



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Special Issue 1, April 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

9940 572 462

6381 907 438

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Design and Performance Analysis of Highly Reliable Transformerless Three-Phase Solar Photovoltaic Inverters

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ABSTRACT: Increased energy demand, depletion of fossil fuels, and increased efforts to reduce CO₂ emissions are driving increased power generation from renewable energy sources. Today, solar power generation is on the rise due to the reliability and long-term availability of solar energy. A transformerless inverter topology that can simultaneously solve leakage current and pulsating power problems in grid-connected photovoltaic (PV) systems. Leakage currents caused by parasitic capacitance between PV and ground can be bypassed by introducing a common-mode (CM) conduction path in the inverter without adding any components to the system. The resulting ground leakage current is therefore well controlled and below regulatory limits. This analysis addresses the design and performance analysis of a reliable transformerless three-phase photovoltaic inverter. An improved synchronous reference frame control based on a moving average filter is used to extract the active load current component and improve PV performance. The proposed system combines the benefits of clean power generation with improved power quality. Steady-state and dynamic performance of the system are evaluated by his Matlab-Simulink simulations under nonlinear loads.

KEYWORDS: Power Quality, shunt compensator, series compensator, Solar PV

I. INTRODUCTION

Many concerns have arisen as a result of the use of fossil fuels as a primary source of power production. In terms of power generation, India ranks sixth. Thermal power plants produce approximately 65 percent of India's energy, while hydroelectric power plants generate 22 percent, nuclear power plants generate 3%, and other alternative sources such as solar, wind, and biomass generate the remaining 10%. India's large coal reserves have 53.7 percent of the country's commercial electricity demand. The use of green technology, such as a solar energy system, is often used to remove or mitigate such problems. The most serious problem associated with the use of fossil energy is global warming; where the rise in fossil fuels such as oil and natural gas are used to generate electricity through several decades result a number of environmental as well as health issue.

Solar cell-based photovoltaic power generation that is ready to direct conversion of solar energy to DC Electricity has the potential to be a clean energy source and it can be broadly pertinent renewable energy source accessible for forthcoming energy production. As a result of photovoltaic processing developments over the last few decades, the participation and role of electric utilities in PV has increased significantly. Observations on the inverter's DC side are needed thus to measure and sustain tracking, MPPT algorithms are used for the highest operating point at every instant. Numerous approaches have been found and discussed in this decade in order to reduce or to get rid of these measurements, the system's complexity is minimized, and it is more cost-effective.

Transformerless grid-connected photovoltaic (PV) inverters are widely accepted in the PV market mainly because of their high efficiency, low cost, small volume, and light weight. These features may not be possessed by their transformer galvanically isolated counterparts [16]. However, since the PV panels in such systems have direct electrical

connection with the power grid, the PV-to-ground parasitic capacitance, the PV inverter, and the utility grid may then form a conduction loop. High frequency common mode (CM) voltage-induced leakage current can flow through this loop if the unipolar modulation strategy is adopted for full-bridge inverters [12]. The leakage current is definitely adverse to the system performance, and it may potentially lead to a series of problems, e.g. harmonic current, increased power losses, safety issues, and electromagnetic interference (EMI) issues. Therefore, the leakage current must be suppressed into a certain level in order to comply with the standard and improve the reliability of PV systems [15].

Various inverter topologies have recently been proposed to address the leakage current issue in transformerless PV systems, and the basic idea is to introduce new freewheeling paths into the inverter so that the PV panel can be isolated from the ac grid during freewheeling modes. This can be achieved by cutting off the common mode (CM) current conducting path when zero voltage vectors are applied to the full-bridge inverter, and it can be implemented either on the dc side or ac side. Example topologies include the H5 inverter from SMA the HERIC inverter from Sunways and many of their derivatives recently reported [8]. Another possible solution is to directly clamp the potential of PV terminals with respect to the ground of the ac grid.

The performance and efficiency of Solar PV Plant is depending on the power conversion stages through power electronics converter interfaced between PV plant and Grid. Although Solar PV system is reliable, the efficiency of Solar PV array is around 15-20%. Therefore, Solar panel should be operated in maximum power generating position every instant. MPPT Algorithms are widely used to extract maximum power from solar PV plant by electrically tracking PV in maximum power generating position [1]. In transformerless PV plant, there is no galvanic isolation between inverter and utility grid. In transformer connected PV system, Low frequency transformer (acts as galvanic isolation) is connected in between PV inverter and Utility Grid which has less efficiency compared to transformer-less grid tied solar plant. Voltage source Inverter becomes most familiar for conversion of DC to AC Conversion process. The output of Inverter is modulated Sinusoidal wave which produces distorted currents with THD of 31% . To filter out distortion, LCL filter is used due to small size and high efficiency of active power transfer but LCL makes system unstable because of generation of resonance peaks. Passive damping technique is preferred to eliminate resonance peaks.

Normally, grid-connected PV systems can be deployed by means of single-stage (S-S) or double-stage (D-S) power conversion. S-S PV systems are usually composed of only a grid-tied inverter (dc/ac converter). In this case, the PV array is directly connected to the dc-bus of the grid-tied inverter. On the other hand, in D-S PV systems, an additional dc/dc converter is placed between the PV array and the inverter. In this configuration, the Maximum Power Point Tracking (MPPT) is performed by the dc/dc converter. Considering SS-PV systems, the task to perform the MPPT is assumed by the grid-tied inverter, combined with the advantage of achieving more efficiency when compared to DS-PV systems. In both the mentioned PV system topologies, the dc/ac converter controls the amplitude of the currents injected into the grid, in order to guarantee the balance between the power produced to the PV array and that absorbed by the grid.

