ISSN: 2321-2152
IJMECE
International Journal of modern electronics and communication engineering
E-Mail
editor.ijmece@gmail.com
editor@ijmece.com
www.ijmece.com

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

A NOVEL CONTROL STRATEGY BASED ON GRID CONNECTED SOLAR/BATTERY SYSTEMS FOR ENERGY MANAGEMENT

Pilli Srinivasarao[1], V Vijay Kumar[2]

Abstract: In general, Solar Photovoltaic (SPV) is integrated to grid through a DC-DC converter and Voltage Source Converter (VSC) for real power injection (called two-stage conversion). In view of efficiency point, the single-stage conversion becomes popular and in which Incremental Conductance Maximum Power Point Tracking (IC-PPT) of SPV and real power injection are achieved with VSC alone. But, if Battery Energy Storage (BES) supported by bidirectional DC-DC converter is presented in the single-stage conversion system, then co-ordination between DC-DC converter and VSC is required to achieve simultaneous operation of MPPT and real power injection. In this paper, a co-ordinated A new control strategy of single-stage grid connected SPV and BES system is proposed along with energy management. In which, the algorithm coordinates VSC and bidirectional DC-DC converter based on the State of Charge (SoC) of the battery such that MPPT and power injection is achieved simultaneously. The proposed method not only injecting real power, but also works to compensate load reactive power and unbalanced neutral current minimization. Further, an active rectification operation during non-SPV hours is discussed for better utilization of VSC capacity. The multi-functional features of the proposed method are explained using simulation studies.

Keywords: Solar Photovoltaic (SPV), Battery, Voltage Source Converter (VSC), Incremental Conductance Maximum Power Point Tracking (IC-PPT), State of Charge (SoC)

I. INTRODUCTION

Solar Photovoltaic (SPV) energy is one of the most important renewable energies, and now a days it has been widely used in distributed generation systems. The rapid growth in development of SPV technologies, applications of SPVs in grid-connected systems indicate that SPVs are very attractive to produce environmentally friendly electricity for diversified purposes [1]. In grid connected SPV system, the maximum available power is delivered to the grid by operating the SPV system at Maximum Power Point (MPP) [2]. The conventional Voltage Source Converter (VSC) along with interfacing inductor (also called DSTATCOM) is the most used interfacing unit in grid-connected SPV system technology due to its simplicity and availability [3]. In three-phase systems, two-stage and single-stage grid connected SPV systems are commonly used topologies. The two-stage system consists of two conversion stages as shown in Fig. 1(a): a DC-DC converter stage for MPP tracking and voltage boosting, and a DC-AC inverter stage for interfacing the SPV system to the grid [4], [5]. In [6], a cooperative operation of two-stage grid connected PV and battery energy management system based on ANFIS for voltage regulation is discussed. In [7], two-stage power management of solar PV and energy storage system based on time of use electricity pricing is implemented for residential application. The two stage method suffers from reduced efficiency and higher cost, therefore it is not attractive for efficient grid-

[1]PG Scholar, Department of Electrical and Electronics Engineering, Nalla Malla Reddy Engineering college, Divya Nagar, Kachivani Singaram, Ghatkesar, Hyderabad, Telangana 500088
[2] Assistant Professor, Department of Electrical and Electronics Engineering, Nalla Malla Reddy Engineering college, Divya Nagar, Kachivani Singaram, Ghatkesar, Hyderabad, Telangana 500088
email: [1]srinivasaraopilli111@gmail.com, [2] vijay.victory.259@gmail.com

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

connected system. On the other hand, a single-stage topology (shown in Fig. 1(b)) have gained attention especially in low voltage applications due to high efficiency when compared to two-stage conversion. Different single-stage topologies have been proposed, and a comparison of the available interface units is presented in [8], [9]. In [10], [11], [12], a grid connected single-stage solar system with improved performance is discussed. But, the neutral current compensation is not presented, which will increase the %THD of grid current. In single-stage gridconnected system, the SPV system utilizes a single conversion unit (DC-AC power inverter) to track MPP and interface the SPV system to the grid. In such a topology, the maximum SPV power is delivered into the grid with high efficiency, small size, and low cost. However, the efficiency of conversion stage is improved in grid connected SPV system, it has facing challenge of intermittent energy production with the dynamic power demand. To overcome this, energy storage system is added to the grid connected SPV system [13], [14]. The grid connected SPV with energy storage requires energy management scheme to improve performance, which are discussed in literature [15], [16]. However, these systems have hybrid energy storage devices, the power conversion is implemented based on two stages. In [17], a two-stage grid connected SPV and battery system with optimum power flow management is discussed for the system shown in Fig. 1(c). In [18], an energy management control was proposed for hybrid storage system for different operating modes. A Reconfigurable Solar Converter (RSC) for photovoltaic (PV) and battery application with single-stage conversion is implemented [19].

