A NOVEL CONCEPT OF CONTROL AND POWER MANAGEMENT TECHNIQE FOR PV-BATTERY-BASED HYBRID MICROGRIDS

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Abstract: - Recent increasing in the demand of Photovoltaic (PV) systems due to the decrease in the insulation cost and abundant source of solar energy. Battery storage is usually employed in photovoltaic (PV) system to avoid power fluctuations due to characteristics of PV panels and solar irradiance. Proposed control methods for PV-battery systems must be stabilize the bus voltages as well as to control the power flow flexible. This project proposes a comprehensive control and power management system (CAPMS) for PV-battery-based hybrid microgrids with both AC and DC buses. The proposed CAPMS is successful in regulating the DC and AC bus voltages and frequency stably, 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. Both simulation and experimental case studies are carried out to verify the performance of the proposed method.

Keywords: Photovoltaic (PV) System, Battery, Control and Power Management System, Distributed Energy Resource, Microgrid.

1. Introduction

As demand for energy is increasing day by day using conventional sources for power production will deterioration the environment, so electrical engineers has to find other methods of power generation. Distributed generations (DG) in the form of renewable sources, such as solar energy, are alternate sources to reduce the environmental deterioration and for power production as availability of these sources is more and at free of cost [1]. In such renewable sources Photovoltaic (PV) power systems are the most usable source because of abundance of solar and clean energy. As technology for preparation of PV-panels is increasing day by day in such a way that cost of production and the output energy from the PV-panels is increasing [2], [3]. But this technology is dependent on environmental conditions like solar irradiance and temperature, so to maintain continuous power battery storage system are integrated to form a hybrid system. The configuration of PV-battery system is shown in figure 1, which is called as hybrid microgrid. In this microgrid battery is used for power storage, and bidirectional inverter is used which will interfaces the DC to AC power system [4], [5]. To control the power of PV arrays a unidirectional DC/DC converter is used while battery bank is controlled by the bidirectional converter. Load such as AC loads are supplied from the point of common coupling (PCC) and DC loads are directly coupled to DC bus. A transformer is also used in system for step up the AC voltage to that of grid. The system can be working in grid connected mode or islanded mode by changing the breaker status at the PCC [6].
As power output power from solar cells and load demand are changing, so for reliable power management methods are proposed in the literature. An energy management and

control system is introduced in [7]. Ref. [8] introduces another control method for a wind-PV-battery system, which focuses on optimizing the sizes and costs of the PV array and battery instead of dynamic power balancing. Similarly many other power management methods are proposed in Ref [9], [10], [11], which are focused on optimization, cost of the production.

