

GRID CONNECTED INVERTER SYSTEM WITH RESPONSIVE POWER CONTROLLER FOR PV APPLICATIONS

CHADA PRATHYUSHA,

*Research Scholar, Dept. of Electrical & Electronics Engineering,
Sri Satya Sai University of Technology & Medical Sciences,
Sehore, Bhopal-Indore Road, MadhyaPradesh, India*

Dr. Subhashish Boss

*Research Guide, Dept. of Electrical & Electronics Engineering,
Sri Satya Sai University of Technology & Medical Sciences,
Sehore, Bhopal Indore Road, Madhya Pradesh, India*

Abstract

Due to the instantaneous changing of sun oriented irradiance and temperature, it is desirable to determine the ideal voltage that ensures maximum energy yield. So as to optimize the photovoltaic energy generation, the MPPT is integrated in the inverter control. The maximum power generated by the photovoltaic system is sent to the power grid to be consumed by the nearest customers. A steady exchanging frequency is used for the current controlled inverter.

Introduction

In the present scenario of world energy sector renewable sources are developing their importance step by step. This is chiefly because of limited resource and terrible environmental impacts of the conventional energy. Among the all renewable energy resources available, sun based energy seems to be a significant competitor as it is bountiful in nature and its conversion to electricity through photovoltaic (PV) process is contamination free. Increasing interest in PV systems, demands development in research and development activities in different aspects, for example, Maximum Power Point Tracking (MPPT), PV exhibits, hostile to islanding protection, steadiness and reliability, power quality and power electronic interface. With increase in penetration level of PV systems in the existing power systems, these issues are expected to become more basic in time since they can have remarkable impact on the overall system performance. More efficient

and financially savvy PV modules are being developed and manufactured, in response to the concerns raised by the PV system developers, utilities and customers.

Tracking the maximum power point (MPP) of a photovoltaic (PV) cluster is generally an essential aspect of a PV system. In that capacity, many MPP tracking (MPPT) methods have been developed and implemented. The overall effortlessness and efficiency of PV system depends on the MPPT technique employed. Different alternatives architectures for grid connected PV system designs are available, for example, centralized module, AC module and particular arrangement where the last topology perfectly fits with an intelligent PV module concept. The AC module setup, which is a simplified version of the centralized inverter topology. Here a single line of PV module is connected with an inverter. Each string can be applied with a separate MPPT, as there is no misfortune attributed to string diodes. In contrast with the centralized inverter the overall efficiency is increased. A typical inverter is joined with multiple strings connected to singular DC-DC converter. The benefit of this particular setup over centralized system is that each string can be controlled exclusively and ensure less cabling misfortune thereby enhancing the overall system efficiency.

Overview of Photovoltaic Systems

PV clusters exhibit nonlinear characteristics, which change as the light and temperature change. A variety of models of PV cells has been reported in the literature for MPPT. An equivalent circuit of the PV cell model; known as a single-diode model, is appeared in Figure 1.

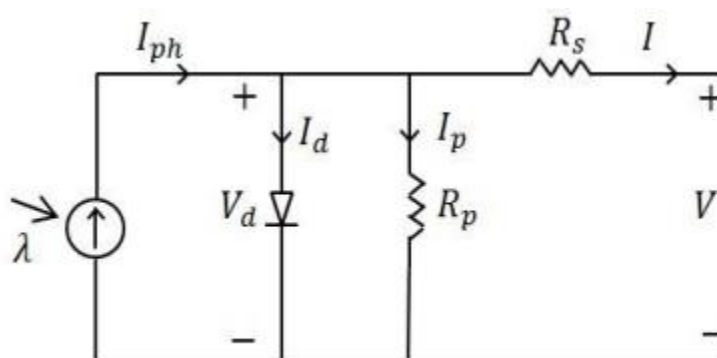


Figure 1. Solar cell equivalent circuit

The equations that represent the current-voltage (I-V) characteristics are as follows