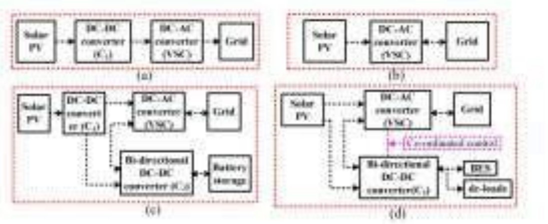


Fig. 1: Grid connected SPV: (a) two stage, (b) single-stage (c) two-stage with BES and (d) proposed single-stage with BES.

In which, the MPP is achieved only during charging of battery or injecting power to grid, but simultaneous charging battery and injecting power to grid is not possible. Also, while charging the battery, the inverter is disconnected from grid. Therefore, resynchronization technique is required in this method. In this paper, a single-stage SPV-DSTATCOM and battery storage with co-ordinated control is proposed as shown in Fig. 1(d). It has multi-functional features, like real power injection, reactive power compensation and active rectification. In case of SPV and battery storage system, the single-stage operation is achieved by co-ordinating the VSC and DC-DC converter based on State of Charge (SoC) of the battery unit. Depending on available SPV power, the proposed control operation is divided into three modes 1) Surplus Power Mode (SPM), 2) Balanced Power Mode (BPM) and 3) Deficit Power Mode (DPM). During non-SPV hours, the SPV-DSTATCOM is operated in active rectification to charge the battery or supply power to dc-loads.

II. LITERATURE SURVEY

[1] F. Blaabjerg, Z. Chen, and S. B. Kjaer, ''Power electronics as efficient interface in dispersed power generation systems,'' IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1184–1194, Sep. 2004.

The global electrical energy consumption is rising and there is a steady increase of the demand on the power capacity, efficient production, distribution and utilization of energy. The traditional power systems are changing globally, a large number of dispersed generation (DG) units, including both renewable and nonrenewable energy sources such as wind turbines, photovoltaic (PV) generators, fuel cells, small hydro, wave generators, and gas/steam powered combined heat and power stations, are being integrated into power systems at the distribution level. Power electronics, the technology of efficiently processing electric power, play an essential part in the integration of the dispersed generation units for good efficiency and high performance of the power systems. This paper reviews the applications of power electronics in the integration of DG units, in particular, wind power, fuel cells and PV generators.

[2] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. Potillo, M. M. Prats, J. I. Leon, and N. Moreno-Alfonso, ''Power- electronic systems for the grid integration of

renewable energy sources: A survey,'' IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, Jun. 2006.

The use of distributed energy resources is increasingly being pursued as a supplement and an alternative to large conventional central power stations. The specification of a power-electronic interface is subject to requirements related not only to the renewable energy source itself but also to its effects on the power-system operation, especially where the intermittent energy source constitutes a significant part of the total system capacity. In this paper, new trends in power electronics for the integration of wind and photovoltaic (PV) power generators are presented. A review of the appropriate storage-system technology used for the integration of intermittent renewable energy sources is also introduced. Discussions about common and future trends in renewable energy systems based on reliability and maturity of each technology are presented

[3] S. Wen, S. Wang, G. Liu, and R. Liu, ''Energy management and coordinated control strategy of PV/HESS AC microgrid during Islanded operation,'' IEEE Access, vol. 7, pp. 4432–4441, 2019.

An energy management control strategy is proposed for an islanded AC microgrid with the hybrid energy storage system, including the battery and the supercapacitor (SC). According to the state of charge of the battery, the photovoltaic system can work in either maximum power point tracking mode or load power tracking mode to prevent the battery from over charging. Similarly, the load shedding control is adopted to prevent the battery from over discharging. A virtual impedance control strategy is proposed to achieve effective power sharing in hybrid energy storage systems, where the battery provides steady state power and the SC only supports transient power fluctuations. The terminal voltage of the SC can be restored to the initial value automatically by introducing a high-pass filter in the voltage control loop. The AC bus voltage remains constant using the voltage secondary controller to compensate the voltage drop caused by the virtual impedance control strategy. The simulation results under typical working conditions verify the correctness and effectiveness of the proposed control strategy.

[4] J. P. Barton and D. G. Infield, ''Energy storage and its use with intermittent renewable energy,'' IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 441–448, Jun. 2004.