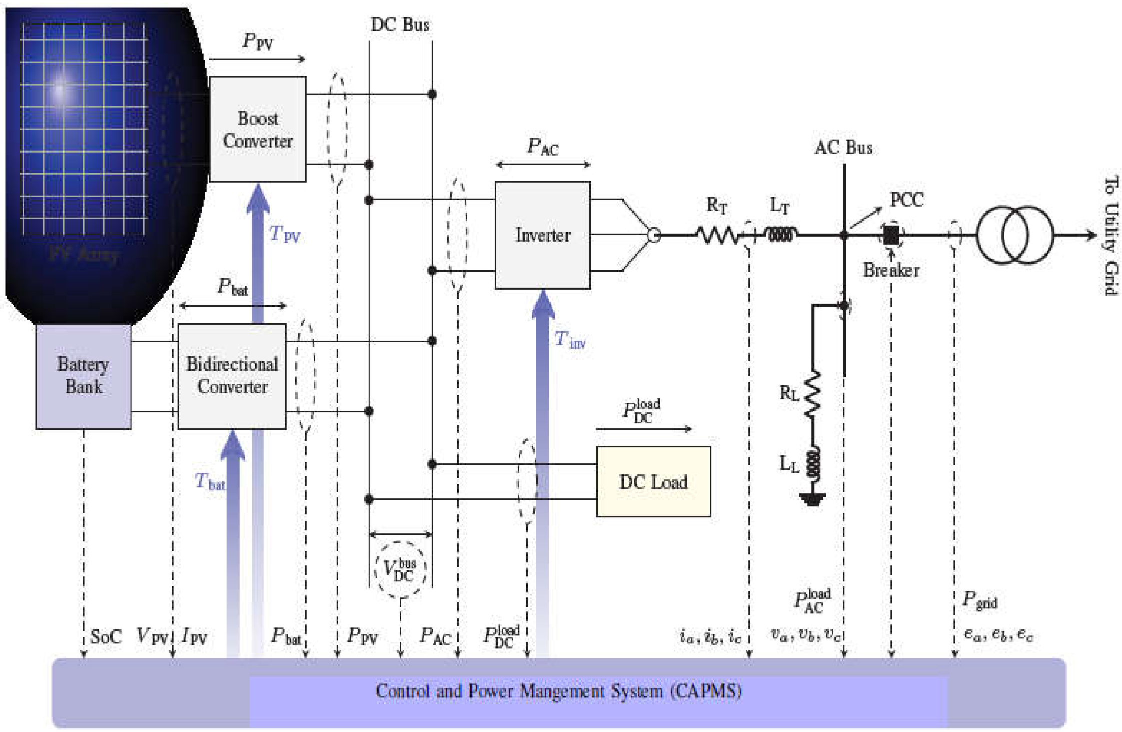

Figure 1 Proposed control and power management system for PV-battery hybrid microgrid

A hierarchical control algorithm for a PV-battery-hydropower system in [12] regulates the AC bus voltage by the hydropower generator and manages the active and reactive power by the PV-battery unit, and Ref. [13] introduces a similar method for a hybrid PV-battery-diesel system.But all these methods fail to consider the voltage for diesel generator is out of service. A decentralized method for an islanded PV-battery system is presented in [14]. This method aims at solving load sharing insystem configurations with multiple PV and battery units. Ref. [15] introduces a similar method which only aims at single phaselow voltage islanded microgrids.

All the methods which are discussed are fail at the maintaining the system stably and DC bus voltage at constant. This paper present paper proposes a new control and power management system (CAPMS) method which will able to control the system and maintain stability. The rest of the paper is organized as section 2,3 explains the proposed system, section 4 explains case studies and section 5 explains conclusion of the paper.

*2.*PROPOSED CONTROL METHOD

As shown in figure 1, which is proposed configuration of the system contains a PV-battery array interfaced with DC bus by DC/DC boost converter while battery bank uses a bidirectional DC/DC converter. One centralized inverter is used to interconnect DC and AC networks. CAPMS method decides the scenarios and select control schemes to be applied for grid-connected mode and islanded mode. Detailed schemes ofthe CAPMS are explained below for both modes of operation.

The PV-battery system, which connected to grid via circuit breaker, can operate either in grid connected mode or islanded mode, depends on the position of the circuit breaker, CAPMS firs monitors status of circuit breaker and implement the require control mechanisms to corresponding converter or inverter. In particular, in grid-connected mode, the inverter controls DC bus voltage and reactive power that is exchanged with the AC side. To control the voltage output of the PV array, charging or discharging of the battery bank and to regulate the frequency of the system within acceptable limits we use PV array controller, battery controller, inverter controller. CAPMS is aware of the available energy storage that can be used in the battery. The upper and lower limits of the SoC (SoC upper limit and SoC lower limit) are set up to make sure the battery is not over-charged or discharged and to increase its cycle life [27]. Depending on the PV output power, SoC and power limit of the battery, DC and AC loads, and the grid demand, CAPMS decides the operation modes of the PV array (MPPT or power-reference mode) and the battery (charging or discharge mode) and provides proper reference values to the controllers, if applicable. Therefore, power flows in the hybrid microgrid are always balanced. The power balance equations followed by the system are stated below.

Grid-connected mode: $P_{PV} + P_{bat} = P_{DC}^{load} + P_{AC}^{load} + P_{grid}$

Islanded mode: $P_{PV} + P_{bat} = P_{DC}^{load} + P_{AC}^{load}$

2.1 Control scheme for grid connected mode

1) In this mode circuit breaker will be in closed position and AC load bus is regulated by grid, DC load bus is regulated by battery converter.
2) Now the control scheme check the charging status of battery here we will get three cases as battery is charged fully up to its upper limit, in between lower limit and upper limit, charging of battery below its lower limit.
3) Consider when battery is fully charged then control scheme check the load demand if the demand is lower than the energy generated in MPPT mode of PV system, then PV system will work in the reference mode otherwise it will work in the MPPT mode and battery will be in discharge mode and in this stage control scheme.
4) When battery charging is in between lower and upper limit the PV system will work in MPPT mode load demand is supplied all sources here if the load demand combination is higher than the battery power then it will discharge otherwise it will be in reference mode and excess power will be sent to the grid.
5) When battery charging is below its lower limit then load demand will be supplied by the PV system alone, and battery will be charged if load demand is less than the PV system energy in MPPT mode otherwise power from the grid will be demanded.

2.2 Control scheme for islanded mode

1) When the position of the circuit breaker is in open position system will be operated in islanded mode and here AC load bus is controlled by inverter DC load bus is controlled by battery.
2) In this mode total load is supplied by the battery and PV system only, here also charging status of battery will be checked by the control scheme.