$$I = I_{ph} - I_d - V_d/R_p$$

$$V_d = IR_s + V$$

$$I_d = I_o \left[\exp \left(\frac{qV_d}{AKT} \right) - 1 \right]$$

$$I_{ph} = [I_{sc} + Ki(T - Tr)]\lambda$$

where I_{ph} is the photocurrent, I_d is the average current through the diode, and V_d is the average voltage of the photovoltaic cell. I_o is the reverse immersion current at the reference temperature T_r , A is the diode ideal factor, T is the solar cell panel temperature in absolute scale (), I_{sc} is the short out current at the reference temperature and radiation, Ki is the short out current temperature coefficient, and λ is the solar radiation. K is the Boltzmann steady = $1.38 \times 10^{-23} \text{ J/oK}$, q is the electron charge $q = 1.6 \times 10^{-19}$ Coulombs.

For grid-connected PV systems applications, it is necessary to have an interface between the PV array and the grid to regulate the PV voltage hence to get the maximum power of the PV array and to inject sinusoidal current to the grid. The designs appeared in Figure 2 are used to achieve these requirements,

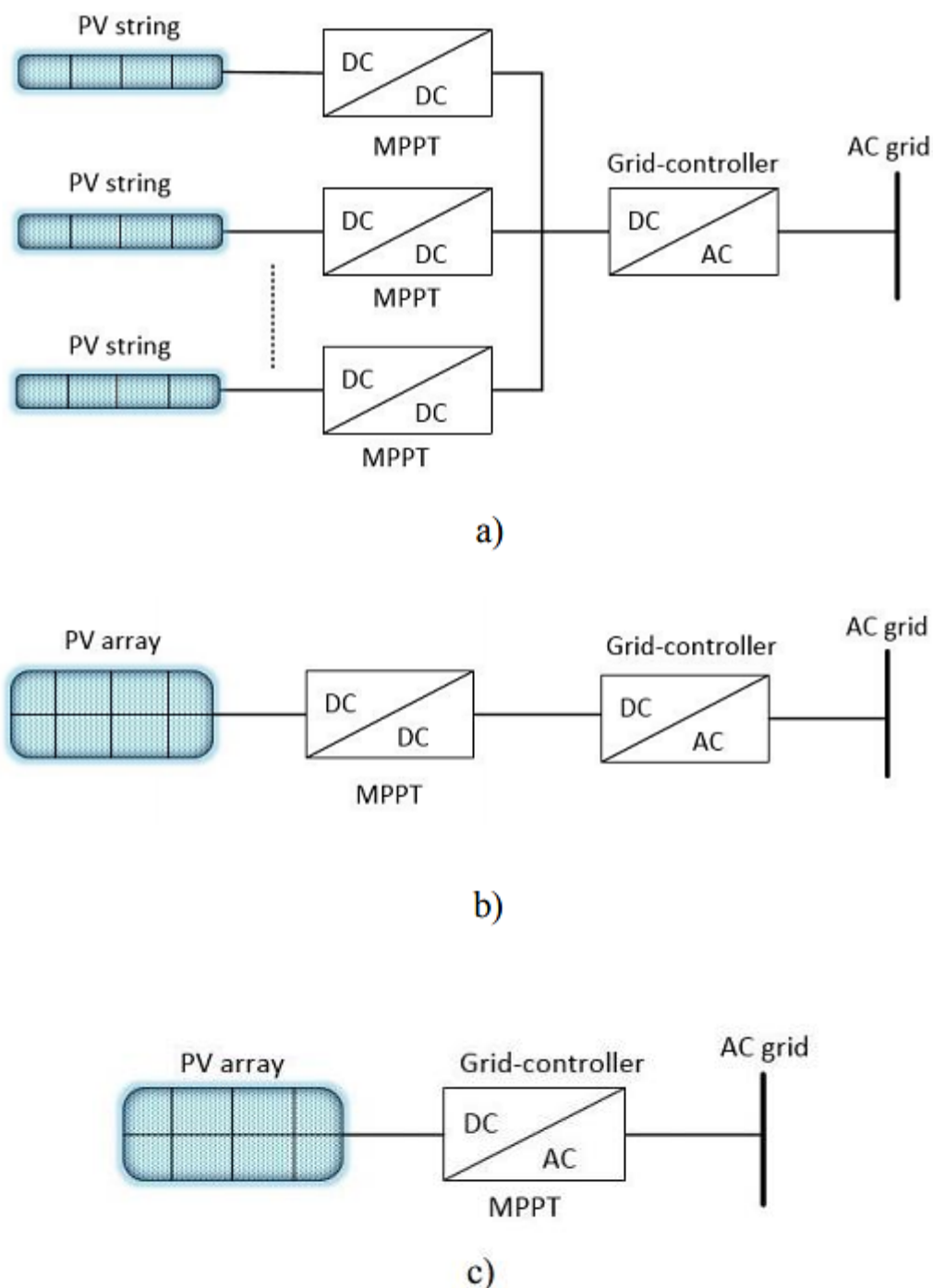


Figure 2. a) Multi-stage, b) Two-stage, c) Single-stage PV systems configurations

From efficiency and reliability point of view, single-stage PV systems; as is appeared in Figure 2 c), have gained attention in the research world. Single-stage PV systems have been reported by

researchers utilizing many circuits topologies and different control approaches to dealing with the active and reactive power of grid-connected PV systems with MPPT. Depending on the range of the electric power, PV systems are classified as three phase or single-phase systems. For low power application of around few kilowatts, single phase PV systems are required to operate at solidarity power factor (PF) with maximum power point tracking.