In most applications, PV systems are connected to the electrical distribution system, as well as microgrids where local generation is carried out. Besides energy production, and according to a suitably adopted control strategy, PV systems can also carry out other roles in a microgrid, such as active filtering and/or reactive power compensation. In other words, PV systems can perform tasks similar to those performed by conventional Parallel Active Power Filters (P-APF).

II. LITERATURE SURVEY

Villalva, Marcelo Gradella, and Jonas Rafael Gazoli et. al., [2] explained the current ecological and climate conditions, particularly sun-oriented irradiance, temperature, and wind speed, are reported and analyzed. At around the same time, the prompt information from the plant including PV module temperature, electricity, current, and voltage are provided timely. The power reduces as the surrounding temperature rises. Another Fuzzy Logic-based approximation is proposed to greatly reduce the power decline under halfway concealing conditions.

Sridhar, R., et al., [3] proposed the display and reconstruction of a photovoltaic model. The PV exhibit is displayed, and its voltage current characteristics, as well as the strength and voltage values, are recreated, taking into account the temperature and sun's irradiance. This allows the PV framework's components to be successfully recreated and advanced. The natural components have an effect on the yield qualities of a PV exhibit, and the transformation productivity is poor. As a result, a maximum power point monitoring (MPPT) protocol is required to monitor the maximum potential in order to increase the generated vitality.

E. Vartiainen et. al., [13] explained the radiant irradiance on a sloping or leaning in a particular direction surface is usually estimated from hourly flat irradiance estimations using a slant irradiance model. It is also possible to calculate the slant irradiance by using a sky brilliance model to include the sky brilliance conveyance. Five slant irradiance models and six sky dissemination models are compared in this article, as well as hourly irradiance estimations on 24 slanted surfaces.

R. K. Agarwal, I. Hussain, and B. Singh, et.al [4] described the demand for clean energy as well as stringent power quality requirement of sophisticated electronic loads, there is need for multifunctional systems which can integrate clean energy generation along with power quality improvement. A three phase multi-functional solar energy conversion system, which compensates for load side power quality issues.

Y. Singh, I. Hussain, B. Singh, and S. Mishra, et.al [5] described A single phase solar pv inverter along with active power filtering capability. Major research work has been done in integrating clean energy generation along with shunt active filtering. Though shunt active filtering has capability for both load voltage regulation, it comes at the cause of injecting reactive power. Thus shunt active filtering cannot regulate PCC voltage as well as maintain grid current unity power factor at same time.

M. Rauf and V. Khadkikar, et.al [9] explained a solar photovoltaic system integrated along with dynamic voltage restored. Compared to shunt and series active power filters, a unified power quality conditioner (UPQC), which has both series and shunt compensators can perform both load voltage regulation and maintain grid current sinusoidal at unity power factor at same time. Integrating PV array along with UPQC, gives the dual benefits of clean energy generation along with universal active.

S. Devassy and B. Singh, et.al [6] described the integration of PV array with UPQC. Compared to conventional grid connected inverters, the solar PV integrated UPQC has numerous benefits such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. With the increased emphasis on distributed generation and microgrids, there is a renewed interest in UPQC systems.

B. Singh and J. Solanki, et.al [17] introduced the Time domain techniques are commonly used because of lower computational requirements in real-time implementation. The commonly used techniques include instantaneous reactive power theory (p-q theory), synchronous reference frame theory (d-q theory) and instantaneous symmetrical component theory.

B. Singh, C. Jain, S. Goel, A. Chandra, and K. Al-Haddad, et.al [7] described the main issue in use of synchronous reference frame theory based method is that during load unbalanced condition, double harmonic component is present in the d-axis current. Due to this, low pass filters with very low cut off frequency is used to filter out double harmonic component. This results in poor dynamic performance.

I. Serban , et.al [10] presents a differential buck converter which does not require additional switches for power decoupling. However, only the autonomous mode is studied and its grid-connected mode, especially the leakage current issue under transformerless operation remains unexplored. Simultaneous solving leakage current and pulsating power issues may impose a design challenge to the PV system.

Y. Tang, F. Blaabjerg, P. C. Loh, C. Jin, and P. Wang, et.al [11] auxiliary circuits to absorb the pulsating power, which can be stored either by inductors or film capacitors. Inductors are reliable, but when used for energy storage purpose, they will be very bulky and may induce high power losses due to their high equivalent series resistance (ESR). Therefore, more research attentions have been put on film capacitor-based power decoupling circuits.

M. Amirabadi, A. balakrishman, H. A. Toliyat, and W. C. Alexander, et.al [14] dc-link capacitors have to be employed to keep relatively constant PV voltage so that the maximum power point tracking (MPPT) efficiency will not be compromised. Unfortunately, because of the large capacitance requirement, these dc-link capacitors are usually of electrolytic type, whose operation lifetime is quite limited and may be contradictive to the high reliability requirement of PV systems. Therefore, the dc-link capacitors have to be over designed in order to gain longer operation lifetime. The same issue may also exist in unbalanced three-phase systems.

III. DESIGN OF THE THREE-PHASE SOLAR PHOTOVOLTAIC INVERTERS

A transformerless inverter topology that can simultaneously eliminate the leakage current and pulsating power in grid-connected PV systems. Its attractiveness is that it does not require any additional current switches to resolve these two difficulties, and the circuit configuration is very simple with only one additional current sensor introduced for current control. The leakage current can be controlled by introducing a CM conducting path inside of the PV inverter, so that it will not flow through the ground.

