Future Energy
Open Access Journal
ISSN 2832-0328

August 2023| Volume 02 | Issue 01 | Pages 07-19

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.2.3.2

Future Publishing LLC

Article

Power management of grid-connected PV wind hybrid system incorporated with energy storage system

Mayank Patel, Shabbir Bohra*

Department of Electrical Engineering, Sarvajanik College of Engineering and Technology, Surat-395001, India

A R T I C L E I N F O

Article history:
Received 08 November 2022
Received in revised form
09 December 2022
Accepted 12 December 2022

Keywords:
PV-wind hybrid system, Battery energy storage system (BESS), Power management system (PMS), Grid connected / Island mode

*Corresponding author
Email address:
shabbir.bohra@scet.ac.in

DOI: 10.55670/fpll.fuen.2.3.2

A B S T R A C T

Renewable Energy Sources (RES) such as solar photovoltaic (PV) and wind-based generation cannot meet dynamic load demand all the time because of their intermittent nature. Battery Energy Storage System (BESS) is integrated with RES to meet dynamic load demands. Proper power management is needed for the efficient and reliable performance of the system. This paper presents power management of PV-Wind- Battery hybrid system for both grid-connected and islanded modes of operation as well. The power balance is maintained by a power management system (PMS) under different environmental conditions and load conditions, and modes of operation. The control method for state-of-charge (SOC) and battery charge/discharge is applied to ensure efficient performance and safe operation of BESS. Different cases, such as surplus/deficit power available from RES with respect to load demand and battery capacity, have been considered and carried out to verify the performance of PMS using the MATLAB/Simulink platform.

1. Introduction

The increase in energy demand is considered one of the most critical issues nowadays. Conventional power sources have some serious adverse effects on the planet, like raising greenhouse gas emissions, which may be the key source of global warming. This topic took center stage at COP26, the UN climate change conference in Glasgow. The goal is to secure global net zero emissions by 2050. The power sector produces 25% of global greenhouse gas emissions, so to reach net zero emissions, we need to move away from conventional power sources and utilize renewable energy sources (RES) five times faster than the present. Wind and solar are the most promising such RESs. They can offer high reliability in the hybrid system of their complementary nature to produce power. The RES cannot meet load demand at all times because of its intermittent nature. This problem can be addressed to some extent by employing energy storage systems such as batteries, fuel cells, hydrogen storage, flywheel, and pumped-storage, etc. in a suitable hybrid framework. Battery Energy Storage Systems (BESS) are a more viable option compared to other energy storage systems due to their technical as well as economical merits. A number of topologies and control schemes for hybrid systems have been proposed in the literature [1-10]. Among them, Omar [1] presented a performance analysis of a grid-connected PV-wind hybrid power system during variations of environmental as well as load conditions. P.Satish [2] developed a standalone DC micro-grid which consists of a PV, wind, and battery system. Zhehan [3] introduced PV-battery-based hybrid microgrids for bothgrid-connectedd and islanded modes. Nahidul [4] proposed a PV-wave energy hybrid system with battery storage for island electrification in Malaysia. Muhmud [5] showed a grid-connected PV system with battery energy storage. Seema [6] presented a PV-wind-battery-based system for grid-connected mode and island mode. Somnath [7] presented a standalone PV-wind-battery hybrid renewable energy system. Muhamad [8] presented the performance evolution of a grid-connected PV system with battery energy storage. Morouace [9] showed an analysis of a grid-connected Doubly Fed Induction Generator (DFIG) and PV-based hybrid system. Chaitanya [10] proposed a hybrid wind-PV energy system with energy storage for an isolated system. Since the majority of RES generate dc power or need a dc link for grid connection and as a result of increasing modern dc loads, dc microgrids have recently emerged for their benefits in terms of efficiency, cost, and system that can eliminate the DC-AC or AC-DC power conversion stages and their accompanying energy losses. However, since the majority of the power grids are present of ac type, AC microgrids are still dominant, and purely DC microgrids are not expected to emerge exclusively in power grids. Therefore, DC microgrids are prone to be developed in AC types even though in subordinate [11]. There are two operation modes of a Hybrid Renewable Energy System (HRES): grid-connected mode and stand-alone mode. Normally, an HRES remains connected to the main grid for the majority of the time. In the standalone mode, HRES is isolated from the main grid; the highest priority for HRES is to keep a reliable power supply to customers instead of economic benefits [12]. Eghtedarpour [11] presented the power flow control and management issues amongst multiple sources dispersed throughout both ac and dc microgrids. S. Ezhilarasan [13] proposed an energy management algorithm for a grid-connected hybrid energy system addressing issues of integration of PV panels and wind power into the grid, managing the peak load demand, and also it improves the stability of the system under different transient conditions by maintaining the frequency and voltage under dynamic load conditions. Zhehan [3] proposed comprehensive control and power management system (CAPMS) which is successful in regulating the DC and AC bus voltages and stable frequency, controlling the voltage and power of each unit flexibly, and balancing the power flows in the systems automatically under different operating circumstances, regardless of disturbances from switching operating modes, fluctuations of irradiance and temperature, and change of loads. This paper presents a power management system for a PV-wind hybrid system with a battery storage system for both grid-connected and islanded modes of operation in order to maintain power balance among generation from PV and wind, battery, grid, and load.

2. System description

Figure 1 shows a schematic diagram of the proposed hybrid system. The system is comprised of a PV system, wind energy conversion system (WECS), and BESS connected to an 11kV AC bus. The system operates in grid-connected mode or islanded mode, depending on requirements. The power capacity of the hybrid system, PV, and WECS is 250kW, 100kW, and 250kW, respectively. The rating of BESS is 120Ah and 50kW for one hour. PV array is connected to the point of common coupling (PCC) through a DC-DC converter and DC-AC converter. In order to tap the maximum amount of solar energy from PV arrays, the Incremental and Conduction (I&C) MPPT technique has been employed. The power reference control method is incorporated to extract the desired amount of power from the PV array, which is less than the maximum available power. The transformer is used to step up the voltage level of the PV system, WECS, and BESS after rectification from 415V to 11kV. The BESS is assumed to be made up of a lead-acid battery, bidirectional AC/DC converter, and BESS controller. The role of the bidirectional AC/DC converter is to maintain power flow between the battery and PCC as per power requirements. The BESS controller controls the charging and discharging of the battery as per power requirements. WECS consists of a doubly fed induction generator (DFIG), rotor side converter (RSC), and load side converter (LSC). The RSC is connected to the rotor, and LSC is connected to the stator and PCC.

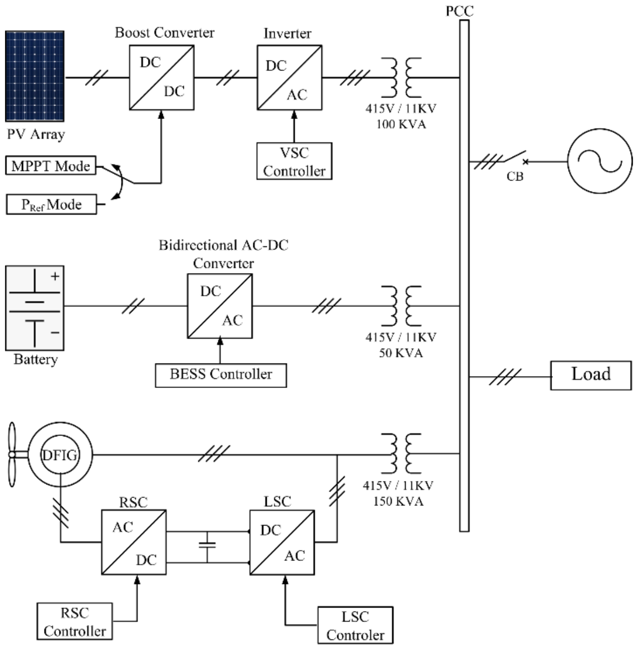

Figure 1. PV-Wind Hybrid System with BESS

3. Controller for power electronics converters

3.1 PV system

The PV system consists of a PV array, a DC-DC converter (Boost converter), and a DC-AC converter (inverter). The DC-DC converter and DC-AC converter are controlled by the DC-DC converter controller and VSC controller, respectively.

