Engineering Universe for Scientific Research and Management
ISSN (Online): 2319-3069
Vol. XV Issue VIII
Aug 2023

Comparative Analysis of Active and Reactive Powers of STATCOM with PI and DSM-PI Controllers

Swarndeep Saxena[1], Indrajeet Kumar[2], Priyank Gour[3]
Research Scholar, Department of Electrical and Electronics Scope College of Engineering, Bhopal (M.P.)[1]
Assistant Professor, Department of Electrical and Electronics Scope College of Engineering, Bhopal (M.P.)[2,3]

Abstract

Electricity generation from the wind and solar photovoltaic (PV) systems are highly dependent upon weather conditions. Their intermittent nature leads to fluctuations in their output. Therefore, the need for rapid compensation for energy transmission and distribution systems is increasingly important. Static Synchronous Compensator (STATCOM) can be adopted for reactive power compensation and for decreasing the voltage fluctuation caused by the system and renewable energy sources. This study presents modelling of a Solar PV-Wind Hybrid Micro-grid and the increase of the stable operating limit of the system in case of the incorporation of STATCOM is examined. The major contribution of this paper is the sliding control of PI gains using DSM-PI (Dual Sliding Mode Proportional Integral) and therefore obtaining better responses and voltage stability in terms of nonlinear nature of solar-wind hybrid micro-grid. The Simulink models of the system architecture include a 1.5 MW wind turbine model based on a doubly fed induction generator (DFIG), 0.1 MW solar PV power system model and a STATCOM rated at 3 MVAR. It is certified that the voltage fluctuation at the end of the bus bar is reduced by 8 % using conventional PI controller. The results obtained by DSM-PI controller are compared with that of the conventional controller and better results attained.

Keywords: Photovoltaic; Static Synchronous Compensator (STATCOM); PI controller; DSM-PI (Dual Sliding Mode Proportional Integral); Solar PV-Wind Hybrid Micro-grid.

1. Introduction

Climate change and the responsible management of the world's depleting fossil fuel resources are the two greatest problems the planet now facing. Reducing our dependence on fossil fuels and significantly cutting down on emissions of greenhouse gases is necessary if we want to provide future generations with a safe planet. Investment in renewable energy has expanded significantly as the price of technologies drops and their efficiency keeps getting better; this is because renewable energy is an essential aspect of lowering global carbon emissions. [1]

Centralized power plants have several drawbacks: First, most power plants use fossil fuel, which increases CO2 emissions and wastes rejected heat; second, large amounts of power must be delivered using transformers and long transmission and distribution lines; third, power losses and voltage drop seem to be significant problems due to the length of the transmission lines and the transformers; and fourth, this does not offer a financially viable solution to supply power to poor and isolated communities. We can reduce our reliance on fossil fuels and our impact on the environment by switching to renewable energy sources like wind and solar photovoltaic (PV) generation.

Microgrids are small-scale power networks made up of renewable energy generators, battery storage, and end-use consumers. There are various benefits to using a microgrid, including more dependability, greater controllability, and higher quality electricity. There are two types of microgrids: those that are linked to the larger grid and those that are completely separate from it. Operating the grid-connected microgrid in tandem with a reliable electric power system means worrying less about unwanted frequency fluctuations. Therefore, from a financial perspective, microgrids that are linked to the grid need to focus on increasing electric power exchanges and profits. In contrast, without access to the larger electric grid, isolated microgrids have challenges with voltage and frequency fluctuation maintenance. [2]

Distributed microgrids based on renewable power generation techniques like solar, wind, and biogas can help meet the growing global demand for electricity while reducing the associated costs and emissions of harmful greenhouse gases (GHGs) from traditional central power plants that rely on fossil fuels. Use of renewable energy sources is the only viable option for creating a better, pollution-free planet. Producing electricity from renewable resources is feasible.

Conventional renewable sources are being used efficiently over the world to provide a long-term solution to the energy dilemma, and they include solar, wind, and hydro.