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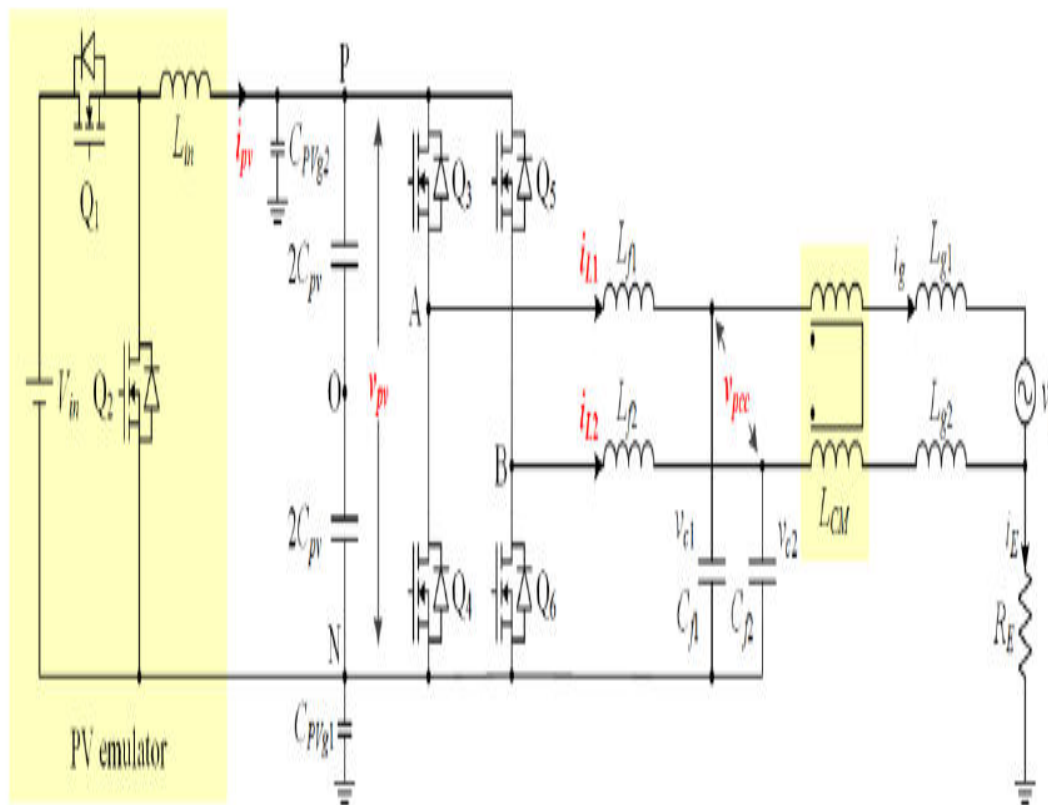


Fig.1: Circuit Diagram Of The Proposed Transformerless Inverter For Grid-Connected PV Systems

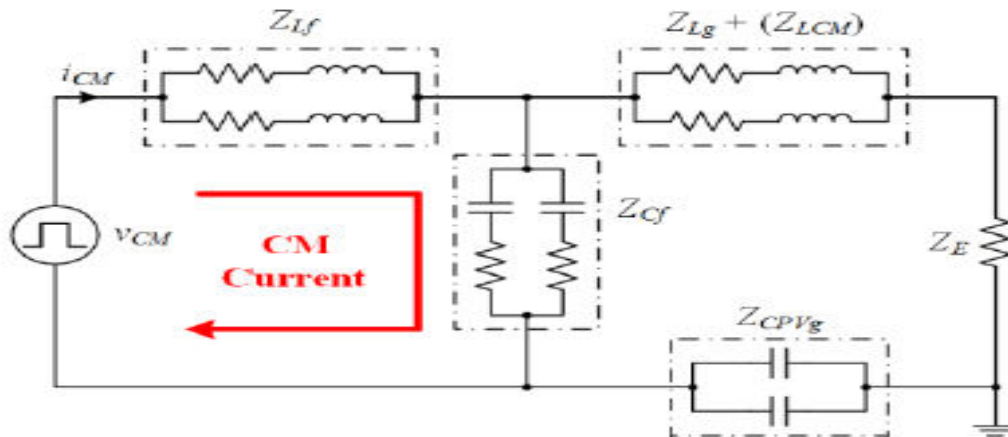


Fig. 2. CM Equivalent Circuit Of The Proposed PV Inverter.

By further injecting CM voltages to the output capacitors, the second order pulsating power originated from the ac side can be decoupled, and will not be seen by the dc-link as well as the PV input. In this case, the dc capacitance requirement can be substantially reduced, and it is feasible to design an all-film-capacitor supported PV inverter with high efficiency and high reliability. The mechanism of leakage current suppression and the closed-loop control of pulsating power decoupling are discussed in the paper in details. A 500 W prototype was also built and tested in the laboratory, and both simulation and experimental results are finally presented to show the excellent performance of the proposed PV inverter.

The proposed transformerless PV inverter is essentially derived from a conventional full-bridge inverter with an output LC filter. The LC filter is split into two identical parts, having $L_{f1} = L_{f2} = L_f$ and $C_{f1} = C_{f2} = C_f$. They are distributed into the two switching legs as shown in Fig. 1. More advanced LCL or LLCL filters can also be adopted, but they may increase the complexity of the system. The midpoint of the two capacitors is then connected to the negative dc bus in order to provide a conducting path for the CM current. Because of the symmetrical circuit configuration, its differential mode (DM) operation, i.e. active power injection and reactive power support will not be affected. In order to investigate the ground leakage current, the equivalent CM circuit is presented in Fig. 2, where the grid voltage is neglected because it is of fundamental frequency only. The CM voltage v_{CM} and its induced CM current i_{CM} can then be respectively written as, $V_{CM} + Z_{CPVG}$

$$V_{CM} = \frac{V_{AN} + V_{BN}}{2} \text{ ----- (1)}$$

where V_{AN} and V_{BN} are the two converter pole voltages measured with respect to the negative dc bus. Z_{CM} is the equivalent CM loop impedance, consisting of the impedance of the output filter inductors Z_{Lf} , the impedance of the output filter capacitors Z_{Cf} , the impedance of the parasitic capacitors Z_{CPVG} , the grid impedance Z_{Lg} , and the grounding impedance Z_E . As discussed above, the leakage current is induced by the CM voltages at switching frequencies (usually in the kHz range), where the impedance of capacitors is very small. By considering the worst case situation and neglecting the grid impedance.

