Hindawi
Wireless Communications and Mobile Computing
Volume 2022, Article ID 6574825, 10 pages
https://doi.org/10.1155/2022/6574825

Research Article

An Optimized PI Controller-Based SEPIC Converter for Microgrid-Interactive Hybrid Renewable Power Sources

Harish Chandra Mohanta,[1] B. T. Geetha,[2] Mohammed S. Alzaidi,[3] Inderjit Singh Dhanoa,[4] Pankaj Bhambri,[5] Udit Mamodiya,[6] and Reynah Akwafo[7]

[1]*Department of Electronics and Communication Engineering, Centurion University of Technology and Management, Odisha, India*
[2]*Department of ECE, Saveetha School of Engineering, SIMATS, Tamil Nadu, India*
[3]*Department of Electrical Engineering, College of Engineering, Taif University, Taif 21944, Saudi Arabia*
[4]*Department of Computer Science and Engineering, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India*
[5]*Department of Information Technology, Guru Nanak Dev Engineering College, Ludhiana, Punjab, India*
[6]*Department of Electrical Engineering, AICTE-IDEA Lab Co-Coordinator, Poornima Institute of Engineering and Technology, Jaipur, Rajasthan, India*
[7]*Department: Electrical and Electronics Engineering, Bolgatanga Technical University, Ghana*

Correspondence should be addressed to Reynah Akwafo; reynah.akwafo@bolgatu.edu.gh

Received 4 March 2022; Revised 5 April 2022; Accepted 21 April 2022; Published 29 June 2022

Academic Editor: Mohammad Farukh Hashmi

With the use of hybrid renewable sources for example solar and wind turbines, an autonomous electric power generation system based on self-sufficient electric power generation is built in order to promote a smart and ecologically friendly environment. The three-phase inverter that links this scattered generating unit to the grid is in charge of ensuring that it is properly connected to the grid. While the energy produced by the hybrid unit is being utilized, it is also being stored in the batteries so that it may be used to transport power when other sources of power are not available, such as when the grid is down. This stand-alone power conversion and storage system is being built with the aid of power electronic converters and controllers, among other components, in order to ensure balanced power flow operation. To produce PWM pulses for the generator side converter, a PI controller is utilized. On the PV side, an improved PI controller is used to drive the SEPIC converter, which increases the transient responsiveness of the converter while it is being controlled by the controller. In order to communicate with the grid, the generated electricity is routed via a three-phase inverter that is controlled according to the DQ theory. The challenges connected with poor power quality are substantially resolved by the converters that have been presented. For simplicity of use, an automated control function has been introduced; in addition, an interactive MATLAB model of the system is being developed for minor and medium-scale microgrid applications; also, a prototype is being created to verify the simulation results.

1. Introduction

We cannot picture our lives without electricity, which is one of the most basic and vital technologies that science has ever given us. The bulk of the world's population, on the other hand, continues to be without reliable and high-quality energy. The total demand has not been completely met despite the fact that most of the outlying areas have been declared electrified. As a consequence, they are suffering higher power supply challenges as a result of both unforeseen and planned blackouts. Interruptions caused by natural and human-made reasons like as overloading, snapping, and short-circuiting are all instances of unanticipated events that might happen. In spite of the fact that electricity is readily accessible, it is found that the voltage has been decreased and that the voltage is uneven. Power outages may also be imposed on a regular basis by businesses in order to safeguard their own financial interests.

On the brink of joining forces with industrialized countries in order to secure green energy generation via the use of renewable energy sources, developing countries are announcing their intention to do so. The advancement of industrialization is one of the most important factors influencing the advancement of energy security in the world today. Energy demand all over the world has adjusted the outage duration with disruptive changes in reaction to the loading effects of renewable energy sources, with the goal of limiting the use of polluting sources of energy in the power grid and, as a result, reducing pollution. When it comes to energy, distributed generation makes use of locally available recyclable energy source (for example, sun, biomass, small hydro, and wind) in order to achieve self-reliability in energy, as well as high quality and independence in power production; distributed generation is a good choice. Using clean energy encourages the utilization of renewable resources while also removing the issues connected with conventional fossil fuels. In their research, engineers observed that the interface of connected components and the couplings that connect them is a significant source of problems and a significant cause of worry. To get specified output power, it is necessary to optimize design as well as the electromechanical components that are involved. Comparing renewable energy source to traditional electricity production sources, renewable power sources are preferable in that they can be replaced more readily. For the purpose of constructing an intelligent grid structure, it is feasible to integrate a wide range of renewable energy sources with combustible fuel generators in a single system.

In contemporary nations, power electronic systems handle 50-60 percent of all electric power transmission and distribution. Since the development of power electronic technology, the proportion of people who use power electronic gadgets has increased dramatically worldwide nature. The nonlinear features of power electronic devices have an impact on their performance.

By adding harmonics into the system, we may improve the quality of the electricity. Harmonics are a kind of music having a knock-on impact on the characteristics of the grid as well as on the equipment attached according to the grid. As a result, the prognosis for the APFs has improved in recent years. This chapter describes the SAPF as a harmonic filter, as well as how to use it. The specifics of the modeling are explored in depth. The model that has been constructed is linked to utilizing the MATLAB/SIMULINK platform, to run the grid in parallel and simulate it.

The results of the simulations are used to ensure that the model that has been built behaves as predicted in the real world.

In order to expand the capacities of self-sufficient renewable energy systems, efforts have been made all over the globe. Renewable energy systems have been installed as part of this project, and through the integration of more renewable sources of energy, they have the ability to generate self-sufficient electricity [1] as well as the reduction of carbon emissions. This project has cemented the way for future renewable energy system. Renewable energy sources like photovoltaics and wind energy [2] are the two broadly utilised renewable sources of energy. Wind energy provides for 10% of overall power production in the Indian subcontinent, but solar energy accounts for more than 30% of all renewable energy sources on the continent.

