PV-Wind-Battery based Hybrid Standalone Microgrid with Seven Level Parallel Inverter

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Abstract: Electricity generation using a combination of renewable energy sources is an effective solution for addressing various challenges. To optimize the system's performance, it is essential to integrate a multilevel inverter between the DC-link and the load bus. Despite the complexity associated with multilevel inverters due to a high number of switches, this paper introduces a control methodology in closed-loop for a 7-level parallel inverter to enhance power quality. The study focuses on a PMSG coupled wind power conversion unit, as well as a photovoltaic (PV) and battery powered standalone power supply system. The parallel multilevel topology being proposed necessitates only half the amount of switches in comparison to traditional topologies. Additionally, a novel Sinusoidal Pulse Width Modulation (SPWM) method is employed to generate the necessary pulses for the inverter. The Hardware – in the – Loop (HIL) simulation with OPAL-RT devices is performed to assess the system's reaction in different operational scenarios.

Keywords: Novel Multilevel inverter, Wind, PV, Standalone hybrid system.

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1. INTRODUCTION

Every client needs high-quality electricity to run their loads and meet their demands. In this context, a locally located or standalone power supply (SPS) unit is well-known in many areas for supplying power to loads [1-3] is considered. As a result, renewable energy-powered standalone microgrids are becoming more popular and simple to install in a variety of locations across the world. Maximum loads in a 3-phase distribution network are, in general, single phase loads. As a result, an appropriate control method is necessary to maintain constant voltage during imbalance operation [3-4]. Solar and wind energy are two important power producing sources. As a result, this article explores a hybrid system for the SPS unit. The combination of PMSG-powered wind and PV can provide consistent electricity to loads. Unfortunately, both sources are subject to natural fluctuations. To alleviate this issue, the system includes a battery bank.

A battery unit consists of multiple batteries has been integrated into the DC-link using a bidirectional DC to DC circuit [4-6]. The control strategy has been developed to supervise the battery bank's discharging and charging operations. Additionally, an inverter needs to be positioned between the dc-link and AC loads for supplying AC power. Consequently, an inverter is connected via a filter between the dc-link and the load bus. Nevertheless, most inverters change direct current to square wave alternating current, resulting in increased harmonics. This may negatively impact sensitive loads. To ensure the safe operation of loads, a multilayer inverter should be installed. Many configurations are accessible around the world, but those with the most switches suffer the most. The employment of more switches in the design of a multilayer inverter has numerous drawbacks, including size, compactness, efficiency, operation, and so on. As a consequence, utilizing a modest number of switches, this article constructs a revolutionary design known as a parallel inverter.

AC power is supplied from DC by using a 7-level parallel inverter positioned between the filter and the dc-link. In proposed seven-level architecture, a novel SPWM (NSPWM) method is used to produce pulses for switches. In the 7-level parallel inverter configurations, just six switches were required per phase.

The system links multiple converters to create a constant dc-link voltage. Boost converters build an MPPT circuit with both PV and wind units [7]. The photovoltaic system is linked directly to the dc-link in order to minimize the amount of converters needed, while the dc to dc bidirectional circuit's control can function as an MPPT circuit for the photovoltaic modules. This study utilizes a new closed loop inverter control to ensure high-quality power supply to various loads.

The remaining sections of the document are organized in the following manner. Section-2 discusses the setup of a 7-level parallel inverter as well as a standalone system's system description. Section-3 puts the control approach into action. OPAL-RT devices are employed in Section - 4, and Hardware - in - the - Loop (HIL) is built to deliver a variety of outputs. Section-5 is densely packed with conclusions. At the end of the paper, there is a reference list.

2. SYSTEM DESCRIPTION AND CONFIGURATION

The layout of a 7-level inverter shown in Figure 1 was achieved with the utilization of only six switches in a single phase. One advantage of this configuration is that only (p-1) switches are needed for every level 'p' in a phase. This suggested inverter is utilized in SPS models that are operated by sustainable energy sources. Figure 2 illustrates a system model block diagram. The wind & PV systems share the same voltage at dc-link, and the battery has a bidirectional circuit. A closed loop based on RMS voltage control method is implemented to change the voltage at the load bus. The PV array's ratings are displayed in Table-1, while the wind unit's ratings can be found in Table-2. A constant torque-based MPPT model is utilized on a boost converter for a wind system. All AC loads, depicted in Figure 2, are interconnected at the point of common coupling (PCC). The remaining system parameters are taken from [1-4].

