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Stand-alone hybrid PV system by using the bypass converter topology to optimize the reliable of device

Fadillah Prasojo[1], Nur Alif Mardiyah*[1], Khusnul Hidayat[1]
Universitas Muhammadiyah Malang, Indonesia [1]

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*Corresponding author.
Nur Alif Mardiyah
E-mail address:
nuralif@umm.ac.id

Abstract

One of the applications of DC-DC converters in photovoltaic-battery hybrid systems is a two-way converter used for battery charging. The power supplied to the two-way converter experiences twice the power lost during the battery charging process. Therefore, it is necessary to arrange a phovoltaic-battery hybrid system topology so that only one stage of power conversion occurs when charging the battery so that the power loss is smaller. The proposed topology of this system uses three DC-DC converters connected to a battery and a DC bus. The one-way converter used in this system allows cross-connection between other DC-DC converters. Two one-way converters connect the phovoltaics to the DC bus and the photovoltaics to the battery, and the other one-way converter connects the battery to the DC bus. The purpose of using a one-way converter for charging the battery is called a bypass converter so that charging the battery does not go through two power conversions which cause twice the lost power. To make the proposed system more reliable, an inverter is added to the self-contained photovoltaic-battery hybrid system. Therefore, a control system is needed to maintain the DC bus voltage as input to the inverter using a double-loop control system. The two-loop Proportional-Integral control system is used for the DC electricity section while the Proportional-Resonant control system is used as an inverter control to maintain the balance of AC power. The results of system testing using Simulink/Matlab simulations show that the proposed topology uses a one-way converter capable of carrying out the battery charging process and can control the flow of power while maintaining DC and AC voltages.

1. Introduction

One of the applications of Renewable Energy is PV photovoltaic or solar panels which have their own advantages because they are environmentally friendly and free of carbon emissions. The development of PV systems continues to be carried out, one of which is to increase the electrification rate in places where there is no electricity grid source. PV system development due to energy needs that cannot be separated from daily life, a PV system connected to a battery is created[1]. A PV system that can only produce electricity during the day but not continuously until nighttime is designed for an energy storage area called a self-contained PV-battery hybrid system that can simultaneously balance battery charging with supplying load.[2].

Cannot be separated from the design of the solar panel system consisting of solar panel modules, batteries, and several supporting components, one of which is a converter. The converter is a device to obtain the voltage resulting from the conversion of DC electricity using an electronic circuit[2]. The output voltage results from the converter vary according to the performance of the solar panel or photovoltaic (PV) module which follows the intensity of sunlight or irradiation. However, PV power performance must be maintained and improved with the help of the Maximum Power Point Tracker (MPPT) so that the efficiency of the PV system is maintained.[3]. Another independent PV system efficiency increase is adding an inverter with a DC bus input, where the inverter will convert the DC input to an AC output[4]. The changes made by the inverter produce a two-level output, namely harmonic distortion and lower efficiency. Therefore, to obtain a pure sinusoidal signal and reduce harmonics, inverter control is needed to maintain the stability of the AC bus voltage.[5], [6].

The efficiency of the PV system that has been designed by previous studies uses a bidirectional converter type in a battery-PV hybrid system. the use of a bidirectional converter can pass two power flows both when charging the battery and discharging the battery. The process of charging the battery in this system still has drawbacks, because the output power of the converter will not be the same as the input power of the converter. The PV-battery hybrid system in previous studies resulted in a two-time loss of power when charging the battery[7], [8]. The PV system when it is charging the battery experiences a decrease in performance when the condition of meeting the needs of the network load changes[9]–[12]. The problem of unbalanced power flow on the DC bus in a PV system can result in overvoltage or Over Voltage as a result of sufficient load fulfillment but the PV power exceeds the load fulfillment capacity[13]. The solution to this problem uses a combination of PV with a converter to the battery system as a diversion of excess PV power and battery charging.

The previously developed PV-battery hybrid system uses three converters with a complex control system, but still uses a Proportional, Integral, Derivative (PID) control system. The conventional PID control system used to control the DC bus still has disadvantages compared to the Proportional Integral (PI) control system, because it has better efficiency than the PID control system.[14]. A reliable control system is needed to keep the DC bus stable as well as efficient settings in this study using a PI control system. Changing the flow of power from the DC bus to the inverter to the AC bus using a 1-phase unipolar switching technique still has drawbacks because it does not see output harmonics, power factor and losses[4]. The use of PI control on inverters in other studies still has drawbacks because it still has an output error at steady state[5], [6]. In order for the inverter output to have a better output advantage, this study uses a Proportional, Resonant (PR) control system to eliminate errors in the steady state and maintain the AC bus voltage.

Reliable devices used in independent systems, due to the use of various electrical loads for daily needs. The proposed system topology uses a control system that regulates the flow of power to both the load and the battery. The proposed control system is capable of charging and discharging the battery while maintaining the balance of the DC bus using a dual loop dual PI control system. The DC bus acts as an inverter input which will regulate the AC bus output using a two double loop PR control system[6]. Therefore, the purpose of a reliable system is to be able to charge and discharge the battery simultaneously and is able to maintain DC and AC bus stability against both DC and AC loads. This research focuses more on how to design a PV-battery hybrid system topology using a bypass converter by looking at the performance results of the bypass converter for battery charging. The renewable device presented is in the form of an additional AC load using a single phase inverter.

