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Relevance of Energy Storage Technology in the Development of Solar Power

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Abstract
There is a growing concern in the operating of solar power as a stand-alone and its connection to the grid. This is because; its power quality and sustainability are being affected by intermittency and variability. As the time of the day and the solar intensity changes, the quality of power generation is affected. This has made the use of energy storage inevitable for a quality power generation. This paper considers some existing technologies of energy storage that is applicable in mitigating the challenge facing the deployment of solar power systems. The variability and effectiveness of these storage techniques were considered in terms of technology, efficiency, environmental impact, and response. In conclusion, it was resolved that a self-sufficient solar power system requires appropriate storage techniques to complement its operation. Therefore, understanding the different options of storage is required for a careful selection of the technology which can support the required level of efficiency and effectiveness in electrical energy generation.
Keywords: Solar Power, Storage Technologies, Solar Energy, Limitations
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1. Introduction

As a result of increasing electrical energy demand and climate changes experienced in the recent time, there is an increasing attention in the opportunities offered by renewable energy sources (RES). This has been noticed across the nations of the world considering the number of researches on renewable energy in recent time. Renewable energy sources include geothermal, tides, wind, biomass and solar energy. They are now being considered as a substitute for non-renewable sources in energy generation (Tsioliaridou *et al.,* 2006; Kaldellis & Zafurakis, 2007; Sansaniwal *et al.,* 2017). This can be linked to some of the advantages such as its free nature, environmental friendliness and inexhaustibility. Among the renewable energy sources (RES), solar energy seems to be one of the most reckoned with (Sampaio & Gonzalez, 2017; Ram *et al.,* 2017). (REN 21, 2016; Modi *et al.,* 2017) reported an increase interest in the use and installation of solar power systems. The technologies for harnessing its resources, economic implication have been demonstrated and well understood. This coupled with the need for no fuel has made the installation of the solar system to be achievable.

Despite this overwhelming advancement in solar, a lot of limitations still exists (REN 21, 2016). The high variability and intermittency associated with solar energy owing to its dependence on weather conditions have constrained its full adoption (Rehman *et al.,* 2015; Kabir *et al.,* 2018). The recent continuous effort on seamless methods of sufficient generation in stand-alone scenario and integration of the solar power to the national grid has been marred by such limitations. Making the incorporation into national grid a slow process and further discouraging sole dependency on solar power system. As a way of solution, various methods which include hybridisation with other renewable energy sources and conventional generation have been adopted. These have increased the technical complexity and the cost of generation. Also, the former set-up may not be efficient if the underlying resources are not abundantly available while the latter contributes to the air pollution. Therefore, there is a need to rethink on other methods such as hybridisation with storage systems to remove the fluctuation (Rogeau *et al.,* 2017) in solar power generation. Hybridising storage facilities with solar requires a detailed understanding of the available storage facilities, principles of operation, strength and weaknesses if a productive system is to be developed. Knowing this will aid the search and matching of the best storage with solar power system. However, this is to be preceded by the proper understanding of the various limitations of solar power and the best way in which storage facilities can aid. This is required for proper analysis prior final selection of storage facilities.

This paper identified and discussed some of the limitations of solar power generation. The limitations were discussed under three main factors and discovered various applications of energy storages in energy supply chain which suits the mitigation of the limitations. The study later surveys various energy storage methods that can be integrated with solar power and reveals some of their advantages and disadvantages to guide energy stakeholders in making careful selection. These are potential ways of increasing the reliability, stability and security of solar power in energy systems.

2. Limitations of solar power

The challenges of slow adoption faced by solar power technology in energy supply chain come as a result of some limitations. Large-scale solar power generation and its integration to the national grid have been surrounded by much fear of the variability and intermittency of solar resources because of a possible grid distortion. Its unpredictable nature (Espinar *et al.,* 2010; Lara-Fanego *et al.,* 2012) has made the energy planning and projection a difficult task. Therefore, energy systems operators find it difficult to depend solely on solar power because of uncertainties in prediction of quantity of energy generated and consequently the distribution. Other limitations affecting the technology are further discussed under the following three factors. They are perceived to have slackened development in solar power as a major source of electrical energy generation in many countries.

