Analysis of Single Phase Grid Connected PV System to Identify Efficient System Configuration

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***Abstract*— Deregulated power system nowadays is grooming rapidly. Distributed generators are providing support to existing power system to fulfill the demand of power. Solar Photovoltaic system is one of the distributed generators which are being utilized by the customers globally. Small and medium power consumers have started striving on solar power for economically and environmentally reasons. Most of the customers on distribution side have single phase connection. Presently the single phase grid connected photovoltaic system is getting popularity among all renewable energy sources used for the distribution side. This paper mainly focuses on the component analysis of single phase grid connected photovoltaic system. For better understanding of the system and for attaining maximum efficiency of the PV system, an efficient power electronics converter is being required. The paper reviews the existing topologies of the various components used in a single phase grid-tied PV system which leads to identify the efficient system configuration of the PV system.**

Keywords— Solar Photovoltaic; grid connected system; Modeling, MPPT; DC-DC Converter; Transformerless inverter

I. INTRODUCTION

To boost the renewable energy application in modern power system, government agencies all over the globe are introducing new schemes and policies. Agencies are trying to motivate the customers by initiating monetary benefits for using renewable source of energy for power generation. Solar photovoltaic energy being a well known and established technology for power generation in the category of renewable energy is nowadays mushrooming. People all over the world are awaked by the importance and benefits of solar photovoltaic power system. But the solar power itself is not sufficient to fulfill the requirement of the consumers. So next possible solution emerges is the grid connected system. In grid connected system, the requirement of power is being filled by both an infinite source of power called grid and solar photovoltaic power. Thus the evolution of grid connected photovoltaic system evolved. Few standards are also being imposed by the governments so that the quality and safety of existing power system could be maintained. IEEE has also prepared the standards for connecting distributed resources like solar photovoltaic with the power system, which is accepted globally [1-2].

Solar being an easily available free source of energy is always be the area of interest for the researchers. Power electronics has a significance role in the field of solar photovoltaic system. The enhancement of efficiency of the solar PV system is mainly depends on the power electronics based devices like converter and inverter. The conversion efficiency and losses have significantly reduced by the application of these devices. Advancement in the power electronics field leads to new cost effective and efficient solar power system.

The main drawbacks of the solar photovoltaic system are the need of ample space for generation and its dependence on environmental conditions [3-4]. Also the small power consumers always have a risk and uncertainty in terms of investment [5-6]. To overcome this uncertainty, few researchers have developed the methods for reducing investment uncertainty [7].

To overcome these technical challenges, the researchers are trying for the efficient and reliable solar photovoltaic system integrated into distribution grid so that power can be produced in effective manner and uncertainty can be reduced. The main components of the grid connected photovoltaic power plant comprises of solar PV panel which combines to form an array, DC-DC converter for constant DC supply and inverter for converting this constant DC into AC so that it can inject into existing grid. For better power quality, advancements have already being developed and tested like interleaved boost converter, transformer less inverter and single stage solar power system.

This paper presents the analysis of single phase grid connected PV system to identify efficient system configuration. The paper provides a comprehensive idea about the system and its requirements. It also offers the latest development in this field which helps in finding and configuring the cost effective and efficient solar photovoltaic system for single phase application.

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II. Modelling of SPV Panel

To reduce the burden on electric utilities and consumers, who are paying hefty electricity bills; has marked the beginning of a new revolution of On-line grid systems wherein solar photo-voltaic system are integrated with modern grids. It has become imperative to analyze the interaction of SPV system with modern grid for proper functioning of the system through model and computer simulation.

In recent times various specific application based PV models have been developed on different software platforms such as MATLAB/SIMULINK, P-SPICE, PSCAD, etc. The PV model obtained requires an iterative solver due to complex parameterization. Moreover, since I-V characteristic of a PV panel is not linear due to dependency on solar irradiation and temperature, a PV model having conventional DC voltage or current source cannot be used. Thus, we require a general model of PV panel based on equivalent single diode circuit to improve its feasibility in any execution method and at the same time increase the efficiency and reduce the computational work for any system simulation. Fig 1. is the most basic and well known circuit for modeling the PV cell. [8].