In the scientific literature, there has been some discussion about a photovoltaic (PV) system that is powered by the wind. Consequently, the integration and permeation of renewable energy sources will confront significant hurdles in the next years as a result of the worldwide expansion of the power sectors. In combination with large-scale electricity production units, renewable sources of energy like wind and solar, as well as continuously improving control systems, are helping to provide the groundwork for the development of future green energy-based power-producing facilities. The integration of wind-generated electricity into the electrical grid is progressing at an exponential rate, thanks to today's technological advancements. Because blackouts are less likely to occur when power suppliers raise the stiffness of the system state, grid stability is maintained as a result of this increase in rigidity. Large quantities of power have been flowing at a gigantic scale from stand-alone renewable energy facilities to the grid utility system in recent years [3], and this trend is expected to continue.

When wind turbine and solar system are integrated, combined capacity of two systems is greatly improved, which is further enhanced by the employment of intelligent controllers. It is feasible to increase the energy-gathering capacity of a system by using various MPPT approaches and operating the system at full power while employing diverse MPPT methods. Power electronic components may be used to their maximum potential by combining solar and wind energy sources in a hybrid configuration, to the greatest extent possible.

Various control systems may be employed to ensure effective power flow in a hybrid power system, and each has its own advantages and disadvantages. The sort of conversion system that will be used and the types of converters that will be used in the system are all crucial variables to take into account. As a consequence, various studies [4–7] have been undertaken on the modelling of system design, which has compelled researchers to pay even closer attention to technological challenges. A hybrid distributed renewable energy system hardware design has been developed to accommodate small-scale and laboratory-scale generating devices [8–13]. Researchers in [10–12] researched PV-wind hybrid systems that were linked to the power grid, while researchers in [13, 14] investigated a freestanding hybrid system. 14 and 15 are instances of [14–16] and examples of [14–16].

It is necessary to integrate storage units (batteries) in order to compensate for the intermittent nature of energy produced by PV-wind systems in order to provide continuous power, particularly when operating as a stand-alone system.

In the opinion of the researchers, an autonomous operation would increase the performance of distributed centres by managing microgrid resources via the use of an artificial intelligence-enabled control system, which would be managed by a control system. A power-management and control system of this kind is being developed with the goal of regulating the flow of electricity in the grid [17] via the management and control of energy sources and sinks.

Specifically, we will develop and build a laboratory-scale hybrid renewable system that will employ wind and solar energy in addition to an energy storage system, in order to demonstrate the system's viability and practicality. Control approaches that are adequate for real-world regulating situations are used in order to ensure that the power emanating from the two unique sources is monitored and regulated in an efficient manner. Among the areas where the proposed technique has the potential to be used for real-time investigation and analysis is field of renewable source of energy. It is feasible to adopt and test a broad variety of power electronic converters and regulating ways in order to evaluate the functioning of the microgrid when using an open architectural design.

As a consequence of the required characteristics of a hybrid wind-PV-producing system, the creation of a unique, but simple and effective design for integrating the PV-wind with the grid and an energy storage device, which is discussed in this paper, has occurred. The following are the most important contributions made by this research, in no particular order.

To supply the grid with environmentally friendly electrical power, a grid-connected PV-wind system is implemented via the use of independent variable speed controllers (VSCs) and energy storage device, as shown in Figure 1.

Efficacy of the proposed microgrid-producing system is further explored in simulation under a variety of operating situations in the time domain, and the findings are confirmed with the laboratory prototype setup, as presented in Figure 1.

2. The System under Consideration

It is proposed a hybrid microgrid system that includes a combination of PV and wind energy.

3. Proposed System

A hybrid microgrid system is presented in which a mix of PV- and DFIG-based wind generators serves as the major energy source, with the battery backup serving as a secondary energy source.

Figure 2 gives the circuit diagram. In order to monitor the most efficient solar and wind energy, the power conversion stage makes use of a SEPIC converter and a three-phase IGBT-based PWM rectifier. Using a buck-boost converter with bidirectional power flow capacity, the battery arrangement is connected to the power converter (PCC) [18]. Using this method, the intermittent character of renewable energy sources is reduced, and local support to the grid is provided when renewable energy sources are not accessible [19]. It is feasible to offer a flexible and cost-effective interface solution by transmitting all of the power through a highly accessible and energy efficient dc transmission system [20]. Maintaining a reference voltage of 600 V and connecting the PCC to the power grid via a three phases inverter is required in order to keep PCC operational. In addition to lowering the overall cost by eliminating the need for multiple inverters for each source of energy, the efficiency of power conversion is improved by increasing the utilization of converters to their maximum capacity [21]. As a result, the recommended system represented in Figure 2 has a high potential for integrating renewable energy source into the grid though simultaneously enhancing the characteristics and availability of power. A reference dc potential of 600 V is used as a reference for comparison between the output of the SEPIC converter positioned on the PV side and the output of PI controller [22]. In order to identify an error, it is passed to the comparator, which generates command pulses for the SEPIC converter using a 10 kHz triangle carrier wave in order to detect the error. The tuning of the variables in the PI controller is accomplished via the use of the GWO algorithm [23]. Wind turbines are equipped with DFIGs that receive three-phase power from the grid, and the rotor is linked to a pulse width modulation rectifier that also gets three-phase power. When the rotor speed surpasses the synchronous velocity, the wind energy is converted into an equivalent quantity of alternating current [24]. This is known as synchronous velocity (AC). In the simulation, the wind speed is set to vary between 4 and 16 miles per hour, with the maximum speed being 16 miles per hour. The rectifier is in charge of converting the alternating current voltage that is generated into alternating current direct current [25]. To produce the error in PI controller, this value is compared to the reference dc voltage in the circuit. In order to generate the right pulses for the rectifier, this error is sent to the comparator.

In addition to being used as a backup power source, the electricity generated by solar and wind energy is stored in batteries [26]. Battery and PCC communication is accomplished by a bidirectional buck-boost converter. The charging and discharging phases of batteries are controlled by an ANN-based controller, which in turn regulates the power flow in one direction. The reference voltage of batteries is set at a level that is 10 percent lower than the potential of the dc-link. As a result, in this circumstance, the reference battery voltage is indicated as 540 V. As long as the voltage across the battery stays constant in relation to the reference voltage, the ANN controller will maintain the duty ratio of the converter's pulses constant at 0.5, resulting in the converter being unable to obstruct the flow of power in either direction, as shown in Figure 1. It is possible that the battery voltage will reach its maximum voltage when it reaches 540 V, at which point the converter will enter boost mode (with a duty ratio greater than 0.5) and power will begin to flow from the battery to the inverter, indicating that the battery has reached its maximum voltage. When the battery voltage falls below 540 V, the ANN controller changes the converter's operating mode to buck mode (duty ratio 0.5), which allows the battery to be charged and the voltage to be restored [27].

