International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

IJIEMR Transactions, online available on 15 Oct 2019.

Link :

https://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=3206923&dgcid=EngRN-PIP-IJIEMR_email_netann

Title:- A Three-Phase Grid Tied SPV System With Adaptive Dc Link Voltage For CPI Voltage Variations.

Volume 08, Issue 09, Pages: 779 - 787.

Paper Authors

D.JAYACHAITANYA, R.S.SRINIVASARAO.

Dept of EEE, ANU College of Engineering and Technology.

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

A THREE-PHASE GRID TIED SPV SYSTEM WITH ADAPTIVE DC LINK VOLTAGE FOR CPI VOLTAGE VARIATIONS

[1]D.JAYACHAITANYA, [2]R.S.SRINIVASARAO
[1]PG Scholar, Dept of EEE, ANU College of Engineering and Technology, Guntur; Guntur (Dt); A.P, India.
[2]Assistant Professor, Dept of EEE, ANU College of Engineering and Technology, Guntur; Guntur (Dt); A.P, India.

ABSTRACT: This project deals with a three-phase two-stage grid tied SPV (solar photo-voltaic) system. The first stage is a boost converter, which serves the purpose of MPPT(Maximum Power Point Tracking) and feeding the extracted solar energy to the DC link of the PV inverter, whereas the second stage is a two-level VSC(Voltage Source Converter) serving as PV inverter which feeds power from a boost converter into grid. The proposed system uses an adaptive DC link voltage which is made adaptive by adjusting reference DC link voltage according to CPI (Common Point of Interconnection) voltage. The adaptive DC link voltage control helps in the reduction of switching power losses. A feed forward term for solar contribution is used to improve the dynamic response. The system is tested considering realistic grid voltage variations for under voltage and over voltage. The performance improvement is verified experimentally. The proposed system is advantageous not only in cases of frequent and sustained under voltage (as in the cases of far radial ends of Indian grid) but also in case of normal voltages at CPI. The THD (Total Harmonic Distortion) of grid current has been found well under the limit of an IEEE-519 standard. This system is incorporated into ability network by means that of force electronic converters. The model is tried considering cheap matrix voltage varieties for below voltage varieties.

Keywords: SPV (solar photo-voltaic), THD (Total Harmonic Distortion), MPPT (Maximum Power Point Tracking), VSC (Voltage Source Converter), CPI (Common Point of Interconnection)

1. INTRODUCTION

The electrical energy has a vital role in development of human race in the last century. The diminishing conventional primary sources for electricity production have posed an energy scarcity condition in front of the world. The renewable energy sources such as solar, wind, tidal etc are few of such options which solve the problem of energy scarcity. The cost effectiveness of any technology is prime factor for its commercial success. The SPV (Solar Photovoltaic) systems have been proposed long back but the costs of solar panels have hindered the technology for long time, however the SPV systems are reaching grid parity [1], [2]. The solar energy based systems can be classified into standalone and grid interfaced systems. The energy storage (conventionally batteries) management is the key component of standalone system. Various problems related to battery energy storage standalone solar energy conversion systems are discussed in [3]–[6]. Considering the problems associated with energy storage systems, the grid interfaced systems are more preferable, in case the grid is present. The grid acts as an energy buffer, and all the generated power can be fed into the grid. Several grid interfaced SPV systems are proposed in past addressing various issues related to islanding, intermittency, modelling etc. With growing power system, the attention is moving from centralized generation and radial distribution to distributed generation.

The distributed generation can bring in several advantages such as reduction in losses, better utilization of distribution resources, load profile flattering etc.

The SPV systems provide a good choice for distributed generation system considering small scale generation from rooftop solar, modularity of power converter and static energy conversion process. The initial investment in SPV systems is high because of high cost of solar panels [3]. Therefore, considering the initial investments for any installed plant, the aim is to extract maximum energy output from the given capacity. grid tied PV generation system. In general, grid tied VSCs have under voltage and overvoltage protection. The nominal range of set point for under voltage and over voltage is around 0.9 pu and 1.1 pu [9]. This range is very narrow because of reasons such as converter may lose control, increase in converter rating, and converter losses at low voltage etc. In case of weak distribution system, a wide voltage variation is observed. During peak loading condition, a sustained voltage dip or under voltage is observed commonly. The practical range of voltage variation is about ±15% of the nominal voltage. Normally in such wide variation of distribution system the shunt connected converter trips frequently. However, in case of tripping of converter the PV generation is lost even when PV power is available. Therefore, minimizing converter trips indirectly increases energy yield from the installed plant. The proposed system is capable of working with wide range of voltage variation hence avoids the generation loss. The use of two stage SPV generation system has been proposed by several researchers.