3.1.1 DC-DC converter controller

Figure 2 shows a block diagram of the DC-DC converter controller. There are two control schemes for DC-DC converter: MPPT control and power reference (PRef) control. The operation of the control scheme depends on power generation by RES, battery status, and mode of operation, whether it is grid-connected or island mode. In grid-connected mode system always operates in MPPT mode. In the islanded mode of operation, if generated power is less than the load demand, then the system operate on MPPT mode, and if power generation is more than the load demand and battery charging capacity, then the system operate on power reference mode.

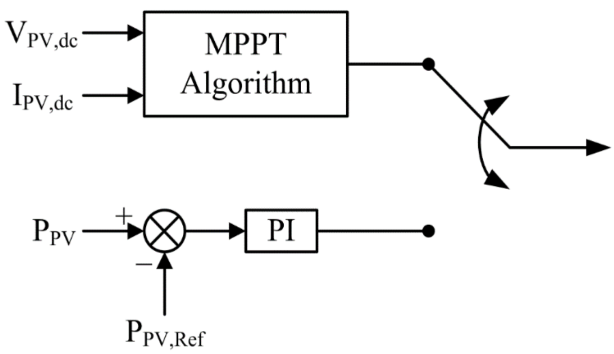

Figure 2. DC-DC Converter Controller

3.1.1.1 Maximum power point tracking algorithm

According to variations in solar irradiance and temperature, the output power of the PV array varies. The MPPT technique is used to extract maximum power from the PV array. Several literatures introduce different MPPT techniques like Perturb and Observe (P&O), Incremental and conductance (I&C), fuzzy logic etc. In this paper, the I&C MPPT algorithm is used to take advantage of better performance under rapid variation of solar irradiation [1]. Figure 3 shows the flow chart of the incremental conductance MPPT technique.

3.1.1.2 Power reference (PRef) mode

In this mode of operation, PMS decides the power reference for the controller. According to reference power, the operating voltage of the PV array (VPV) moves between a voltage corresponding to the maximum power point (VMPP) and open circuit voltage (V_{oc}). The PI controller processes power errors, so the system follows the power reference value.

3.1.2 Voltage source controller (VSC)

The VSC aims to control the active and reactive power transfer between the PV system and the PCC. The control method adopted is based on the current-mode control scheme in which the phase angle and magnitude of the VSC terminal voltage are controlled in a d-q rotating reference frame. The control block diagram for the VSC control scheme is shown in Figure 4. In grid-connected mode, a phase-locked loop (PLL) is used to extract the angle θ of the grid voltage. In the PLL, the grid voltage vector (V_{abc}) is projected on the d, and q axes of the d-q frame, and the d-q frame is rotated in such a way that Vq is forced to zero [6].

The settling of V_q at zero makes the d-axis of the d-q frame aligned with the grid voltage vector, and the d-q frame rotational speed becomes equal to the grid angular frequency [6]. Regarding this, the synchronization scheme based on PLL makes the value of P and Q proportional to I_d^{PV} and I_q^{PV}, respectively, so P and Q can be controlled by I_d^{PV} and I_q^{PV}, respectively, as follows:

$$P = \frac{3}{2} V_d I_d^{PV}$$

$$Q = \frac{3}{2} V_d I_q^{PV}$$

In islanded mode, θ is generated locally, which periodical ramp signal varies from 0 to 2π with a frequency 50Hz. The synchronous scheme ensures that the d-axis of the d-q frame is aligned with the reference voltage vector in islanded mode. In this mode, PCC voltage control by adjusting the reference $V_{d,ref}$ and $V_{q,ref}$ is employed.

4. Wind energy conversion system

WECS consists of two control strategies: RSC Control and LSC Control.

4.1 RSC Controller

The main purpose of the RSC controller (Figure 5) is to maintain voltage, maintain frequency, and extract maximum power. As the RSC is controlled in a stator flux-oriented reference frame, stator active and reactive powers (P_S & Q_S) are controlled by quadrature and direct axis rotor currents (i_{qr} & i_{dr}), respectively. The terminal voltage at the stator is controlled by controlling the direct axis rotor current (i_{dr}). The direct axis rotor reference current ($i_{dr,ref}$) is obtained from the voltage controller. The active component of rotor current (i_{qr}) is controlled for achieving maximum power point operation.