For a stiff ac power grid where the grid impedance is negligible, the ground leakage current in such systems will be very small, because the value of the filter capacitors is usually in the μF range, while for the parasitic capacitors, it is normally around 100 nF for a 1 kW PV system. Moreover, the grounding resistance is usually not zero, and 10 Ω and 15 Ω are considered. Therefore, the impedance of C_{f1} and C_{f2} will be much lower than that of the grounding loop in

the switching frequency range. In this case, most of the CM currents will be bypassed by the two filter capacitors, and it is possible to limit the ground leakage current to comply with the standard.

Another uncertainty of the grounding loop comes from the parasitic capacitance, which can reach μF level if rainy weathers and film type PV modules are considered. In this case, the resonance frequency of $CPVg$ and Lg may also vary and probably overlap with the switching frequency. Similarly, a CM choke can be inserted to avoid this, and its value shall be determined by the minimum value of $CPVg$. Alternatively, the metal frames of PV modules can be grounded through a small resistance, e.g. 5Ω in order to block the CM current. In practice, the grounding resistance may always exist in the system, and the leakage current will be insignificant.

In addition to the leakage current issue, transformerless PV inverters should also solve dc current injection and safety issues. The dc current injection is mainly caused by the measurement errors from current sensors, and it may affect the normal operation of distribution transformers. To cope with this issue, an additional dc suppression loop can be introduced to control the dc current injection as discussed. Regarding the safety issue, the PV module frames should be grounded in transformerless PV systems in order prevent electric shocks and fire hazards. Moreover, a residual current device (RCD) should also be installed to monitor the leakage current. The RCD will disconnect the inverter if a 30 mA jump in the leakage current is detected, or the leakage current exceeds 300 mA.

IV. RESULT ANALYSIS

The steady state and dynamic performances of three phase solar PV inveters are analyzed by simulating the system in Matlab-Simulink software.

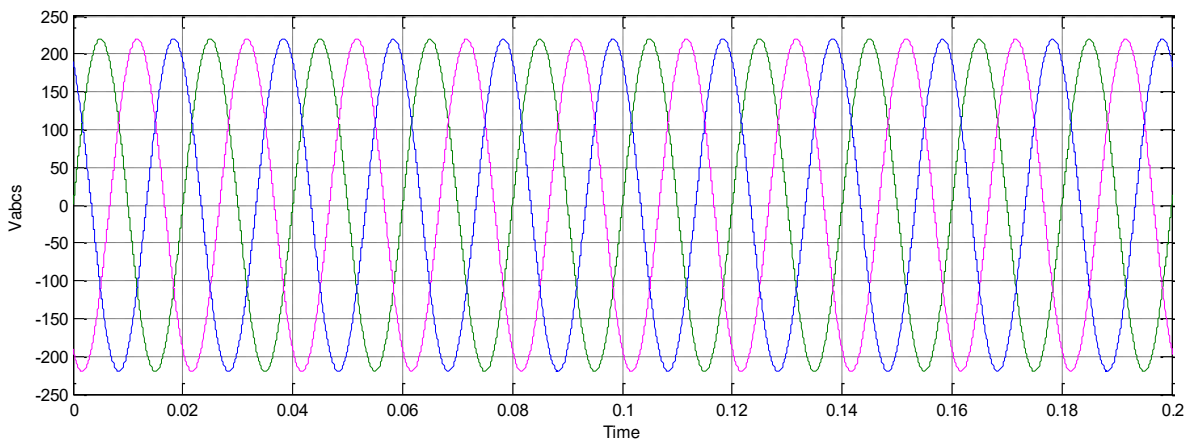


Fig. 3 Output Waveform Of Source Voltage

Fig. 3 represents the source voltage wave form, it has 230V magnitude and three phase are maintain 120 degree phase shift with each other. It indicates the input voltage is given to the system.

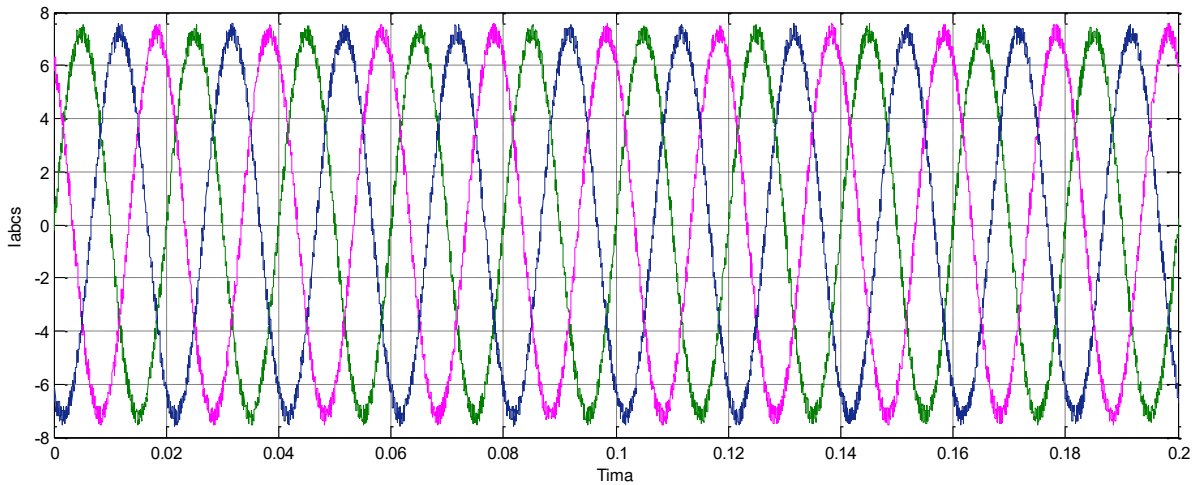


Fig. 4 Output Waveform Of Source Current

Fig. 4 represents the source current wave form, it has 7.5A magnitude and three phase are maintain 120 degree phase shift with each other.