Via the use of a three-phase inverter, the direct current (DC) link voltage is converted to alternating current (AC), which is then fed into the utility grid, where grid synchronization is performed through the use of the differential quadrature theory. With the help of the voltage and current sensors, it is possible to estimate the actual power available on the grid, and this estimate is compared to the reference 1 kW power. After the comparator generates an inaccurate output, it is submitted to the dq theory for further investigation. As a result of this theory, the three-dimensional power

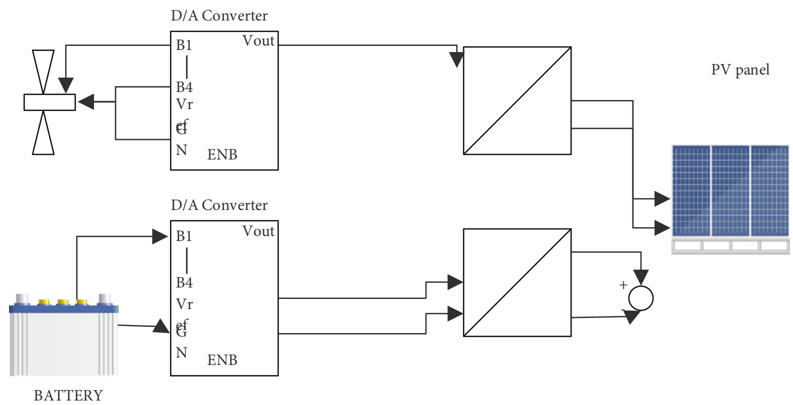


Figure 1: System block diagram.

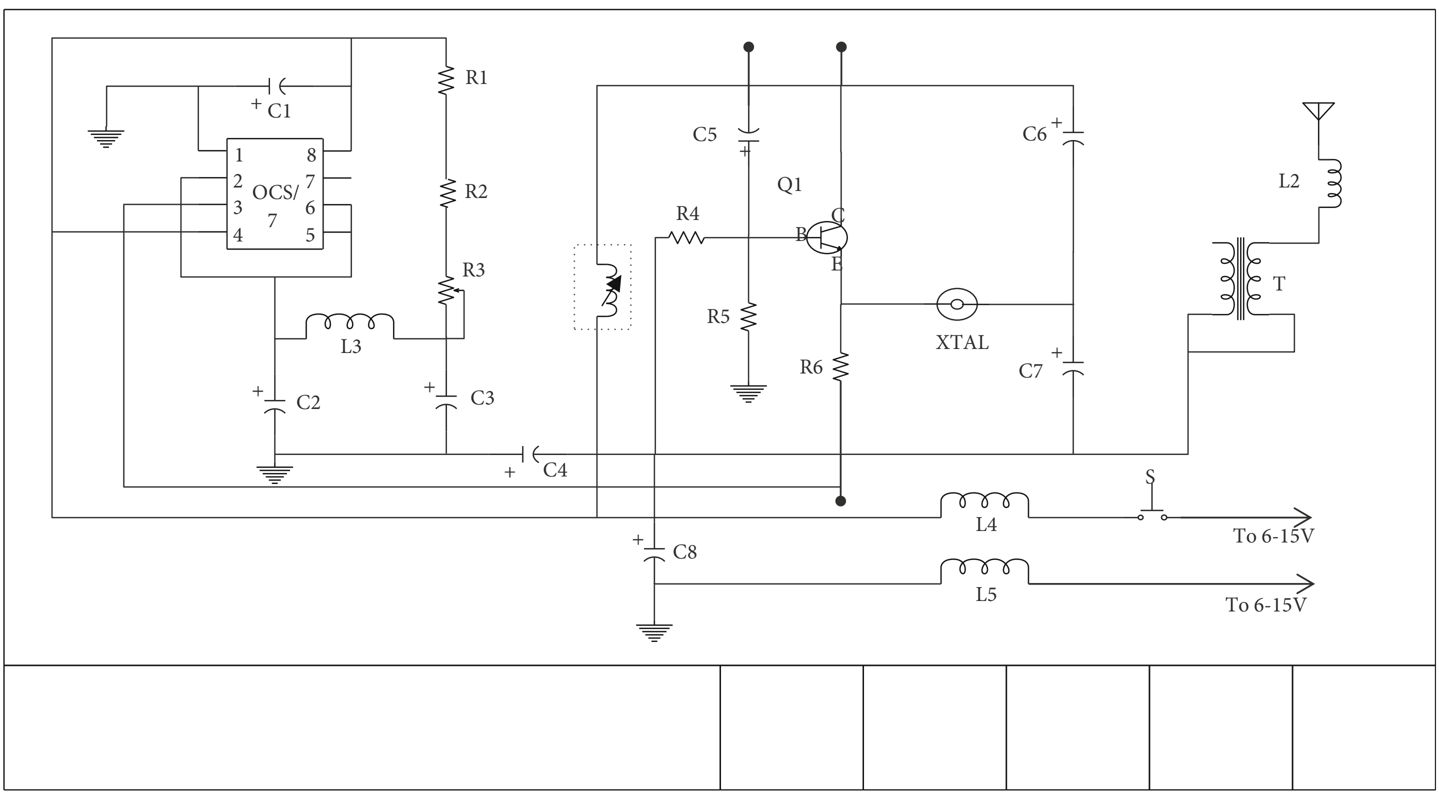


Figure 2: Outcomes of the proposed architecture.

component is subdivided into two-dimensional direct and quadrature components, respectively [28]. According to the figure, this current is in contrast to grid current, in which the output of the comparator represents the quantity of reactive component present in the grid. The hysteresis controller, which is coupled to the comparator's output, creates the pulse width modulation (PWM) signal that the inverter requires [29].