Conventionally a DC-DC converter is used as first stage which serves the purpose of MPPT. The duty ratio of DCDC converter is so adjusted that PV array operates at MPP point. The second stage is a grid tied VSC (Voltage Source Converter) which feeds the power into the distribution system. A single phase two stage grid tied PV generation system with constant DC link voltage is shown in [2].

Moreover, the three phase grid tied PV generation system with constant DC link voltage control is also shown. The concept of loss reduction by adaptive DC link voltage for VSC in hybrid filters is shown in [4] wherein, the DC link voltage is adjusted according to reactive power requirement of filter. However, in the proposed system the DC link voltage of VSC is made adaptive with respect to CPI voltage variation. Moreover, the circuit topologies in both the systems are different. Therefore, the work presented in [3], [4] is very different from the proposed work. For proper control of VSC currents, the DC link voltage reference is set more than peak of three phase line voltages. The limitation for current control in single-phase grid connected converter is shown in [5]. Considering the variation of CPI (Common Point of Interconnection) voltage, the reference DC link voltage is kept above the maximum allowable CPI voltage. Therefore in case of fixed DC link voltage control for VSC, the system always operates at a DC link voltage corresponding to worst case condition. In this paper, a simple control scheme is presented for grid interfaced PV system with adaptive DC link voltage structure for CPI voltage variation. A boost converter is used as the first stage and a two level VSC is used as the second stage. Unlike the earlier work with constant DC link voltage for VSC, the presented work proposes an adaptive DC link voltage structure for the VSC and associated

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

benefits. The adaptive DC link voltage mainly reduces switching losses in all power devices and high frequency ohmic losses in the interfacing inductor.

The maximum benefit of proposed DC link voltage structure is found not only during under voltage (common in far radial ends) but also under nominal grid voltage condition as the DC link voltage is kept just necessary for proper current control not according to worst case scenario. The claimed benefits of the system are verified experimentally along with comparison with conventional system. Moreover, the feed-forward term for PV contribution is included to improve the dynamic response.

The two stage grid interfaced three phase systems are proposed by several researchers, however, none of them have

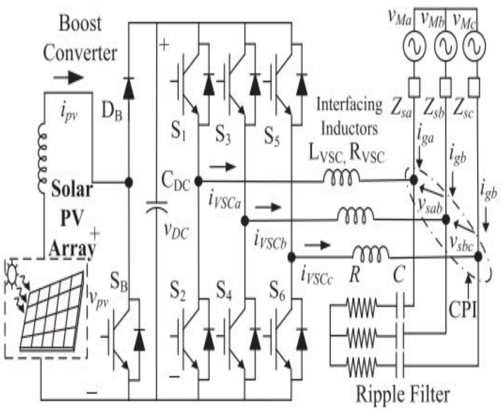

Fig. 1. System configuration.

Shown performance for such wide range of CPI voltage variations (350 V to 480 V for nominal of 415 V). The operation of the system for a wide range of CPI voltage variation increases the rating of the VSC and further the cost. However, small increment in the cost of VSC can be justified on account of large initial investment on PV array. The THD of grid current and voltages has been found well under IEEE-519 standard (less than 5%) under all operating conditions [26]. Moreover, it should be noted that none of the ratings of the power devices are compromised in the proposed system as compared to conventional system, as in both the cases the ratings are decided based on worst case scenario. Therefore, the system with proposed control approach yields more energy output with the same hardware resources.