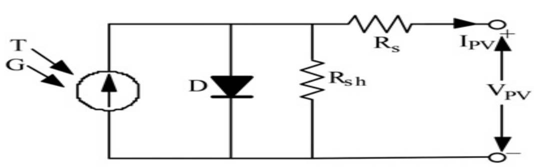


Figure 1. Equivalent circuit of PV

I_{ph} is the total current generated by the PV cells that is photovoltaic current. Diode represents the p-n junction of the PV cell. R_s and R_{sh} are the approximate resistances of the PV cells. The values of R_s and R_{sh} are not mentioned by the manufactures and need to be calculated as given in [9]. I and V are the terminal current and voltage respectively.

The main five governing equations for a single diode PV cell are:

(i) $I = I_{pv} - I_o [\exp(V + IR_s / aV_T) - 1] - V + IR_s / R_{sh}$

(ii) $V_T = N_s kT/q$

(iii) $I_{pv} = G/G_n [I_{pvn} + K_1(T - T_n]$

(iv) $I_o = I_{on} (T/T_n)^3 \exp[qE_g/ak (1/T_n - 1/T_a)]$

(v) $I_{on} = I_{scn}/ \exp(V_{ocn}/ aV_{Tn}) - 1$

$$I_{ss} = I_{scs} / e^{(qVocs/ kATcs)} - 1 \quad (1)$$

where, I_{ss} is Diode reverse bias saturation current at STC

I_{scs} is PV short circuit current at STC

PV model can further be simplified by removing series R_s and shunt R_{sh} resistances which reduce tuning parameters and increase the computational efficiency compared to standard single diode model discussed. I-V characteristic of such a model is given by [10]:

$$I_{ss} = I_{scs} / e^{(qVocs/ kATcs)} - 1 \quad (2)$$

where I_{ss} is Diode reverse bias saturation current at STC

I_{scs} is PV short circuit current at STC

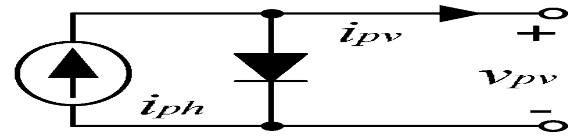


Figure 2. Equivalent circuit for the ideal single-diode PV-cell model

The datasheet of the module defines few parameters. With the help of these parameters, the modeling of solar photovoltaic panel is done in [9]. The author in this paper developed a generalized model of the panel which provides a universal equation which is also dependent on environmental conditions.

III. Dc-Dc Converter Topologies

In application such as roof top PV systems, it is necessary to step up the dc voltage from dc-dc boost converter so that the DC voltage obtained from PV modules can further be used to obtain the required RMS AC voltage. Thus, large voltage conversion ratio and high voltage gain is required which can be obtained from isolated dc-dc topologies by enhancing the high frequency transformer's turn ratio. However, due to pulsating input current and reduced efficiency as a result of high voltage stress across output diode compared to output voltage put limits to its use. Thus, applications where no galvanic insulation is required it can be a good idea to switch to non-isolated dc-dc converters for the same purpose [11] which will also increase the efficiency of the system due to omission of high frequency transformer from the system.

Non-isolated dc-dc boost converts can be classified as:

(A) Step-up topologies without wide conversion ratio

i) Conventional boost converter
ii) Conventional interleaved boost converters
iii) Three level boost converters

(B) Step-up topologies with wide conversion ratio

i) Cascaded boost converters
ii) Coupled-inductor based boost converters
iii) Switched-capacitor based boost converters
iv) Interleaved boost converters
v) 3-SSC based converters

Conventional boost converters cannot be used in high power applications as it suffers from few shortcomings: reverse recovery diode issues, only two semiconductors are used to process the load power while high duty cycle is required for high voltage which limits the voltage conversion ratio to a finite value.