Engineering Universe for Scientific Research and Management
ISSN (Online): 2319-3069
Vol. XV Issue VIII
Aug 2023

1.1 Doubly Fed Induction Generator (DFIG)

Wind turbines have come a long way since their inception in 1975, when they were first used to generate electricity. In the 1980s, the first modern turbine was wired into the grid. The widespread use of DFIG may be traced back to the rise in popularity of wind energy and wind power generation. The term "doubly fed induction generator" refers to the fact that the electrical power generated is sent in both directions (between the stator and the rotor). Since these generators can adapt to changing wind conditions, they have garnered a lot of interest. There are benefits to using variable-speed wind power plants rather than constant-speed wind power plants. [6]
Variable-speed wind farms cover a larger energy range than their constant-speed counterparts, and they do so with less mechanical stress and less noise than stationary wind farms. The advancement of power electronics has made it practical and inexpensive to regulate every speed. Working with varying wind speeds has unique challenges, and this research focuses on variable-speed DFIGs to address those needs. Wind power plants, as depicted in the figure, have a layout in which the stator's orbit of the DFIG is connected directly to the grid, while the rotor's orbit is connected to the grid through a back-to-back converter (generator side converter and grid-side converter) with slippery rings. A capacitor connected as a dc connection between the two converters acts as a ripple-smoothing energy saver and reduces the voltage rise that may occur between the two. [7]

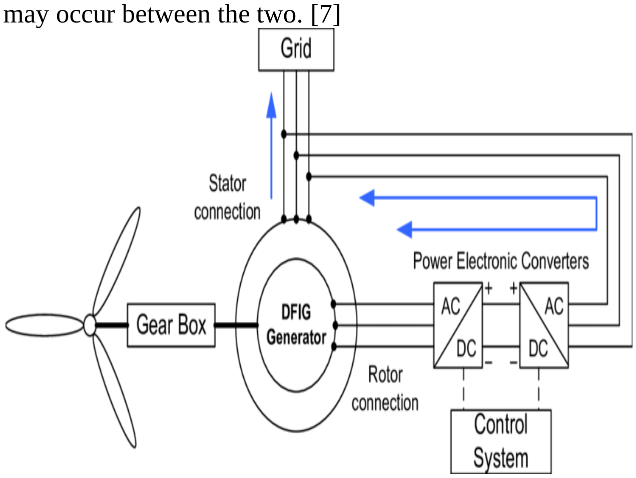

Figure 1 Schematic diagram of DFIG Generator

In its normal mode of operation, DFIG's grid-side converter allows for independent regulation of active and reactive power. In addition, the soft starter may be omitted during grid connection if the converter is installed on the rotor side. The DFIG's control plane may be subdivided into its two main subsystems, the mechanical and electrical systems. Although the control systems were developed with a variety of objectives in mind, regulating grid-injection power has always been a top priority. The rotor-side converter regulates the grid-exposed active power, while the stator- and rotor-side converters regulate the reactive power injection. [8]

1.2 Microgrid

The following definition of a microgrid was provided by the United States Department of Energy (DOE).
"A microgrid is a local network of energy. It offers integration of DER with a local load that can be operated with islanding or grid mode to provide flexibility to grid disturbances and high reliability. This distribution system addressed the essential for the application in place with electrical supply and delivery constraint in a remote area and critical load protection economically growth".
Briefly defined, a microgrid is a small-scale electrical system that may operate alone or in combination with the larger utility grid. [9]

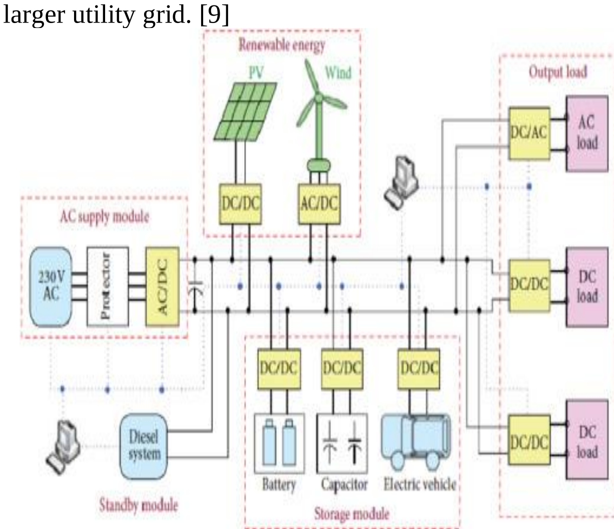

Figure: 2 microgrid architecture

Because of DG integration, the microgrid is expanding quickly. Growth in DG has created as many issues for the distribution network as it has resolved. If the distribution system is unstable or unreliable, then the DG has a major issue.
Due to this, a microgrid is not formed when distributed generators are connected to the distribution grid. It has to be kept under tight supervision, however. It generates the concept of microgrids, which allow for decentralized power production and delivery. [10]

2. Methodology

2.1 Essential Components of the System

The suggested model treats photovoltaic (PV) and wind power systems as modular systems, allowing for the required installed capacity to be obtained by adjusting the number of PV modules and wind turbines. By calculating the optimal area covered by the PV modules and the number of wind turbines, the system size may be optimized.