A simple probabilistic method has been developed to predict the ability of energy storage to increase the penetration of intermittent embedded renewable generation (ERG) on weak electricity grids and to enhance the value of the electricity generated by time-shifting delivery to the network. This paper focuses on the connection of wind generators at locations where the level of ERG would be limited by the voltage rise. Short-term storage, covering less than 1 h, offers only a small increase in the amount of electricity that can be absorbed by the network. Storage over periods of up to one day delivers greater energy benefits, but is significantly more expensive. Different feasible electricity storage technologies are compared for their operational suitability over different time scales. The value of storage in relation to power rating and energy capacity has been investigated so as to facilitate appropriate sizing.

[5] M. S. Whittingham, ''History, evolution, and future status of energy storage,'' Proc. IEEE, vol. 100, pp. 1518–1534, May 2012.

Advanced energy storage has been a key enabling technology for the portable electronics explosion. The lithium and Ni-MeH battery technologies are less than 40 years old and have taken over the electronics industry and are on the same track for the transportation industry and the utility grid. In this review, energy storage from the gigawatt pumped hydro systems to the smallest watt-hour battery are discussed, and the future directions predicted. If renewable energy, or even lower cost energy, is to become prevalent energy storage is a critical component in reducing peak power demands and the intermittent nature of solar and wind power. An electric economy will demand more electrification of the transportation sector and it is likely that all vehicles sold by the end of this decade will have some level of hybridization. Energy storage capabilities in conjunction with the smart grid are expected to see a massive leap forward over the next 25 years.

III. PROPOSED ENERGY MANAGEMENT SCHEME

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

The configuration of the proposed grid connected SPV with battery energy storage system in three-phase network is shown in Fig. 1.1 It consists of SPV string, VSC, bi-directional DC-DC converter, battery, source, and load. The SPV string consists of series and parallel combination of photovoltaic modules to match the required voltage and power ratings. The VSC is mainly employed for real power injection with MPP tracking of SPV. The additional services provided by VSC are power factor improvement by reactive power compensation, balancing of grid currents, and active rectification. In proposed method, battery energy storage is connected to dc-link of VSC through a bi-directional DC-DC converter to meet the requisite of power management in the grid and load environment. In single-stage SPV-battery grid connected system, both VSC and bi-directional DC-DC converter are responsible for MPP tracking and real power injection to grid. For that, co- ordination between VSC and bi-directional DC-DC converter is required for MPP tracking. In this paper, a co-ordinate control is implemented, which is not discussed in the existing literature. The evidence for requirement of co-ordinate control is discussed below based on power balance theory.

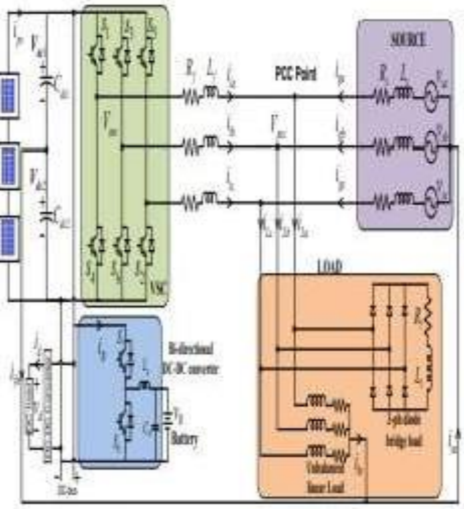


Fig.1.1: Grid connected SPV and BES system in three-phase network.

a) Grid Connected SPV without Storage: In grid connected SPV system without storage system, the MPPT is achieved by DC-link voltage control loop of VSC, such that power balance is achieved. The power balance equation for VSC on dc-side and ac-side is given below.

$$P_{ac} = P_{dc} - P_{loss} \tag{1}$$

$$3V_{ac}I_{ac} = V_{dc}I_{dc} - P_{loss} \tag{2}$$

$$\frac{3}{2}V_m\left(\frac{V_m}{R_{ac}}\right) = V_{dc}I_{dc} - P_{loss} \tag{3}$$

$$\frac{3}{2}\frac{(m_a^2 V_{dc}^2)}{4R_{ac}} = \frac{V_{dc}^2}{R_{dc}} - P_{loss} \tag{4}$$

where, ma is amplitude modulation index. Pac and Pdc are powers on ac-side and dc-side of VSC, respectively. Rac and Rdc are equivalent resistances on ac-side and dc-side of VSC, respectively. Ploss is loss in VSC. For idle case, Ploss = 0, then$m_a = \sqrt{8R_{ac}/3R_{dc}}$. For non-idle case, Ploss 6= 0, then

$$m_a = \sqrt{\frac{8}{3}\left(\frac{R_{ac}}{R_{dc}} - \frac{P_{loss}R_{ac}}{V_{dc}^2}\right)} \tag{5}$$