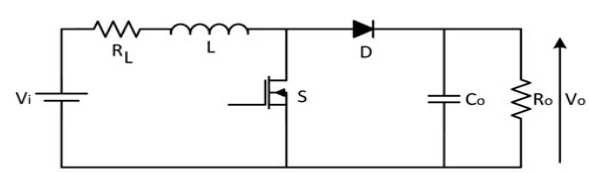


Figure 3. Conventional dc-dc boost converter

As potential remedies, three-level converter doubles the static gain achieved with conventional boost converter. However, much greater conversion ratio is achieved with cascaded converters wherein in the first leg input voltage is stepped up using high duty cycle while in the second leg switching losses are reduced due to less duty cycle.

Coupled inductors also provide an alternative to step-up by voltage in place of transformer which obviate extreme duty cycle and reduce ripple current. Switched capacitor-inductor approach allows for high step-up but at the same time reduce efficiency due to greater component count.

3SSC-based topologies are highly preferable for high power applications as large voltage step-up can be achieved. It also has various advantages [11] such as reduced current stress, better heat distribution, reduced size, weight and volume.

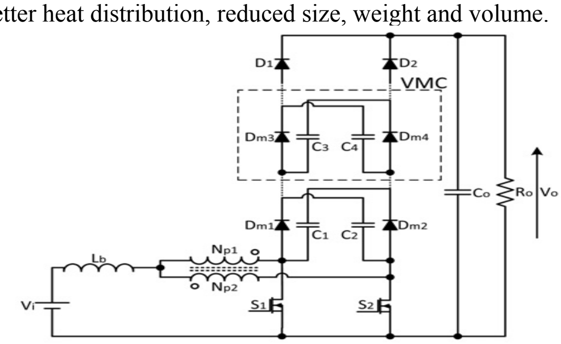


Figure 4. 3SSC-based boost converters using VMCs

IV. MPPT Techniques For Solar Pv System

To make the PV system operate at Maximum power point under any environmental condition several MPPT techniques are available which can be applied on different solar applications.
Different MPPT techniques based on the number of control variables involved, types of control strategies, circuitry, and cost of applications, are listed below [12]:

i. Curve-Fitting Technique
ii. Fractional Short-Circuit Current (FSCI) Technique
iii. Fractional Open-Circuit Voltage (FOCV) Technique
iv. Look-up Table Technique
v. One-Cycle Control (OCC) Technique
vi. Differentiation Technique
vii. Feedback Voltage or Current Technique
viii. Feedback of Power Variation With Voltage Technique
ix. Feedback of Power Variation With Current Technique
x. Perturbation and Observation (P&O) And/Hill-Climbing Technique
xi. Incremental Conductance (Inc-Cond) Technique
xii. Forced Oscillation Technique
xiii. Ripple Correlation Control (RCC) Technique
xiv. Current Sweep Technique
xv. Estimated-Perturb-Perturb (EPP) Technique
xvi. Parasitic Capacitance Technique
xvii. Load Current/Load Voltage Maximization Technique
xviii. DC Link Capacitor Droop Control Technique
xix. Linearization-Based MPPT Technique
xx. Intelligence MPPT Techniques
xxi. Sliding-Mode-Based MPPT Technique
xxii. Gauss-Newton Technique
xxiii. Steepest-Descent Technique
xxiv. Analytic-Based MPPT Technique
xxv. Hybrid MPPT (HMPPT) Techniques
xxvi. MPPT Techniques for Mismatched Conditions

Now, MPP is unique in case of uniform solar irradiation conditions while multiple MPPs exist in case of non-uniform solar irradiation condition. Thus, to achieve optimal utilization of solar energy through PV system we need to implement MPPT technique to operate the PV system at MPP anytime.
Different MPPT techniques functioning depends on operational complexity, execution of optimization algorithm, operational characteristics of PV source, speed of driving the MPP of PV source, drift of PV module characteristics etc.[13]
The author has differentiate the MPPT techniques in two categories

(A) For uniform solar irradiance

(B) For non-uniform solar irradiance

MPPT for uniform and non uniform solar irradiance further classified according to its operation [13]. Hence, it is imperative to analyze the PV system requirements, environmental conditions and output calculations before selecting and incorporating certain MPPT technique into the PV solar system.