Proposed Methodology

The system that has been simulated comprises of a photovoltaic array with a peak power of 100kW connected through a DC transport to a three-phase inverter that is connected to an ideal 400V grid through a simple filter, as appeared in Figure. 3.

The MPP tracker is integrated in the inverter control (Figure. 4), as there is no DC-DC converter in the chosen design.

PV array simulation

The PV array is simulated utilizing a model of moderated complexity based on [1]. In this model, a PV cell is represented by a current source in parallel with a diode, and a series resistance. There is no need for a more complex model with a second diode and/or a shunt resistance. The photograph current I_{ph} depends on the irradiance G and the cell temperature T_c . The current I_c provided by the cell can be calculated as:

$$I^c = I_{ph} - I_D = I_{ph} - I_0 \left(\exp \frac{e(V + IR_s)}{nkT^c} - 1 \right)$$

Where the immersion current I_0 is temperature dependent, e is the charge of an electron, k is Boltzmann's gas steady and n is the idealizing element of the diode.

The module is an association of solar cells in parallel and series. Extending the previous cell model to a module, a comparative equation can be found. Yet, it is more useful to express such an equation in terms of the open circuit voltage V_{oc} and short out current I_{sc} , as these can be estimated from the open circuit voltage and short out current in standard conditions that are

typically provided by module manufacturers, and their linear dependence on T_c and G respectively.