b) Grid Connected SPV with Battery Storage: In grid connected SPV system battery storage supported by DC-DC converter on dc-side of VSC, the MPPT is achieved by co-ordinate control of VSC and DC-DC converter. The power balance equation in this case is given as,

$$P_{ac} = P_{dc} \pm P_B - P_{loss} \tag{.6}$$

$$3V_{ac}I_{ac} = V_{dc}I_{dc} \pm V_{dc}I_B - P_{loss} \tag{7}$$

$$\frac{3}{2}V_m\left(\frac{V_m}{R_{ac}}\right) = V_{dc}I_{dc} \pm V_{dc}\frac{V_{dc}}{R_B} - P_{loss} \tag{8}$$

$$\frac{3}{2}\frac{(m_a^2 V_{dc}^2)}{4R_{ac}} = \frac{V_{dc}^2}{R_{dc}} \pm \frac{V_{dc}^2}{R_B} - P_{loss} \tag{9}$$

where, +PB and −PB are the battery powers during dis charging and charging of battery, respectively. For idle case, Ploss = 0, then

$$m_a = \sqrt{\frac{8}{3}\left(\frac{R_{ac}}{R_{dc}} \pm \frac{R_{ac}}{R_B}\right)} \tag{10}$$

For non-idle case, Ploss 6= 0, then

$$m_a = \sqrt{\frac{8}{3}\left(\frac{R_{ac}}{R_{dc}} \pm \frac{R_{ac}}{R_B} - \frac{P_{loss}R_{ac}}{V_{dc}^2}\right)} \tag{11}$$

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

From the above power balance theory, the amplitude modulation index (ma) of VSC is different in case of single stage SPV without battery and SPV with battery storage supported by bi-directional DC-DC converter. This analysis is evident that the MPPT of SPV by single stage method is achieved by co-ordinated control of VSC and bi-directional DC- DC converter. The conditions for MPP tracking with only VSC and combination of VSC plus bi-directional DC-DC converter are tabulated in Table I. The overall control algorithm of the proposed method is shown in Fig.2 It mainly consists of reference current generation, power management algorithm, current control and switching pulse generation for DC-DC converter and VSC.

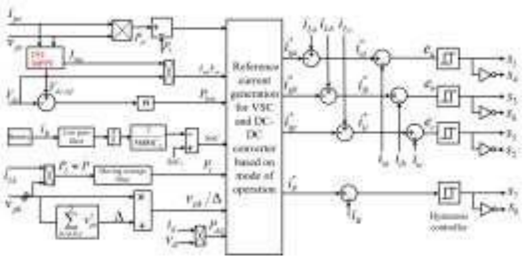


Fig2. Overall control algorithm for switching gate pulses generation in the proposed method.

TABLE I: MPPT conditions of grid connected SPV with and without battery storage system

Topology	Condition for MPPT	Modulation index (m_a)	SPV power (P_{pv})
VSC	$8R_{ac} = 3R_{dc}$	$m_a = 1$	$P_{pv} = P_{max}$
	$8R_{ac} < 3R_{dc}$	$0 < m_a < 1$	$P_{pv} = P_{max}$
	$8R_{ac} > 3R_{dc}$	$m_a > 1^*$	$P_{pv} < P_{max}$
VSC+	$8R_{ac} = 3R_{dc}\left(\frac{1}{1 \pm R_{dc}/R_B}\right)$	$m_a = 1$	$P_{pv} = P_{max}$
DC-DC	$8R_{ac} < 3R_{dc}\left(\frac{1}{1 \pm R_{dc}/R_B}\right)$	$0 < m_a < 1$	$P_{pv} = P_{max}$
converter	$8R_{ac} > 3R_{dc}\left(\frac{1}{1 \pm R_{dc}/R_B}\right)$	$m_a > 1^*$	$P_{pv} < P_{max}$

* indicates, m_a not possible more than unity, so it is forced to unity but loose the MPP tracking

The sensor signals of SPV voltage (vpv) and SPV current (ipv) are given to Perturb and Observe (P & O) algorithm. The outputs of P & O algorithm are, estimated voltage (Vmp) and current (Imp) corresponding to maximum power point and which are derived from voltage and current perturb algorithm, respectively. To operate the SPV at MPP, the DC-link voltage (Vdc) of VSC is forcefully maintained to the reference dclink voltage of (Vdc,ref) by PI controller. The output of PI controller is taken as power loss (Ploss), which is supplied by grid. The reference dc-link voltage is calculated from [20],

$$V_{dc,ref} = \frac{1.6\sqrt{2}V_{LL}}{\sqrt{3}m_a} \quad 12$$

where, Vdc,ref is reference dc-link voltage, VLL is line-to-line PCC voltage, and ma is considered as unity. The term Ploss is supplied from the grid through controlling the VSC. The average real power (PL) is calculated from the measured instantaneous load currents (iLk) and PCC voltages (vpk). Moving Average Filter (MAF) is implemented to eliminate oscillation in average real power. Depending on the difference between available SPV power (Ppv) and load real power demand (PL), the modes of operation is decided. In the proposed energy management, three different modes (SPM, BPM, DPM) of operation are explained. In each mode of operation of the proposed control algorithm, the calculation of SoC of battery is important for energy management. The SoC of battery is calculated from Coulomb counting method, and which is given below [21].