The proposed configuration in [15], overcome the above drawbacks by using a power conditioner unit between the battery and the load. The given system is an optimized one-stage solution for the charging and discharging modes of the battery. However, the proposed system uses a complementary switch scheme in a two-way drive converter. Use of complementary schemes in two-way converters may result in overlapping of charge and discharge modes. Furthermore, the given control scheme does not provide a controller design for separate charging and discharging modes using buck and boost converter respectively.

However, judging from the various designs and methods that have been used in optimizing reliable PV power, there is still a need to develop a more reliable and efficient system. The development of a PV-battery hybrid system used in this research is to reduce the power loss when charging the battery using a buck type bypass converter. The same good control system is also used to maintain the stability of the DC and AC bus voltages both during changes in irradiation and changes in load. System testing in this study uses Simulink Matlab r2020a by testing system performance with changes in PV irradiation and changes in AC loads and adding DC loads.

2. Research Method

The proposed system consists of four basic DC-DC converters namely boost converter, buck converter and inverter as shown in Figure 1. The given system is a good solution for stand-alone loads where the grid is not present. Thus, in the proposed system, solar PV is the only source of electricity generation. Therefore, it is important to use PV energy efficiently and effectively. This can be achieved by operating the PV source near the MPP and using single stage power conditioning for PV power. Furthermore, the PV power uncertainty is handled by battery storage. The battery stores excess power when the load demands less and supplies deficit power when the available power from the PV source is insufficient to meet the load demands. Thus, the power obtained from the PV source is shared between the load and the battery. To operate the PV source near the MPPT, a boost converter is used between the PV source and loads. To divert the excess PV power into the battery, a buck converter is used between them as shown in figure 4. Thus, the generated PV power is conditioned in a single stage whether feeding to the load or the battery. This helps in the effective utilization of PV resources. The proposed configuration is primarily designed to extract maximum power from the PV source. The PSO-based MPPT algorithm is used which operates the PV source close to the maximum power point (MPP). The maximum power extracted from the PV Source is shared by the load and the battery.

The resulting VLoad load voltage defines the operation of the buck and boost converters for charging or discharging the battery respectively. The Vbus output voltage as the inverter input to the load is maintained between the required voltage using PV and battery power. Battery power is used to maintain Vload during low or zero insulation. So, the battery only supplies less power required by the load to maintain the required Vload. On the other hand, if excess power is generated at the PV source, after meeting the load requirement. It is conditioned and diverted to battery charging, where electrical energy can be stored for future use.

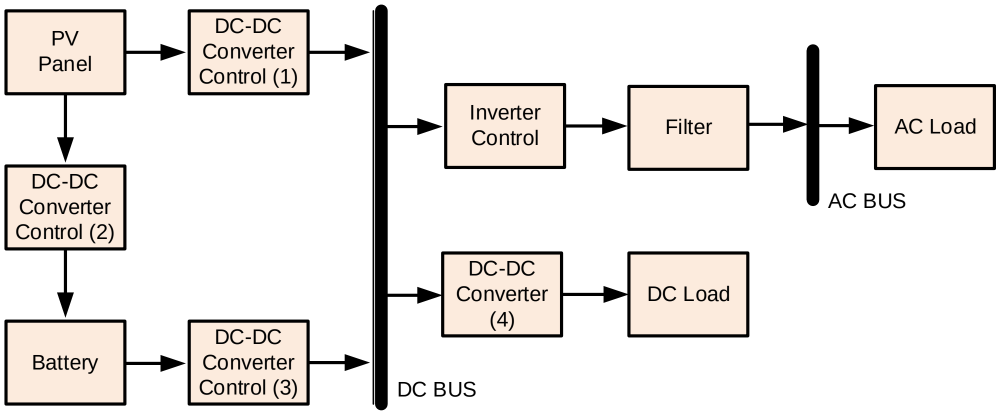

Figure 1. PV-Battery Hybrid System Topology Using Bypass Converter to Optimize the Reliable of Device

Other important solutions using the multi-port concept are given in the literature[16], [17]. In the solution given the author has used a 3-port converter. The given solution is good, as it has low voltage overvoltage across active switches, reducing the number of semiconductor devices. However, this architecture suffers from complex, system-dependent control loops and no strategy is provided for seamless flow/control of power between sources. Furthermore, to increase battery life, simultaneous charging and discharging of the battery in a switching cycle should be avoided. It is also difficult to instantly adapt to transitions between different operating modes in a given system. Apart from the converter configuration, many control strategies are also given in the literature.