2.1 Environmental Factors

Variations often occurred in the level of availability of necessary environmental parameters and variables for designing and developing solar power. These result from differences in geographical locations and change in weather. One of the major draw backs of solar power is its specificity nature. The underlying resources are not evenly distributed across the land. Thus, the positioning often requires the best location that can gives a fair share of the environmental factors. Environmental factors such as, solar radiation, humidity, and ambient temperature etc. are part of the key factors in developing the system. The charaterisation of these factors demonstrates different design criterion. Conflictions in the design criteria have led to decision making problems because of the need to develop an optimal solar power system. Thus, the effectiveness of energy generation solely depends on the maximum availability of these required environmental factors. The maximum availability becomes difficult to achieve at every geographical area and time for the designer. That is the reason for propositions on environmental feasibility and appropriate site selection for optimum solar system performance (Khan & Rathi, 2014; Vafaeipour *et al.,* 2014). However, effective modeling of the selection considering the range of all the design factors still needs more improvement and standardisation. Such as, multi-criteria decision making approaches that can be used to develop a standard procedure for optimal considerations of all the conflicting factors.

2.2 Technical Factors

Developing a solar power system requires some level of technical know-how on the design, components and other instrumental factors. These include knowledge of electrical connection, estimations and energy balance of the demand and supply. This is important for the selection of the appropriate components in terms of technical specification that match the energy demand and supply. This aids the optimisation of the available resources for maximum solar power generation. For instance, the solar panel generation factor which is influenced by the sunshine hours and solar radiation in the environment (Chandel *et al.,* 2014) influences the quantity of modules to be procured. Mathematical models that demonstrate the behaviour and determines appropriate sizing are required during this process (Blaabjerg *et al.,* 2005) to support optimal use of available data and functional design within the operating scenarios. Operation scheduling that best suit each location are to be developed for optimality. Technologies to aid seamless integration of the energy generated from solar into the grid without distorting the grid needs to be given more attention. A model that correctly determines the key design parameters to avoid wrong predictions and energy losses associated with conversion in the face of the changing weather requires improvement. This technological advancement is observed to have received low attention.

2.3 Economic Factors

Costs associated with the development of solar power generation are very high due to the high initial cost (Akuru *et al.,* 2017; Kabir *et al.,* 2018). This has been described through various costing techniques and analysis. Economic analyses have further shown that solar power generation is achievable and cost-effective (Vides-Prado, 2018) but the high initial cost stands to be the major stumbling block to major development. Predictions about future price have proposed future price reduction as a result of improved innovations and manufacturing of modules (Bhandari & Stadler, 2009). However, without a standardised template and explicit analysis that can explain the investment, encouraging more investment may be difficult. For instance, works that exposes the recovery of investment on solar and its link up with storage systems requires more attention. Also, necessary models to assist potential investors in the design and selection of components given a real energy market scenario need further consideration and publicity. Economic policies to promote solar power generation in energy market are yet to be fully developed in many Africa countries. This may not have really attracted many investors who wish to invest in solar power.

3.0 Energy Storage Technology Applications in Solar Power Technology

Solar power has been adjudged to be eco-friendly and economically suitable means of generating electricity but the intermittency still exists. The assurance of continuous electricity power supply on its own or a supply without variability still remains dicey. In lieu of this, methods of solving the challenges through different storage devices have been reported. These methods can heighten up the constant supply of electrical energy from solar. The effects of this energy storage are noticed in improving power quality and system stability. During the excess energy generation from the solar power, this storage stores in a form that is usable or that can be converted back to work. Such forms are chemical energy, mechanical energy, thermal energy and electrochemical energy (BEAMS, 2010;