$$\mathrm{SoC}(t) = \mathrm{SoC}_i + \frac{1}{3600C_N}\int i_B(t)dt \quad 13$$

where, iB is battery current, SoCi is initial SoC and $C_N = \frac{Cap(T)}{\eta(i_B(t),T)}$. Cap(T) is capacity of battery and η(iB(t), T) is Coulombic efficiency of battery. The estimated SoC is effected due to measuring noise and errors, power losses and variation of battery capacity and Coulombic efficiency. Therefore, to avoid the over charging of battery, the SoC of battery is limited to upper threshold limit (H). After selecting mode of operation, the reference currents (iga*, igb*, igc*) on grid side are generated. These reference currents are phase opposition to grid voltage in case of power is injecting to grid and in-phase with grid voltage in case of power is drawn from grid.

IV. PROPOSED INC MPPT

This method consists in using the slope of the derivative of the current with respect to the voltage in order to reach the maximum power point [2].

What advantage does MPPT give in the real world that depends on the array, their climate, and their seasonal load pattern. It gives us an effective current boost only when the Vpp is more than about 1V higher than the battery voltage. In hot weather, this may not be the case unless the batteries are low in charge. In cold weather however, the Vpp can rise to 18V.

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

Outside temperature: 20°F (-7°C) Wind is blowing a bit, so the PV cell temperature rises to only around 32°F (0°C). Vpp = 18V Batteries are a bit low, and loads are on, so battery voltage = 12.0 Ratio of Vpp to battery voltage is 18:12 = 1.5:1 Under these conditions, a theoretically perfect MPPT (with no voltage drop in the array circuit) would deliver a 50% increase in charge current. In reality, there are losses in the conversion just as there is friction in a car's transmission. Reports from the field indicate that increases of 20 to 30% are typically observed.

Both the wind turbine and the photovoltaic array must be adjusted to operate at their point of maximum power. Many different maximum power point tracking (MPPT) algorithms like perturbation observation method, incremental conductance method have been developed and widely used for such systems. The perturbation observation method is adopted in this paper for both the wind turbine and the photovoltaic array for it simplicity and accuracy. The algorithm starts by choosing an initial reference rotor speed for the wind turbine and an initial reference voltage for the photovoltaic array. The corresponding output powers of the two systems are measured. If this power does not correspond to their maximum powers, then their initial reference values are incremented or decremented by one step. If this adjustment leads to an increase in their output powers then the next adjustment is made in the same direction and vice- versa.

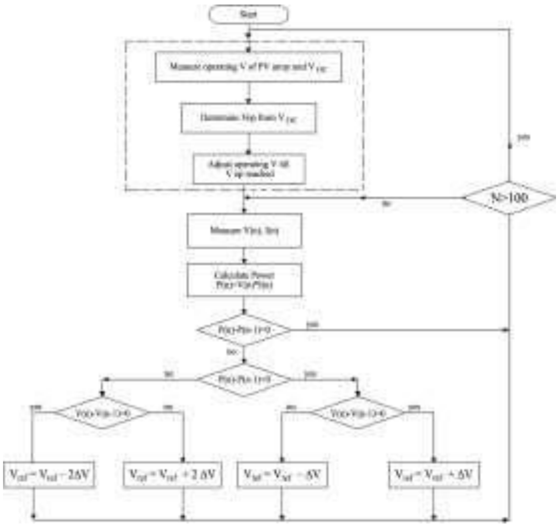


Fig 3: Incremental Conductance Method Algorithm

The above steps are repeated till the maximum power points of the wind turbine and photovoltaic array are reached.

V. SIMULATION RESULTS

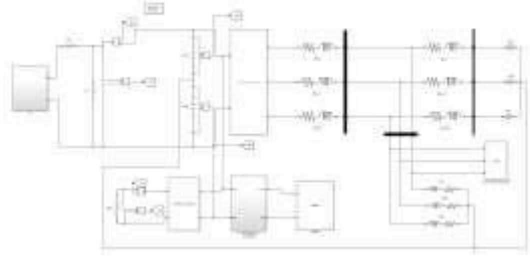


Fig.4 MATLAB/SIMULINK circuit diagram of Grid connected SPV and BES system in three-phase network.