The suggested HRES cost-optimization approach may be used in a variety of settings, owing to its adaptability in light of the typology of the various renewable power subsystems. To achieve this, the user need just modify the input variables that pertain to the size of the system, such as the installed capacities and efficiencies of the biomass or wind subsystems, and to the location, such as the sun irradiation and wind speed data series.

The system is structured such that renewable energy sources like sun and wind are preferred over grid-based energy sources like biomass. If there is a shortage of renewable energy sources like solar panels or wind turbines, the biomass engine is run at maximum capacity, and any excess electricity is sent to the grid and sold. When renewable sources like solar, wind, and biomass aren't able to meet current demand, the system will turn to the grid for backup.

The literature study reveals a lack of studies on the effects of hybrid solar-wind microgrids on voltage variations in the STATCOM system. In order to keep up with the growing demand for PV and wind power systems, traditional FACTS devices must undergo further refinements of controllers and in-depth study across a wide range of operating situations.

The purpose of this research was to include STATCOM for reactive power compensation into the current power system design in order to expand its dependable working limit. Moreover, it aims to mitigate voltage fluctuations brought on by the intermittent nature of renewable energy sources.

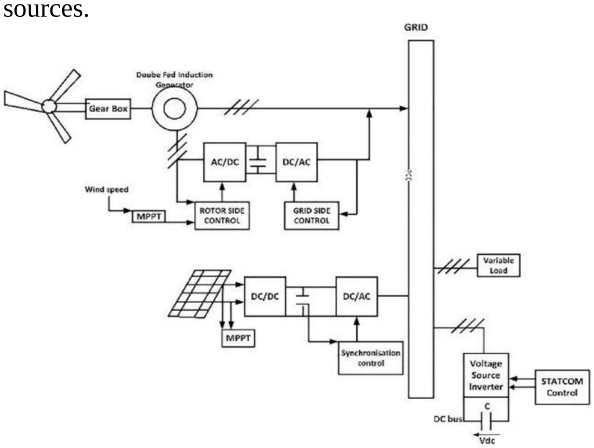

Figure 3 Proposed system

Voltage Source Inverter: A voltage source inverter (VSI) is a device that inverts the polarity of a direct current (DC) voltage so that it may be used with alternating current (AC) devices. A efficient voltage source inverter maintains a stable voltage throughout the operation.

In most cases, a VSI will have one large DC link capacitor, one DC voltage source, one switching transistor, and one DC voltage source. Transistors used may be IGBTs, BJTs, MOSFETs, or GTOs, and DC voltage sources may come from batteries, generators, or solar cells. There are two main types of VSI topologies: single-phase and three-phase inverters, with further subcategorization into half-bridge and full-bridge inverters for each phase. The DFIG is made up of a series of voltage-induced converters that are linked in both directions to the rotor windings and directly coupled to the fixed frequency three-phase grid. Power factor and converter operation are both regulated by the grid-side inverter, which also regulates the DC link voltage.

Variable Load: The needs of the users are taken into account while planning an electric power plant. A continuous, long-lasting load is desirable for a power plant since it allows for planning and regular maintenance.

Effects of variable load. A power plant's functioning is complicated by the fluctuating demand on it. Variable load has several significant consequences for a power plant, including but not limited to:

(i) Need of additional equipment. When the demand for electricity at a power plant fluctuates, it's important for the facility to have flexible power generation capabilities. As an example, picture a steam power plant. The plant uses air, coal, and water as its primary inputs. A variable power plant needs a variable supply of these resources. In order to keep up with the plant's increasing power demand, for instance, the coal, air, and water supply to the boiler must be increased. That's why we need to set up some supplementary machinery to get the task done. In a modern power plant, most of the machinery exists only to regulate the input of raw materials at variable rates in response to fluctuations in power demand.

(ii) Increase in production cost. Having a plant's load fluctuate throughout the day raises the price of generating electricity. An alternator's output is most reliable around its rated capacity. When the plant operates under light loads, the efficiency of a single alternator drops significantly. Thus, in reality, many alternators of varying capacities are placed, allowing for the majority of the alternators to be run at near maximum load capacity.