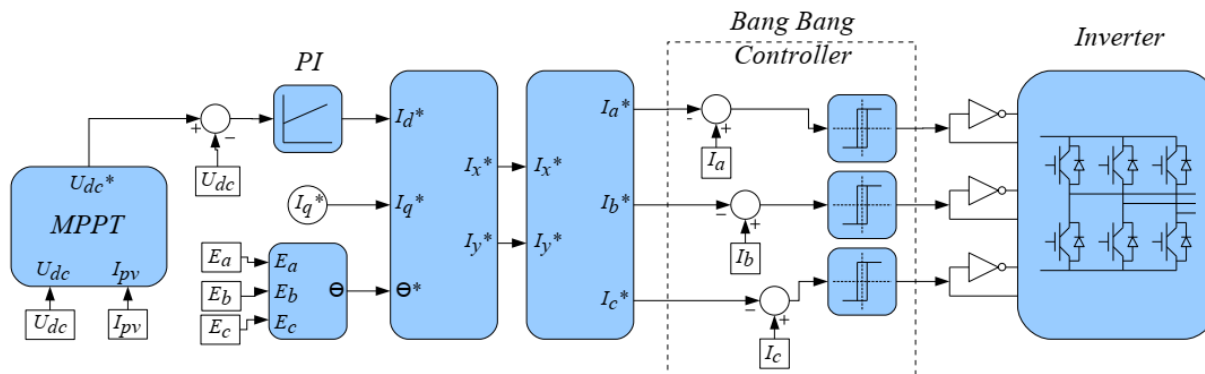


Figure 3. Proposed control scheme

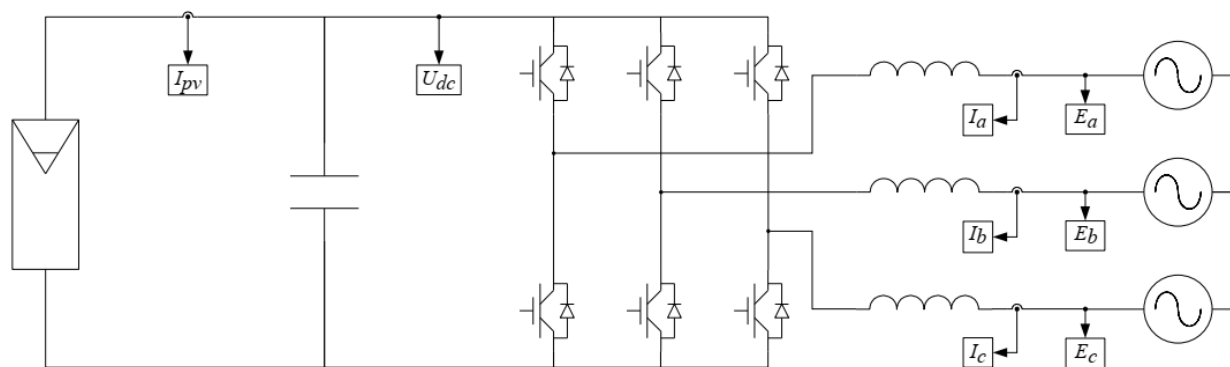


Figure 4. Proposed electrical scheme

The cell temperature T_c is estimated considering its linear dependence on G and the cell temperature in ordinary operating conditions that is provided by the module manufacturer. The last model used to determine the relationship of a module current and voltage is appeared in below equation, where m designs module magnitudes.

$$I^m = I_{sc}^m \left(1 - \exp \left(\frac{e(V^m - V_{oc}^m + I^m R_s^m)}{N_s \cdot nkT^c} \right) \right)$$

The model parameters were adjusted to simulate the static response of a Kyocera KC167GH-2 module based on the data provided by the manufacturer. The PV array is made of 20 strings of 35 series connected modules each, connected in parallel. This gives an absolute peak power of around 100kW. All modules are considered to be identical, and to work in identical states of temperature and irradiance.

Fuzzy MPPT

For a given set of operating conditions G and T our module model shows that the relationship between voltage, current and power are capacities like the ones appeared in Figure. 5. The voltage that corresponds to the module maximum power varies with temperature and irradiance varieties, so a MPP tracking system is needed to ensure that we remain as close as possible to the ideal. Regular MPPT methods include Perturb and Observe (P&O), incremental conductance, fuzzy logic and other methods.