A) EXISTING RESULTS (P AND O MPPT)

A. Performance During SPV Hours

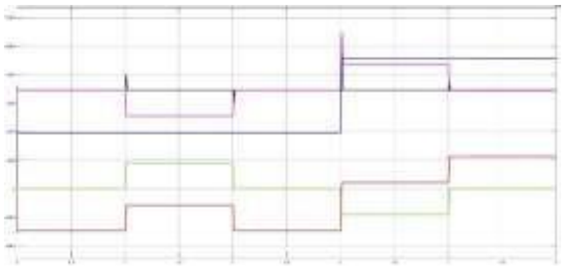


Fig.5: Dynamic of power flow during SPV hours (Ppv: SPV power, Pvsc: VSC injecting power, PL: load real power, PB: battery power, Pg: grid power).

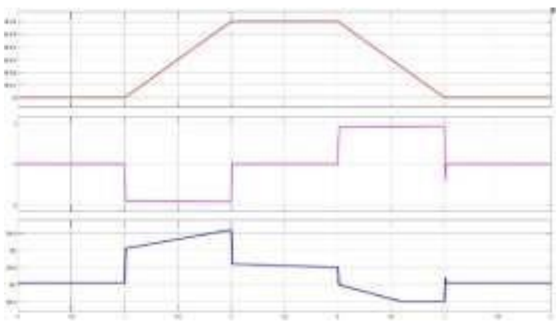


Fig.6: Battery dynamics (a) SoC, (b) battery current (iB) and (c) battery voltage (vB)

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

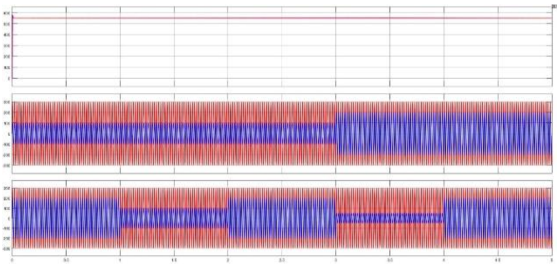


Fig. 7: (a) DC-link voltages (Vdc1, Vdc2), (b) PCC voltage (vpa) and load current (iLa), and (c) PCC voltage (vpa) and grid current (iga).

Fig.8 PCC Voltage THD

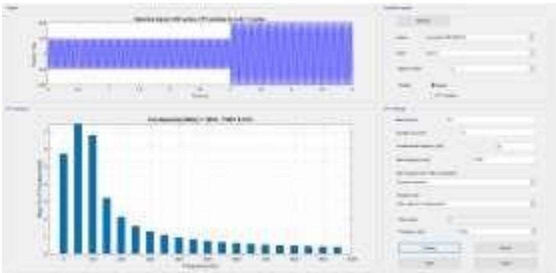


Fig.9 Load current THD

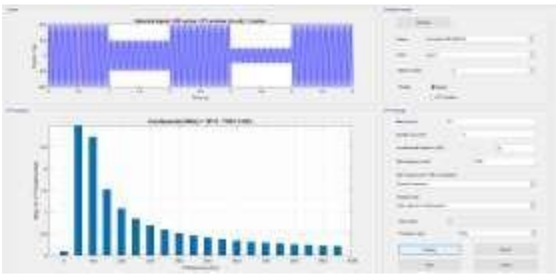


Fig.10 Grid current THD

B. Performance During Non-SPV Hours with Variable Load

(a)

(b)

Fig. 11: (a) Dynamic power flow during non-SPV hours (PdcL: dc-load power, Pvsc: VSC injecting power, PL: ac-load power, PB: battery power, Pg: grid power), and (b) DC-link voltages (Vdc1, Vdc2).

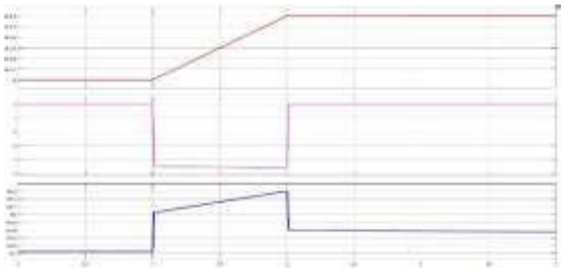
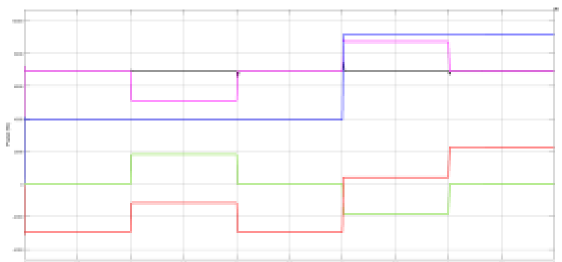


Fig. 12: Battery dynamics (a) SoC, (b) battery current (iB) and (c) battery voltage (vB).