Now, in research[18], a power management strategy using passive based control is proposed. The proposed system provides details with respect to PV power control based on MPPT and battery charge/discharge. However, a simple scheme for seamless power control between PV and battery is necessary as MPPT integration with State of Charge (SoC) can be added to the system. Else, the concept of adding a battery connected directly across the load on the DC bus is given in the literature [Modeling and Control]. The output power of the PV array in such a system is usually controlled to maintain the battery state of charge (SOC) within predetermined limits using complex computational control techniques such as switch condition control etc. As a result, the DC-DC converter will not be controlled to track the point of maximum power over time. Furthermore, the basic control scheme does not support smooth power management. It also doesn't get rid of the drawback of switching between charge and discharge modes when the system is operating near the limit. Also, large inrush currents can potentially damage the battery during sudden large load changes due to the absence of PEC between the battery and the DC bus. Thus, PEC is required for the battery to connect to the system. Another good approach using a typical PI linear controller is given in the literature. One uses voltage and power information for control with ultra-capacitors[19]. While others use droop control to adjust the power balance in the system. Both solutions use bi-directional converters with a simultaneous charge-discharge mode. But, still, the given control strategy does not provide smooth power control among sources.

Another good and efficient solution with PV source in DC bus is given by Oluwaseun et. Al.[20]. The use of a PV source in the DC bus in the system increases its voltage rating requirements. The solutions provided use power calculations at both input and output, which increases the sensor requirements. Also, the use of a PV source on the DC bus increases the risk of feedback power. Another new single-stage transformerless hybrid system featuring amplification, inversion, etc. However, these systems use more passive components and switching devices leading to increased costs and lower reliability. The system rendered in also suffers from the same drawbacks of a greater number of sensors, switching between different modes and so on. Thus, there is a seamless control requirement between various operating conditions.

A good solution for this topology is proposed by Dhara et.al.[21], The given solution processes PV power optimally in a single stage. The state of charge and discharge of the battery is separated because two separate power converters are used for each operation. Manuscripts provide details of modes of operation. However, details regarding the control strategy and passive component design are not provided in the manuscript. Full details of the control strategy by supporting experimental and simulation results are given in this paper. The proposed system optimally processes PV and battery power using single-stage power conditioning and avoids simultaneous battery charging and discharging in the switching cycle. In addition, a control scheme has been proposed which provides seamless control of power flow between the PV and the battery source. The given control scheme regulates the power flow using information from the DC bus or the output load voltage. It does not require information about the PV power to determine the operating mode. Furthermore, the given control scheme eliminates switching between various modes. Or it differentiates the mode of operation required and avoids over-lapping the two conditions. Thus, during the battery charge mode, its overlap with the battery discharge mode is eliminated.

2.1 Control Strategy

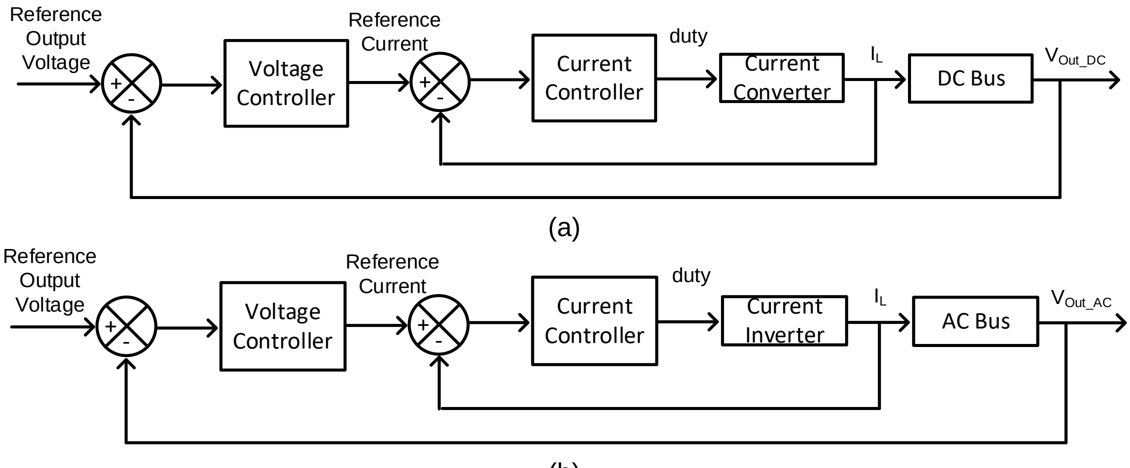

Figure 2. Schematic of Dual Dual Loop Control System, (a) DC-DC Converter Control System Block Diagram, (b) Inverter Control System Block Diagram

The control system proposed in this study is shown in figure 2. All control systems proposed in this study use a double-loop control system. The control system in figure 2. PI-based control system, which is designed as a voltage control PI and output current control PI on a converter connected to Maximum Power Point Tracking (MPPT)[22]. The DC-DC converter 1 in Figure 2 uses a boost converter type connected to PV which is controlled together with MPPT. The MPPT algorithm used in this study is Particle Swarm Optimization (PSO), this algorithm was chosen because of its accuracy and speed in finding the best power point compared to other algorithms[23]–[25]. The PSO algorithm flowchart is shown in Figure 3. The DC-DC converter 2 in Figure 2 uses a buck converter type that is cross-connected between the PV and the battery as charging the battery to prevent overlapping when charging the battery. Therefore, the second DC-DC converter is called as Converter Bypass. Then the third DC-DC converter as a supply of battery power to the DC Bus, between converters 2 and 3 is controlled in a double loop two PI control system to regulate when to charge and discharge. In order for the PV-battery independent system to have more advantages, an inverter is used to supply the AC load, the PR control system is used to maintain the balance of the AC bus when there is a change in irradiation or load requirements.