Another important component of the SAPF is a three-phase voltage feed inverter that is based on metal oxide semiconducting field effect transistors (MOSFETs) technology. Six MOSFETs with the required rating are used in this application. It will regulate the charging and discharging of the DC link capacitor in order to provide compensatory current that is necessary. Antiparallel diodes are linked through the MOSFETs in order to do two different tasks. Both of these functions are necessary for the protection of switching devices as well as the provision of the reverse route for recharging the DC capacitor in the event that its value is less than the reference value. The design of the control block has a significant influence on the switching function of this converter [30].

3.1. Capacitor for the DC Link. The utility provides active power for the operation of the DC link capacitor, and this capacitor is responsible for meeting the reactive power requirements of the connected load. The use of large-capacity capacitors is often recommended for maintaining steady direct current voltage. However, there should be a trade-off in the selection of a value between the lowest and the maximum value.

3.2. Inductor for the Output Filter. It is critical in connecting the SAPFs to grid at point of common coupling, that is, where they are associated to the grid (PCC). Because it functions as a low pass filter (LPF), it is able to smooth out and reduce both the amplitude and the frequency of ripples in current harmonics introduced into the power system by the converter block [31]. It also offers isolation for components with a high frequency of operation. As long as the leakage reactance of the coupling transformer is sufficiently high, the filter inductance is given by the coupling transformer.

3.2.1. Modeling of the Proposed System. Solar PV-based generation systems are turning out to be important renewable energy sources as they provide several benefits like no fuel requirements, pollution free, less maintenance, and noise less, among other renewable sources. The equation relating the voltage–current of PV panel is given below

$$V_{\mathrm{PV}} = n_S \frac{AKT}{q} \ln\left\{\frac{n_p I_{SC} - I_{PV} + n_p I_o}{n_p I_o}\right\} - \frac{n_s}{n_p} I_{\mathrm{PV}} R_S, \quad (1)$$

$$P_{\mathrm{PV}} = V_{\mathrm{PV}} \bullet I_{\mathrm{PV}}. \quad (2)$$

Each characteristic has its own maximum power point where the PV system can operate effectively. Figure 3 gives the performance of PV array.

3.2.2. SEPIC Converter. Kk899bjical model is often developed for any form of issue in order to arrive at a solution…. Nevertheless, the process of solving harmonic problems in three phase circuits by incorporating all system parameters into the model is time-consuming and complicated. The mathematical expression of the system must be reduced to execute suggested harmonic correction method in electrical simulation/hardware, as described above. Harmonic currents should be reformed by applying transformation in order to get a straightforward implementation. Nonetheless, the calculation has been performed using the reformed model; however, the parameters must be changed back to their original coordinates once again [32].

The three-phase currents in the "*abc*" coordinate system are translated to the "dq" coordinate system in this step. The low pass filter receives input as the altered vectors contained in "dq" (LPF).

SEPIC converter has the ability of operating in either buck or boost mode by following optimum power from the PV system. The circuit of the SEPIC converter is provided in Figure 4.

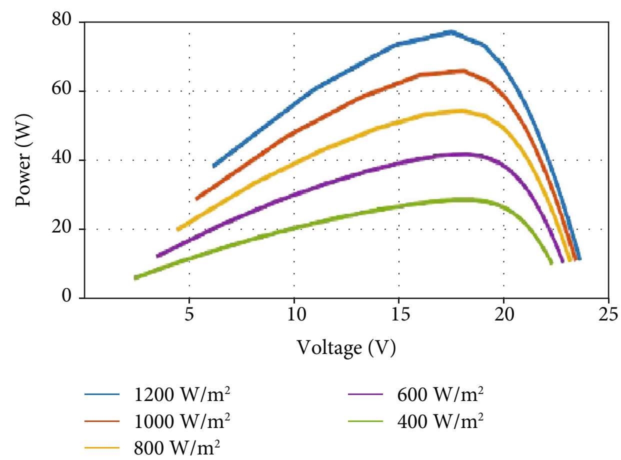


Figure 3: Performance of PV array at $T = 25^{\circ}$C.

Based on the switch positions (S_c), the differential equations are written as

$$\begin{aligned} L_1 \frac{di_{L1}}{dt} &= -(1 - S_c)(v_1 + v_2) + V_{pv}, \\ L_2 \frac{di_{L2}}{dt} &= S_c v_1 - (1 - S_c)(v_2), \\ C_1 \frac{dv_1}{dt} &= (1 - S_c)(i_{L1}) - S_c i_{L2}, \\ C_2 \frac{dv_2}{dt} &= (1 - S_c)(i_{L1} + i_{L2}) - \frac{V_2}{R}. \end{aligned} \quad (3)$$

The state space modeling of the SEPIC converter is expressed as

$$\dot{x} = [i_{L1}\, i_{L2}\, v_1\, v_2]^T, S = [V_{pv}], \quad (4)$$

$$A = \left[0\,0 - \frac{(1 - S_c)}{L_1} - \frac{(1 - S_c)}{L_1}\,0\,0\,\frac{S_c}{L_2} - \frac{(1 - S_c)}{L_2}\,\frac{(1 - S_c)}{C_1} - \frac{S_c}{C_2}\,0\,0\,\frac{(1 - S_c)}{C_2}\,\frac{(1 - S_c)}{C_2}\,0 - \frac{1}{RC_2}\right], \quad (5)$$

$$B = \left[\frac{1}{L_1}\,0\,0\,0\right]^T, C = [0\,0\,0\,1]. \quad (6)$$

3.2.3. Grey Wolf Optimization. The metaheuristic GWO algorithm imitates the grey wolves' social manners. The wolves stay in a group of 5-12 associates. Inside that gathering, dominant pecking order is rehearsed; here, gathering has a pioneer called alpha (α), upheld through auxiliary member called beta (β), that help α in taking judgement. The remaining individuals of gathering are called δ and ω as appeared in Figure 4.