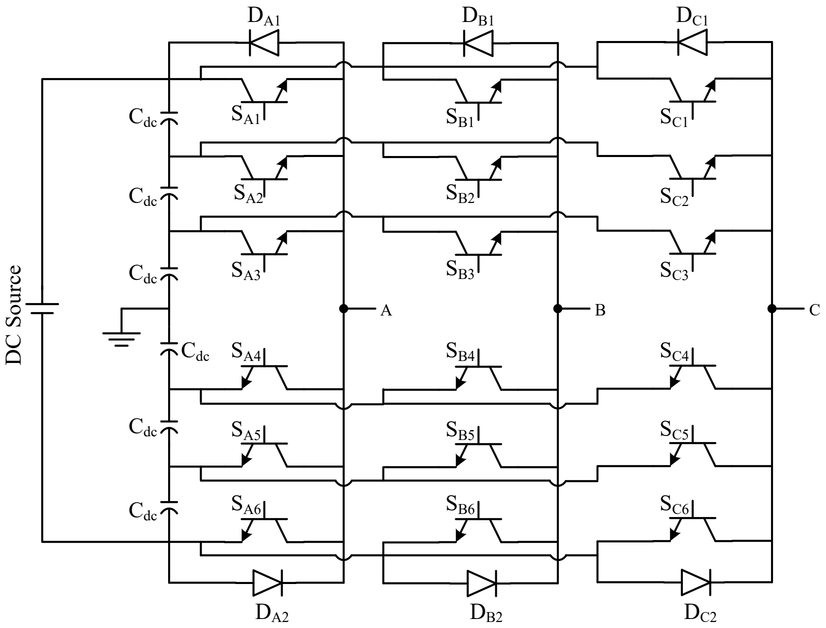

Fig. 1: 7-level parallel inverter (three phase configuration).

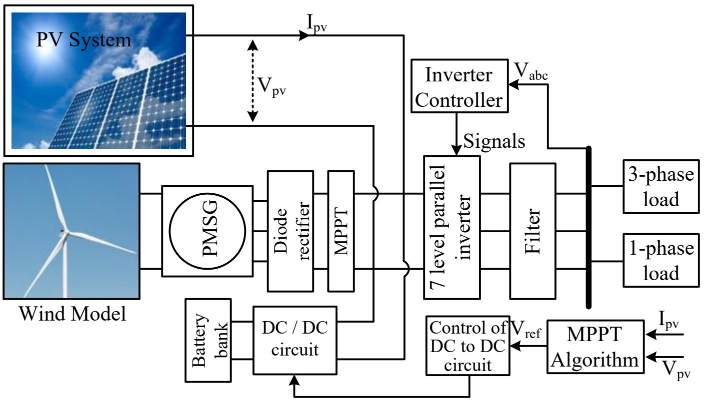

Fig. 2: Standalone hybrid model.

Table-1: Parameters of PV model [9-10].

Parameters	Values
Module voltage (at open).	36.90V
Current when circuit shorted.	8.01A
V_{mpp}	30.30V
I_{mpp}	7.10A
Series resistance.	0.0045 Ω
Shunt resistance.	0.9822 Ω
Voltage at cell diode.	0.5367V
Modules in series.	22
Irradiance G^*.	1000 W/m^2
Maximum power.	4.730kW

Table-2: Parameters of Wind system [1, 11]

Parameters	Values
Air density.	1.255Kg/m^3
Blades Area swept.	1.06m^2
Optimum coefficient.	$1.678\text{x}10^{-3}$Nm/(rad/s)
Rated speed.	153 rad/s
Wind speed base.	12.0 m/s
Pair of poles.	5
Flux linkage.	0.4330wb
Armature resistance.	0.4250Ω
Inductance in stator winding.	8.40mH
Maximum torque.	40.0N-m
Operating current.	12.0A
Maximum power.	6.40kW