3) When battery is in fully charged load demand will compared with energy of PV in MPPT mode if load is lesser value then PV system will supply power to the load, battery will set in reference mode means it neither charged nor discharged.
4) When charging of battery in between lower and upper limit load demand is supplied both PV system and battery if energy from PV system is more than load battery will be charged.
5) When batter charging is below its lower limit load will be supplied by PV system alone if load is less battery will be charged, otherwise total demand supply will be reduced.

3.Controllers design

3.1 PV array controller

PV array converts solar energy into DC power, which is connected through a boost converter in proposed configuration, due variation of solar irradiance time to time, there is always a maximum power point tracking (MPPT) for every specific operating situation of a PV array. Therefore, maximum power point tracking (MPPT) algorithms are typically implemented in PV system to extract the maximum power a PV array can provide [28]. The proposed CAPMS employs one of the most popular methods, the P&O MPPT, which provides a reference voltage V MPPT that the PV array will track to produce the maximum power under various operation conditions. Here, there will be three possible control schemes for the PV array, those are MPPT mode, power-reference mode, and DC bus voltage control. In every situation CAPMS monitors operating situation and automatically set the required mode of PV array by controlling swathes of the controller.

3.2 Battery Controller

Battery support for PV system is necessary for power balancing. The battery bank of this system is connected to the DC bus and is controlled by a bidirectional DC/DC converter, charging/discharging of the battery will be controlled by two switches. CAPMS monitors the every situation of the proposed system and set the mode of the battery in power reference mode, maximum power discharging mode, or charging mode according to situations.

3.3 Inverter controller

Inverter is a power electronic device used to covert DC to AC power. . Similar to the converters discussed above, the control scheme of inverter depends on the operating (grid-connected or islanded) mode of the system. A phase locked loop (PLL block) is used to extract angle in grid-connected mode. In islanded mode angle is generated locally, which periodical ramp signal is varying from 0 to 360 with frequency f. It is used to decompose the three-phase AC bus voltages ($v_a, v_b and\ v_c$) and the inverter output currents ($i_a, i_b and\ i\_c$) into d-q frame variables $V_d and\ V_q$, and $I_d and\ I_q$ by Park transformation, respectively, for control purpose. In this controller also CAPMS will set the required mode of inverter depending on the operating situation.

4. Case studies

The case studies of the proposed system also carried in two mode such as grid-connected mode and islanded mode. For verifying the performance of proposed system numerous simulations are done with the help of matlab/simulink case studies are done on the system with parameters listed below table.

Table 1 Basic parameters of the PV-battery system

parameters	values
PV Maximum Power (P_{PV}^{MPPT})170kW	
PV Maximum Power Voltage (V_MPPT) 122V	
Battery Capacity 45 kAh	
Battery Fully Charged Voltage 412.5V	
Battery Nominal Voltage 400V	
Battery Max Charge/Discharge Power 150kW	
DC Bus Voltage (V_{DC}^{ref})450V	
AC Bus Voltage (line to line) 208V	
Transformer Voltage Ratio 208V : 1.2 kV	

4.1Grid-connected mode

Case 1- This is a normal operating state means battery charging is in between its upper limit and lower limit, PV system is operating in MPPT mode. Depending on the generation, load and demand battery balancing the power by absorbing or releasing fig shows the power flow and voltages of $P_{PV}, P_{grid}, P_{bat}$. According to requirement of demand control scheme set the PV- system either in MPPT mode or reference mode and battery also set in reference or maximum power mode setting of these values is showed in figure.2,3 at required time intervals.