The order of prey chasing by the grey wolves is: searching for prey, encompassing prey, chasing, and assaulting the

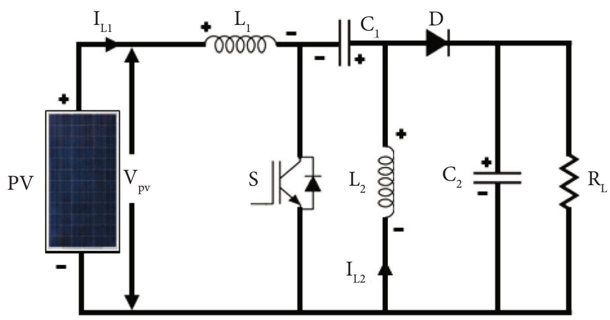


Figure 4: PV fed SEPIC converter.

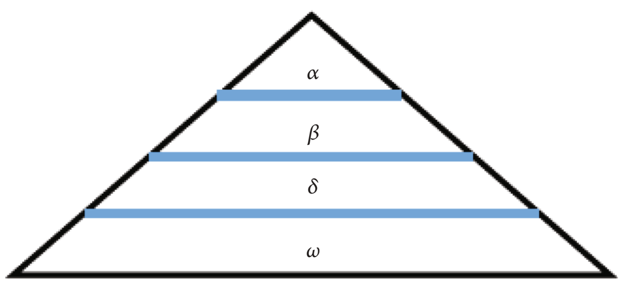


Figure 5: Grey wolf optimization.

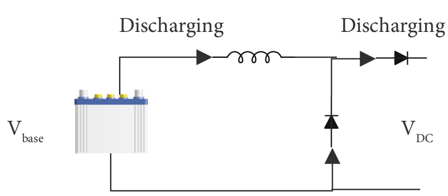


Figure 6: Bidirectional power-flow in battery setup.

prey.

$$\vec{D} = \left| \vec{C} \bullet \overrightarrow{x_p} - \overrightarrow{x_i} \right|, \tag{7}$$

$$\overrightarrow{x_{i+1}} = \overrightarrow{x_p} - \vec{A} \bullet \vec{D}. \tag{8}$$

x_i is the location of grey wolves; x_p is the location of food; D is the distance; A and C are vectors

$$\vec{A} = 2\vec{a} \bullet \overrightarrow{\overrightarrow{r_1}} - \vec{a}\ ; \vec{C} = 2\overrightarrow{r_2}, \tag{9}$$

where r_1 and r_2 are arbitrary numbers between [0, 1].

Figure 5 shows the grey wolf optimization of the proposed work.

$$\begin{gathered} \overrightarrow{D_\alpha} = \left| \overrightarrow{C_1} \bullet \overrightarrow{x_{\alpha i}} - \overrightarrow{x_i} \right| ; \overrightarrow{D_\beta} = \left| \overrightarrow{C_2} \bullet \overrightarrow{x_{\beta i}} - \overrightarrow{x_i} \right|, \\ \overrightarrow{D_\delta} = \left| \overrightarrow{C_3} \bullet \overrightarrow{x_{\delta i}} - \overrightarrow{x_i} \right| ; \overrightarrow{x_1} = \overrightarrow{x_{\alpha i}} - \overrightarrow{A_1} \bullet \overrightarrow{D_\alpha}, \\ \overrightarrow{x_2} = \overrightarrow{x_{\beta i}} - \overrightarrow{A_2} \bullet \overrightarrow{D_\beta} ; \overrightarrow{x_3} = \overrightarrow{x_{\delta i}} - \overrightarrow{A_2} \bullet \overrightarrow{D_\delta} ; \overrightarrow{x_{i+1}} = \frac{\overrightarrow{x_1} + \overrightarrow{x_2} + \overrightarrow{x_3}}{3}. \end{gathered} \tag{10}$$

3.2.4. Modeling of Wind Turbine. Wind energy system composed of the turbine, a DFIG, AC-DC rectifier, and PI controller. The electrical energy output through wind is written as

$$P_w = \frac{1}{2} \rho A v^3 C_p(\lambda, \theta). \tag{11}$$

ρ denotes density of air (kg/m^3); A denotes area surrounded by the blade of rotor (m^2); v denotes wind velocity (m/s); C_p denotes power parameter which is depending on tip velocity ratio and angle of pitch.

A variable velocity wind turbine is utilized in the work. The output of DFIG dependent on velocity of wind that is then rectified with the help of 3ϕ IGBT PWM rectifier and integrated at PCC.

The parameters K_p and K_i of the PI controller are enhanced, then error voltage $e(t)$ will be minimalized to get anticipated performance.

The output $u(t)$ of the PI controller is given by

$$u(t) = K_P e(\mathrm{t}) + K_i \int_0^t e(t) dt. \tag{12}$$

The best relevant function for reducing the error-integrating function in this scenario, with regard to control goals, is integral absolute error:

$$\mathrm{IAE} = \int |e(t)| dt. \tag{13}$$

3.2.5. Modeling of Battery. The batteries require a bidirectional power converter so as to keep the dc-link potential at the optimal voltage level of 600 V at the grid that is typically greater than the maximum voltage level of battery (540 V). Figure 6 gives battery setup.

Initially, the duty ratio is kept as 0.5, and the converter will neither operate in boost nor buck mode; hence, there will not be power flow across batteries. According to the variation between the magnitude of dc-link potential level and battery terminal reference voltage level, the duty cycle of converter is varied by an ANN controller. Figure 7 gives a control unit of converter.

3.2.6. DQ-Based Control of 3ϕ Inverter. The grid synchronization is achieved by considering the phases of grid voltage and inverter output voltage. Among several methods of grid synchronization, grid voltage filtering can be used in dq and $\alpha\beta$ reference frames.

Initially, the 3ϕ *abc* is transformed into 2ϕ $\alpha\beta$ stationary reference frame and then to dq reference frame which revolves at synchronous velocity.

Various control methods are available to control the 3ϕ PWM VSI connected with grid to control active and reactive powers. A well-known small signal model can be used to control where 3ϕ system is converter into dq frame (rotating references) that is called as Park's transformation.