3. CONTROL STRATEGY

The control strategy utilized in the newly created technique, as illustrated in Figure 3, involves a closed-loop system designed to uphold a specified voltage level at the PCC. The separate phase RMS voltages are compared to their reference signal using a PI controller, and a modulation index is derived. As demonstrated in Fig. 4, an NSPWM strategy based on comparing carrier and reference waves is also developed. Where $AT_{1,2,3}$ are pulses formed by comparing their reference and carrier waveforms. The inverter may be regulated using the conventional SPWM method. When a switch is turned on during the SPWM technique, it will get a pulse. However, no switching pulses must be generated continuously in the proposed approach. As a result, gates are used to construct NSPWM. Each device's typical ON time is 1/(N-1) times the total period, where 'N' denotes the number of switches. All other switches in the same phase are switched off at the same time.

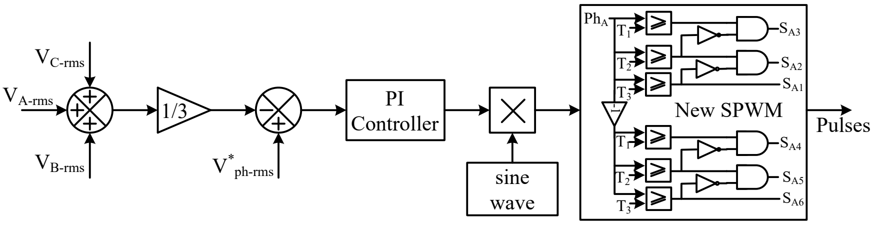

Fig. 3:In a basic control method.

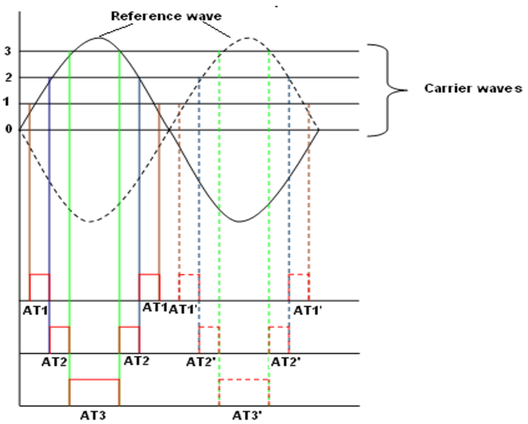

Fig. 4: NSPWM methodology.

Optimized gains of various controllers are given in Table-3.

Table-3: Various Gains.

S.No	Parameter	values
Pi of dc/dc circuit.		
1	Proportional.	2.641
2	Integral.	82.42
PI of 7-level inverter.		
3	Proportional.	4.19
4	Integral.	37.12
Current band of Hysteresis loop of MPPT = 8%.		

4. VARIOUS RESULTS

Real-time simulators (RTS) are widely recognized for their ability to enhance system performance [1, 12-14]. The RTS modules developed by OPAL-RT technologies have been utilized in this study to construct a laboratory HIL setup. In order to facilitate real-time testing of advanced controllers, two OPAL-RT devices have been interconnected. The first OPAL-RT module, referred to as module-1, receives the independent system plant, while module-2 (also known as OPAL RT-2) receives all the controllers. Analog signals are converted into digital signals through appropriate channels and then fed into the controller unit (i.e., OPAL-RT-2) via data cards. The controller unit is capable of functioning as a scheduled controller, producing switching pulses for the converters of the plant. These digital pulses are subsequently converted back into analog signals before being supplied to the plant through external data cards. To ensure enhanced visibility, the significant results are analyzed on a laptop instead of an oscilloscope. The fundamental HIL design, incorporating two OPAL-RT units, is shown in Figure 5 [15-20]. Different factors considered in formulating the suggested method have been accounted for.