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Lefebvre & Tezel, 2017). Applications of energy storage in electrical energy are in diverse ways. They have been successfully applied generally in energy supply chain. Some of its reviewed applications which revealed its potency in solving the challenges of solar power are discussed. The technology helps in time of deficit by allowing continuity of energy supply which could have been affected by intermittency and variability of solar energy. These are part of the advantages which has made it an important part of energy managements with application ranging across generation, transmission, distribution, and consumption (Fuchs *et al.,* 2012; Metz & Saraiva, 2018);

1. Rapid or Spinning Reserve or Contingency Reserve: this is a kind of generation that serves as a back-up power for the likely failure of a generator. It is used as a means of failure compensation in a functioning generation plant (Allan & Billinton. 2013; Motalleb *et al.,* 2016). This has being a proven substitute for combustion engines which are used as a cover-up for the energy deficits.
2. Frequency Responsive Reserve and Area Control: there is always a possibility of a mismatch in generation and load demand especially in small-scale and islanded network areas. Energy storage is a critical tool which helps to counterbalance potential load fluctuations and regulates the frequency (Scmidt *et al.,* 2014; Stroe *et al.,* 2015). This protects the consumer electrical appliances and the utility equipment.
3. Arbitrage: it is applicable in taking the advantage of price variation for energy trading (Amamra *et al.,* 2015). Energy storage allows for the price spread of energy in peak and off-peak periods.
4. Peak Shaving: it is applied in the reduction of peak loads (Sigrist *et al.,*2013) that can lead to payment of high demand charges. This prevents the occurrence of peak that leads to penalties and has been found supportive in Demand Side Management (Uddin *et al.,* 2017).

4.0 Various Energy Storage Technologies

The existing energy storage technologies, forms of energy and some characteristics are described in table I. Some of the technologies involved are further explained to inform on the ranges of storage that can be adopted during the development of solar power system while considering the strengths and weaknesses.

Table 1: Various Energy Storage Technologies

S/N	Form of Energy Storage		Technology	Duration
1	Electrical Energy Storage	Magnetic/Current Energy Storage	Superconducting Magnetic Energy Storage (SMES)	Short
		Electrostatic Energy Storage	Capacitors, Super Capacitors	Short
2	Mechanical Energy Storage	Kinetic Energy	Flywheels	Short
		Potential Energy	Pumped Hydroelectric Storage	Long
		Elastic Potential Energy of Compressed Air	Compressed Air Energy Storage (CAES)	Medium
3	Chemical Energy Storage	Electrochemical Energy	Conventional Batteries: Lead Acid Battery (L/A), Sodium Sulphur Batteries (NaS), Nickel Cadmium Batteries (NiCd), Sodium Nickel Chloride Batteries (ZEBRA- Batteries), Lithium Ion Batteries. Vanadium Redox Batteries (VRB), Zinc Bromine	Medium
		Flow Batteries	Batteries (ZnBr), Polysulphide Bromide Batteries (PSB).	Medium
		Chemical Energy	Fuel Cells	Medium
		Metal Air Batteries	Metal-air	Medium
		Thermo-Chemical	Solar-Fuel	Medium
4	Thermal Energy Storage	Low Temperature Energy	Aquiferous Low TES (AL-TES) Cryogenic Energy Storage (CES)	Medium
		High Temperature Energy	HT-TES (High Temperature Energy Storage)	Medium

Source: Ayodele & Ogunjuyigbe (2015)

4.1 Superconducting Magnetic Energy Storages (SMES)

SMES know-how is based on the storage of electrical energy into electric current directly (Chen *et al.,* 2009). Electrical energy is stored as a direct electric current using an inductor (coil) which is made from a superconducting material. It is circular to allow current to circulate without losses. SMES are also relevant in storing energy as the magnetic field which is formed by the flow of electric current (Vazquez *et al.,* 2010). Maintaining the inductor in its superconducting state is achieved by dipping it in liquid helium which is contained in vacuum-insulated cryostat. SMES components include superconductor, cryogenic refrigerator, power conversion system and control. Its applications are in short term power quality and stability (Sabihuddin *et al.,* 2014). SMES displays a great energy storage competence of about 98% and life span greater than 20 years. However, the associated system cost and environmental issues are its major limitations (Vazquez *et al.,* 2010).