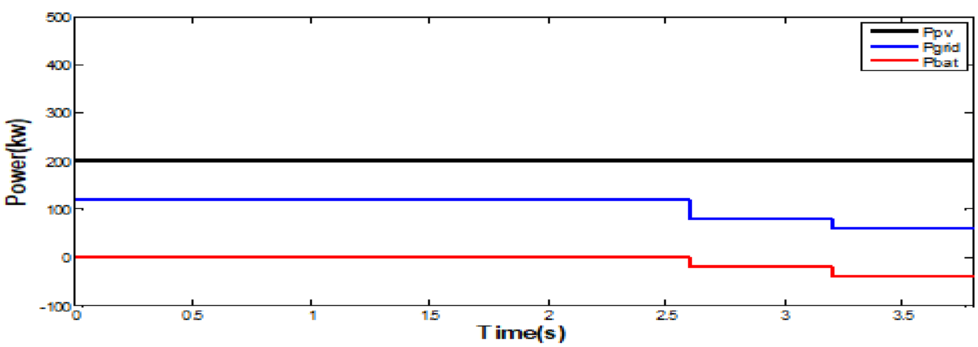

Figure.2 Grid-connected mode power supplies

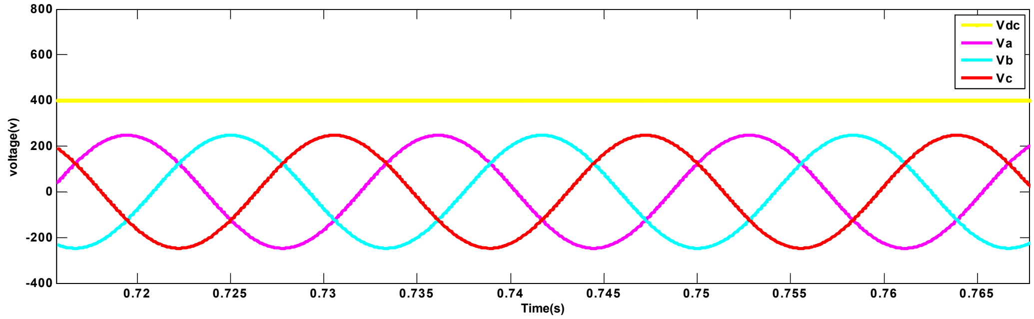

Figure.3 Grid-connected mode voltages

Case 2- In this case we are avail of battery at fully charged then CAPMS stops charging the battery and excess power will be sent to the grid otherwise if load increase the battery will be supply the load increased figure.4 shows this complete process.

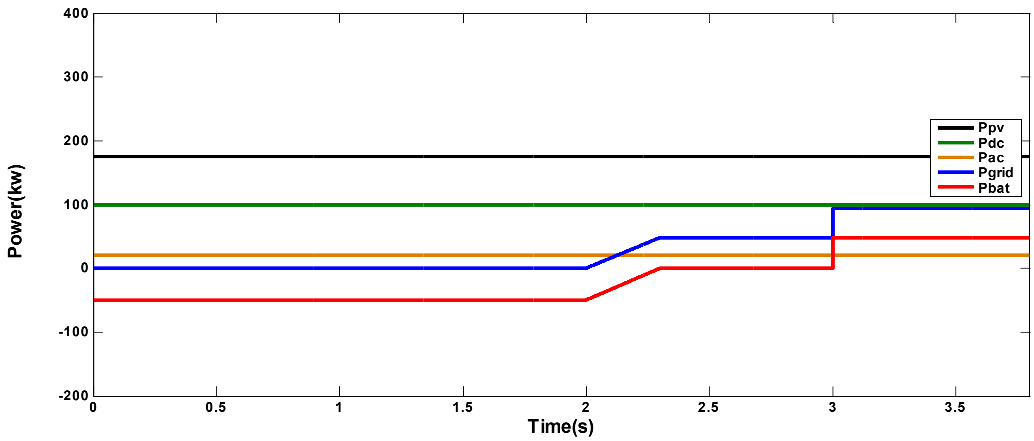

Figure.4 Grid-connected mode power flow of PV-battery system

Case 3- There is also a case occurs where PV-system in MPPT mode, battery is fully charged; grid is in state that cannot absorb excess power. Then CAPMS will set PV-system in reference mode to balance system. Figure.5,6 shows complete process and setting modes by CAPMS.

Case 4- In this case power flow in the inverter is bidirectional, as if power of PV-battery system is required will demand power grid, the CAPMS can reverse power through the inverter to supply the system. The battery charging is less than the lower limit in this case figure.7 shows this complete process.

Case 5- In this case, since inverter has full control of the DC bus voltage as well as the reactive power, it is able to provide reactive power to grid. The wave forms of this case are shown in figure where one line indicates active power and other reactive power those are specified in figure.8.