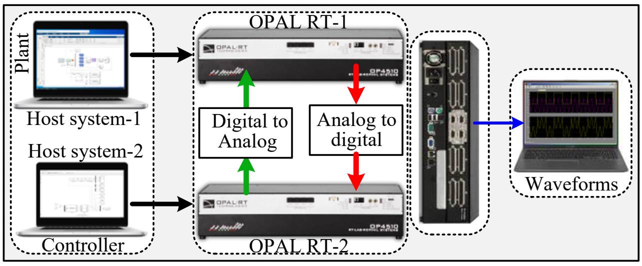

Fig. 5: HIL configuration (a laboratory setup).

Case 1: Because of the changes in loads

The load is raised for four seconds at t = 2 seconds in this case and the output current, voltage, and modulation index (MI) are monitored. As seen in Fig. 6, the initial load current is 4 amps and has increased to 16.240 amps peak. The controller reference signal, on the other hand, maintains the load voltage at 220V. As seen in Fig. 7, the load voltage does not vary considerably. The modulation indices are depicted in Figure 8.

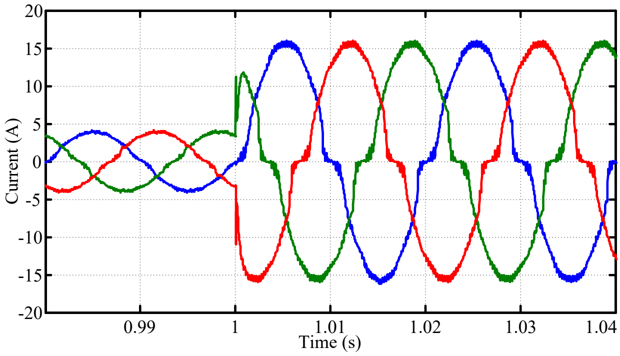

Fig. 6: Currents of Inverter.

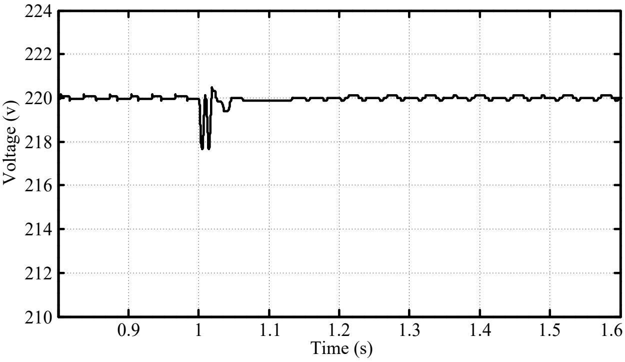

Fig. 7: Load Voltage.

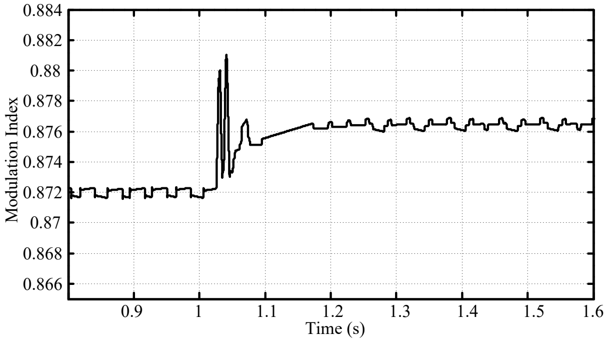

Fig. 8: MI of inverter leg.

Case 2: Operation during unbalanced load at PCC

At present, the system is undergoing testing with an uneven load. The load bus is linked to the three-phase unbalanced load illustrated in Figure 9. Constant RMS voltages at the load bus during this approach are depicted in Fig. 10.

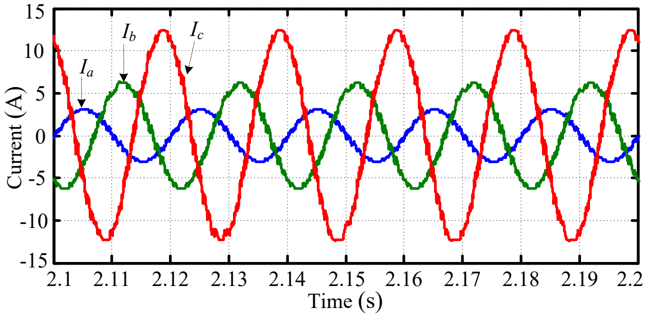

Fig. 9: Load current.