However, the initial cost per kW of the plant capacity and the necessary floor space rise with the addition of more producing units. As a result, the price of producing energy rises.

MPPT: To provide the best possible compatibility between a solar array (PV panels) and a battery bank or utility grid, a "maximum power point tracker (MPPT)" is used. In a nutshell, they reduce the DC output of solar panels (and sometimes wind turbines) to the level required to charge batteries.

The primary goal of maximum power point tracking is to maximise the output of a PV system by operating each module at its optimal voltage (maximum power point). Simply define:

The maximum power point tracking (MPPT) system analyses the power generated by the PV modules and compares it to the voltage of the batteries in order to determine the optimal voltage at which the most current

Engineering Universe for Scientific Research and Management
ISSN (Online): 2319-3069
Vol. XV Issue VIII
Aug 2023

may be drawn from the PV modules to charge the batteries. Also, if a DC load is connected directly to the battery, it can power that as well.

For optimal performance, MPPT is used when:

Cold weather, cloudy or hazy days: The maximum power point tracking (MPPT) method is often used to get the most out of PV modules, which perform better in colder temperatures.

When battery is deeply discharged: If the battery's state of charge is low, MPPT will be able to extract more current and charge it more quickly.

Double Fed Induction Generator: Wind turbines that use doubly-fed induction generator converters (DFIG) have their generators' stator wired directly to the power grid. There is a back-to-back power converter linking the rotor to the mains. This variable-speed layout is commonly used for outputs between 1.5 MW and 6 MW. Only about a third of the energy produced by a DFIG converter is used in both directions, passing via the power semiconductors.

With the DFIG, you may enjoy the benefits of speed control at a lower cost and with less power losses, all due to the fact that the power electronics only process the rotor power, which is often less than 25% of the entire output power.

2.2 DSM-PI Controller

The gains are locked to a certain value in a “conventional PI controller”. Differently the value of the “DSM-PI controller” is continuously altered by mistake.

This "DSM-PI controller" lowers response time by continuously monitoring the proportional and integrated gains of Kp and Ki. This system's main perk is that it shortens response times by dampening vibrations and tremors.[2]

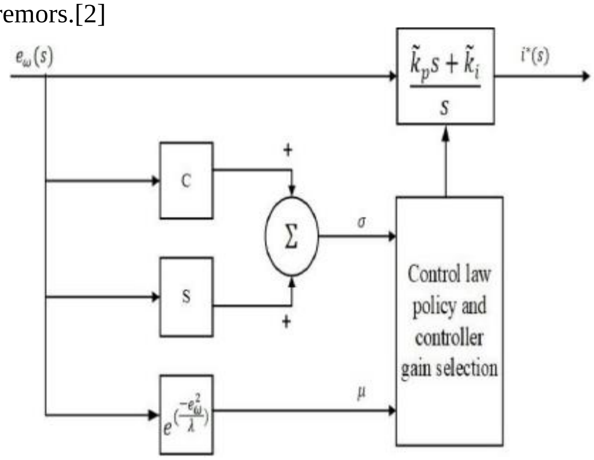

Figure 4 DSM-PI block diagram

Therefore, the “DSM-PI controller” accelerates the speed response and causes reduced oscillations and perturbations. [3]

“DSM-PI controller continually monitors Kp and Ki's gains of proportional and integral gains,” therefore the reaction time is much decreased. Reduced oscillations and disturbances speed up the speed-time response, which is a major benefit of this design.

- Figure 4 depicts a block schematic of the DSM PI controller under consideration. Sliding surface blocks C and S determine the switching laws that define the DSM PI controller gains kp and ki.

3. Simulation model and Result Analysis

As per the given test system the modeling of grid with DFIG wind farm, PV source and STATCOM connected at PCC is given below in figure 5