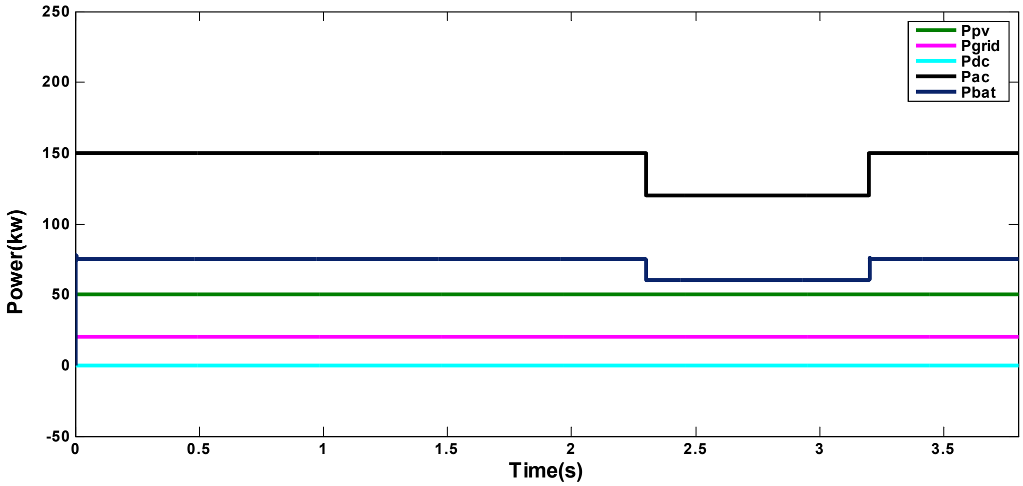

Figure.5 Grid-connected mode PV array in power reference mode

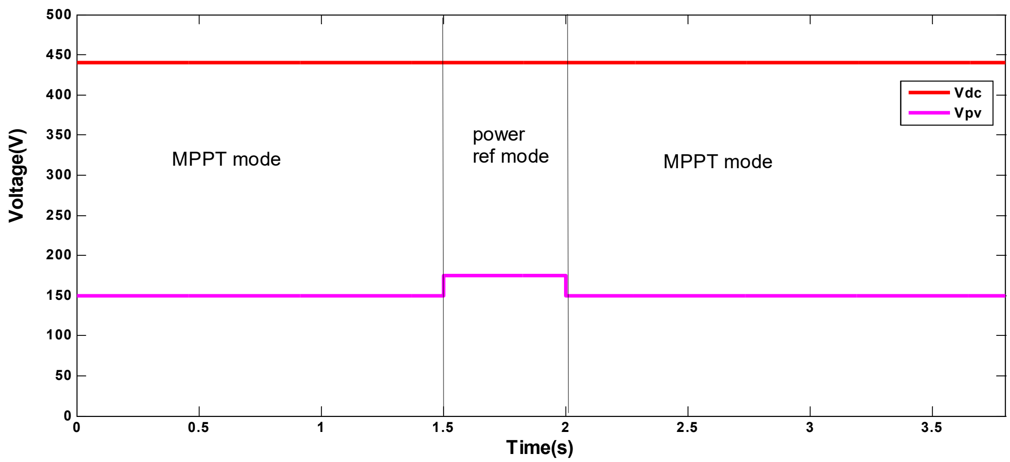

Figure.6 Grid-connected mode transitions between MPPT to power reference mode

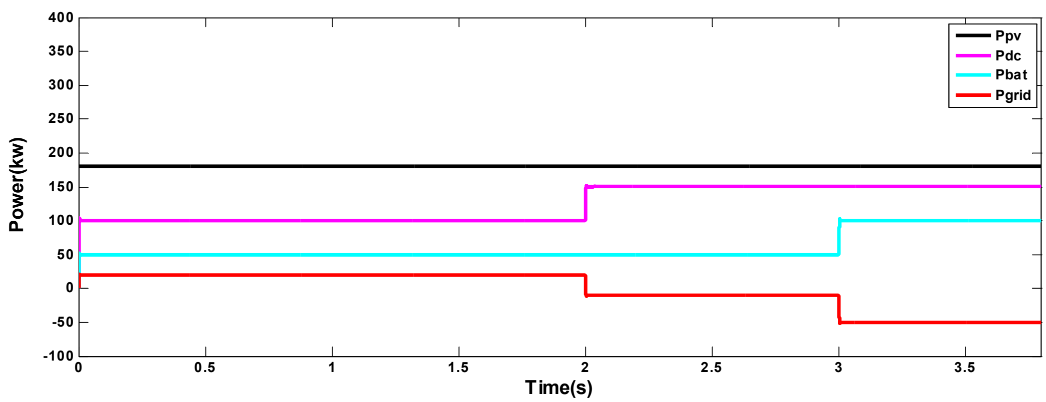

Figure.7 Grid-connected mode PV-battery system receiving power from grid after 2.2s

Case 6- As discussed in the previous cases system will be operated either in grid connected mode or islanded mode. If there is a fault in AC side then breaker will open, inverter will control the AC side power DC side controlled by the battery this process is showed in below figure.9.