2 SYSTEM CONFIGURATION

The system configuration for the proposed system is shown in Fig. 1. A two stage system is proposed for grid tied SPV system. The first stage is a DC-DC boost converter serving for MPPT and the second stage is a two-level three phase VSC. The PV array is connected at the input of the boost converter and its input voltage is controlled such that PV array delivers the maximum power at its output terminals. The output of boost converter is connected to DC link of VSC. The DC link voltage of VSC is dynamically adjusted by grid tied VSC on the basis of CPI voltage. The three phase VSC consists of three IGBT legs. The output terminals of VSC are connected to interfacing inductors and the other end of interfacing inductors are connected to CPI. A ripple filter is also connected at CPI to absorb high frequency switching ripples generated by the VSC. The values of various components and parameters used in simulation and experimentation.

3 CONTROL APPROACH

The basic control approach for the SPV system is shown in Fig. 2. The control of the system can be divided into two main parts, which are control of the boost converter and control of a grid tied VSC. The input voltage of a boost converter is adjusted according to MPPT algorithm and the output voltage of boost converter, which is also the DC link voltage of VSC is also kept adaptive according

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

to CPI voltage condition. In overall, the proposed system is operated such that both the input and output voltages of boost converter are adjusted according to

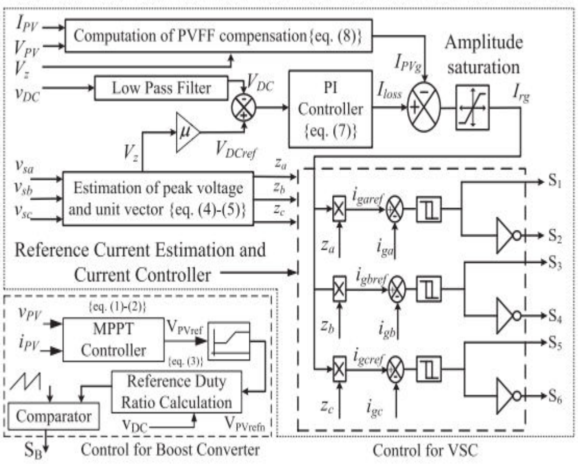

Fig. 2. Block diagram for control approach.

sensed variables of the circuit. The boost converter feeds the power to the DC link of VSC, which then feeds that power into the three-phase grid at unity power factor with respect to CPI. A composite InC based MPPT technique is used to estimate the reference PV array voltage and a PLL-less control is proposed for the control of the VSC. The amplitude of the refrence grid currents is estimated using a PV feedforward (PVFF) term and a PI controller DC link voltage error. A set of unit vectors is estimated from grid voltages to synchronize output currents of VSC. The estimated reference grid currents are compared with sensed grid currents and a hysteresis current controller is used to generate switching logic for VSC. The detailed formulation for control algorithm is presented in the later half of this section.

3.1 Maximum Power Point Tracking

A composite InC based MPPT algorithm is used. A range of voltage for peak power is known with the knowledge from fractional Voc MPPT, which is 0.7Vocmax to 0.9Vocmax, where Voc is open circuit voltage and Vocmax is maximum open circuit voltage. The voltage for peak power is always searched in this range for fast search of Vmpp. The InC algorithm works in order to minimize the difference between the incremental conductance and the conductance offered by the PV array. At first, the reference PV array voltage is estimated based on the InC principle then that reference voltage is used to estimate the duty ratio of the boost converter. For calculation of an incremental conductance ΔIP V and ΔVP V are estimated as,

$$\Delta I_{PV} = I_{PV}(k) - I_{PV}(k-1)$$
$$\Delta V_{PV} = V_{PV}(k) - V_{PV}(k-1)$$

(1)

where IPV(k) and VPV(k) are the instantaneous sampled current and voltage of the solar array. The governing equations for InC based MPPT algorithm is as,

$$\frac{\Delta I_{PV}}{\Delta V_{PV}} = \frac{-I_{PV}}{V_{PV}}, at\ MPP$$
$$\frac{\Delta I_{PV}}{\Delta V_{PV}} > \frac{-I_{PV}}{V_{PV}}, \text{Left of MPP on} P_{PV} \text{ v/s } V_{PV} \text{ curve}$$

r (2)

$$\frac{\Delta I_{PV}}{\Delta V_{PV}} < \frac{-I_{PV}}{V_{PV}}, \text{Right of MPP on } P_{PV} \text{ v/s} V_{PV} \text{ curve (2c)}$$

(3)

The reference PV array voltage (VP V ref) is estimated using (1) and (2). In order to keep the search in a limited region, the