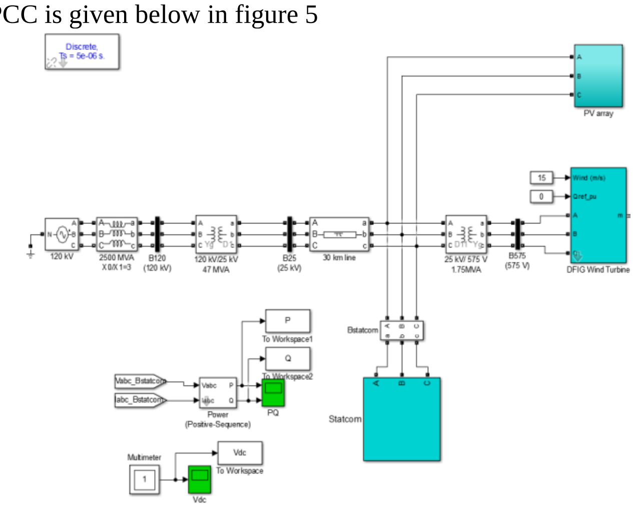

Figure 5 Simulation of Solar-wind hybrid System Including STATCOM

The internal modeling of wind farm and PV source are shown below in figure 6

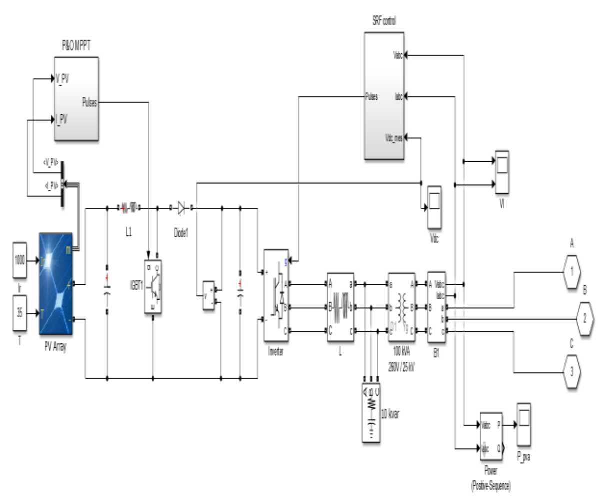

Figure 6 structure of PV Array

The wind farm and the PV source are operated optimally at maximum possible solar irradiation and wind speed with maximum power generation from the renewable sources.

The STATCOM modeling for reactive power compensation is shown in figure 7 below.

Engineering Universe for Scientific Research and Management
ISSN (Online): 2319-3069
Vol. XV Issue VIII
Aug 2023

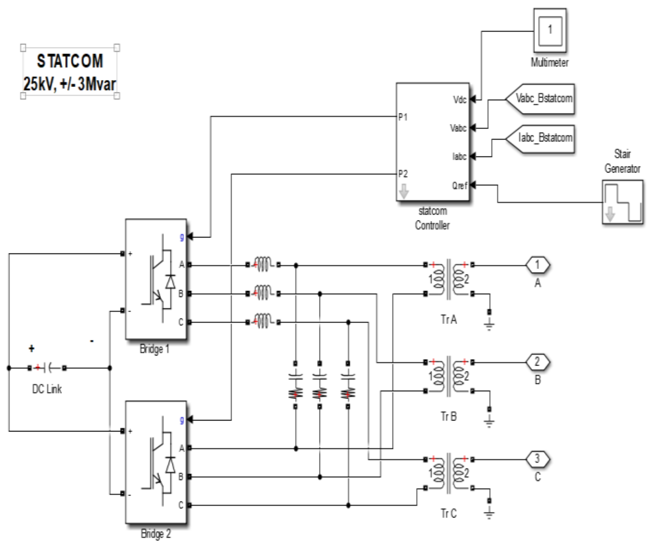

Figure 7 Internal Structure of STATCOM modeling

From 0-0.3sec there is no exchange of reactive power with Qref =0. From 0.3-0.5sec reactive power reference is changed to 1pu which represent 3MVAR absorption from the grid. From 0.5-0.7sec Qref is again made to 0 and change to -1pu from 0.7-0.9sec representing injection of 3MVAR reactive power to the grid.

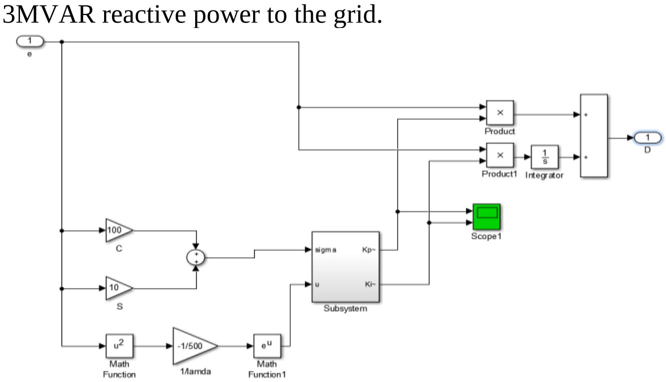

Figure 8 DSM-PI controller modeling

Figure 9 Comparison of active and reactive powers of STATCOM with PI and DSM-PI controllers