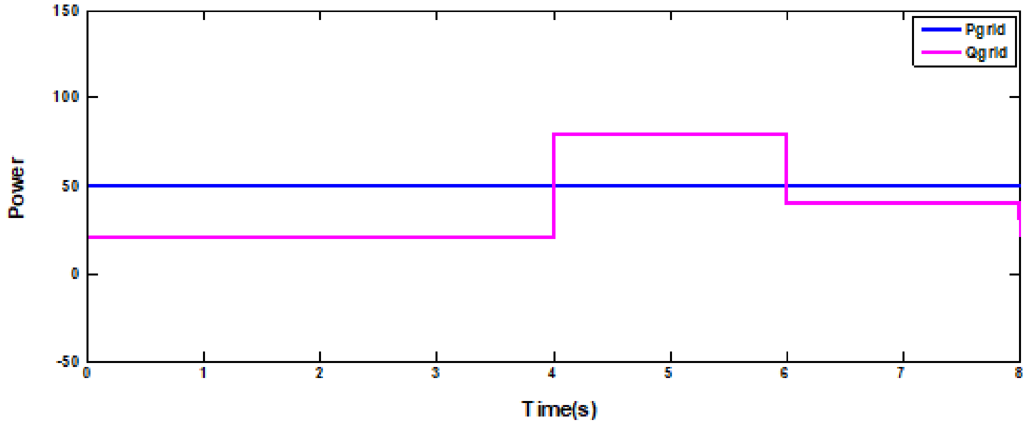

Figure.8 Gird-connected mode reactive power control of the inverter

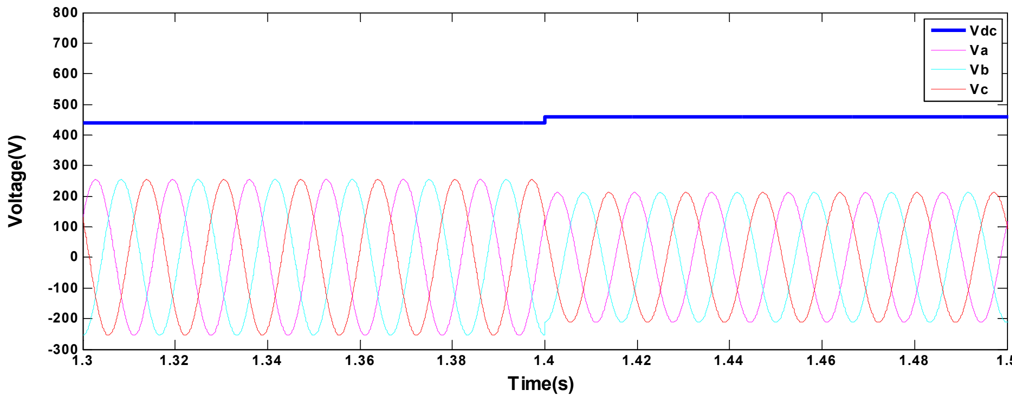

Figure.9 Grid-connected mode transition to islanded mode

4.2 Islanded mode

Case 1-when system is working in islanded mode load is supplied by PV-system and battery bank only, PV-system will work in MPPT mode and battery will charge\discharge depends on the load demand and PV output, the wave forms are shown in the below figure.10.

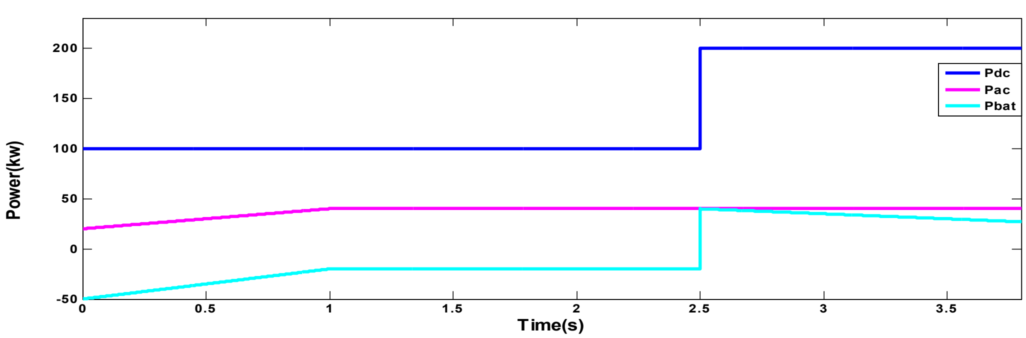

Figure.10 Islanded mode power flow of PV-battery system

Case 2- As in islanded mode load is supplied by PV-system and battery bank, solar irradiance may change in few time, so CAPMS will control the battery bank and balance the power output it is done in time quickly and precisely the process is shown in below figure.11.