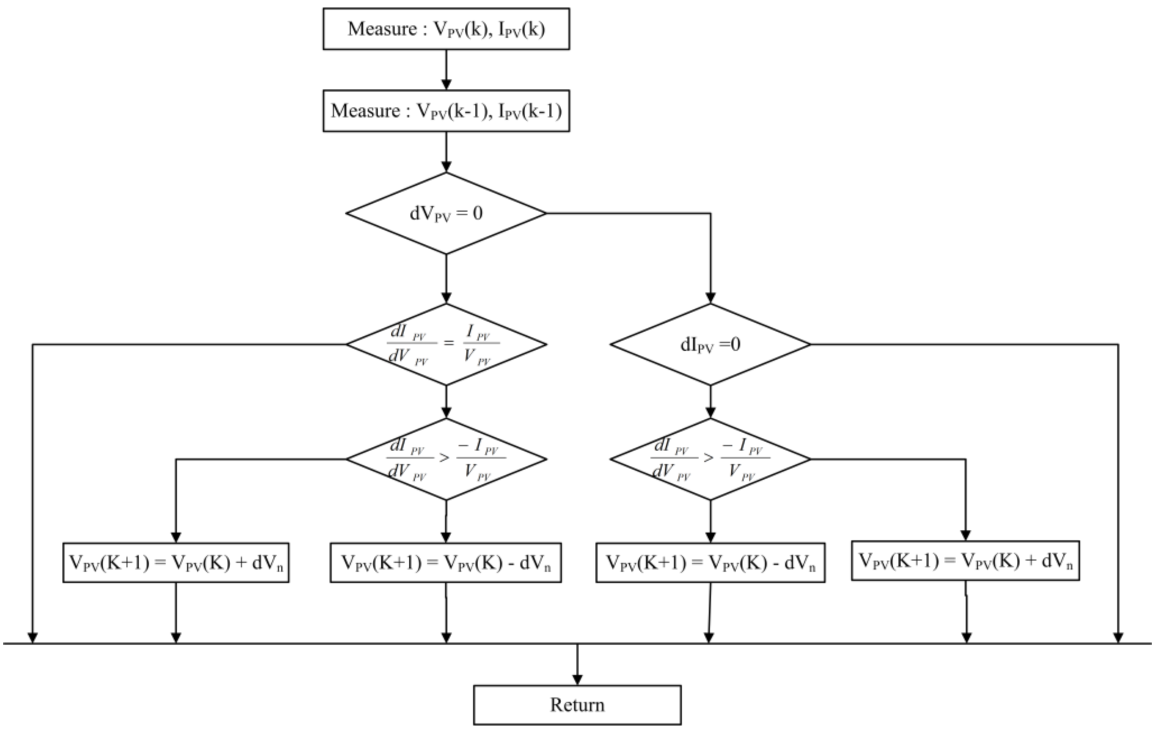

Figure 3. Flowchart of Incremental and Conduction MPPT Technique

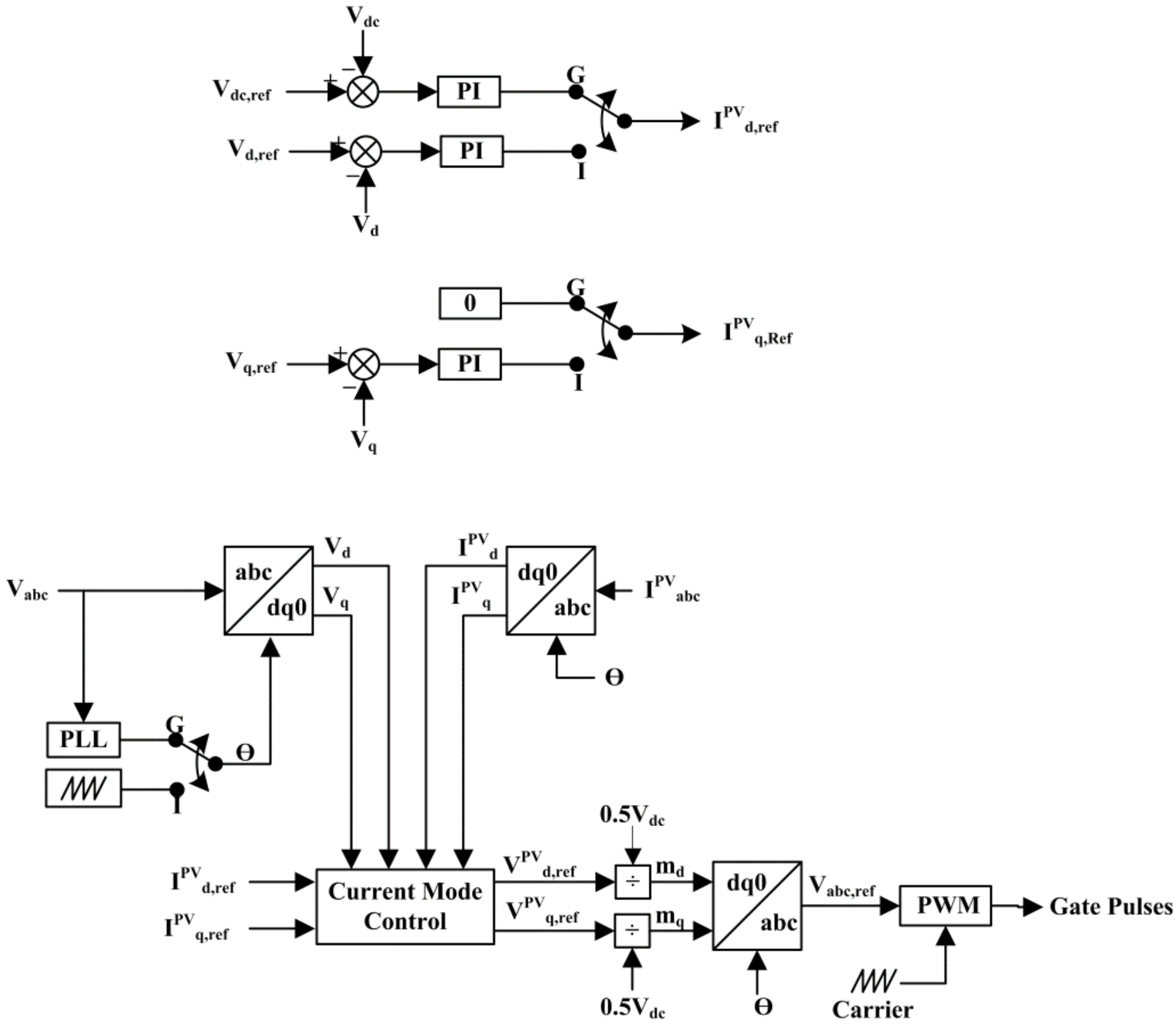

Figure 4. VSC controller

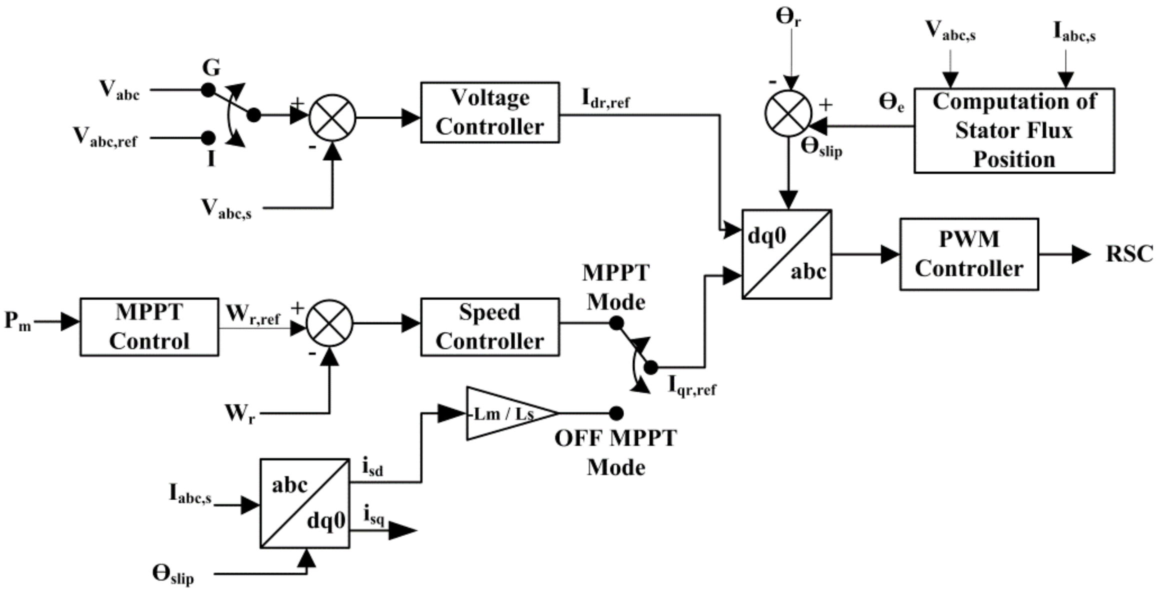

Figure 5. RSC controller

The speed is controlled by controlling quadrature axis reference rotor current ($i_{qr,ref}$), $i_{qr,ref}$ is obtained by processing the speed error (W_{er}) between reference and estimated rotor speeds ($W_{r,ref}$ and W_r) through the PI controller. Here, the tip speed ratio based MPPT control algorithm is used for selecting the reference speed. In the case of Off MPPT mode $i_{qr,ref}$ obtains from stator current.

