seen from the previous discussion, Various ESSs are acceptable for various uses, and no single device can fulfill all of the needs of a DG power system with RERs. Figure 4 illustrates the suitability of several ESSs according to the features specified in section 3. Furthermore, as of the end of 2017, in the form of bar graphs, Figure 5 demonstrates the worldwide financial capacity shares by application and type of ESS.

Figure 4 ESSs' suitability for many applications. The appropriateness level ranges from 0 (least suited) to 3 (most suited) (most suitable), (a) Applications for high-quality power, (b) Applications for bridging power, (c) Energy management applications

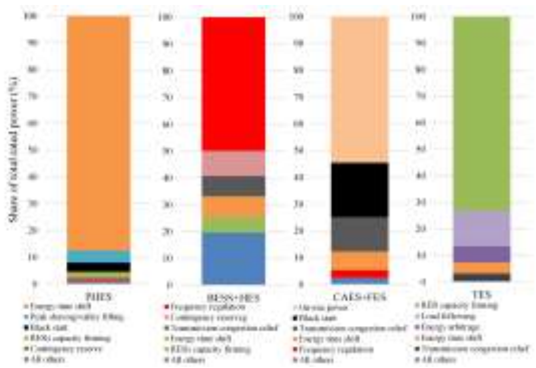

Figure 5 by the end of 2017, world potential for power shares by use and type of ESS had reached that point.

4. CONCLUSIONS

The concepts of operation and specific characteristics are discussed in this paper; of a number of ESSs that are already in use or will be in the future in DG power system applications are described in detail. The technical and economic properties of ESSs are compared and they are classified according to the type of energy they can store. An detailed review has been conducted to define and discuss the potential applications of ESSs in power systems. These ESS applications are classified, in an obviously innovative way, by Discharges period and power cycle (grid side, generating edge, end-user/load side, and RERs integration) (power quality, bridging power and energy management).A comparison of particular ESS applications and some of their implementations from around the world has been presented. The challenges and potential for ESSs have been clearly identified and discussed.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 6, June 2021