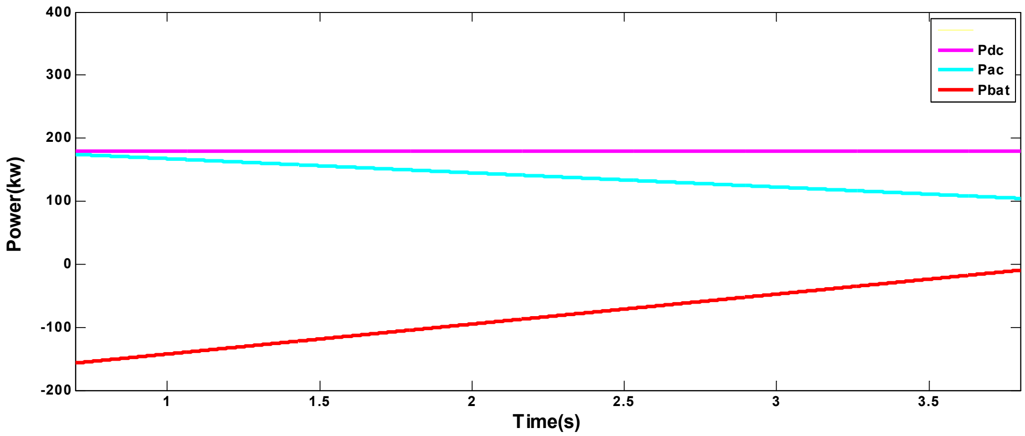

Figure.11 Islanded mode battery power changes with PV generation

Case 3- unlike in grid-connected mode, voltages of DC and AC bus levels has to changed time to time to balance the load demand CAPMS has full control on these voltage sand it will regulate as shown in figure.12.

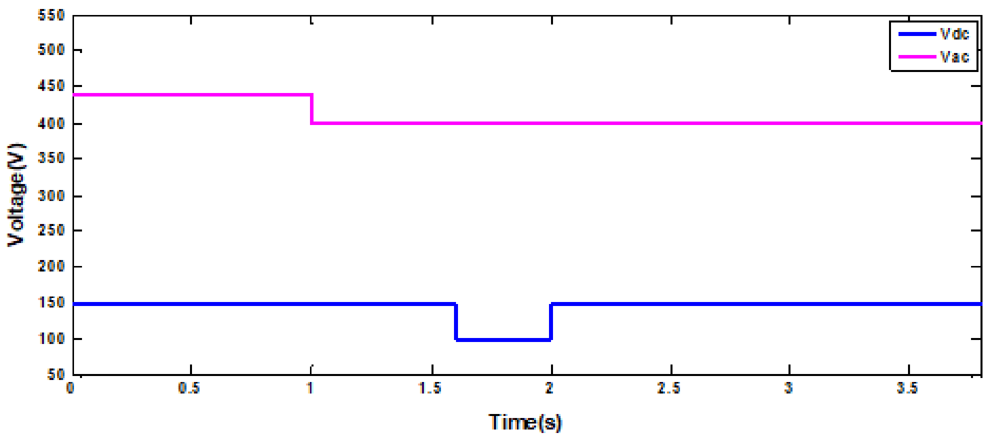

Figure.12Islanded mode bus voltages control of PV-battery system

5. Conclusion

This paper concludes with the statement that CAPMS scheme will able to control voltages and power in the hybrid system, in grid-connected mode or in islanded modes, an d also CAPMS will allows additional loads to access the system without extra converters, reducing operation and control cost.

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References

1. T. A. Nguyen, X. Qiu, J. D. G. II, M. L. Crow, and A. C. Elmore, "Performance characterization for photovoltaic-vanadium redox battery microgrid systems," IEEE Trans. Sustain. Energy, vol. 5, no. 4, pp.1379–1388, Oct 2014.
2. S. Kolesnik and A. Kuperman, "On the equivalence of major variablestep- size MPPT algorithms," IEEE J. Photovolt., vol. 6, no. 2, pp. 590– 594, March 2016.
3. H. A. Sher, A. F. Murtaza, A. Noman, K. E. Addoweesh, K. Al-Haddad, and M. Chiaberge, "A new sensorless hybrid MPPT algorithm based on fractional short-circuit current measurement and P&O MPPT," IEEE Trans. Sustain. Energy, vol. 6, no. 4, pp. 1426–1434, Oct 2015.
4. Y. Riffonneau, S. Bacha, F. Barruel, and S. Ploix, "Optimal power flow management for grid connected PV systems with batteries," IEEE Trans. Sustain. Energy, vol. 2, no. 3, pp. 309–320, July 2011.
5. H. Kim, B. Parkhideh, T. D. Bongers, and H. Gao, "Reconfigurable solar converter: A single-stage power conversion PV-battery system," IEEE Trans. Power Electron., vol. 28, no. 8, pp. 3788–3797, Aug 2013.
6. Z. Yi and A. H. Etemadi, "A novel detection algorithm for line-toline faults in photovoltaic (PV) arrays based on support vector machine (SVM)," in 2016 IEEE Power and Energy Society General Meeting (PESGM), July 2016, pp. 1–4.
7. Merabet, K. Ahmed, H. Ibrahim, R. Beguenane, and A. Ghias, "Energy management and control system for laboratory scale microgrid based wind-PV-battery," IEEE Trans. Sustain. Energy, vol. PP, no. 99, pp. 1–1, 2016.
8. S. Borowy and Z. M. Salameh, "Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system," IEEE Trans. Energy Convers., vol. 11, no. 2, pp. 367–375, Jun 1996.
9. Abbes, A. Martinez, and G. Champenois, "Eco-design optimisation of an autonomous hybrid wind-photovoltaic system with battery storage," IET Renewable Power Generation, vol. 6, no. 5, pp. 358–371, Sept 2012.
10. H. Mahmood, D. Michaelson, and J. Jiang, "A power management strategy for PV/battery hybrid systems in islanded microgrids," IEEE J. Emerg. Sel. Top. Power Electron, vol. 2, no. 4, pp. 870–882, Dec 2014.
11. H. Mahmood, D. Michaelson and J. Jiang, "Decentralized power management of a PV/battery hybrid unit in a droop-controlled islanded microgrid," IEEE Trans. Power Electron., vol. 30, no. 12, pp. 7215–7229, Dec 2015.
12. Y. Guan, J. C. Vasquez, J. M. Guerrero, Y. Wang, and W. Feng, "Frequency stability of hierarchically controlled hybrid photovoltaicbattery- hydropower microgrids," IEEE Trans. Ind. Appl., vol. 51, no. 6, pp. 4729–4742, Nov 2015.
13. J. Philip, C. Jain, K. Kant, B. Singh, S. Mishra, A. Chandra, and K. Al- Haddad, "Control and implementation of a standalone solar photovoltaic hybrid system," IEEE Trans. Ind. Appl., vol. 52, no. 4, pp. 3472–3479, July 2016.
14. Y. Karimi, H. Oraee, M. Golsorkhi, and J. Guerrero, "Decentralized method for load sharing and power management in a PV/battery hybrid source islanded microgrid," IEEE Trans. Power Electron., vol. PP, no. 99, pp. 1–1, 2016.