4.2 LSC controller

The main purpose of the LSC controller (Figure 6) is to regulate DC link voltage and maintain power factor unity at PCC. This LSC is controlled in the voltage reference frame, so the active and reactive power components are controlled with direct and quadrature axis components of LSC currents (i_{ds}, i_{qs}), respectively. The *d*-axis is aligned to the stator voltage vector by using PLL. The active power component of LSC currents ($i_{ds,ref}$) is obtained by processing the DC link voltage error (V_{dce}) between reference and estimated DC link voltages ($V_{dc,ref}$ and V_{dc}) through a PI controller. The LSC is current regulated pulse-width modulation (PWM) converter, with direct-axis current (i_d) to adjust DC bus voltage and quadrature-axis current (i_q) to regulate exchanged reactive power with PCC. The q-axis current reference ($i_{q,ref}$) is imposed to zero to keep the grid at unity power factor.

4.3 Battery energy storage system

The control method adopts a double closed-loop control strategy of the power outer loop and the current inner loop. The synchronous scheme ensures *d*-axis of the *d-q* frame is aligned with the grid voltage vector in case of grid-connected mode, so that P and Q are proportional to and controlled by I_d^B and I_q^B, respectively, as:

$$P = \frac{3}{2} V_d I_d^B$$

$$Q = \frac{3}{2} V_d I_q^B$$

In the case of the islanded mode of operation d axis of d_q frame is aligned with the reference voltage vector.

5. Power management system (PMS)

The role of PMS is to ensure a reliable power supply to the load. The PMS needs real-time data from the PV system, WECS, BESS (Figure 7), and load to decide specific control schemes for converters. The system may operate on grid-connected mode or islanded mode, depending on the status of the system. The DC-DC converter control operates in two modes: MPPT mode and power reference Mode. The WECS operates on either MPPT mode or Off-MPPT mode.