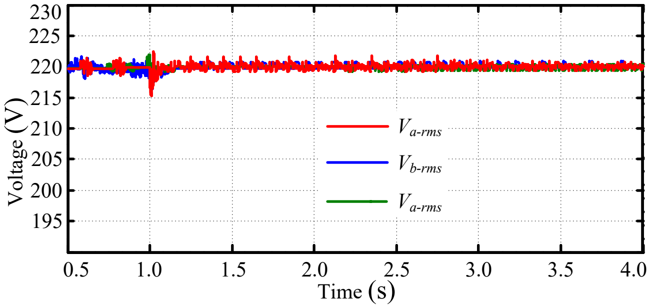

Fig. 10: Voltages at PCC.

Cae-3: Intermittent speed of wind, sun irradiance, and load bus changes:

Loads, wind speed, and solar irradiation all fluctuate at random in practice, as shown in Fig. 11. As illustrated in Fig. 12, the control methodology must maintain constant voltage on both the dc-link and the load bus during this situation. Figure 13 displays the instantaneous voltage profile as well. Figure 14 displays the phase-A matching current.

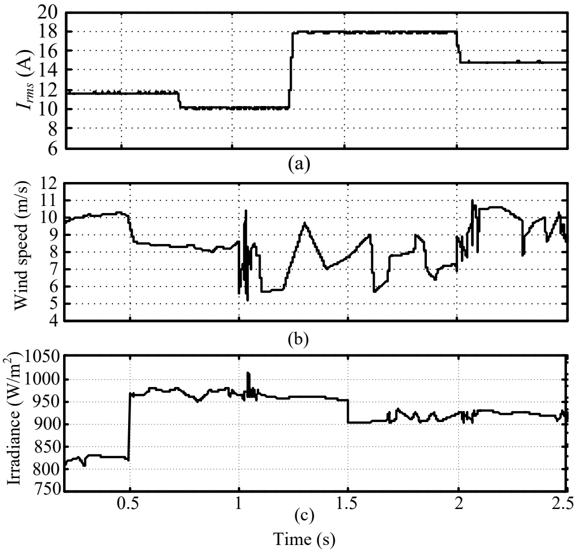

Fig. 11: Changes in (a) Load current, (b) speed of wind, (c) irradiances.

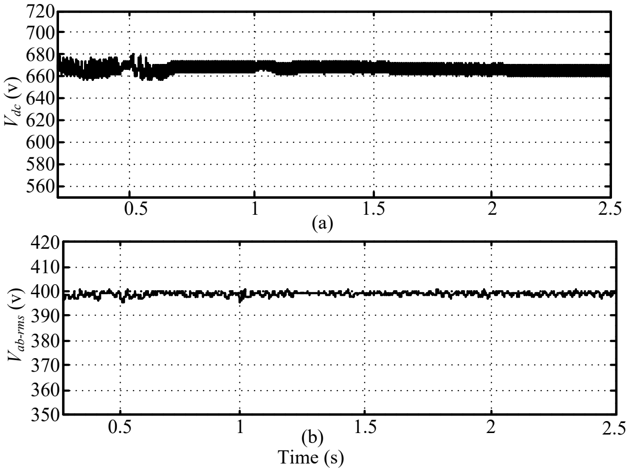

Fig. 12: (a) Dc-link voltage, (b) Voltage at PCC.

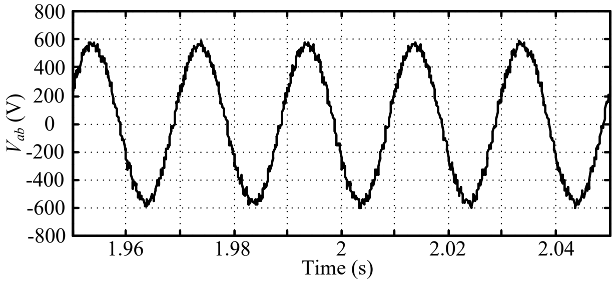

Fig. 13: PCC line voltage.