VP V ref is bounded by corresponding upper and lower saturation values (0.7Vocmaxto 0.9Vocmax). The output of that saturation block is designated as new PV array voltage (VP V refn),

which is then used for estimation of reference duty ration. The reference PV voltage (VP V refn) and sensed DC link voltage (VDC) are then used to estimate the duty ratio for the boost converter. The governing equation for estimating duty ratio is as,

$$D_{ref}(k) = 1 - \frac{V_{PVrefn}(k)}{V_{DC}(k)} \tag{4}$$

This reference duty ratio is compared with saw-tooth waveform to generate switching logic for the boost converter.

3.2 Control Algorithm for VSC

The control approach for VSC is demonstrated in Fig. 2. The main objective of the control algorithm for VSC is to regulate the DC link voltage to the set reference value and to inject the extracted power from PV array into the grid at unity power factor with respect to CPI. In order to control the output currents of VSC (or grid currents), the appropriate reference grid currents are estimated. At first the amplitude of grid currents is estimated and the estimated amplitude is then multiplied with in-phase unit vectors (synchronization signals) to keep the grid currents balanced and sinusoidal.

For control purpose, the CPI line voltages (vsab and vsbc), DC link voltage (vDC) and grid currents (iga and igb) are sensed. The phase voltages are estimated from the line voltages. The in-phase unit vectors are estimated from the estimated phase voltages. For estimation of unit vectors (za, zb, zc), the phase voltages are divided by amplitude of three phase voltages (Vz).

The amplitude of CPI voltage is estimated as,

$$V_z = \sqrt{\frac{2(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)}{3}} \tag{5}$$

The unit vectors for all three phases are estimated as,

$$z_a = \frac{v_{sa}}{V_z}, z_b = \frac{v_{sb}}{V_z}, z_c = \frac{v_{sc}}{V_z} \tag{6}$$

For proper control of VSC output current, the DC link voltage of VSC should be greater than amplitude of line voltage. Moreover, in order to adaptively adjust the DC link voltage with respect to CPI voltage variation, the reference DC link voltage is adaptively adjusted with amplitude of CPI voltage. The reference DC link voltage is estimated as,

$$V_{DCref} = \mu\sqrt{3}V_Z, \text{ where } \mu > 1 \tag{7}$$

For proper current control the DC link voltage must be higher than the amplitude of CPI line voltage. Therefore, reference DC link voltage is kept around 10% higher than the peak of CPI line voltage, considering the drop across switches, interfacing For proper current control the DC link voltage must be higher than the amplitude of CPI line voltage. Therefore, reference DC link voltage is kept around 10% higher than the peak of CPI line voltage, considering the drop across switches, interfacing

$$I_{loss}(k) = I_{loss}(k-1) + K_p\{v_e(k) - v_e(k-1)\} + K_i v_e(k) \tag{8}$$

A PV feed forward (PVFF) term for PV array contribution to grid current is also estimated to provide fast dynamic response for changes in solar insolation and grid voltages. The PV feedforward term is estimated as,

$$I_{PV_g} = (2P_{PV})/\ (3V_Z) \tag{9}$$

It can be observed from the above equation that in case of insolation variation, the PV power (PPV = VPV ∗ IPV) changes and the instantaneous effect can be observed on PV contribution term. Moreover, the in case of voltage variation at CPI, the grid currents need to be adjusted to feed same solar power, which eventually is adjusted due to term Vz in the PV contribution term.

The grid currents are assumed coming out of CPI terminals and considering the direction of grid currents, the losses are drawn from the grid whereas the PVFF is fed into the grid.

Therefore, net amplitude of grid current is estimated as,

$$I_{rg} = I_{loss} - I_{PV_g} \tag{10}$$

The estimated amplitude of grid current Irg is then multiplied with unit vectors of corresponding phases to estimate reference grid currents. The reference and sensed grid currents are then given to current controller. The output of current controller is the switching pulses to the VSC.