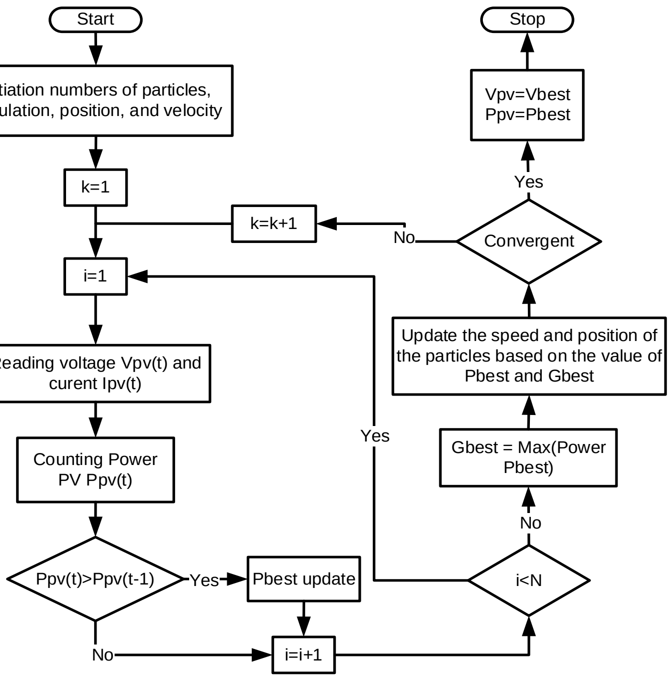

Figure 3. PSO Algorithm Flowchart

The PSO algorithm, which is an optimization algorithm, works based on a population-based search, where each individual or what is commonly called a particle will change its position with time. In this PSO algorithm, the particles fly through the multidimensional search space and adjust their position based on their experiences and the experiences of the particles next to them. From this explanation, it can be concluded that the PSO algorithm combines two methods, namely the local search method and the global search method[26]. The initialization of the PSO optimization algorithm begins by randomly setting the initial position of the particle and then the particle seeks the optimal value by updating its position. Just as has been explained, each iteration of each particle will update its position based on the two best values, namely the best solution obtained by each particle (Pbest) and the best solution based on the population (Gbest). The parameters of the PSO algorithm are shown in Table III while the PSO algorithm flowchart is shown in Figure 4.

2.2 Desain Sistem Hibrid PV-Baterai Mandiri

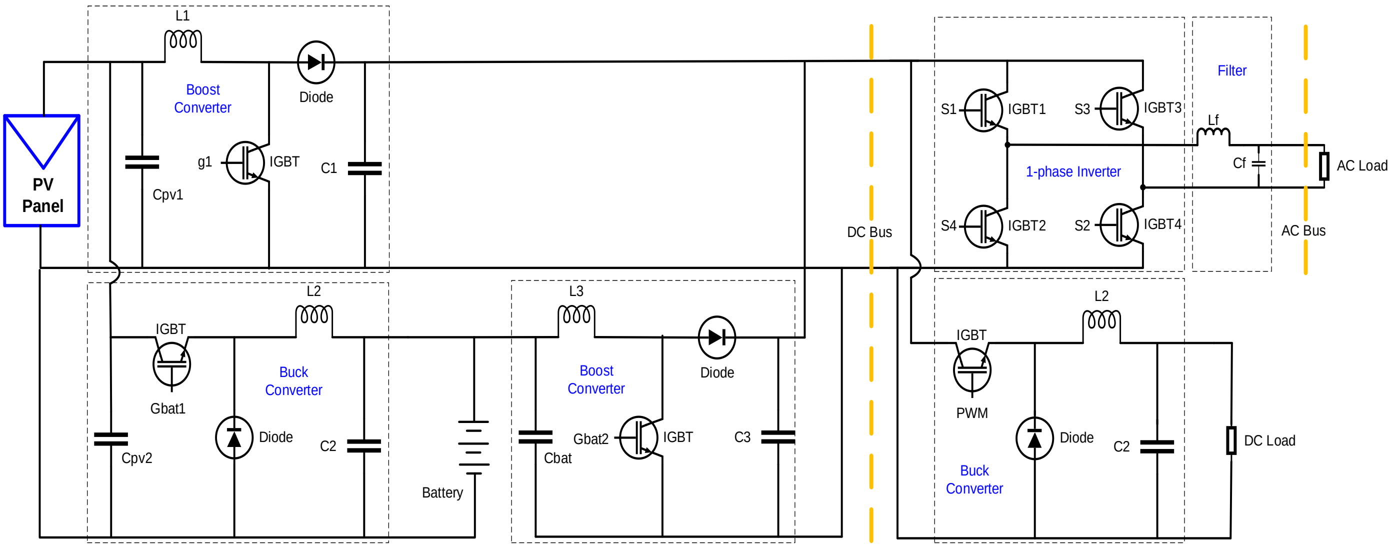

Figure 4. Schematic for a PV-battery standalone hybrid system with bypass converter to Optimize the Reliable of Device