15. M. S. Golsorkhi, Q. Shafiee, D. Lu, and J. M. Guerrero, "A distributed control framework for integrated photovoltaic-battery based islanded microgrids," IEEE Trans. Smart Grid, vol. PP, no. 99, pp. 1–1, 2016.
16. C. Luna, N. L. D. Aldana, M. Graells, J. C. Vasquez, and J. M. Guerrero, "Mixed-integer-linear-programming based energy management system for hybrid PV-wind-battery microgrids: Modeling, design and experimental verification," IEEE Trans. Power Electron., vol. PP, no. 99, pp. 1–1, 2016.
17. Y. Riffonneau, S. Bacha, F. Barruel, and S. Ploix, "Optimal power flow management for grid connected PV systems with batteries," IEEE Trans. Sustain. Energy, vol. 2, no. 3, pp. 309–320, July 2011.
18. M. Brenna, F. Foiadelli, M. Longo, and D. Zaninelli, "Energy storage control for dispatching photovoltaic power," IEEE Trans. Smart Grid, vol. PP, no. 99, pp. 1–1, 2016.
19. J. H. Teng, S. W. Luan, D. J. Lee, and Y. Q. Huang, "Optimal charging/ discharging scheduling of battery storage systems for distribution systems interconnected with sizeable PV generation systems," IEEE Trans. Power Syst., vol. 28, no. 2, pp. 1425–1433, May 2013.
20. S. Mishra, D. Pullaguram, S. A. Buragappu, and D. Ramasubramanian, "Single-phase synchronverter for a grid-connected roof top photovoltaic system," IET Renewable Power Generation, vol. 10, no. 8, pp. 1187– 1194, 2016.
21. F. Nejabatkhah, S. Danyali, S. H. Hosseini, M. Sabahi, and S. M. Niapour, "Modeling and control of a new three-input DC-DC boost converter for hybrid PV/FC/battery power system," IEEE Trans. Power Electron., vol. 27, no. 5, pp. 2309–2324, May 2012.
22. H. Zhu, D. Zhang, B. Zhang, and Z. Zhou, "A nonisolated three-port DCDC converter and three-domain control method for PV-battery power systems," IEEE Trans. Ind. Electron., vol. 62, no. 8, pp. 4937–4947, Aug 2015.
23. L. Xu, X. Ruan, C. Mao, B. Zhang, and Y. Luo, "An improved optimal sizing method for wind-solar-battery hybrid power system," IEEE Trans. Sustain. Energy, vol. 4, no. 3, pp. 774–785, July 2013.
24. M. O. Badawy and Y. Sozer, "Power flow management of a grid tied pv-battery system for charging of electric vehicles," IEEE Trans. Ind. Appl., vol. PP, no. 99, pp. 1–1, 2016.
25. Merabet, K. T. Ahmed, H. Ibrahim, R. Beguenane, and A. M. Y. M. Ghias, "Energy management and control system for laboratory scale microgrid based wind-pv-battery," IEEE Trans. Sustain. Energy, vol. 8, no. 1, pp. 145–154, Jan 2017.

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