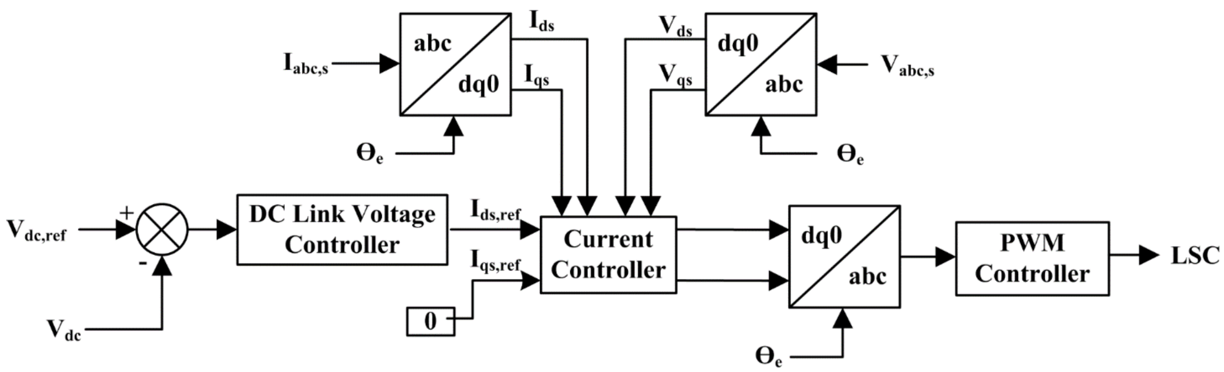

Figure 6. LSC controller

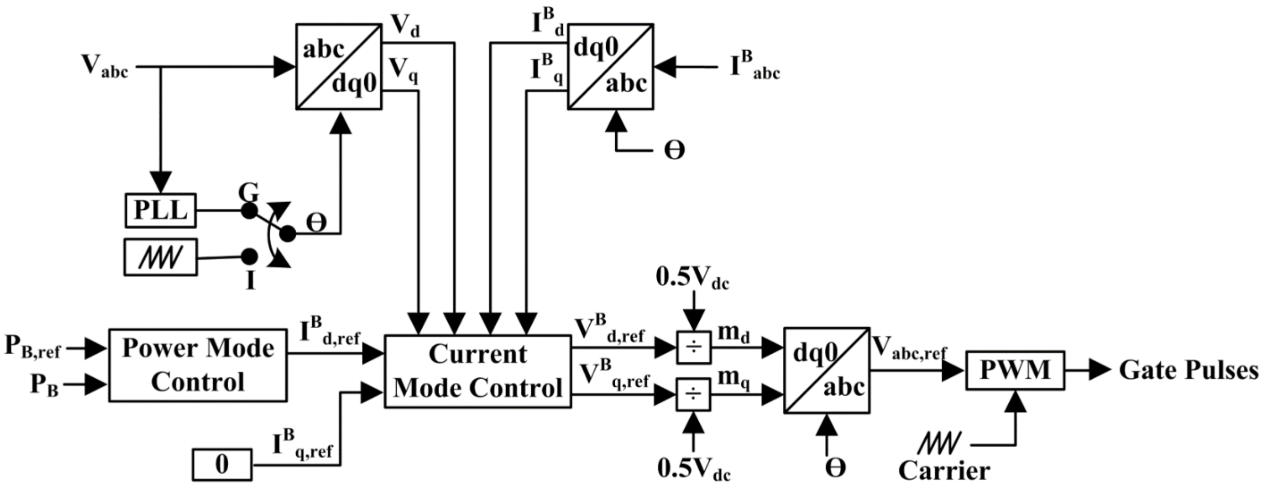

Figure 7. BESS controller

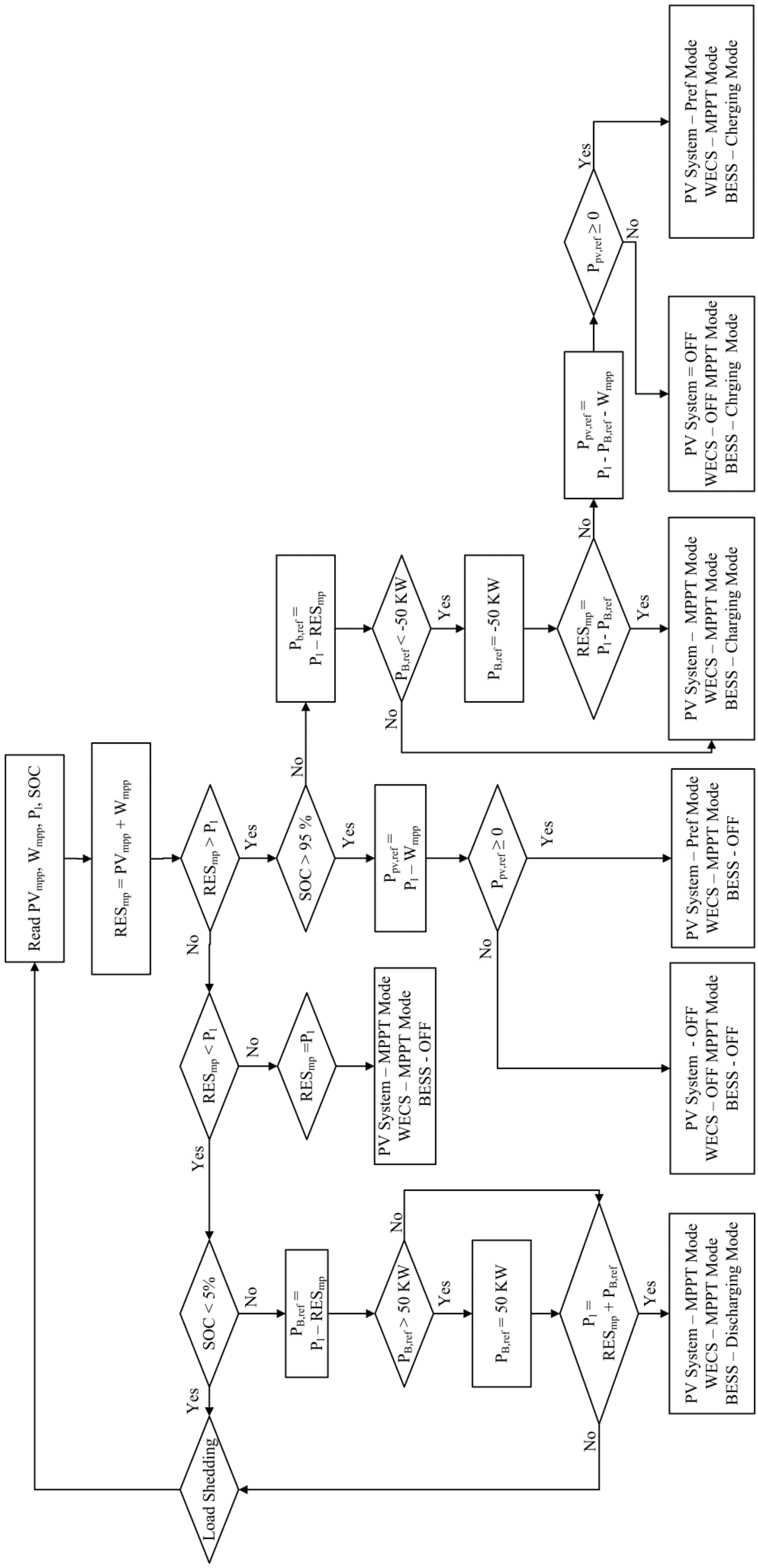

Figure 9. Flowchart for power management in islanded mode

The BESS converter operates in three modes: charging, discharging, and floating mode. To ensure a longer life cycle for the battery, SOC is limited to upper and lower limits.

5.1 Grid-connected mode

The flowchart for power management in the grid-connected mode of operation is shown in Figure 8. In grid-connected mode, the PV system and WECS always operate on MPPT mode, so we have to only control BESS. When power generated by RES is greater than load demand, in this condition, surplus power charges the battery if SOC is within limits; if surplus power is greater than the battery charging capacity, then the battery absorbs power up to its capacity, and the remaining surplus power is fed into the grid. When power generated by RES is less than the load demand, then deficit power is supplied by the battery if SOC is within permissible limits; if the battery is unable to meet deficit power, then the battery supplies power up to its capacity, and the remaining power is supplied by the grid power to meet the load demand.

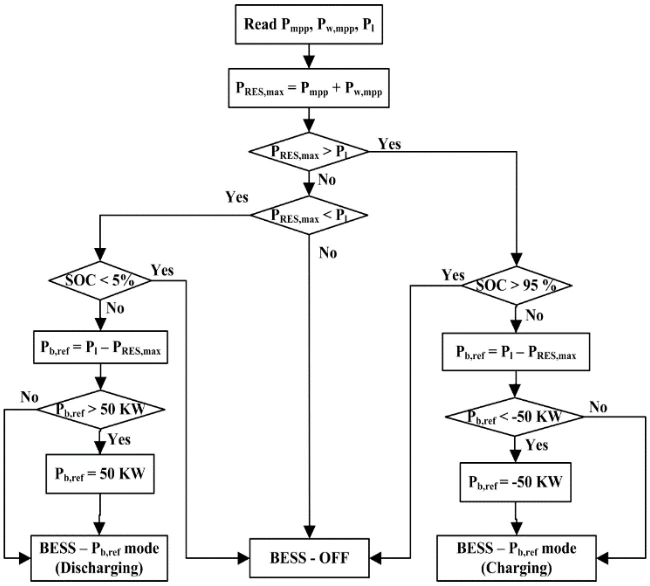

Figure 8. Flowchart for power management in grid-connected mode

5.2 Islanded Mode

The flowchart for power management in the islanded mode of operation is shown in Figure 9. In the island mode of operation, there are seven modes of operation of PMS. Each mode of operation depends on three conditions: power generation by RES, load demand, and SOC of battery. When power generated by RES is greater than load demand, then surplus power is used to charge the battery; if surplus power is more than the battery charging capacity, then the PV system operates on power reference mode. Sometimes wind power generation is more than load demand and battery charging capacity; in this condition, the power reference for the PV system is negative, so we have to isolate the PV system and run WECS on Off-MPPT mode. The PV system generates power only during the daytime; however, the WECS can generate power during the day as well as at night-time, so it's reliable to operate WECS in MPPT Mode all time and operate the PV system on power reference mode. When power generated by RES is less than the load demand, then the deficit amount of power is supplied by the battery; if the battery is unable to supply the deficit power, then load shedding is applied in order to maintain power balance.

6. Different Case Studies

To verify the performance of the proposed PMS, various cases have been studied in this section using MATLAB®/Simulink software. The detailed specifications of the PV-wind hybrid system with battery storage are in the Appendix section. The cases for power management depending on the mode of operation, i.e. grid-connected or islanded mode, power generated by RES, load demand, and battery status. The battery starts drawing power in order to charge as its SOC is less than the upper limit (95%), and the battery is able to supply power if its SOC is more than the lower limit (5%). The maximum absorbing and supplying power capacity of the battery is assumed up to 50kW.

6.1 Grid-connected mode of operation

6.1.1 Case 1:

In this case, power generated by RES is more than load d demand, and SOC is less than the upper limits. As shown in Figure 10, before 1s RES power (170 kW) is more than load demand (150 kW), surplus power (20 kW) is less than battery charging capacity, so surplus power is used to charge the battery. From 1.25s to 1.7s, RES power has increased to 200kW, and load demand remains at 150 kW, where surplus power is 50 kW which is equal to the maximum charging capacity of the battery. From 1.7s to 2s, RES power is 200kW, and load demand is 130kW; here, surplus power (80kW) is more than battery charging capacity, so the remaining power (30kW) is fed into the grid.

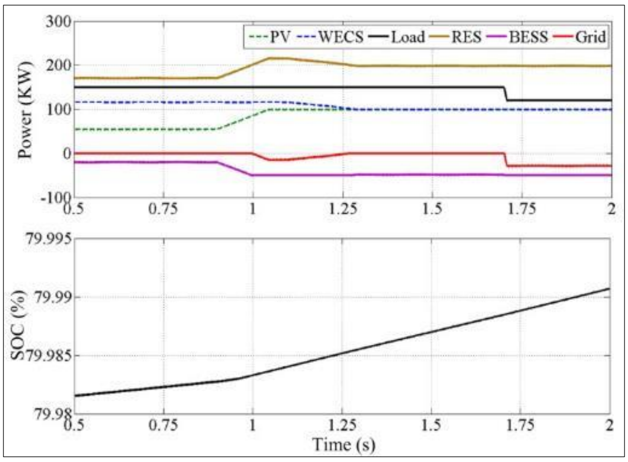

Figure 10. Power flow and SOC of case 1

6.1.2 Case 2:

In this case, the power generated by RES is more than the load demand, and SOC is greater or equal to the upper limit. As shown in Figure 11. After 0.63s, SOC reaches the upper limit, now, the battery is not able to take more power, and RES power is more than the load demand, so surplus power is fed into the grid. From 1.25s to 1.7s, power generated by RES and load demand increases to 200kW and 250kW, respectively; here, deficit power (50kW) is equal to storage battery capacity; hence the deficit amount of power is supplied by the battery only. After 1.7s, the deficit in power reaches 80kW as the load is increased to 280kW. Here, the deficit power is more than the battery capacity, and hence battery storage supplies up to its capacity of 50kW, and the remaining power i.e. 30kW, is to be drawn from the grid.