3. Results and Discussion

This discussion describes the results and analysis of system testing that has been designed according to the design plan that has been made. Tests were conducted to determine the topology performance of the PV-battery hybrid system with converter bypass and the application performance of the PI control system on the DC-DC converter and PR control on the inverter against AC and DC loads. Tests in this study used the Matlab/Simulink application tool version r2020a.

3.1 Analyze System Performance Against Output Power

The proposed PV-battery hybrid system topology with bypass converter with control system on a reliable device has been simulated and obtained the results in Figure 5. Because the radiation varies, various changes are observed and plotted. The condition in Figure 5. when the PV power (Ppv) is greater than the load demand, the charging inductor current starts to flow to maintain the load voltage and the surplus power supplied by the PV is stored in the battery. When the radiation in the next mode changes, the Pvv is just enough to supply the load requirement. Therefore, in this mode, both the charging and discharging currents are reduced to zero, that is, the charging and discharging of the converter is turned off. As radiation decreases further in subsequent modes, Ppv is insufficient to meet load demand. Therefore, the required power is supplied by the battery through the discharging converter. As the irradiance is further reduced to zero, the current that needs to be supplied to the load increases further. Similarly, the irradiance is increased and the system is observed for all system performance in Figure 5 and Figure 6. To test the controller, an abrupt change in irradiance is made and the system is examined as shown in Figure 6. It is noticed that the transition from charge to discharge mode and charge mode restarts pretty smoothly. The DC-DC 1 converter operates on MPP in all modes. Therefore, it can be said that the controller works flawlessly and efficiently in all operating modes. Also, the controller scheme can withstand sudden changes in radiation without losing operating stability.