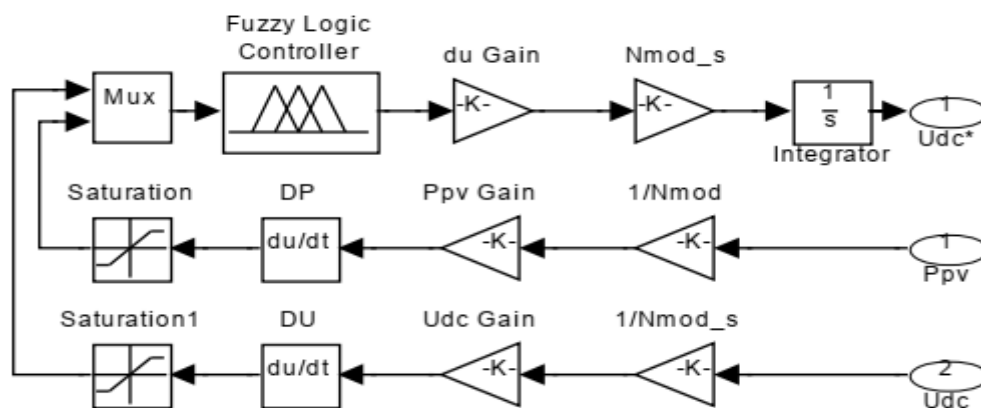


Figure 5. Fuzzy MPPT diagram

Here a method based on a fuzzy controller is presented that differs from current ones, as it has been designed to be integrated in the inverter instead of a DC-DC converter, and uses a reduced set of membership capacities (and therefore is simpler to fine-tune) without trading off performance. Fuzzy logic controllers are suitable for nonlinear problems where the desired system behavior in terms of information and yield variables can be expressed as a set of semantic rules. They present a vigorous performance and good response in boisterous environments.

Typically the MPPT controls a DC-DC converter to keep up a consistent DC voltage at the yield of the generator. With an appropriate estimating of the PV array the DC-DC converter can be avoided due to the relatively little changes in the ideal voltage in operating conditions. This will save one stage in the system and therefore will increase efficiency. In the typical arrangement with a DC-DC converter the MPPT system yields a sign to change the obligation cycle of the converter. In this case, the MPPT will yield a DC voltage reference U_{dc}^* to the inverter control. As sources of info, the MPPT will need the DC transport voltage U_{dc} and the power delivered by the PV array P_{pv} , which is obtained as the product of U_{dc} and the PV array current. The increment of these variables ΔU_{dc} and ΔP_{pv} over a sample period are computed, which will be the contributions of the fuzzy logic controller. The yield will be ΔU_{dc}^* which is then integrated to acquire the desired reference U_{dc}^* .

Generally, a large number of membership capacities are defined, for example, negative-huge, negative-medium, negative little, etc. This isn't necessary, and it introduces an extra complexity to the controller tuning, as the boundaries between seven or more membership capacities have to be defined, for each variable. In this case we have chosen a set of three membership capacities: negative (NEG) positive (POS) and (ZERO).

Inverter

The inverter control is based on a decoupled control of the active and reactive power. The DC voltage is set by a PI controller that compares the genuine DC transport voltage and the reference generated by the MPPT, and provides an I_d^* active current reference in a coordinated reference frame attached at grid voltage vector. The other component of current vector represents the reactive current and it very well may be fixed at the desired level for power factor or voltage control. By applying the inverse Park change to d-q current vector components, the desired I_{abc}^* phase current references are obtained. These are passed to a blast controller, which yields the pulses to drive the inverter switches.

As there is no DC/DC converter between the PV generator and the inverter, the PV array arrangement must be chosen so the yield voltage of the PV generator suits the inverter's requirements. In this case a 400V grid has been chosen, so the inverter will need in any event

600V in the DC transport so as to be able to operate properly. The lowest DC voltage will happen with high ambient temperature and high irradiance (because the irradiance increases the cell temperature, and this effect predominates over the increase of ideal voltage caused by an increment of the irradiance at a consistent cell temperature), so the base number of series connected modules ought to be determined by this most pessimistic scenario. As the PV array model estimates cell temperature as an element of irradiance and ambient temperature, for the most pessimistic scenario an ambient temperature of 50°C and an irradiance of $G=1000\text{W/m}^2$ were chosen. The PV array was found to require 35 series connected modules per string. The ideal voltage for this design should remain around 700-800V more often than not, with some peaks that could reach at least 600V and a maximum of 900V in very extreme circumstances. The main disadvantage of such a voltage is a slight increase of the inverter price as higher rated voltage of DC interface capacitors and switches are required.