DOI: 10.17148/IARJSET.2021.86129

REFERENCES

[1] GLazarov VD, Notton G, Zarkov Z, Bochev I. Hybrid power systems with renewable energy sources types, structures, trends for research and development. In: Proc of International Conference ELMA. 2005. p. 515–20.
[2] Nayar CV. Stand alone wind/diesel/battery hybrid energy systems. Wind Energy 1997;21(1):13–9.
[3] Salas V, Olias E, Barrado A, Lazaro A. Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems. Sol Energ Mater Sol Cells 2006;90(11):1555–78.
[4] Chen YM, Lee CH, Wu HC. Calculation of the optimum installation angle for fixed solar-cell panels based on the genetic algorithm and the simulatedannealing method. IEEE Trans Energ Convers 2005;20(2):467–547.
[5] Rehman S, Al-Hadhrami LM. Study of a solar PV-diesel-battery hybrid power system for a remotely located population near Rafha, Saudi Arabia. Energy 2010;35(12):4986–95.
[6] Yamegueu D, Azoumah Y, Py X, Zongo N. Experimental study of electricity generation by solar PV/diesel hybrid systems without battery storage for offgrid areas. Renew Energ 2011;36(6):1780–7.
[7] Wichert B. PV-diesel hybrid energy systems for remote area power generation – A review of current practice and future developments. Renew Sust Energ Rev 1997;1(3):209–28.
[8] Hrayshat ES. Techno-economic analysis of autonomous hybrid photovoltaicdiesel-battery system. Energ Sustain Dev 2009;13(3):143–50.
[9] Solano-Peralta M, Moner-Girona M, van Sark W GJHM, Vallve X. 'Tropicalisation' of Feed-in Tariffs: a custom-made support scheme for hybrid PV/diesel systems in isolated regions. Renew Sust Energ Rev 2009;13(9):2279–94.
[10] Onar OC, Uzunoglu M, Alam MS. Dynamic modeling, design and simulation of a wind/fuel cell/ultra-capacitor-based hybrid power generation system. J Power Sources 2006;161(1):707–22.
[11] Burke A. Ultracapacitors: why, how, and where is the technology. J Power Sources 2000;91(1):37–50.
[12] Erdinc O, Uzunoglu M. Recent trends in PEM fuel cell-powered hybrid systems: Investigation of application areas, design architectures and energy management approaches. Renew Sust Energ Rev 2010;14(9):2874–84.
[13] Rahman S, Kwa-sur T. A feasibility study of photovoltaic-fuel cell hybrid energy system. IEEE Trans Energ Convers 1988;3(1):50–5.
[14] Esser T. Fuel cells enabling renewable off-grid solutions. In: IEEE 30th International Telecommunications Energy Conference, INTELEC. 2008. p. 1–2.
[15] Markvart T, Castaner ˜ L. Practical handbook of photovoltaics: fundamentals and applications. Elsevier; 2003.
[16] Mellit A, Kalogirou SA, Hontoria L, Shaari S. Artificial intelligence techniques for sizing photovoltaic systems: a review. Renew Sust Energ Rev 2009;13(2):406–19.
[17] Li C-H, Zhu X-J, Cao G-Y, Sui S, Hu M-R. Dynamic modeling and sizing optimization of stand-alone photovoltaic power systems using hybrid energy storage technology. Renew Energ 2009;32(3):815–26.Zhou K, Ferreira JA, de Haan SWH. Optimal energy management strategy and system sizing method for stand-alone photovoltaic-hydrogen systems. Int J Hydrogen Energy 2008;33(2):477–89.
[18] Ardakani FJ, Riahy G,AbediM. Design of an optimum hybrid renewable energy system considering reliability indices. In: 18th Iranian Conference on Electrical Engineering (ICEE). 2010. p. 842–7.
[19] Xu D, Kang L, Chang L, Cao B. Optimal sizing of standalone hybrid wind/PV power systems using genetic algorithms. Canadian Conference on Electrical and Computer Engineering 2005:1722–5.
[20] Moriana I, San Marti˜ın I, Sanchis P. Wind-photovoltaic hybrid systems design. In: International Symposium on Power Electronics Electrical Drives Automation and Motion (SPEEDAM). 2010. p. 610–5.
[21] Nelson DB,NehrirMH,WangC. Unit sizing of stand-alonehybrid wind/PV/fuel cell power generation systems. In: IEEE Power Engineering Society Gen Meet. 2005. p. 2116–22.
[22] Mellit A, Benghanem M, Hadj Arab A, Guessoum A. Modelling of sizing the photovoltaic system parameters using artificial neural network. In: Proc. of IEEE Conference on Control Applications CCA, vol. 1. 2003. p. 353–7.
[23] Senjyu T, Hayashi D, Yona A, Urasaki N, Funabashi T. Optimal configuration of power generating systems in isolated island with renewable energy. Renew Energ 2007;32(11):1917–33.
[24] O. Krishan and Sathans, "Design and Techno-Economic Analysis of a HRES in a Rural Village," Procedia Comput. Sci., 6th International Conference on Smart Computing and Communications, ICSCC 2017, 7-8 December 2017, Kurukshetra, India vol. 125, pp. 321–328, 2018.
[25] O. Krishan and Sathans, "Frequency regulation in a standalone wind-diesel hybrid power system using pitch-angle controller," in Proceedings of the 10th INDIACom; 2016 3rd International Conference on Computing for Sustainable Global Development, INDIACom 2016, 2016.
[26] O. Krishan and Sathans, "Optimum sizing and economical assessment of grid integrated hybrid system for a rural village: A case study," in 1st IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems, ICPEICES 2016, 2017.
[27] O. Krishan and S. Suhag, "An updated review of energy storage systems: Classification and applications in distributed generation power systems incorporating renewable energy resources," Int. J. Energy Res., no. October, pp. 1–40, Nov. 2018.
[28] Koutroulis E, Kolokotsa D, Potirakis A, Kalaitzakis K. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms. Sol Energy 2006;80(9):1072–88.
[29] Hontoria L, Aguilera J, Zufiria P. A new approach for sizing stand alone photovoltaic systems based in neural networks. Sol Energy 2005;78(2):313–9.
[30] Mellit A, Benghanem M, Hadj Arab A, Guessoum A, Moulai K. Neural network adaptive wavelets for sizing of stand-alone photovoltaic systems. Proc of 2nd International IEEE Conference on Intelligent Systems 2004;1:365–70.
[31] Mellit A. ANFIS-based genetic algorithm for predicting the optimal sizing coefficient of photovoltaic supply (PVS) systems. In: Proc. of the Third International Conference on Thermal Engineering: Theory and Applications. 2007. p. 96–102.
[32] Notton G, Lazarov V, Zarkov Z, Stoyanov L. Optimization of hybrid systems with renewable energy sources: trends for research. In: First International Symposium on Environ Identities and Mediterranean Area, ISEIMA. 2006. p. 144–9.
[33] Agustin JLB, Lopez RD. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sust Energ Rev 2009;13(8):2111–8