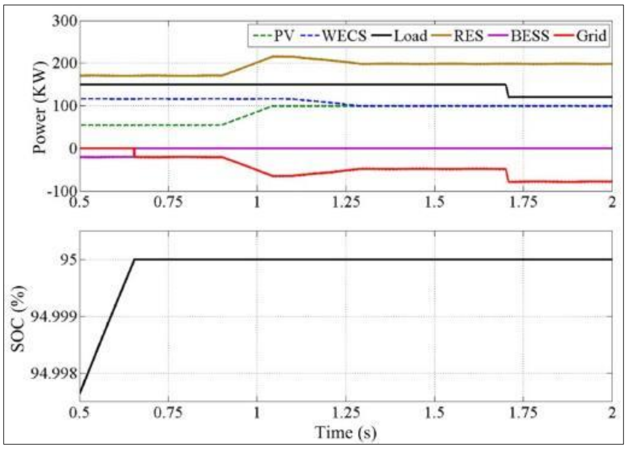

Figure 11. Power flow and SOC of case 2

6.1.3 Case 3:

In this case, the power generated by RES is less than the load demand, and SOC is greater than the lower limit. As shown in Figure 12, before 0.8s, RES power (170kW) is less than load demand (200kW), deficit power (30kW) is less than battery capacity (50kW), and hence the shortfall power is met by battery only.

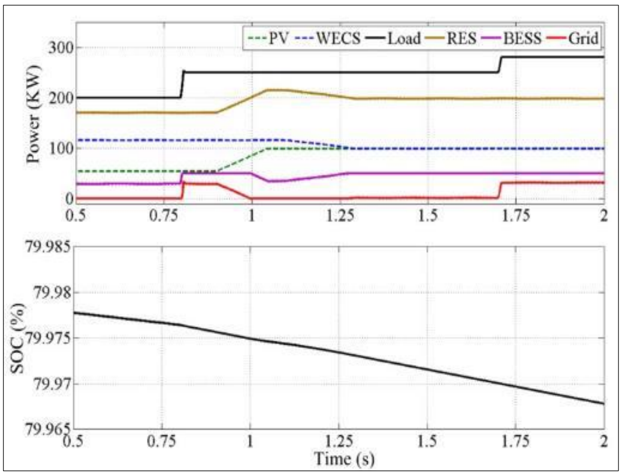

Figure 12. Power flow and SOC of case 3

6.1.4 Case 4:

In this case, the power generated by RES is less than the load demand, and SOC is less than or equal to the lower limit. As shown in Figure 13, after 0.6s, SOC reaches a lower limit, so the battery is not able to supply power. After 0.6s, RES power is less than the load demand, and deficit power has to be supplied by the grid.

6.1.5 Case 5:

In this case, the power generated by RES is Zero and SOC is greater than the lower limit. As shown in Figure 14, before 1.2s, load demand (30kW) is less than battery capacity, so load demand is fulfilled by battery alone. After 1.2s, load demand increases to 80kW, and the battery is able to supply power up to 50 kW, so the difference in power (30kW) is supplied by the grid.

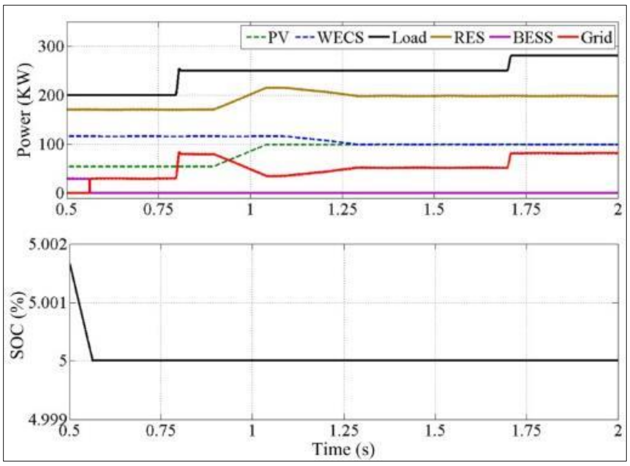

Figure 13. Power flow and SOC of case 4

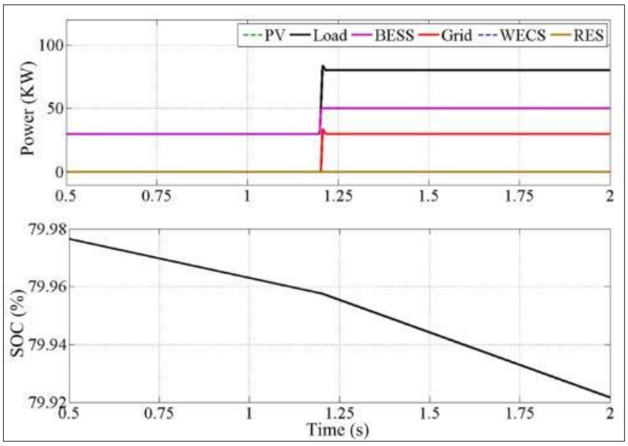

Figure 14. Power flow and SOC of case 5

6.1.6 Case 6:

In this case, the power generated by RES is Zero and SOC is less than or equal to the lower limit. As shown in Figure 15, after 0.75s, SOC reaches a lower limit, so the battery is not able to supply power. Now, after 0.75s, only the grid is available to supply power, so load demand is met by the grid.

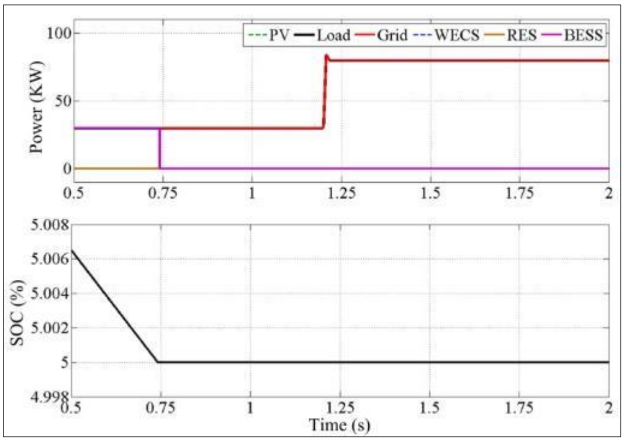

Figure 15. Power Flow and SOC of Case 6

6.2 Islanded mode of operation

To verify the performance of PMS in the islanded mode of operation, the maximum power generated by the PV system and WECS was taken constantly at 100kW and 120kW, respectively.

6.2.1 Case 7:

In this case, the power generated by RES is more than the load demand, and SOC is less than the upper limits. As shown in Figure 16, before 1s, maximum RES power is 220kW, and load demand is 190kW; surplus power (30kW) is less than the battery charging capacity, so surplus power is utilized to charge the battery. After 1s, the load demand decreases to 140kW; to meet the load demand (140kW) and charge the battery (50kW), RES should supply 190kW. Out of 190kW, WECS supplies 120kW, and the remaining 70kW should be supplied by the PV system. The maximum power generated by the PV system is 100kW, and hence PV system should be operated on power reference mode to supply 70kW power and maintain power flow between the PV system, WECS, BESS, and load.