The 3ϕ PWM controller provides 3ϕ PWM signal using three channels. The Clarke transformation is employed in 3ϕ

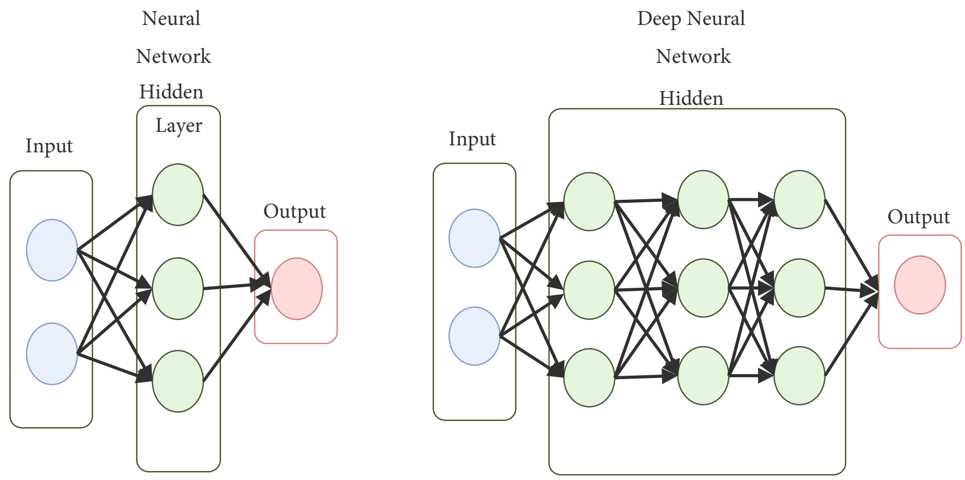


Figure 7: ANN-based control of converter.

system to reduce three-phase components into 2ϕ stationary reference frame components. The latter two components play a primary role in generating the PWM pulses.

$$\left[V_\alpha\, V_\beta\, V_0\right] = \frac{2}{3}\left[\text{sinsin}\,\theta\,\text{sinsin}\left(\theta - 120^0\right)\text{sinsin}\left(\theta + 120^0\right)\text{coscos}\,\theta\,\text{coscos}\left(\theta - 120^0\right)\text{coscos}\left(\theta + 120^0\right)0.5\,0.5\,0.5\right] * \left[V_a\, V_b\, V_c\right]. \tag{14}$$

The below equation represents the Park transformation where the stationary frame is converted into rotating frame

$$\left[V_d\, V_q\right] = \left[\text{coscos}\,\theta_e\,\text{sinsin}\,\theta_e - \text{sinsin}\,\theta_e\,\text{coscos}\,\theta_e\right] * \left[V_\alpha\, V_\beta\right]. \tag{15}$$

4. Experimental Analysis and Results

A time scale simulation setup is developed for PV-wind system in Matlab to evaluate and validate system performance.

Figure 8 gives the solar parameters. The PV-wind generator is rated at 1 kW, which is the maximum power it can produce. The sim power-system toolbox is used to create the whole set of models shown here. The discrete type simulation is employed with a sample time of 20 ms, and the results are shown graphically. A major goal of the proposed system is to provide constant electricity to the grid under a variety of producing scenarios by using hybrid energy resources.

Changing the temperature controls the amount of solar insolation received, which results in a range of irradiance levels ranging from 800 W/m^2 to 1000 W/m^2. Change the fan blower's speed from 4 metres per second to 12 metres per second to alter the wind velocity. Figure 9 gives output optimized graph.

Approximately 15 numbers of 12 V batteries are linked in series in order to provide an output voltage of 180 V. With a primary short circuit current of 10 A, panel arrays maintain an average short circuit current of 2.5 A during the course of the simulation.

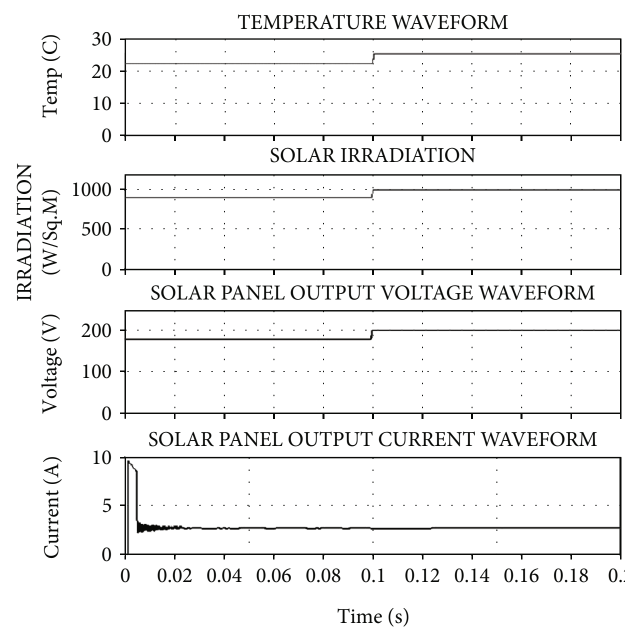
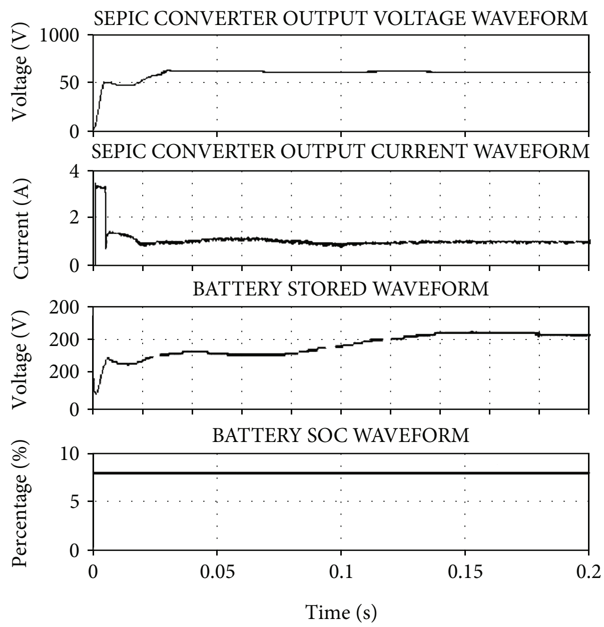


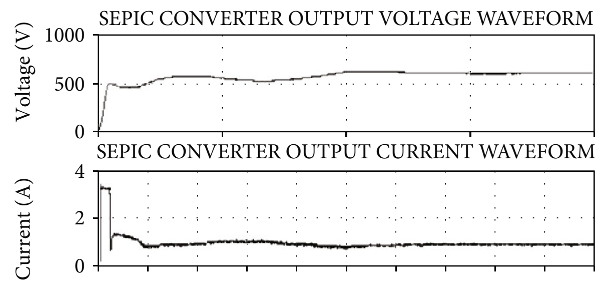
Figure 8: Solar parameters.