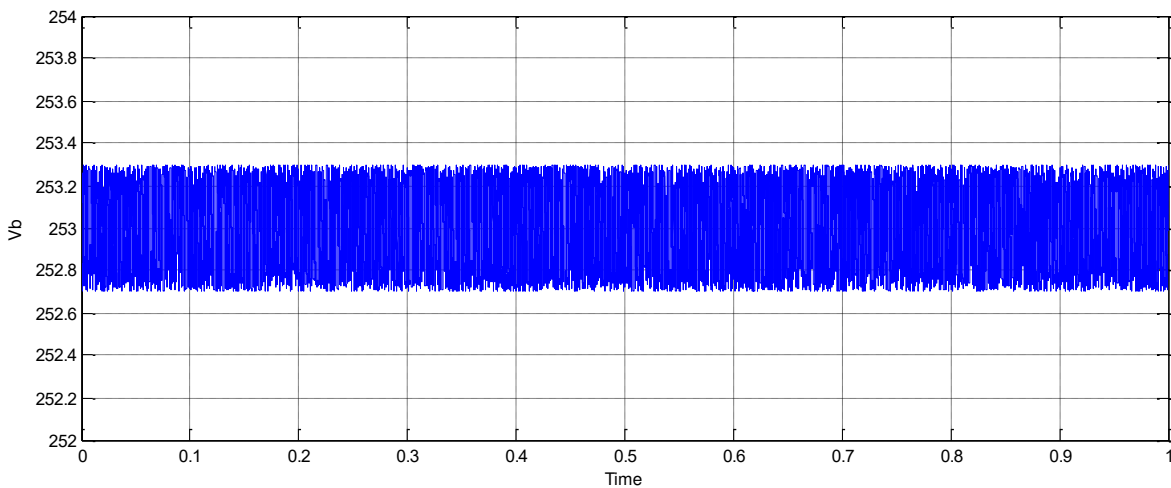


Fig. 5 Output Waveform Of Battery Voltage

Fig. 5 represents the battery output voltage wave form, it has 253V magnitude.

Fig. 6 represents the PV output voltage wave form, it has 306V magnitude.