4.2 Capacitors

It is an electrical energy storage facility which comprises of dual metal plates which are parted by a non-conducting layer known as dielectric. The storage is done on the surfaces of a metalised plastic firm (Guney & Tepe, 2017). As a plate is charged with electricity from direct current source, the other plate gets induced in the opposite sign with a charge. Energy in capacitors is stored at a very fast rate and it is achieved without causing degradation to the material. This feature makes it to be applicable in transient voltage stability (Chen *et al.,* 2009; Denholm *et al.,* 2010; Teleke, 2011). However, there is a very low energy density in capacitors but has an advantage in ability to accept high currents and its delivery.

4.3 Super Capacitors (SCs)

Super capacitor possesses the features of both electrochemical and capacitors batteries with no chemical reaction like that of the battery. Storage of energy in super capacitors is the same as in capacitors. The energy is basically stored as an electrical energy. Electrolyte ionic conductor is used in place of the insulating material. Energy stored is in the form of the electric field between two electrodes and produces better than capacitors but at a higher cost. The serial connection is required contrary to the connections in capacitors if a normal voltage is to be reached. SCs stores energy electrostatically and have good response speed, charging time and high energy discharge rate. It is more advanced than the conventional capacitors, has a higher capacitance and energy density values as a result of its larger surface area (Teleke, 2011). The expensiveness of the technology remains the major challenge as there is yet to be an application of SCs technology recorded at a large scale of energy (Yang *et al.,* 2008).

4.4 Flywheel Energy Storage System (FES)

It is a mechanical storage system with energy fed into the rotational mass of a flywheel. Energy is stored in a kinetic form and made available during demand (Samineni *et al.,* 2006; Bingsen & Venkataramanan, 2009). Flywheel material, geometry, length and the support influences the quantum of energy stored and the specific energy of flywheel. The flywheel is attached to a primary source of energy and stores the energy at a high density. The stored energy is proportional to the rotor mass moment of inertia and square of the wheel speed. Their classification is based on its speed i.e. high or low speed. FES application has been seen in the vehicular application for a large quantity of energy in its rotating mass, aircraft applications, and power smoothing (Mousavi *et al.,* 2017).

During operation of solar power generation, the excess energy generated during the low demand period or high generation period can be stored into the flywheel for the peak period. When the demand becomes very high then the energy can be returned to the grid or interested object. It is a good technology that can come up quickly when needed and it is less sensitive to the depth of discharge. However, it has high capital cost and high rate of discharge (Hadjipaschalis *et al.,* 2009). FES is characterised with long life time of operations, unrestricted charging/discharging cycles and rapid discharge of large amount of energy in seconds (Arani *et al.,* 2017).

4.5 Pumped Hydroelectric Storage (PHS)

PHS is a mature technology which can mitigate the challenges posed by solar energy. PHS can come quickly and can be deployed in large energy generation (Rehman *et al.,* 2015). Its technology is dependent on the elevation and the potential energy in water. During the excess solar energy period, water is pumped to the upper reservoir and it is released through a turbine into the lower generator during the deficit period. The hydraulic power generated during this process drives the generator which in turn generates the electricity.

PHS has been reported to be one of the most successful storage technologies with a moderate efficiency of 68-85%. Other benefits of PHS are prolonged energy storage duration, large capacity (100–1000 MW), long life (30–60 years) and low cycle cost. Basic requirements are to be met to have a relatively fair cost of energy generation because of the high initial cost that can make it unappealing to some investors. Availability of resources such as a natural reservoir, water, good topographical sites would be of greater help in achieving the set target (Akinyele & Rayudu, 2014). However, this tends to be part of its drawbacks because of the over-reliance on the environmental features to achieve good energy generation at a relative cost. The involving construction and the capital required seem to be demanding. Solving part of this challenge could require an additional cost for technical feasibility or scientific ways of choosing the best site that presents optimal energy generation at a minimal cost (Rehman *et al.,* 2015).