It has been determined to adjust the ranges of values from the useable minimum and maximum operating ranges of PV array and wind system to verify behavior of the system in existence of these modifications. In addition, the grid is variable in this case, as it would appear in a real-time environment under the nonloading condition, allowing for the measurement of the operational performance of the power conversion and battery systems in response to changes in the quantity of energy created by the PV and wind energy systems, correspondingly.

To check and analyze the proposed PV-wind-battery system's main qualities, an FPGA-based laboratory setup of the system is being constructed. The PI controller for wind energy has not been tuned in the same way that the SEPIC converter



(a) PI controller optimized by GWO



(b) PI controller without optimization

Figure 9: (a) and (b) SEPIC converter output with and without optimization.

output has not been optimized [33]. It makes use of the DC link voltage as the sole feedback signal, which is provided by a signal conditioning device connected to the appropriate channel. For the controllers to be able to operate the converter through an independent driver circuit, internal PWM modules are needed. It is compulsory to utilise the input-output pins to operate power contactors via use of EM relays. The complete control system has been discretized and coded in the dsPIC3050 FPGA controller (field-programmable gate array).

As a result, the total harmonic distortion (THD) and harmonic content (HC) are kept to a minimum in order to comply with the IEEE current guideline.

The results obtained support the notion of independent control over the various sources of information (PV, wind, and battery). Effective control of solar voltage in order to maintain optimal [34] power, effective control of rectified output from wind generation units in order to maintain optimal power from wind turbine systems, and the intelligent control of battery all contribute to reducing power deficits and ensuring a consistent supply of electricity to the grid, according to the International Energy Agency (IEA).

5. Conclusion

A grid-interactive PV-wind renewable power system fed by an interleaved SEPIC converter controlled by an optimized PI controller and a three-phase PWM rectifier controlled by a conventional PI controller can track MPPT from both solar and wind, allowing regulated dc voltage to be obtained from both sources, as discussed in this paper. Because of the battery backup system, it is feasible for this mixture system to deliver more consistent power while also giving more reliability than power sources that do not have backup system. PI controller and battery controller are well-known in the area of renewable energy system for their ability to keep a steady dc voltage in face of power variations in PV and wind turbine systems. The maximum power from PV and wind is followed in this manner, independent of changes in factors controlling PV and wind. This is true regardless of changes in temperature, irradiance, and wind speed.

ANN manages the charging and discharging states of batteries to provide continuous energy to the grid when major power sources are unable to provide the amount of electricity required by the system. This section discusses the general system description of the proposed power model, as well as the converter and control strategies that are used to implement it. The results of the simulation and hardware validation demonstrate that the system is feasible. Using the GWO-optimized PI controller in conjunction with an unoptimized controller, it is shown that the power fluctuations in the hybrid system are effectively avoided. Choosing the tuning parameters has been done with the purpose of minimizing the IAE while enhancing the converter's flexibility. For a step modifying in input power, the dynamic parameters of converter were examined, and the results of the simulation were also given. It is also feasible to lower the time domain parameters of the controllers with the help of the optimized PI controller, which has been developed. The increased power rating of the system may be used to further enhance this work, and the overall performance of the system can be assessed by integrating the controller with other optimization approaches.

Data Availability

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

All authors declared that they do not have any conflict of interest.

References

[1] F. Qazi, N. Hussain, N. A. B. D. Rahim et al., "Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions," *IEEE Access*, vol. 7, pp. 63837–63851, 2019.

[2] M. H. Nehrir, C. Wang, K. Strunz et al., "A review of hybrid renewable/alternative energy systems for electric power generation: configurations, control, and applications," *IEEE Transaction on Sustainable Energy*, vol. 2, no. 4, pp. 392–403, 2011.

[3] M. Faisal, M. A. Hannan, P. J. Ker, A. Hussain, M. Mansur, and F. Blaabjerg, "Review of energy storage system technologies in microgrid applications: issues and challenges," *IEEE Access*, vol. 6, pp. 35143–35164, 2018.

[4] C. Wang, H. Nehrir, F. Lin, and J. Zhao, "From hybrid energy systems to microgrids: hybridization techniques, configuration, and control," *IEEE PES General Meeting*, pp. 1–4, 2010.

[5] M. Gupta, K. K. Gupta, M. R. Khosravi, P. K. Shukla, S. Kautish, and A. Shankar, "An intelligent session key-based hybrid lightweight image encryption algorithm using logistic-tent map and crossover operator for internet of multimedia things," *Wireless Personal Communications*, vol. 121, no. 3, pp. 1857–1878, 2021.

[6] J. Esch, "High-power wind energy conversion systems: state-of-the-art and emerging technologies," *Proceedings of the IEEE*, vol. 103, no. 5, pp. 736–739, 2015.

[7] M. J. Hossain, H. R. Pota, M. A. Mahmud, and M. Aldeen, "Robust control for power sharing in microgrids with low-inertia wind and PV generators," *IEEE Transactions on Sustainable Energy*, vol. 6, no. 3, pp. 1067–1077, 2015.

[8] M. Gupta, K. K. Gupta, and P. K. Shukla, "Session key based novel lightweight image encryption algorithm using a hybrid of Chebyshev chaotic map and crossover," *Multimedia Tools and Applications*, vol. 80, no. 25, pp. 33843–33863, 2021.

[9] Z. M. Manas, "Renewable energy management through microgrid central controller design: an approach to integrate solar, wind and biomass with battery," *Energy Reports*, vol. 1, pp. 156–163, 2015.

[10] P. Satish Kumar, R. P. S. Chandrasena, G. N. Srinivas, and K. V. S. M. Babu, "Energy management system for small scale hybrid wind solar battery based microgrid," *IEEE Access*, vol. 8, pp. 8336–8345, 2020.