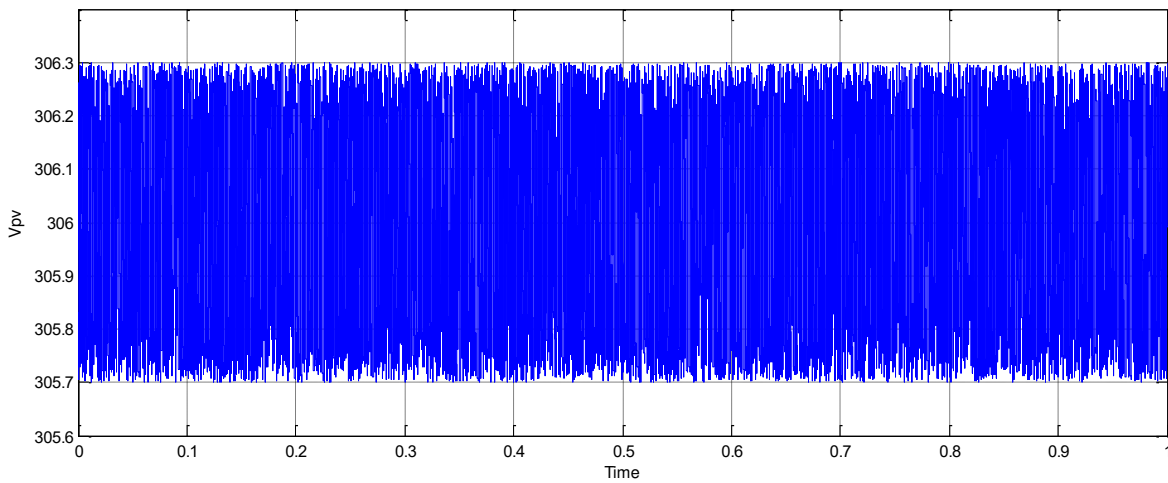


Fig. 6 Output Waveform Of PV Voltage

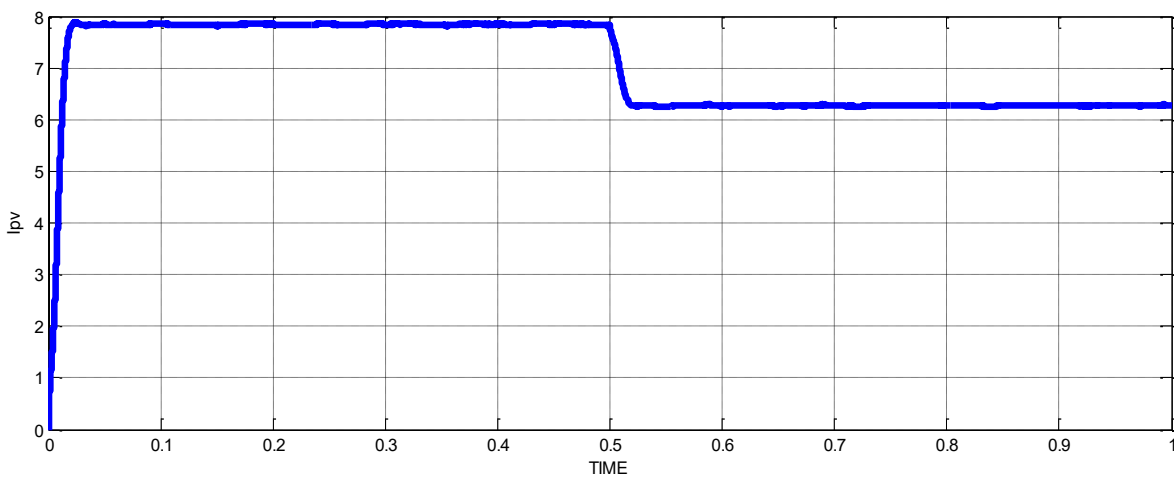


Fig. 7 Output Waveform Of PV Current

Fig. 7 represents the PV output current wave form, it has magnitude is varying from 8A to 6A. From initial value zero to 0.5sec it has 8A magnitude after 0.5sec the PV current magnitude is decrease to 6A due to change in irradiance of PV.

Fig. 8 represents the load current initially the load current has 4A from 0 to 0.5sec, after 0.5sec the load is varying die to change in load condition the load current also change. From the fig. 6 we can understand after 0.5sec the load is decreased so similarly the load current also decreased.

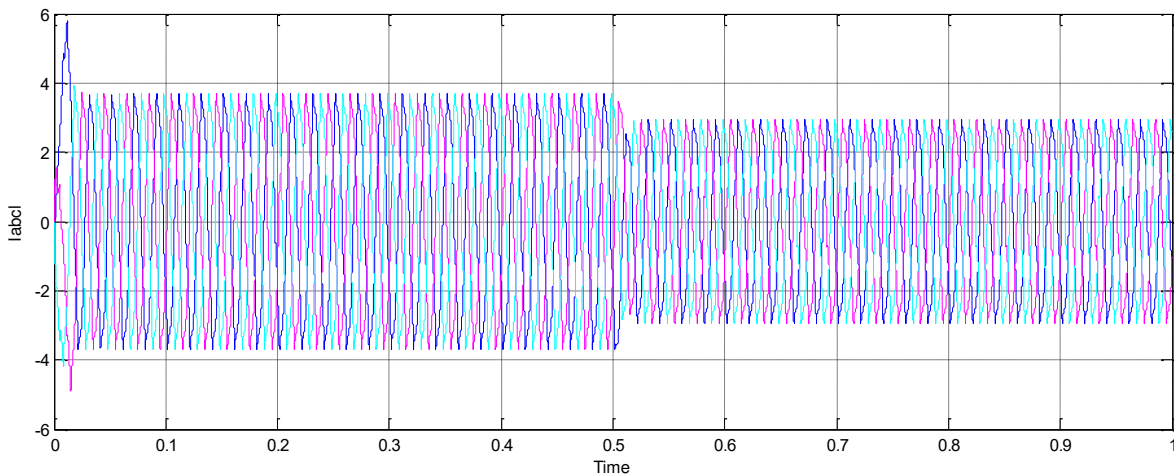


Fig. 8 Output Waveform Of Load Current

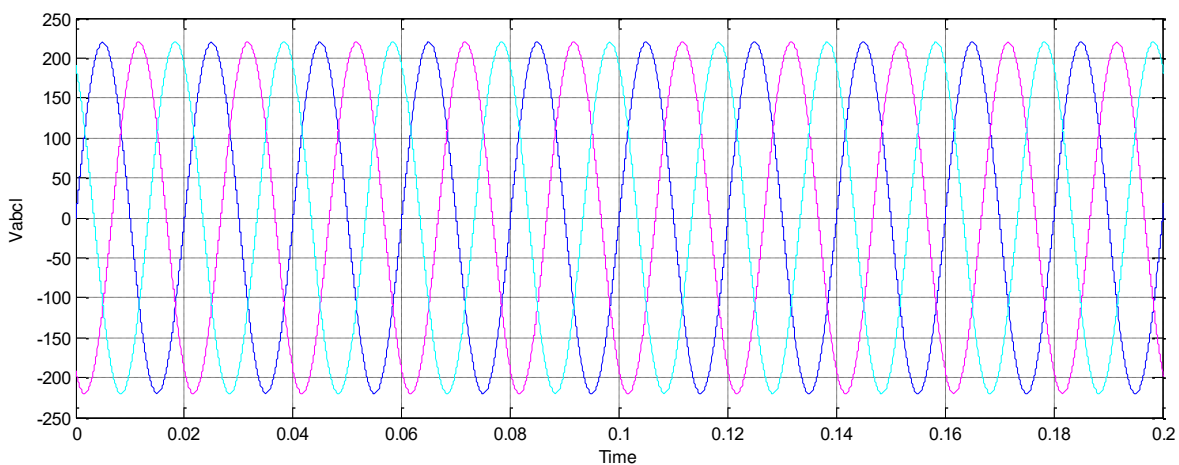


Fig. 9 Output Waveform Of Load Voltage

Fig. 9 represents the load voltage wave form it has 230V magnitude and three phase are maintain 120 degree phase shift with each other. The load voltage maintain equal magnitude in various load conditions also.

Fig. 10 represents the PCC (point of common coupling) voltage wave form, it has 230V magnitude and three phase are maintain 120 degree phase shift with each other. The Fig. 10 voltage taken from the hydro voltage and PV voltage coupling point.