B) EXTENSION RESULTS (INC MPPT)

A. Performance During SPV Hours



ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

Fig. 13 : Dynamic of power flow during SPV hours (Ppv: SPV power, Pvsc: VSC injecting power, PL: load real power, PB: battery power, Pg: grid power).

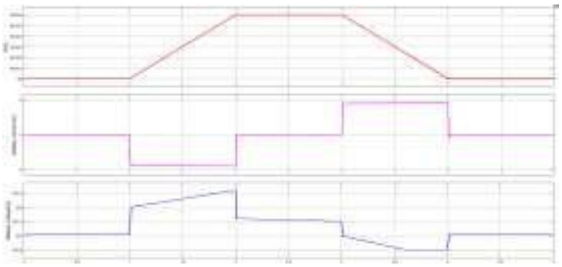


Fig.14 : Battery dynamics (a) SoC, (b) battery current (iB) and (c) battery voltage (vB)

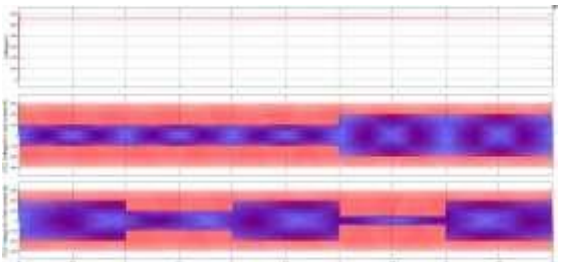
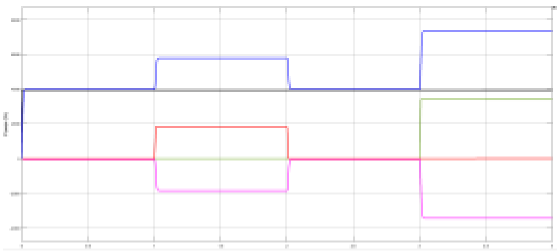


Fig. 15 : (a) DC-link voltages (Vdc1, Vdc2), (b) PCC voltage (vpa) and load current (iLa), and (c) PCC voltage (vpa) and grid current (iga).

B. Performance During Non-SPV Hours with Variable Load



(a)

(b)

Fig. 16 : (a) Dynamic power flow during non-SPV hours (PdcL: dc-load power, Pvsc: VSC injecting power, PL: ac-load power, PB: battery power, Pg: grid power), and (b) DC-link voltages (Vdc1, Vdc2).

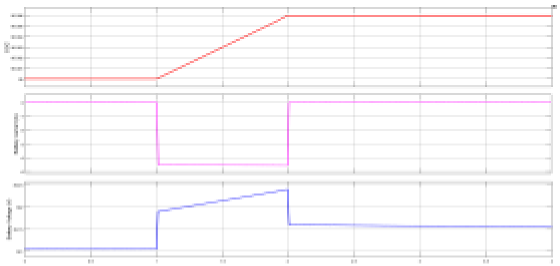


Fig. 17: Battery dynamics (a) SoC, (b) battery current (iB) and (c) battery voltage (vB).