4. MATLAB AND SIMULATION RESULTS:

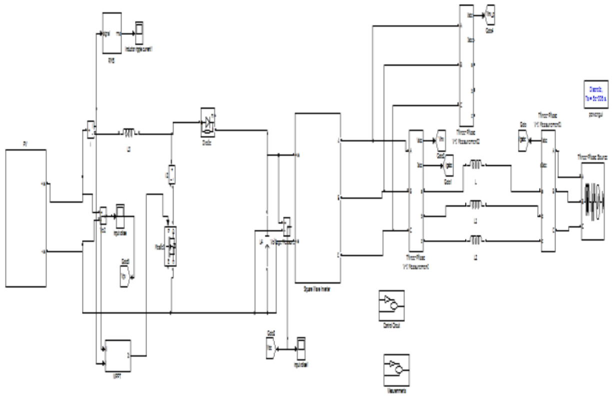

figure 3 simulink diagram of change in solar insolation without feedforward for PV contribution

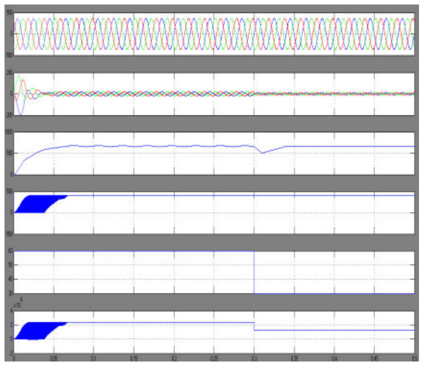

figure 4 Simulated performance for change in solar insolation without feedforward for PV contribution

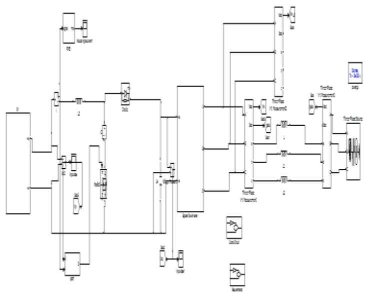

figure 5 simulink diagram of change in solar insolation with feedforward for PV contribution

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

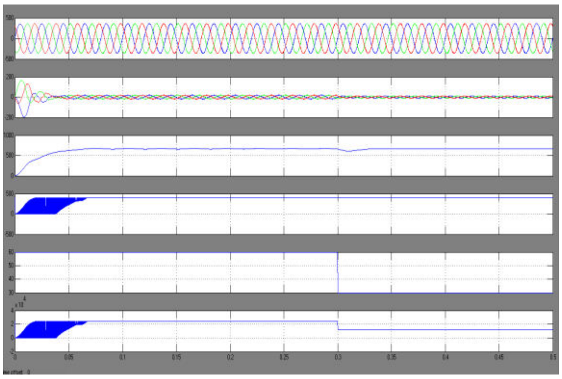

figure 6 Simulated performance for change in solar insolation with feedforward for PV contribution

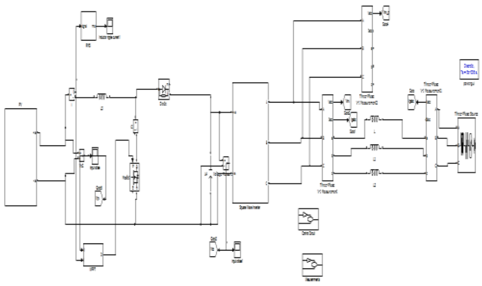

figure 7 simulink diagram of normal to under voltage (415 V to 350 V)

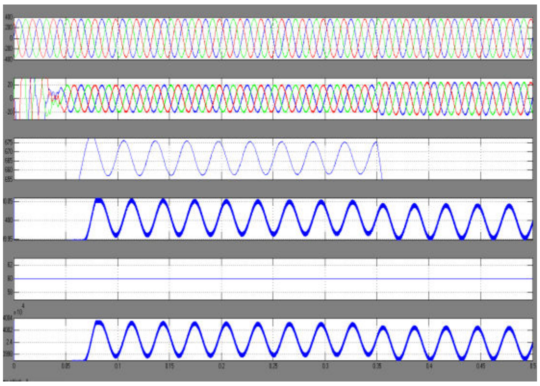

figure 8 Simulated performance for normal to under voltage (415 V to 350 V)

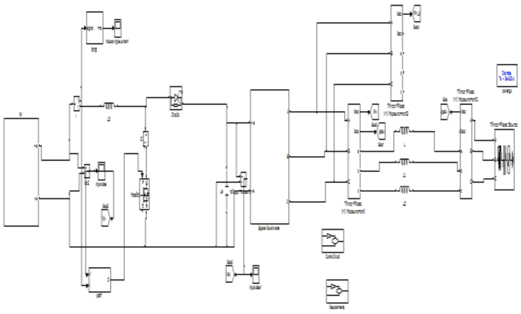

figure 9 simulink diagram of CPI voltage variation from normal to over voltage (415 V to 480 V).