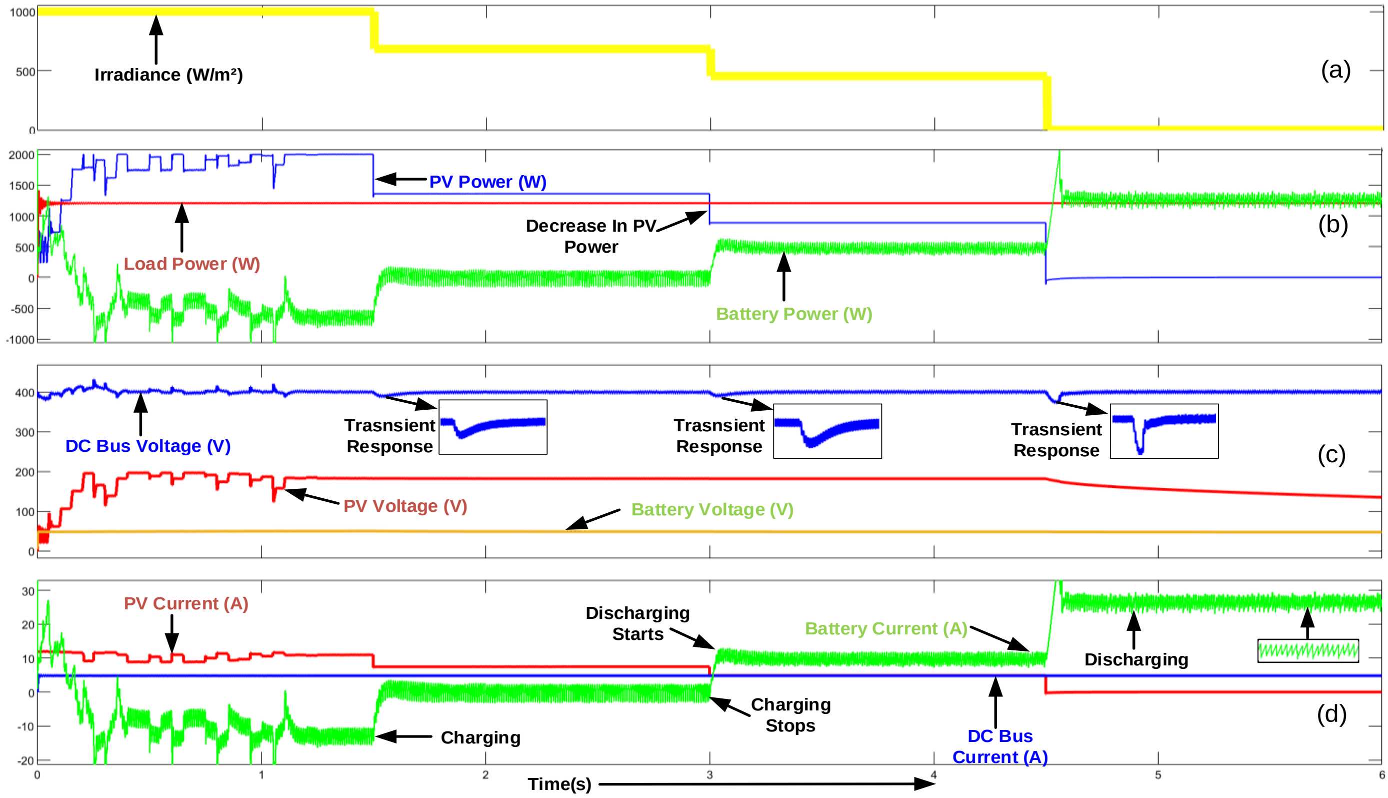

Figure 5. The Results of System Performance Simulation Decrease In PV Power (a) Irradiation Changes, (b) Output Powers, (c) Output Voltages, (d) Output Currents

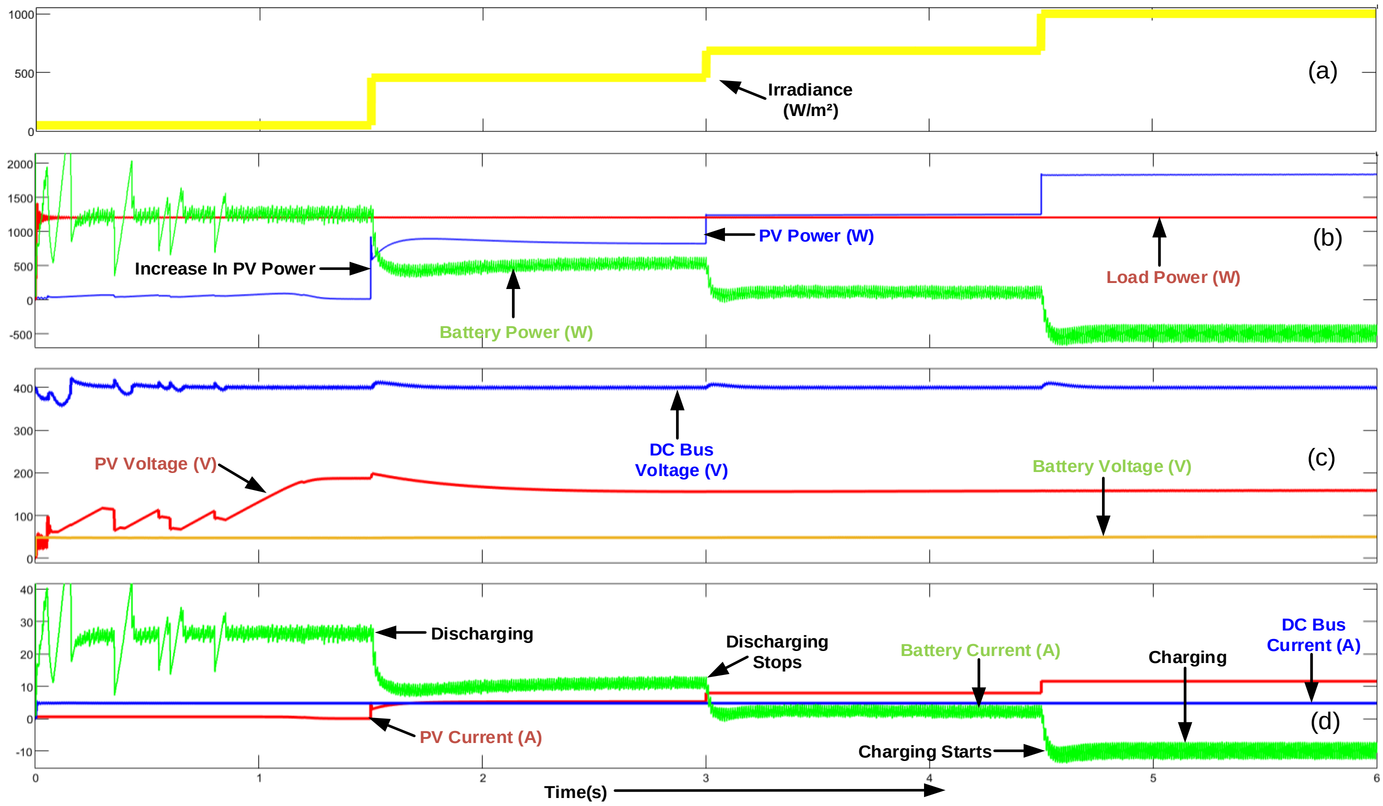

Figure 6. The Results of System Performance Simulation Increase In PV Power (a) Irradiation changes, (b) Output Powers, (c) Output Voltages, (d) Output Currents