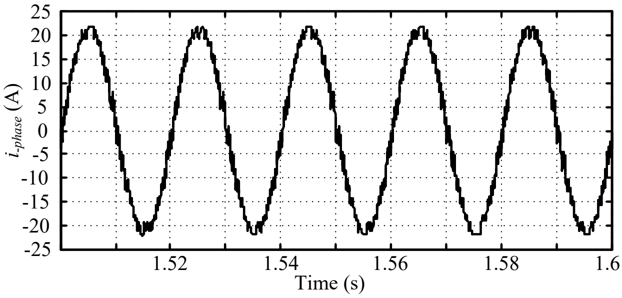

Fig. 14: Currents of phase-A.

5. RESULTS AND DISCUSSIONS

To improve power quality in standalone systems, a novel multilayer inverter design known as parallel inverter is used. A 7-level parallel inverter is used in this article. To ensure power quality at PCC, this study provides a hybrid wind-PV-based standalone system, and a simple control method. Several case studies in this paper use HIL-based outcomes. Even with imbalanced load operations, the proposed approach operates effectively with fluctuations in irradiance, load, and wind speed.

References:

[1]. Siva Ganesh Malla, et al., "Coordinated Power Management and Control of Renewable Energy Sources based Smart Grid", ***International Journal of Emerging Electric Power Systems***, early access, https://doi.org/10.1515/ijeeps-2021-0113

[2]. A. Dash, et al., "DC-Offset Compensation for Three-Phase Grid-Tied SPV-DSTATCOM Under Partial Shading Condition With Improved PR Controller," ***IEEE Access***, vol. 9, 2021, doi: 10.1109/ACCESS.2021.3115122.

[3]. Kandi Bhanu Prakash, "PV-Battery based standalone power supply system for rural applications", International Journal of New Technologies in Science and Engineering (IJNTSE), Vol. 8, Issue. 12, pp. 9-13, Dec. 2022.

[4]. C. Pradhan, et. al., "Coordinated Power Management and Control of Standalone PV-Hybrid System With Modified IWO-Based MPPT", ***IEEE Systems Journal***, vol. 15, no. 3, pp. 3585-96, Sept. 2021, doi: 10.1109/JSYST.2020.3020275.

[5]. D. Bhule, S. Jain and S. Ghosh, "Control Strategy for Photovoltaic-Battery Based Standalone System", ***IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC), 2020***, pp. 1-6, doi: 10.1109/STPEC49749.2020.9297685.

[6]. S. G. Malla, C. N. Bhende and S. Mishra, "Photovoltaic based water pumping system", ***International Conference on Energy, Automation and Signal***, 2011, pp. 1-4, doi: 10.1109/ICEAS.2011.6147148.

[7]. S.G. Malla, C.N. Bhende, "Voltage control of stand-alone wind and solar energy system", ***International Journal of Electrical Power & Energy Systems,*** Volume 56, 2014, Pages 361-373, https://doi.org/10.1016/j.ijepes.2013.11.030.

[8]. S.G. Malla, C.N. Bhende, “Enhanced operation of stand-alone “Photovoltaic-Diesel Generator-Battery” system”, ***Electric Power Systems Research***, Volume 107, Pages 250-257, 2014, https://doi.org/10.1016/j.epsr.2013.10.009.