4.6 Compressed Air Energy Storage (CAES)

Its existence is dated back to 1970s and has been reported to be appropriate for large-scale energy generation. The stored energy is achieved by compressing air into underground containers and solution-mined salt caverns. Presently, the use of CAES is very limited in the world when compared with other energy storage but still the technology has the potential to prevent intermittency. Compressed Air Energy Storage (CAES) is feasible techno-economically and has been found to be a smart energy storage system (Lund & Salgi, 2009; Zhang *et al.,* 2013; Liu & Wang, 2016). The units in CAES include air injection, expander, compressor, motor, cavern and exhaust (Venkataramani *et al.,* 2016). Benefits are in low cost, high energy capacity, low operation and maintenance, high reliability, long life and flexibility (Ghuo *et al*., 2016; Lv *et al.,* 2017) and are applied in large scale and high energy storage (Succar & Williams, 2017). However, the working operation mode often involves the use of fossil fuel to re-introduce the temperature lost during compression (LaMonica, 2013) which is a drawback to clean environment consideration.

4.7 Battery Energy Storage (BES)

It is a widely known type of energy storage systems today which is common in the stand-alone technology today. BES stores energy in a chemical form and it works based on a reversible chemical reaction. It is available at different sizes making it useful for different applications. This includes the high energy batteries (HEB) which are classified as liquid electrolyte flow batteries and high temperature batteries (Denholm *et al.,* 2010). Benefits lie in the ease of scaling down to small-scale energy storage. Various batteries exist with different benefits and drawbacks. Table 2 describes some of the existing batteries, their characteristics, application and some of their limitations (Akinyele & Rayudu, 2014). Batteries advantage lies in their independent nature from the topography or geology of an area. Requires no massive land or special features for its storage unlike PHS and it is independent of environmental conditions. However, the toxic nature of their constituents remains hazardous to human and often leads to disposition problem after its useful life.

Table 2 Batteries and Their Characteristics

S/N	Type of Battery	Properties and Application	Limitations
1	Sodium-Sulphur (NaS)	No self-discharging. High power density. Generates up to 1.2MW for up to 7 hours. It has a good efficiency around 90% (Beaudin *et al.,* 2010). Good application in power quality. Good for power system regulation (Kamibayishi & Tanaka, 2001).	High capital cost, the temperature must be well monitored within a specified range. Environmental concern on the effect sodium.
2	Nickel-Cadmium (Ni-Cd)	Higher energy density and longer life compared to lead-acid batteries. Can withstand more temperature and deep discharge (Yang *et al.,* 2008). Applicable in the stabilization of intermittent energy.	Environmental concerns, High capital cost.
3	Lithium-ion (Li-Ion)	Long life cycle. Low Self-discharge with high energy to weight ratio (Vazquez *et al.*, 2010). Frequency stabilization.	High cost of unit energy.
4	Zinc Bromide (ZBB)	It is a form of hybrid battery with solid zinc being placed at the negative pole. Response time is in milliseconds.	Low efficiency compared to Lithium-ion batteries
5	Sodium Nickel Chloride (ZEBRA)	Has a high temperature property. Liquid Sodium and Nickel Chloride are the anode and cathode used. It functions at temperature up to 70 ^{o}c without cooling (Sudworth, 2001).	Lower power and energy density (Bradbury, 2010)

5.0 Conclusions

This work has reviewed various energy storage technologies as an option in solving the problems militating against solar power as a source of electrical energy and its full incorporation into the national grid. Attention was given to some applications, working principles and their relevance in solar power. The technology, benefits and drawbacks of types of energy storage were discussed to assist in developing effective energy systems. The review shows the strengths and weaknesses of the technologies to enhance the understanding of the energy system's designer for a sound analysis during selection of suitable energy storage. This will aid effective decision-making on appropriate storage technology that can complement solar power and also guide during hybridisation of two or more storage technologies for a high performance (Margeta & Glasnovic, 2012; Gee *et al.,* 2016).

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