V. Single Phase Inverters For SPV Application

For processing the DC power generated from solar PV panels to obtain AC power, solar inverters are used. Grid-tied inverters are used where there is a provision to send the unused electrical energy to electrical board. Grid-tied inverter are designed to provide up to 99% MPPT efficiency and after converting DC power to AC power it feeds the electricity into the grid system. Installing a bi-directional meter will help calculating net power outflow. The amount of power sent back into the grid will be compensated from the power providers.
Grid-tied PV inverter can be classified into [14]:

i. Central inverter;
ii. String inverter;
iii. Module integrated inverter;
iv. Multi-string inverters.

According to the power electronics circuit, the inverter circuit can be classified as:

(A) Grid tied inverter with transformer

(B) Transformerless grid-tied Inverters

Due to the absence of the transformer, the transformerless inverters have advantages in terms of cost and efficiency. Parasitic capacitance is formed between PV module and ground when electrically chargeable surface area facing the ground frame is generated by PV module. As a solution, a transformer is utilized for galvanic isolation between PV module and grid while in a transformerless inverter, such connection already exists that can create a common-mode resonant circuit which can be electrified by varying common mode voltage.

Transformerless topologies can be classified as [20]

i. Zero-state decouple topologies;
ii. Zero-state mid-point clamped topologies
iii. Solidity clamped topologies.

Further the detailed classification of these three types of topologies is done in the paper [20]. The author has also compared these three topologies in terms of leakage current and maximum efficiency. Among all transformerless topologies, the author concluded HRE topology as the highest efficiency with 99.3%.

VI. Simulation And Results

After detailed review of the existing technologies, for the better understanding for the system, a model has been created using MATLAB/SIMULINK. A 10 kW single-phase grid connected PV system is formed. The model is shown in figure 5. The model comprises of the DC-DC converter, incremental conductance based MPPT Algorithm and an inverter.

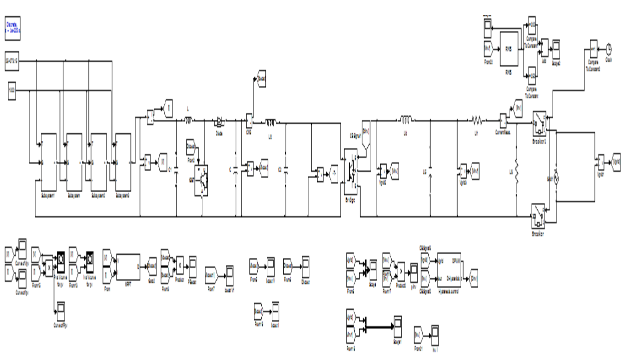


Figure 5. Single phase Grid Connected PV System

This test system comprises of the solar PV module of the parameters mentioned in table I. these values has been considered by refereeing the actual module data sheet so that the module model considered for designing in the PVSyst software should match the modeling and simulation done in the MATLAB software.

TABLE I. Module Parameters

S.No	Module Ratings		
	Parameters	***Symbol***	***Values***
1	Short Circuit Current	I_{sc}	8.87A
2	Open circuit voltage	V_{oc}	37.2 V
3	Current at maximum power point	I_{MPP}	8.3 A
4	Voltage at maximum power point	V_{MPP}	30.1 V
5	Number of cells in series	N_s	60
6	Temperature coefficient of	I_{sc}	0.065 A/K
7	Temperature coefficient of	V_{oc}	-0.34 V/K
8	Maximum power output	P_{max}	250 W

The solar PV module is modeled using the equation defined in [8] and is shown in figure 6. The module has been considered according to the real time data chosen from the data sheet so that the module behaves as of practical one. The voltage-current and the power-voltage characteristics of the module have been verified from the STC condition of module mentioned in the data sheet.