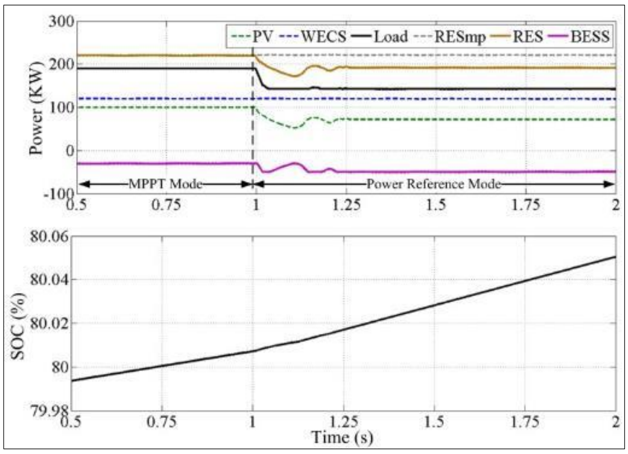

Figure 16. Power flow and SOC of case 7

6.2.2 Case 8:

In this case, the power generated by RES is more than the load demand, and SOC is greater or equal to the upper limit. In this case PV system always operates in power reference mode. As shown in Figure 17, before 1s maximum RES power is 220kW, and load demand is 200kW, so the PV system has to be operated on power reference mode to balance power. After 1s, reference power decreases as load demand decreases to 180kW.

6.2.3 Case 9:

Power generated by RES is less than load demand, and SOC is greater than the lower limit. In this case, the system always operates in MPPT Mode. As shown in Figure 18, before 1s, maximum RES power is 220kW, and load demand is 250kW; deficit power (30kW) is less than battery capacity, so the battery supplies deficit power to balance power. After 1s load is increased to 260kW, still deficit power (40kW) is less than the battery capacity, so the battery supplies power to balance power.

6.2.4 Case 10

In this case, the power generated by RES is less than the load demand, and SOC is less than or equal to the lower limit. As shown in Figure 19, before 0.6s maximum RES power (220kW) is less than load demand (250kW); due to more load demand, voltage sag occurs, as shown in Figure 20, from 0.5s to 0.62s. To balance power, load shedding is applied at 0.6s; after load shedding load is decreased to 200kW; now maximum power generated by RES is more than the load demand, so the PV system operates on MPPT mode to balance power.

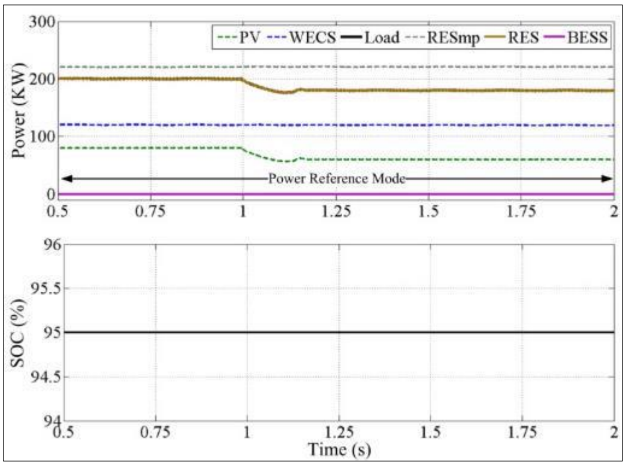

Figure 17. Power flow and SOC of case 8

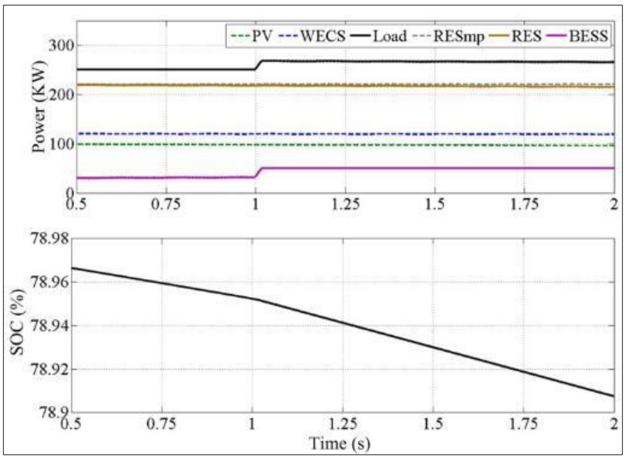

Figure 18. Power flow and SOC of case 9

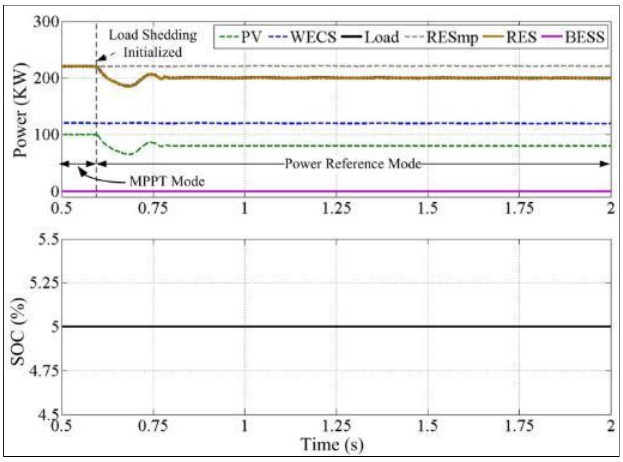

Figure 19. Power flow and SOC of case 10

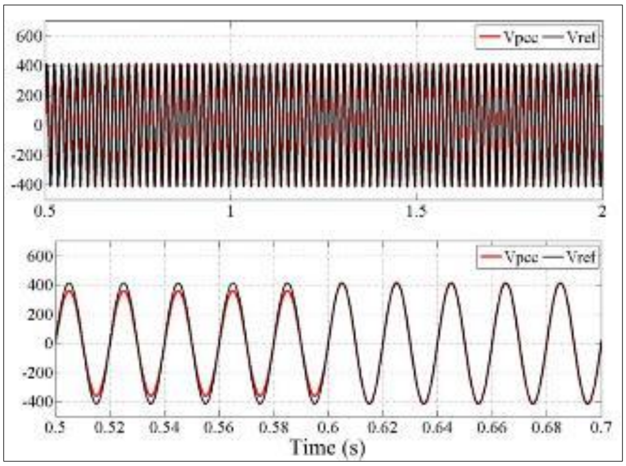

Figure 20. PCC voltage and the reference voltage of case 11

6.2.5 Case 11:

In this case, no power is generated by RES, and SOC is greater than the lower limit. As shown in Figure 21. Before 1s, load demand is 20kW, which is less than the battery capacity, so the battery supplies power to balance power. After 1s load is increased to 40kW, which is still less than the battery capacity. If load demand increases further to more than battery capacity, then load shedding needs to be applied to balance power.