Result

The system response to an irradiance step is appeared in Figure 6, 7. In $t=0.2\text{s}$ the irradiance is changed from 150 to 1000 W/m^2 . It tends to be seen that the system tracks the new operating point very rapidly, faster than most MPPT strategies. It must be said this is an extreme change in illumination levels that is unlikely to happen yet shows the good performance of the MPPT.

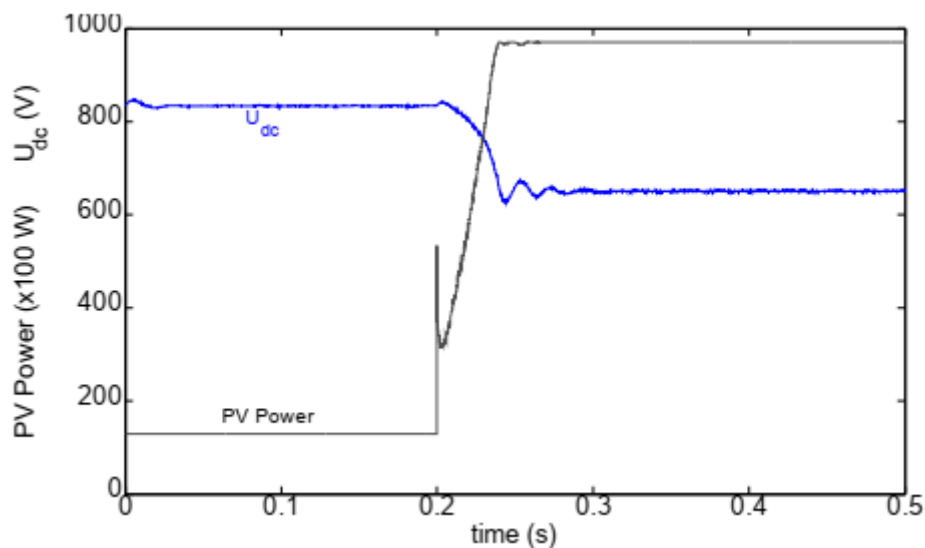


Figure 6. System response to an irradiance step in $t=0.2\text{s}$

The maximum power point is tracked with excellent exactness as can be seen in Figure. 7, where the generated power is compared to the theoretical ideal calculated from the PV array model.