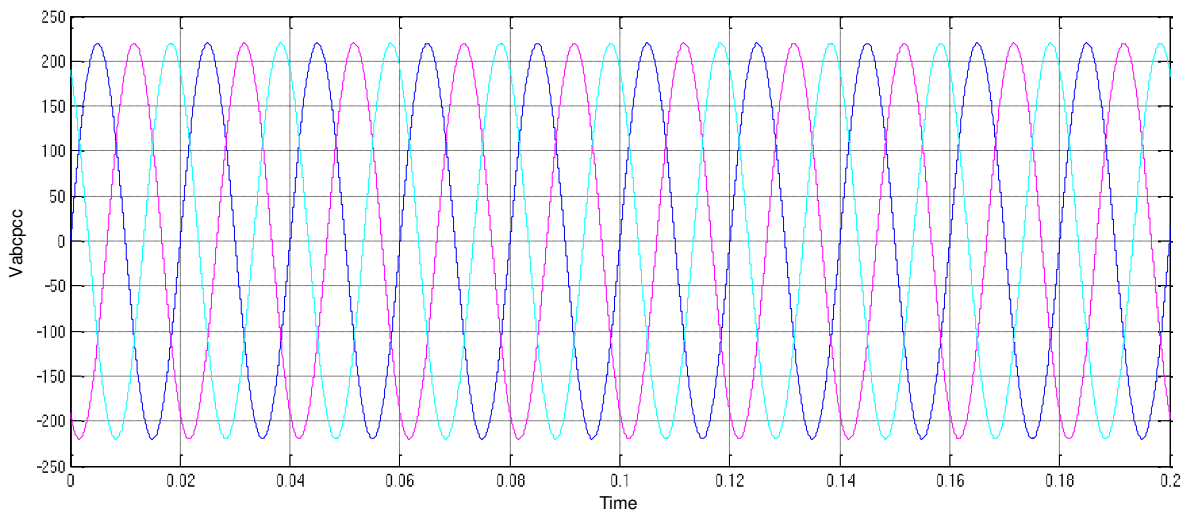


Fig. 10 Output Waveform Of PCC Voltage

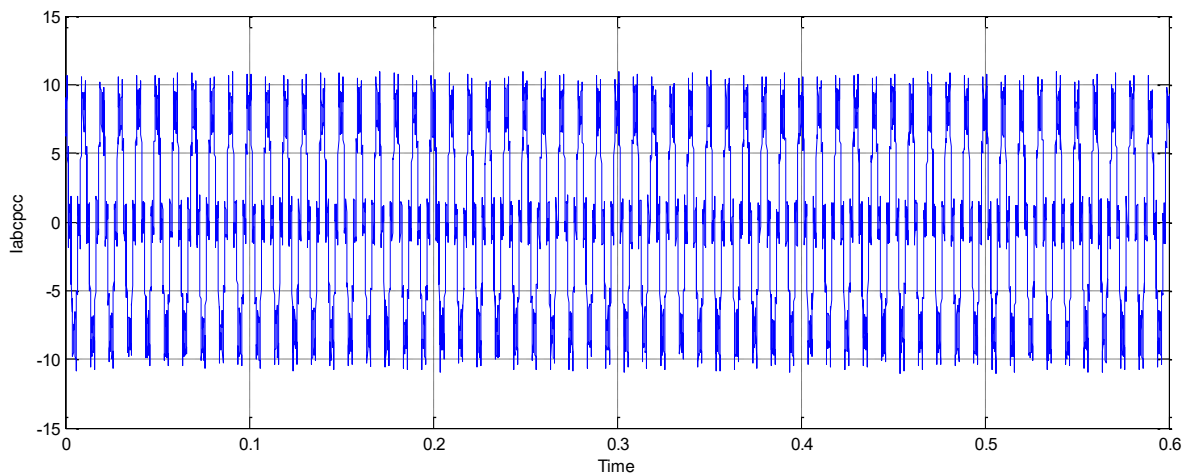


Fig. 11 Output Waveform Of PCC Current

Fig. 11 represents the PCC (point of common coupling) current wave form, the current is taken from the hydro voltage and PV voltage coupling point.

Fig. 12 represents the battery output current, it has magnitude is varying from 0.3A to 0.25A. From initial value zero to 0.5sec it has 0.3A magnitude after 0.5sec the PV current magnitude is decrease to 0.25A due to change in load.