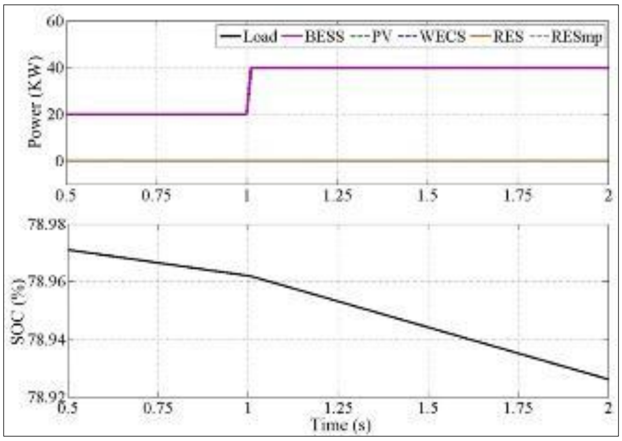

Figure 21. Power flow and SOC of case 11

7. Conclusion

This paper discusses the control and power management of the PV-wind hybrid system. The presented PMS is able to manage power in various load conditions. Various possible causes, such as RES generation more/less than load demand, battery capacity higher/lower than its ability in terms of its SOC level to cater to load under various conditions in both types of situations, i.e. grid-connected and islanded as well have been studied and verified by carrying out exhaustive simulations under dynamic conditions. Under different scenarios of power generation by RES and load demands, the controllers are observed to be performing satisfactorily and at the same time, maintaining the SOC level within acceptable and safe limits. Such an exhaustive analysis would be very useful for novice researchers and planners working in the area of distributed generation and microgrids. In the same line of work few more sources could be incorporated to convert the system into a more versatile one.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] O. Noureldeen and I. Ahmed M. A. , “Performance Analysis of Grid Connected PV/Wind Hybrid Power System During Variations of Environmental Conditions and Load,” INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH , Vols. Vol.8, , pp. 1-13, 2018.

[2] P. S. Kumar, Chandrasena, R. V, G.N. Sreenivas and K. Victor Sam Moses Babu, “Energy Management System for Small Scale,” IEEE ACCESS, 2017.

[3] Z. Y, Wanxin Dong and Amir H. Etemadi, “A Unified Control and Power Management Schemefor PV-Battery-Based Hybrid Microgrids for BothGrid-Connected and Islanded Modes,” IEEE TRANSACTION ON SMART GRID, pp. 1-11, 2017.

[4] N. H. Samrat, Norhafizan Bin Ahmad, Imtiaz Ahmed Choudhury and Zahari Bin Taha, “Modeling, Control, and Simulation of Battery Storage Photovoltaic-Wave Energy Hybrid Renewable Power GenerationSystems for Island Electrification in Malaysia,” Scientific World Journal, pp. 1-21, 2014.

[5] M. Z. Daud, Azah Mohamed and M. A. Hannan, “An Optimal Control Strategy for DC Bus Voltage Regulation inPhotovoltaic System with Battery Energy Storage,” Scientific World Journal, pp. 1-16, 2014.

[6] S. Kewat and B. Singh, "Grid Synchronization of WEC-PV-BES Based Distributed Generation System Using Robust Control Strategy," in IEEE Transactions on Industry Applications, vol. 56, no. 6, pp. 7088-7098, Nov.-Dec. 2020, doi: 10.1109/TIA.2020.3021060.

[7] S. Das and A. K. Akella, “Power Flow Control of PV-Wind-Battery Hybrid Renewable Energy Systems for Stand-Alone Application,” INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH, vol. 8, 2018.

[8] M. Daud, A. Mohamed, M.Z. Che Wanik and M.A. Hannan, “Performance Evaluation of Grid-Connected Photovoltaic System with Battery Energy Storage,” Kota Kinabalu Sabah, Malaysia, 2012.

[9] M. E. Azzaoui, Hassane Mahmoudi and K. B. , “Analysis and Control of Grid Connected DFIG and solar PV Based Hybrid Energy System,” IEEE TRANSACTION ON SAMART GRID, 2016.

[10] C. Marisarla and R. K. , “A Hybrid Wind and Solar Energy System with Battery Energy Storage for an Isolated System,” International Journal of Engineering and Innovative Technolgy (IJEIT), vol. 3, no. 3, 2013.

[11] N. Eghtedarpour and E. Farjah, "Power Control and Management in a Hybrid AC/DC Microgrid," in IEEE Transactions on Smart Grid, vol. 5, no. 3, pp. 1494-1505, May 2014, doi: 10.1109/TSG.2013.2294275.

[12] Q. Jiang, Meidong Xue and Guangchao Geng, "Energy Management of Microgrid in Grid-Connected and Stand-Alone Modes," EEE Transactions on Power Systems, vol. 28, 2013.

[13] S.Ezhilarasan, P. and S. S. , "Design and Development of Energy Management System for DG Source Allocation in a Micro Grid With Energy Storage System," International Journal of Science and Technology, vol. 8, 2015.

[14] A. Merabet, K. T. H. I. and A. G. , "Energy Management and Control System for Laboratory Scale Microgrid based Wind-PV-Battery," IEEE Transactions on Sustainable Energy, 2016.

[15] V. Dahiya and G. Leena, "Simulation and Modeling of DFIG Wind Farm in Wind Energy Conversion System," International Journal of Applied Engineering Research, vol. 14, 2019.

[16] N. K. S. Naidu and B. S. , "Experimental Implementation of Doubly Fed Induction Generator-Based Standalone Wind Energy Conversion System," IEEE Transactions on Industry Applications, vol. 52, no. 4.

[17] J. Han, X. Z. Song Lu and Pinxuan Zhao, "A Three-Phase Bidirectional Grid-Connected AC/DC Converter for V2G Applications," Journal of Control Science and Engineering.

[18] L. G. Meegahapola, Duane Robinson, A. P. Agalgaonkar and S. Perera, "Microgrids of Commercial Buildings: Strategies to Manage Mode Transfer From Grid Connected to Islanded Mode," IEEE Transactions on Sustainable Energy, vol. 5, no. 4, 2014.

[19] "MATLAB Help Centre," Mathworks, [Online]. Available: https://www.mathworks.com/help

[20] J. Magyar, "Forbes," 29 Nov. 2021. [Online]. Available: https://www.forbes.com/sites/sap/2021/11/29/cop 26.

Appendix

Table 1. Specification of Grid

Parameter	Value
Voltage	11 KV
Frequency	50Hz

Table 2. Specification of PV System

Parameter	Value
STC	T_{stc} =25°C, G_{stc}=1000 W/m^2
Number of Parallel String	47
Number of Series Module per String	10
Module Type	Soltech 15TH-215-P
Maximum Power of Array	100 KW
Voltage at MPP (V_{mpp})	290 V (29V per Module)
Current at MPP (I_{mpp})	345.45 A (7.35A per Module)
Open Circuit Volatge (V_{oc})	363 V (36.3 V per Module)
Short Circuit Current (I_{sc})	368.48 A (7.84 A per Module)

Table 3. Specification of DFIG system

Parameter	Value
Rotor Type	Wound Rotor
Rated Power	10*15KW = 150 KW
Stator Nominal Voltage	415 V (L-L)
Nominal Frequency	50 Hz
Stator Resistance	0.02013 pu
Stator Inductance	0.2919 pu
Rotor Resistance	0.2067pu
Rotor Inductance	0.2919 pu
Magnetizing Inductance	1.89 pu
Pair of Poles	2
Nominal DC Link Voltage	600 V

Table 4. Parameter of Battery Storage System

Parameter	**Value**
Type	Lead-Acid
Terminal Voltage	600V
Rating	500Ah
SOC limit	Lower Limit = 5% Upper Limit = 95%
Maximum Charging and Discharging limit	50kW