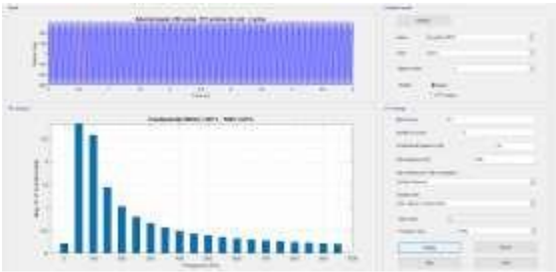


Fig.18 PCC Voltage THD

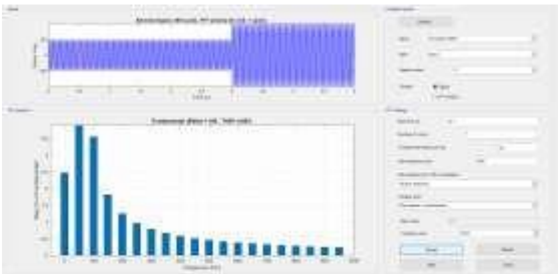


Fig.19 Load current THD

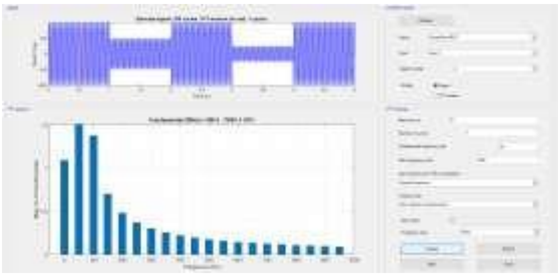


Fig.20 Grid current THD

COMPARISION TABLE

	EXISTING SYSTEM	EXTENSION SYSTEM

ISSN2321-2152
www.ijmece .com
Vol 12, Issue.1Feb 2024

PCC Voltage THD%	4.06%	3.61%
Load Current THD%	8.51%	4.69%
Grid Current THD%	3.82%	1.81%

CONCLUSION

In this paper, single-stage SPV-DSTATCOM with coordinated control algorithm is proposed for INC-MPPT tracking with VSC and DC-DC converter. The performance of the proposed method is demonstrated through simulation studies by operating at three different modes of operation (SPM, DPM and BPM). The advantages of the proposed method are, 1) During SPV hours, in addition to compensation of reactive power, real power injection to grid is possible along with charging/discharging of battery. 2) During non-SPV hours, rectification action is discussed for better utilization of VSC capacity. 3) Reliability of system increases with energy storage device.

REFERENCES

[1] F. Blaabjerg, Z. Chen, and S. B. Kjaer, „„Power electronics as efficient interface in dispersed power generation systems,‟‟ IEEE Trans. Power Electron., vol. 19, no. 5, pp. 1184–1194, Sep. 2004.

[2] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. Potillo, M. M. Prats, J. I. Leon, and N. Moreno-Alfonso, „„Power-electronic systems for the grid integration of renewable energy sources: A survey,‟‟ IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, Jun. 2006.

[3] BP Statistical Review of World Energy, British Petroleum, London, U.K., Jun. 2018.

[4] J. P. Barton and D. G. Infield, „„Energy storage and its use with intermittent renewable energy,‟‟ IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 441–448, Jun. 2004.

[5] M. S. Whittingham, „„History, evolution, and future status of energy storage,‟‟ Proc. IEEE, vol. 100, pp. 1518–1534, May 2012.

[6] C. A. Hill, M. C. Such, D. Chen, J. Gonzalez, and W. M. Grady, „„Battery energy storage for enabling integration of distributed solar power generation,‟‟ IEEE Trans. Smart Grid, vol. 3, no. 2, pp. 850–857, Jun. 2012.

[7] Z. Yi, W. Dong, and A. H. Etemadi, „„A unified control and power management scheme for PV- battery-based hybrid microgrids for both grid connected and islanded modes,‟‟ IEEE Trans. Smart Grid, vol. 9, no. 6, pp. 5975–5985, Nov. 2018.

[8] 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.

[9] K. Sun, L. Zhang, Y. Xing, and J. M. Guerrero, „„A distributed control strategy based on DC bus signaling for modular photovoltaic generation systems with battery energy storage,‟‟ IEEE Trans. Power Electron., vol. 26, no. 10, pp. 3032–3045, Oct. 2011.

[10] S. Adhikari and F. Li, „„Coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage in microgrids,‟‟ IEEE Trans. Smart Grid, vol. 5, no. 3, pp. 1270–1281, May 2014.

[11] S. K. Kollimalla, M. K. Mishra, and N. L. Narasamma, „„Design and analysis of novel control strategy for battery and supercapacitor storage system,‟‟ IEEE Trans. Sustain. Energy, vol. 5, no. 4, pp. 1137–1144, Oct. 2014.

[12] S. Wen, S. Wang, G. Liu, and R. Liu, „„Energy management and coordinated control strategy of PV/HESS AC microgrid during Islanded operation,‟‟ IEEE Access, vol. 7, pp. 4432–4441, 2019

[13]. S.K.Kollimalla, M.K.Mishra, and N.L.Narasamma, „„Designand analysis of novel control strategy for battery and supercapacitor storage system,‟‟ IEEE Trans. Sustain. Energy, vol. 5, no. 4, pp. 1137–1144, Oct. 2014.

[14]. S. Wen, S. Wang, G. Liu, and R. Liu, „„Energy management and coordinated control strategy of PV/HESS AC microgrid during Islanded operation,‟‟ IEEE Access, vol. 7, pp. 4432–4441, 2019.

[15]. E. Kabalcı, F. Batta, O. Battal, “Modelling of a Hybrid Renewable Energy Conversion System”, 3rd International Conference on Nuclear and Renewable Energy Resources (NURER 2012), pp. 1-6, May 20- 23, 2012, Istanbul, Turkey.