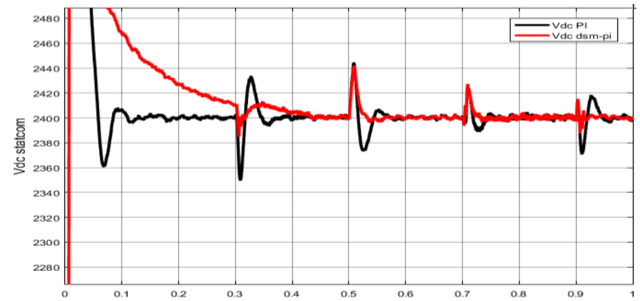

Figure10 DC voltage of STATCOM with PI and DSM-PI controller

As observed in the above graphs in figure 10 of active and reactive powers, DC voltage of STATCOM the damping is reduced during Qref changing conditions. The lower and upper peak value generation is reduced to greater extent and the system is more stable with DSM-PI controller as compared to PI controller.

4. Conclusion

This research looked at how adding a solar power generation system with a capacity of 0.1 MW and a wind power generation system with a capacity of 1.5 MW might affect the existing power grid. It has been suggested that STATCOM may be used to compensate for the reactive power in this hybrid system. The output voltage profiles of a hybrid solar PV-wind power system were analysed.

Reference

[1] S. Ansari, "Assessment of Renewable Energy Sources of Iran," vol. 6, no. 12, pp. 206–211, 2019.

[2] A. Muhtadi, A. M. Saleque, and M. A. Mannan, "Solar and wind energy based microgrid: Study of architecture's potential at coastal areas in Bangladesh," *AIUB J. Sci. Eng.*, vol. 17, no. 2, pp. 31–36, 2018, doi: 10.53799/ajse.v17i2.6.

[3] A. Muhtadi and A. M. Saleque, "Modeling and simulation of a microgrid consisting solar PV & DFIG based wind energy conversion system for St. Martin's island," *2017 IEEE 3rd Int. Conf. Eng. Technol. Soc. Sci. ICETSS 2017*, vol. 2018-Janua, no. August, pp. 1–6, 2018, doi: 10.1109/ICETSS.2017.8324152.

[4] N. H. Baharudin, T. M. N. T. Mansur, F. A. Hamid, R. Ali, and M. I. Misrun, "Performance Analysis of DC-DC Buck Converter for Renewable Energy Application," *J. Phys. Conf. Ser.*, vol. 1019, no. 1, 2018, doi: 10.1088/1742-6596/1019/1/012020.

[5] T. Dobbin, "Modelling and control of a doubly-fed generator with variable speed wind turbine for electromechanical stability studies .," no. July 2014, 2018.

[6] S. Priya, M. Marimuthu, S. Vijayalakshimi, and S. P. Perumal, "MODELLING AND SIMULATION OF HYBRID (WIND and SOLAR) FOR DC MICROGRID," vol. 9, no. 3, pp. 163–167, 2018.

[7] S. M. Mousavi G, F. Faraji, A. Majazi, and K. Al-

Haddad, "A comprehensive review of Flywheel Energy Storage System technology," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 477–490, 2017, doi: 10.1016/j.rser.2016.09.060.

[8] A. Muhtadi, "Solar PV & DFIG based Wind Energy Conversion System for St . Martin ' s Island," *2017 IEEE 3rd Int. Conf. Eng. Technol. Soc. Sci.*, 2017, [Online]. Available: https://ieeexplore.ieee.org/document/8324152

[9] E. O. Ogunniyi and H. C. V. Z. Pienaar, "Overview of battery energy storage system advancement for renewable (photovoltaic) energy applications," *Proc. 25th Conf. Domest. Use Energy, DUE 2017*, no. October, pp. 233–239, 2017, doi: 10.23919/DUE.2017.7931849.

[10] A. R. Vaz and F. L. Tofoli, "Detailed design procedure of a DC-DC buck-boost converter employing a passive snubber," *14th Brazilian Power Electron. Conf. COBEP 2017*, vol. 2018-Janua, no. November 2017, pp. 1–6, 2017, doi: 10.1109/COBEP.2017.8257224.

[11] M. E. Ahamed and S. Senthilkumar, "Review of Bidirectional DC-DC Converters," *Int. J. Adv. Res. Innov.*, vol. 2, no. 4, pp. 433–437, 2017, [Online]. Available: http://www.ijari.org