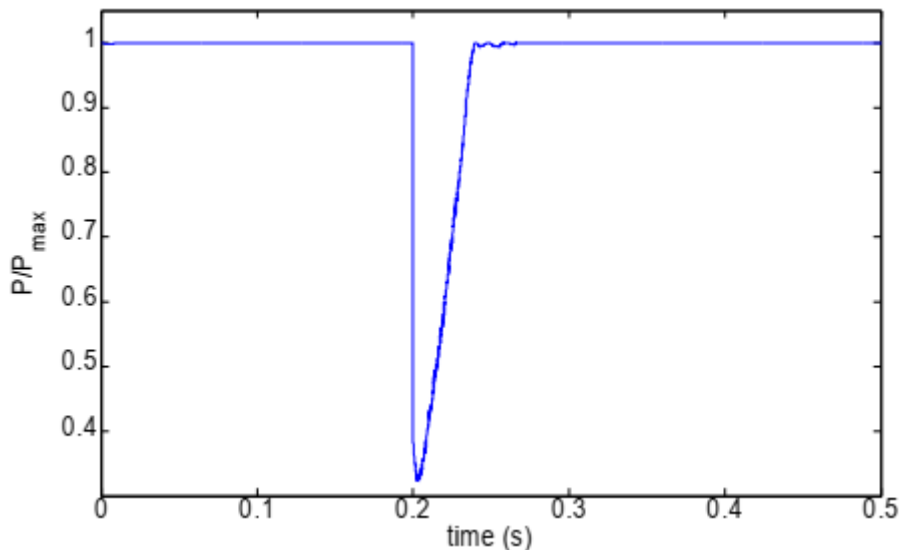


Figure 7 System response to an irradiance step in $t=0.2s$

Conclusion

An inverter for medium or large photovoltaic applications has been presented. The inverter features decoupled control of active and reactive power. It does not require an intermediate stage of DC/DC control, as the ideal DC voltage is set by the inverter itself by means of a fuzzy MPPT. The reenactment of the whole system has been done in Matlab-Simulink and it shows an excellent performance of both inverter and MPPT, with negligible change of the DC transport voltage, optimizing of ideal operating point, and practically instantaneous tracking of power factor reference.

References

- [1] Teodorescu, R, M. Liserre, and P. Rodríguez, “Grid Converters for Photovoltaic and Wind Power Systems,” Piscataway, NJ: IEEE Press/Wiley, 2011
- [2] TERI, ERI, WAU, IIASA. Final report on work package. New Delhi: Tata Energy Research Institute; 1999, accessed on 25, 2015
- [3] “Trends in Photovoltaic Applications Survey Report,” International Energy Agency, 2009.
- [4] Al-Soud MS, Hrayshat ES. “Rural photovoltaic electrification program in Jordan,” *Renew Sustain Energy Rev*, ,8,(6),pp.593–598, 2004
- [5] Yang, B., Li, W., Zhao, Y., & He, X., “Design and analysis of a grid-connected photovoltaic power system,” *IEEE Trans. Power Electron.*, 25,(4),pp.992–1000, 2010
- [6] Meral, M.E, Dinçer, F, “A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems,” *Renew. Sustain. Energy Rev.*,15, (5), pp. 2176–2184. 2011
- [7] Lopez, O, F. D. Freijedo, A. G. Yepes, P. FernandezComesana, J. Malvar, R. Teodorescu, and J. DovalGandoy, “Eliminating ground current in a transformerless photovoltaic application,” *IEEE Trans. Energy Convers.*, 25, (1), pp. 140–147, 2010
- [8] Xiao, H and S. Xie, “Leakage current analytical model and application in single-phase transformerless photovoltaic grid-connected inverter,” *IEEE Trans. Electromagn. Compat.*, 52,(4), pp. 902–913, 2010
- [9] Barater, D., Buticchi, G., Lorenzani, E., Concari, C., “Active Common-Mode Filter for Ground Leakage Current Reduction in Grid-Connected PV Converters Operating With Arbitrary Power Factor,” *IEEE Trans. Ind. Electron.*, 61,(8), pp.3940-3950, 2014
- [10] Buticchi, G. Barater, D. Lorenzani, E. Franceschini, G., “Digital Control of Actual Grid-Connected Converters for Ground Leakage Current Reduction in PV

Transformerless Systems,” IEEE Trans. Ind. Informat., 8,(3), pp.563-572, 2012

[11] Dugan, R.C.,Key, T. S. andBall, G. J., “Distributed Resources Standards,” IEEE Ind. Appl Mag.,12, (1),pp. 27–34, 2006

[12] Kouro, S., Leon, J. I., Vinnikov, D., &Franquelo, L. G. "Grid-Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology." IEEE Ind. Electron. Mag., 9,(1),pp. 47-61, 2015

[13] IEC 61727 Ed. 2, Photovoltaic (PV) Systems – Characteristics of the Utility Interface, December 2004.

[14] VDE V 0126-1-1, “Automatic Disconnection Device between a Generator and the Public Low-Voltage Grid,”Document 0126003, VDE Verlag, 2006.

[15] UL Std 1741, “Inverters, Converters, and Controllers for Use in Independent Power Systems,” Underwriters Laboratories Inc. US, 2001