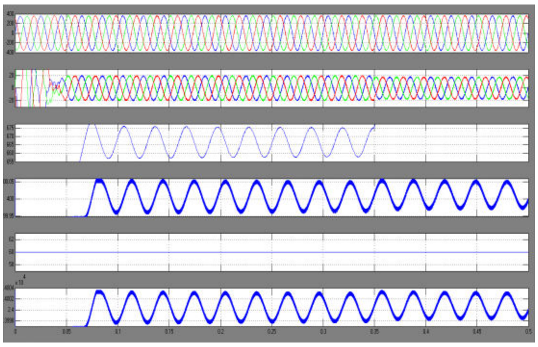

figure 10 Simulated performance for CPI voltage variation from normal to over voltage (415 V to 480 V).

5. CONCLUSION

A two-stage system has been proposed for three-phase grid connected solar PV generation. A composite In C based MPPT algorithm is used for control of the boost converter. The performance of proposed system has been demonstrated for wide range of CPI voltage variation. A simple and novel adaptive DC link voltage control approach has been proposed for control of grid tied VSC. The DC link voltage is made adaptive with respect to CPI voltage which helps in reduction of losses in the system. Moreover, a PV array feed forward term is used which helps in fast dynamic response. An approximate linear model of DC link voltage control loop has been developed and analyzed considering feed forward compensation. The PV array feed forward term is so selected that it is to accommodate for change in PV power as well as for CPI voltage variation. A full voltage and considerable power level prototype has verified the proposed concept. The concept of adaptive DC link voltage has been proposed for grid tied VSC for PV application however, the same concept can be extended for all shunt connected grid interfaced devices such as, STATCOM, D-STATCOM etc.

The proposed system yields increased energy output in DC link voltage control structure. The THDs of the grid currents and voltages are found less than 5% (within IEEE-519 standard). The simulation results have confirmed the feasibility of proposed control algorithm.

REFERENCES

[1] M. Pavan and V. Lughi, "Grid parity in the Italian commercial and industrial electricity market," in Proc. Int. Conf. Clean Elect. Power (ICCEP'13), 2013, pp. 332–335.

[2] M. Delfanti, V. Olivieri, B. Erkut, and G. A. Turturro, "Reaching PV grid parity: LCOE analysis for the Italian framework," in Proc. 22nd Int. Conf. Exhib. Elect. Distrib. (CIRED'13), 2013, pp. 1–4.

[3] H. Wang and D. Zhang, "The stand-alone PV generation system with parallel battery charger," in Proc. Int. Conf. Elect. Control Eng. (ICECE'10), 2010, pp. 4450–4453.

[4] M. Kolhe, "Techno-economic optimum sizing of a stand-alone solar photovoltaic system," IEEE Trans. Energy Convers., vol. 24, no. 2, pp. 511–519, Jun. 2009.

[5] D. Debnath and K. Chatterjee, "A two stage solar photovoltaic based stand alone scheme having battery as energy storage element for rural deployment," IEEE Trans. Ind. Electron., vol. 62, no. 7, pp. 4148–4157, Jul. 2015.

[6] S. Krithiga and N. G. Ammasai Gounden, "Power electronic configuration for the operation of PV system in combined grid-connected and stand-alone modes," IET Power Electron., vol. 7, no. 3, pp. 640–647, 2014.

[7] I. J. Balaguer-Álvarez and E. I. Ortiz-Rivera, "Survey of distributed generation islanding detection methods," IEEE Latin Amer. Trans., vol. 8, no. 5, pp. 565–570, Sep. 2010.

[8] 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.

[9] W. Xiao, F. F. Edwin, G. Spagnuolo, and J. Jatskevich, "Efficient approaches for modeling and simulating photovoltaic power systems," IEEE J. Photovoltaics, vol. 3, no. 1, pp. 500–508, Jan. 2013.