3.2 Evaluating The Performance of The MPPT

In this test the system was tested using MPPT with the PSO optimization algorithm given an AC load of 40 ohms and a DC load of 130 ohms. From the MPPT test with the PSO algorithm that has been carried out, it was found that the input voltage is in the range of 181.5 V with the input current in the range of 10.5 A to 11.1 A. Meanwhile the output voltage on the DC bus is in the range of 395 V to 416 V which still within tolerance. The DC bus as inverter input will experience the influence of losses from the inverter which causes sinusoidal signal oscillations. This shows that the DC-DC converter works to increase the voltage and is able to charge and discharge the battery without having to work all and the inverter controlled by PR control is able to maintain the balance of the AC bus with values ranging from 219 V to 221 V. The output current values range from 10.2 A to 11.05 A indicates that an increase in the output voltage causes a decrease in the current value at the output of the converter. Meanwhile, for the output power, good efficiency is obtained, because the average output power is relatively better than the input power. However, in some circumstances, the output power is less than the input power, which is caused by the high value of the output voltage rises.

4. Conclusion

The proposed simple and seamless performance control strategy for a battery powered PV hybrid system using simulation and experimental results. The topology used for verification of the control strategy has specific DC-DC converters and inverters for each operation. The configuration employed processes power whether extracted from PV or battery sources in parallel operation and single stage improves system performance. Furthermore, the proposed control strategy supports smooth power management between PV, battery and load. The same is verified in the simulation and experimental results. The proposed control strategy avoids switching between charge and discharge modes between them. It also eliminates switching charge and discharge modes with intermediate PV mode by using another internal voltage control. Thus, the given control scheme avoids overlapping or the occurrence of two modes simultaneously and is able to maintain the DC and AC bus voltages according to the reference. Furthermore, eliminating overlap between charging and discharging modes also extends battery life. The smooth power control, when the system moves from charge to discharge mode or vice versa, is also verified from the simulation and experimental results. Thus, the given control strategy is simple and easy to implement as it is based on output voltage control. It does not require individual power calculations and complex calculations such as AC and DC load sharing. This can be easily applied to a PV hybrid system which has independent controls for charging, discharging and MPPT operation.

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References

[1] Ramadhan. Anwar ilmar, E. Diniardi, and Mukti. S.H, "Analisis Desain Sistem Pembangkit Listrik Tenaga Surya Kapasitas 50 WP," *Tek. Mesin UNDIP, 37 (2), 2016, 59-63*, vol. 11, no. 2, pp. 61–78, 2016. https://doi.org/10.14710/teknik.v37n2.9011
[2] A. Komarudin, "Desain Dan Analisis Proporsional Kontrol Buck-Boost Converter," J. ELTEK, Malang Vol 12, No.02, Oktober 2014
[3] N. Fauzi, M. Ashari, H. Suryoatmojo, and P. Alat, "Desain Dan Implementasi Maximum Power Point Tracker (Mppt) Solar Pv Berbasis Fuzzy Logic Menggunakan Mikrokontroller AVR," *Tek. Elektro-FTI*, vol. 1, pp. 1–7, 2015.
[4] T. Tri Arvianto, E. Wahjono, and I. Irianto, "Perancangan boost converter menggunakan kontrol proporsional integral (PI) sebagai suplai tegangan input inverter satu fasa untuk sistem uninterruptible power supply," *J. Sains dan Teknol.*, vol. 16, no. 02, pp. 136–146, 2020. http://dx.doi.org/10.36055/tjst.v16i2.8511
[5] G. Ramalingam, A. K. Choudhary, and S. Mikkili, "Modeling and Analysis of a PV-based Shunt Active Filter with BESS for Power Quality Enhancement Under Dynamic Load Conditions," *2018 15th IEEE India Counc. Int. Conf.*, vol. 0, no. 4, pp. 1–6. https://doi.org/10.1109/INDICON45594.2018.8987181
[6] Güler N., "Proportional Resonant and Proportional Integral Based Control Strategy for Single Phase Split Source Inverters," *9th Int. Conf. Renew. Energy Res. Appl. ICRERA*, pp. 510–514, 2020. https://doi.org/10.1109/ICRERA49962.2020.9242690
[7] Hidayat, K., M. C. Hasani, N. A. Mardiyah, and M. Effendy, "Strategi Pengisian Baterai pada Sistem Panel Surya Standalone Berbasis Kontrol PI Multi - Loop," *J. Tek. Elektro*, vol. 13, no. 1, 2021. https://doi.org/10.15294/jte.v13i1.29765
[8] Pratiwi A. S., S. D. Nugraha, and E. Sunarno, "Desain dan Simulasi Bidirectional DC-DC Converter untuk Penyimpanan Energi pada Sistem Fotovoltaik (Design and Simulation of Bidirectional DC-DC Converter for Energy Storage in Photovoltaic System)," *J. Nas. Tek. Elektro dan Tek. Inf.*, vol. 9, no. 3, pp. 305–310, 2020. https://doi.org/10.22146/.v9i3.377
[9] Kasan N., "Perubahan Beban Pada Ac To Dc Dan Dc To Ac Converter Menggunakan Trafo Up-Down," SENTRA, pp. 97–104, 2020.
[10] Asy H. and Adi D, "Pengisian Baterai Menggunakan Converter Pada Sistem Energi Surya," Edu Elektr. J., vol. 8, no. 2, pp. 91–95, 2019.
[11] Y. Rahayu, R. Amri, and E. Hamdani, "Perancangan Konverter DC ke DC untuk Menstabilkan Tegangan Keluaran Panel Solar Cell Menggunakan Teknologi Boost Converter," vol. 1099, pp. 61–66.
[12] M. Z. E. Wasith Dany Mufty, Dimas Okky Anggriawan, "Baterai Charger Vrla Dengan Metode Constant Current Constant Voltage Berbasis Kontrol PI Wasith," ISAS Publ. SENTRINOV Ke-6, vol. 6, no. 1, pp. 235–243, 2020.
[13] A. Pradipta, *Kontrol Aliran Daya Sistem Managemen Baterai Dengan Kontrol Droop Pada Sistem Pembangkit Hibrid PLTS-PLTB*. 2018.
[14] Husnaini Irma dan Krismadinata, "Komparasi Pengendali Pi Dan Pid Untuk Tegangan Keluaran Konverter Buck," *Jur. Tek. Elektro, Fak. Tek. Univ. Negeri Padang*, vol. 6, no. 3, 2017. https://doi.org/10.25077/jnte.v6n3.387.2017