[11] P. K. Shukla, K. Gupta, S. Silakari, and A. S. Saxena, "An ethical way of encrypt data transfer in Bluetooth mobile using chaos based feedback technique," in *2009 Sixth International Conference on Information Technology: New Generations*, pp. 1583-1584, Las Vegas, NV, USA, 2009.

[12] A. Merabet, K. T. Ahmed, H. Ibrahim, R. Beguenane, and A. M. Ghias, "Energy management and control system for laboratory scale microgrid based wind-PV-battery," *IEEE Transaction on sustainable energy*, vol. 8, no. 1, pp. 145–154, 2017.

[13] B. Priyadharshini, V. Ganapathy, and P. Sudhakara, "AN optimal model to meet the hourly peak demands of a specific region with solar, wind and grid supplies," *IEEE Access*, vol. 8, pp. 13179–13194, 2020.

[14] P. K. Shukla and M. Dixit, "Big data: an emerging field of data engineering," in *Handbook of Research on Security Considerations in Cloud Computing*, K. Munir, M. S. Al-Mutairi, and L. A. Mohammed, Eds., pp. 326–344, IGI Global, Hershey, PA, 2015.

[15] F. Chishti, S. Murshid, and B. Singh, "LMMN-based adaptive control for power quality improvement of grid intertie wind-PV system," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 9, pp. 4900–4912, 2019.

[16] A. A. A. Radwan and Y. A.-R. I. Mohamed, "Grid-connected wind-solar cogeneration using back-to-back voltage-source converters," *IEEE Transactions on Sustainable Energy*, vol. 11, no. 1, pp. 315–325, 2020.

[17] V. Bhandari, P. K. Shukla, S. Tamrakar, and A. Bhandari, "Development of secure image transposal algorithm using 16*16 quantization table," *International Journal of Scientific Research & Engineering Trends*, vol. 4, 2018.

[18] T. Wang, D. O'Neill, and H. Kamath, "Dynamic control and optimization of distributed energy resources in a microgrid," *IEEE Transaction on Smart Grid*, vol. 6, no. 6, pp. 2884–2894, 2015.

[19] D. Somwanshi, H. Saini, A. Sharma, and U. Mamodiya, "Performance analysis of temperature controllers for injection molding machine," in *International Conference on Recent Advances and Innovations in Engineering (ICRAIE)*, pp. 1–6, Jaipur, 2016.

[20] B. K. Santhoshi, K. Mohanasundaram, and L. A. Kumar, "ANN-based dynamic control and energy management of inverter and battery in a grid-tied hybrid renewable power system fed through switched Z-source converter," *Electrical Engineering*, vol. 103, no. 5, pp. 2285–2301, 2021.

[21] S. Stalin, P. Maheshwary, and P. K. Shukla, *An Improved NVSS Scheme Based on Blocked Compression Scheme*, pp. 960–966, 2008.

[22] M. H. Qais, H. M. Hasanien, and S. Alghuwainem, "A grey wolf optimizer for optimum parameters of multiple PI controllers of a grid-connected PMSG driven by variable speed wind turbine," *IEEE Access*, vol. 6, pp. 44120–44128, 2018.

[23] N. K. Rathore, N. K. Jain, P. K. Shukla, U. S. Rawat, and R. Dubey, "Image forgery detection using singular value decomposition with some attacks," *National Academy Science Letters*, vol. 44, no. 4, pp. 331–338, 2021.

[24] D. Singh, M. Kaur, M. Y. Jabarulla, V. Kumar, and H. -N. Lee, "Evolving fusion-based visibility restoration model for hazy remote sensing images using dynamic differential evolution," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1–14, 2022.

[25] N. Koli and U. Mamodiya, "Review paper on automation of robotics in spatial with life forms," *International Journal of Engineering Science Invention Research & Development*, vol. 5, no. 11, pp. 349–353, 2018.

[26] A. Kumar, M. Saini, N. Gupta et al., "Efficient stochastic model for operational availability optimization of cooling tower using metaheuristic algorithms," *IEEE Access*, vol. 10, pp. 24659–24677, 2022.

[27] G. Khambra and P. Shukla, "Novel machine learning applications on fly ash based concrete: an overview," *Materials Today: Proceedings*, 2021.

[28] V. Kumar, D. Kumar, M. Kaur, D. Singh, S. A. Idris, and H. Alshazly, "A novel binary seagull optimizer and its application to feature selection problem," *IEEE Access*, vol. 9, pp. 103481–103496, 2021.

[29] A. P. Ambalgi, S. K. Sujata, U. Mamodiya, and P. Sharma, "Effects of single and double wide slots on microstrip patch antennas characteristics using direct contact probe feed excitation with broadsided radiation," in *Proceedings of Second International Conference on Smart Energy and Communication, Algorithms for Intelligent Systems*, Singapore, 2021.

[30] U. Mamodiya and H. M. GirrajRaigar, "Design & simulation of tiffin food problem using fuzzy logic," *International Journal for Science and Advance Research In Technology*, vol. 4, no. 10, pp. 55–60, 2018.

[31] R. Janarthanan, R. U. Maheshwari, P. K. Shukla, P. K. Shukla, S. Mirjalili, and M. Kumar, "Intelligent detection of the PV faults based on artificial neural network and type 2 fuzzy systems," *Energies*, vol. 14, no. 20, article 6584, 2021.

[32] R. Bhatt, P. Maheshwary, and P. Shukla, "Application of fruit fly optimization algorithm for single-path routing in wireless sensor network for node capture attack," in *Computing and Network Sustainability*, S. L. Peng, N. Dey, and M. Bundele, Eds., vol. 75, pp. 129–136, Springer, Singapore, 2019.

[33] A. K. Chaturvedi and P. K. Shukla, "Non-separable histogram based reversible data hiding approach using inverse S-order and skew tent map," *International Journal of Computer Science and Information Security (IJCSIS)*, vol. 16, 2018.

[34] D. Singh, V. Kumar, M. Kaur, M. Y. Jabarulla, and H. -N. Lee, "Screening of COVID-19 suspected subjects using multi-crossover genetic algorithm based dense convolutional neural network," *IEEE Access*, vol. 9, pp. 142566–142580, 2021.