[10] P. Chiradeja, "Benefit of distributed generation: A line loss reduction analysis," in Proc. IEEE/PES Transmiss. Distrib. Conf. Exhib.: Asia Pac., 2005, pp. 1–5.

[11] A. Yadav and L. Srivastava, "Optimal placement of distributed generation: An overview and key issues," in Proc. Int. Conf. Power Signals Control Comput. (EPSCICON'14), 2014, pp. 1–6.

[12] K. A. Joshi and N. M. Pindoriya, "Impact investigation of rooftop Solar PV system: A case study in India," in Proc. 3rd IEEE PES Int. Conf. Exhib. Innovative Smart Grid Technol. (ISGT Europe), 2012, pp. 1–8.

[13] E. Drury, T. Jenkin, D. Jordan, and R. Margolis, "Photovoltaic investment risk and uncertainty for residential customers," IEEE J. Photovoltaics, vol. 4, no. 1, pp. 278–284, Jan. 2014.

[14] B. Subudhi and R. Pradhan, "A comparative study on maximum power point tracking techniques for photovoltaic power systems," IEEE Trans. Sustain. Energy, vol. 4, no. 1, pp. 89–98, Jan. 2013.

[15] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, "A variable step size INC MPPT method for PV systems," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2622–2628, Jul. 2008.

[16] M. Farhat, A. Flah, and L. Sbita, "Photovoltaic maximum power point tracking based on ANN control," Int. Rev. Model. Simul., vol. 7, no. 3, pp. 474–480, 2014.

[17] J. Ghazanfari and M. M. Farsangi, "Maximum power point tracking using sliding

mode control for photovoltaic array," Iran. J. Elect. Electron. Eng., vol. 9, no. 3, pp. 189–196, 2013.
[18] M. Adly, H. El-Sherif, and M. Ibrahim, "Maximum power point tracker for a PV cell using a fuzzy agent adapted by the fractional open circuit voltage technique," in Proc. IEEE Int. Conf. Fuzzy Syst. (FUZZ'11), 2011, pp. 1918–1922.
[19] M. E. Ropp, J. G. Cleary, and B. Enayati, "High penetration and antiislanding analysis of multi-single phase inverters in an apartment complex," in Proc. IEEE Conf. Innovative Technol. Efficient Reliab. Electr. Supply (CITRES'10), 2010, pp. 102–109.
[20] S. Deo, C. Jain, and B. Singh "A PLL-Less scheme for single-phase grid interfaced load compensating solar PV generation system," IEEE Trans. Ind. Informat., vol. 11, no. 3, pp. 692–699, Jun. 2015.
[21] B. Singh, D. T. Shahani, and A. K. Verma, "Neural network controlled grid interfaced solar photovoltaic power generation," IET Power Electron., vol. 7, no. 3, pp. 614–626, Jul. 2013.
[22] C. Jain and B. Singh "A frequency shifter based simple control for multifunctional solar PV grid interfaced system," in Proc. 37th Nat. Syst. Conf., 2013, pp. 363–374.
[23] C.-S. Lam, W.-H. Choi, M.-C. Wong, and Y.-D. Han, "Adaptive DC-Link voltage-controlled hybrid active power filters for reactive power compensation," IEEE Trans. Power Electron., vol. 27, no. 4, pp. 1758–1772, Apr. 2012.
[24] C.-S. Lam, M.-C. Wong, W.-H. Choi, X.-X. Cui, H.-M. Mei, and J.-Z. Liu, "Design and performance of an adaptive low-DC-voltagecontrolled LC-hybrid active power filter with a neutral inductor in threephase four-wire power systems," IEEE Trans. Ind. Electron., vol. 61, no. 6, pp. 2635–2647, Jun. 2014.
[25] Y.-M. Chen, H.-C. Wu, Y.-C. Chen, K.-Y. Lee, and S.-S. Shyu, "The AC line current regulation strategy for the grid-connected PV system," IEEE Trans. Power Electron., vol. 25, no. 1, pp. 209–218, Jan. 2010.
[26] IEEE Recommended Practices and Requirement for Harmonic Control on Electric Power System, IEEE Standard 519, 1992.