[15] S. Park, J. Shin, J. Park, and H. Jeon, “Dynamic Analysis and Controller Design for Standalone Operation of Photovoltaic Power Conditioners with Energy Storage,” vol. 9, no. 6, pp. 2004–2012, 2014. https://doi.org/10.5370/JEET.2014.9.6.2004

[16] D. Bhule, S. Jain, and S. Ghosh, “Power Management Control Strategy for PV-Battery Standalone System,” *IEEE*, no. PIICON 2020-9th IEEE Power India Int. Conf., pp. 0–5, 2020. https://doi.org/10.1109/PIICON49524.2020.9112970

[17] S. Jain, S. M. Ieee, S. Dhara, S. Member, V. Agarwal, and F. Ieee, “A Voltage-Zone Based Power Management Scheme with Seamless Power Transfer between PV- Battery for OFF-Grid Stand-alone System,” vol. 9994, no. c, pp. 1–10, 2020. https://doi.org/10.1109/TIA.2020.3031265

[18] M. Kalantar, “Power management of PV / battery hybrid power source via passivity-based control,” vol. 36, pp. 2440–2450, 2011. https://doi.org/10.1016/j.renene.2011.01.029

[19] H. Fakham, D. Lu, B. Francois, and S. Member, “Power Control Design of a Battery Charger in a Hybrid Active PV Generator for Load-Following Applications,” vol. 58, no. 1, pp. 85–94, 2011. https://doi.org/10.1109/TIE.2010.2062475

[20] O. Akeyo, N. Jewell, and D. M. Ionel, “Improving the Capacity Factor and Stability of Multi-MW Grid Connected PV Systems with Results from a 1MW / 2MWh Battery Demonstrator,” pp. 2504–2509, 2018. https://doi.org/10.1109/ECCE.2018.8558253

[21] S. Dhara, “A Novel Voltage-Zone based power management scheme for PV- Battery based Standalone System,” *2018 8th IEEE India Int. Conf. Power Electron.*, vol. 333, pp. 1–6, 2018. https://doi.org/10.1109/IICPE.2018.8709592

[22] Putra. F.T.W., “Rancang Bangun DC - DC Sepic Converter dengan Kontrol MPPT pada Panel Surya Berbasis PID,” Elektro, Jur. Tek. Tek. Fak. Jember, Univ., 2020.

[23] Hakim, E.A, T. Al Ghufran, M. Effendy, and N. Setyawan, “MPPT Menggunakan Algoritme Particle Swarm Optimization dan Artificial Bee Colony "MPPT Using Particle Swarm Optimization and Artificial Bee Colony Algorithm” *J. Nas. Tek. Elektro dan Teknol. Inf.*, vol. 9, no. 2, pp. 218–224, 2020. https://doi.org/10.22146/jnteti.v9i2.81

[24] Yanaratri D.S., L. P. S. R, I. Ferdiansyah, and R. P. E, “Desain dan Implementasi MPPT PSO pada Sistem Pembangkit Listrik Tenaga Surya Portable,” *J. Teknol. Terpadu*, vol. 9, no. 1, pp. 34–43, 2021. https://doi.org/10.32487/jtt.v9i1.964

[25] Ferlita O., “Optimasi maximum power point tracking pada array photovoltaic menggunakan algoritma particle swarm optimization dan firefly algorithm,” Universitas Brawijaya, 2018.

[26] Setyawan, N., Hakim, E.A. and Zulfatman, “Signature Pso: Modified Particle Swarm Optimization Dengan Fuzzy Signature Dan Implementasi Pada Optimalisasi Kendali LQR,” *Multitek Indones. J. Ilm.*, vol. 13 No. 2, no. 2, pp. 29–38, 2019. http://dx.doi.org/10.24269/mtkind.v13i2.2227