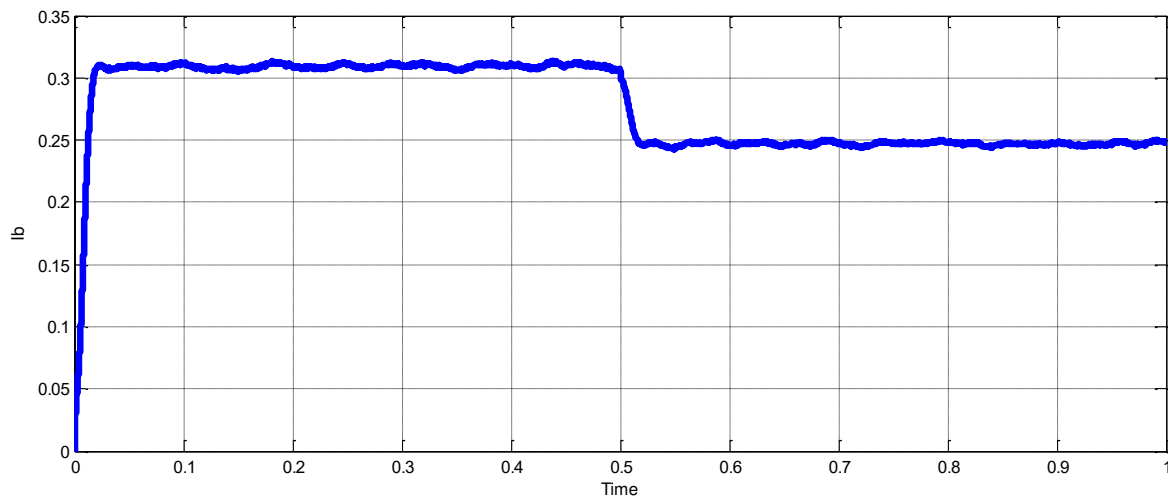


Fig. 12 Output Waveform Of Battery Current

V. CONCLUSION

The design and dynamic performance of three-phase PV have been analyzed under conditions of variable irradiation and grid voltage sags/swells. The performance of the system has been validated through experimentation on scaled down laboratory prototype standard. The system is found to be stable under variation of irradiation, voltage sags/swell and load unbalance. The performance of d-q control particularly in load unbalanced condition has been improved through the use of moving average filter. It can be seen that PV is a good solution for modern distribution system by integrating distributed generation with power quality improvement. In this three-phase transformerless inverter topology has been presented for grid-connected PV applications. By introducing a CM conducting loop into the inverter system, the ground leakage current issue can be solved without adding additional active components to the circuit, and the system cost and complexity can be reduced. Therefore, long lifetime film capacitors can be used in the dc-link to replace those less reliable electrolytic capacitors. A dual mode closed-loop controller is also proposed to completely decouple the pulsating power even in the presence of system uncertainties and disturbances. Comprehensive experimental results have been presented to show the excellent performance of the proposed inverter.

REFERENCES

- [1] Preethi G, Lavanya D, Sreesureya V, Boopathimanikandan S, —Real Time Monitoring and Controlling of Solar Panel Using LabVIEWWl, International Journal of Scientific & Technology Research Volume 8, Issue 08 2019.
- [2] Villalva, Marcelo Gradella, and Jonas Rafael Gazoli. "Comprehensive approach to modeling and simulation of photovoltaic arrays." Power Electronics, IEEE Transactions on 24.5, 2019 pp. 1198-1208.
- [3] Sridhar, R., "Modeling of PV array and performance enhancement by MPPT algorithm." Int J Comput Appl 7.5: 2018, pp. 35-39.
- [4] R. K. Agarwal, I. Hussain, and B. Singh, "Three-phase single-stage grid tied solar pv ecs using PLL-less fast CTF control technique," *IET Power Electronics*, vol. 10, no. 2, pp. 178–188, 2017.

- [5] Y. Singh, I. Hussain, B. Singh, and S. Mishra, "Single-phase solar gridinterfaced system with active filtering using adaptive linear combiner filter-based control scheme," *IET Generation, Transmission Distribution*, vol. 11, no. 8, pp. 1976–1984, 2017.
- [6] S. Devassy and B. Singh, "Design and performance analysis of threephase solar pv integrated upqc," in *2016 IEEE 6th International Conference on Power Systems (ICPS)*, March 2016, pp. 1–6
- [7] B. Singh, C. Jain, S. Goel, A. Chandra, and K. Al-Haddad, "A multifunctional grid-tied solar energy conversion system with anf-based control approach," *IEEE Transactions on Industry Applications*, vol. 52, no. 5, pp. 3663–3672, Sept 2016.
- [8] T. K. S. Freddy, N. A. Rahim, W. P. Hew, and H. S. Che, "Modulation techniques to reduce leakage current in three-phase transformerless H7 photovoltaic inverter," *IEEE Trans. Ind. Electron.*, vol. 62, no. 1, pp. 322–331, Jan. 2015
- [9] M. Rauf and V. Khadkikar, "Integrated photovoltaic and dynamic voltage restorer system configuration," *IEEE Transactions on Sustainable Energy*, vol. 6, no. 2, pp. 400–410, April 2015.
- [10] I. Serban, "Power decoupling method for single-phase H-bridge inverters with no additional power electronics," *IEEE Trans. Ind. Electron.*, vol. 62, no. 8, pp. 4805–4813, Aug. 2015.
- [11] Y. Tang, F. Blaabjerg, P. C. Loh, C. Jin, and P. Wang, "Decoupling of fluctuating power in single-phase systems through a symmetrical half-bridge circuit," *IEEE Trans. Power Electron.*, vol. 30, no. 4, pp. 1855–1865, Apr. 2015.
- [12] D. Barater, G. Buticchi, E. Lorenzani, and C. Conrari, "Active common-mode filter for ground leakage current reduction in grid-connected PV converters operating with arbitrary power factor," *IEEE Trans. Ind. Electron.*, vol. 61, no. 8, pp. 3940–3950, Aug. 2014.
- [13] E. Vartiainen, "A new approach to estimating the diffuse irradiance on inclined surfaces," *Renewable Energy*, Vol. 20, 2014.
- [14] M. Amirabadi, A. balakrishman, H. A. Toliyat, and W. C. Alexander, "High-frequency AC-link PV inverter," *IEEE Trans. Ind. Electron.*, vol. 61, no. 1, pp. 281–291, Jan. 2014
- [15] M. C. Cavalcanti, A. M. Farias, F. A. S. Neves, and J. L. Afonso, "Eliminating leakage currents in neutral point clamped inverters for photovoltaic systems," *IEEE Trans. Power Electron.*, vol. 59, no. 1, pp. 435–443, Jan. 2012.
- [16] T. Kerekes, R. Teodorescu, P. Rodríguez, G. Vázquez, and E. Aldabas, "A new high-efficiency single-phase transformerless PV inverter topology," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 184–191, Jan. 2011.
- [17] B. Singh and J. Solanki, "A comparison of control algorithms for dstatcom," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 7, pp. 2738–2745, July 2009.
- [18] R. Gonzalez, J. Lopez, P. Sanchis, and L. Marroyo, "Transformerless inverter for single-phase photovoltaic systems," *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 693–697, Mar. 2007.
- [19] V. Matthias, G. Frank, B. Sven, and H. Uwe, German Patent H5- Topology, DE 102004030912 B3, Jan. 2006.
- [20] S. Heribert, S. Christoph, and K. Juergen, German Patent HERIC Topology, DE 10221592 A1, Apr. 2003.



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