[9]. Jorge Cervantes, *et al*, “Takagi-Sugeno Dynamic Neuro-Fuzzy Controller of Uncertain Nonlinear Systems, ***IEEE Transactions on Fuzzy Systems***”, Vol. 11, No. 4, Dec 2012, doi 10.1109/TFUZZ.2016.2612697,

[10]. Mariana Landína, R.C. Roweb, P. Yorkb, “Advantages of Neurofuzzy Logic Against Conventional Experimental Design and Statistical Analysis in Studying and Developing Direct Compression Formulations”, ***European Journal of Pharmaceutical Sciences***, Vol. 38, pp. 325–331, 2009, doi:10.1016/j.ejps.2009.08.004

[11]. U. R. Muduli, et al., “Cell Balancing of Li-ion Battery Pack with Adaptive Generalised Extended State Observers for Electric Vehicle Applications”, ***IEEE Energy Conversion Congress and Exposition (ECCE)***, 2021, pp. 143-147, doi: 10.1109/ECCE47101.2021.9595601.

[12]. U. R. Muduli, et al., “Predictive Battery SoC Control for Dual Propulsion Differential Four Wheel Drive Electric Vehicle”, ***IEEE Energy Conversion Congress and Exposition (ECCE)***, 2021, pp. 1490-95, doi: 10.1109/ECCE47101.2021.9595587.

[13]. NagarajuMotaparthi, MalliguntaKiran Kumar, “Seven-Level Symmetrical Series/Parallel Multilevel Inverter with PWM Technique Using Digital Logic” ***International Journal of Electrical and Computer Engineering Systems***, Vol. 12, no. 3, pp. 123-130, Sep 2021, doi: https://doi.org/10.32985/ijeces.12.3

[14]. Dursun, EmreHasan and Kulaksiz, AhmetAfsin. "MPPT Control of PMSG Based Small-Scale Wind Energy Conversion System Connected to DC-Bus" ***International Journal of Emerging Electric Power Systems***, vol. 21, no. 2, 2020, pp. 20190188. https://doi.org/10.1515/ijeeps-2019-0188.

[15]. Behera, Maheswar Prasad and Ray, Pravat Kumar. "Reactive power and harmonic compensation in a grid-connected photovoltaic system using fuzzy logic controller" ***International Journal of Emerging Electric Power Systems***, vol. 22, no. 2, 2021, pp. 161-175.https://doi.org/10.1515/ijeeps-2020-0204

[16]. AzharuddinShamshuddin, Mohammed, ThanikantiSudhakarBabu, TomislavDragicevic, MasafumiMiyatake, and NatarajanRajasekar. "Priority-based energy management technique for integration of solar PV, battery, and fuel cell systems in an autonomous DC microgrid**."** ***Electric Power Components and Systems*** 45, no. 17 (2017),pp. 1881-1891, doi: 10.1080/15325008.2017.1378949

[17]. Rezk, Hegazy, ThanikantiSudhakarBabu, Mujahed Al-Dhaifallah, and Hamdy A. Ziedan. "A robust parameter estimation approach based on stochastic fractal search optimization algorithm applied to solar PV parameters." ***Energy Reports*** vol. 7, Nov 2021, pp. 620-640, https://doi.org/10.1016/j.egyr.2021.01.024

[18]. Nazeri, Mohammad NorRafiq, Mohammad FaridunNaimTajuddin, ThanikantiSudhakarBabu, AzralmukminAzmi, Maria Malvoni, and NallapaneniManoj Kumar. "Firefly Algorithm-Based Photovoltaic Array Reconfiguration for Maximum Power Extraction during Mismatch Conditions." ***Sustainability*** 13, no. 6,Mar2021, 3206, pp. 1-30, doi: https://doi.org/10.3390/su13063206.

[19]. A. Dash, D. P. Bagarty, P. K. Hota, U. R. Muduli, K. A. Hosani and R. K. Behera, "Performance Evaluation of Three-Phase Grid-Tied SPV-DSTATCOM With DC-Offset Compensation Under Dynamic Load Condition," in ***IEEE Access***, vol. 9, pp. 161395-161406, 2021, doi: 10.1109/ACCESS.2021.3132549.

[20]. V. Narayanan, S. Kewat and B. Singh, “Solar PV-BES Based Microgrid System With Multifunctional VSC”, ***IEEE Transactions on Industry Applications***, Vol. 56, no. 3, pp. 2957-2967, May-June 2020, doi: 10.1109/TIA.2020.2979151.