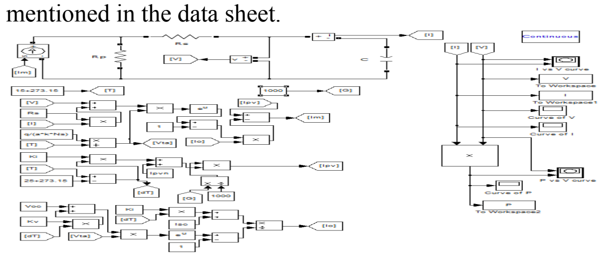
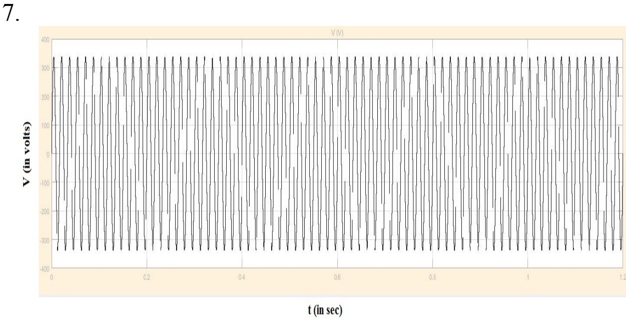
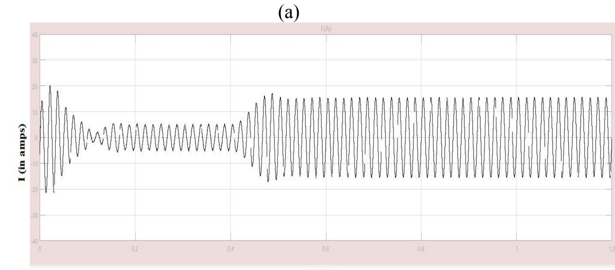


Figure 6. Modeling of PV module

The following graphs are obtained when the test system is connected to the distributed grid. As we know that the grid voltage at distribution side is 240 V in a single phase application. The grid voltage and current obtained in the figure 7.



(a)



(b)

Figure 7. (a) Grid Voltage (b) Grid Current

The peak value of the grid voltage is obtained as 350 V. Thus the rms value of the voltage can be obtained as 0.707 × peak value which results 238V AC supply.

The system yield is then checked in the PV SYST software. The test system is modeled in the software in which the 20 panels of 250W are connected in series and there are two such strings connected in parallel. Thus an array is formed which gives total generating 10 kW of power. The irradiance is considered by considering actual area's geographical location and the actual losses in wiring, module miss match and soiling losses. Thus the report is generated as shown in figure 8. The figure 8 shows that all expected losses like irradiance loss, loss due to temperature, soiling loss, module mismatch loss, wiring loss, inverter loss, AC wiring losses etc. has been considered for calculating the exact expected generation.

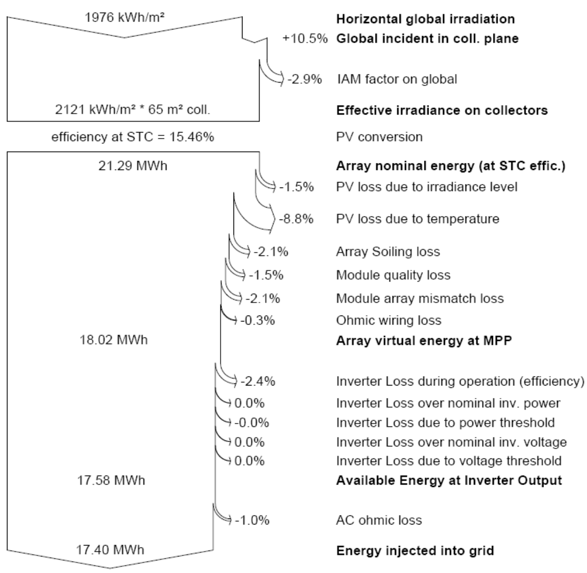


Figure 8. Yield calculation of 10 kW SPV system using PVSYST

The report shows that a 10 kW PV system can produce 21290 kWh of energy per year. But due to loss calculation, the expected energy produced by the 10 kW of the system is 17400 kWh which means the rest 3890 kWh of energy is lost in the whole process.

This loss calculation is entirely depends on environmental conditions of the area and the topologies adopted while designing the PV system. The researchers could not change or improve the environmental conditions of the area but can work on the efficient topologies of the PV system components.

VII. Conclusion

This paper reviews all the components of the single-phase grid tied PV system to aims that an efficient and effective PV system can be formed. Three main components on which the generation is entirely depends on are DC-DC converter topology, MPPT technique selected and inverter topology. A 10 kW single-phase grid tied PV system is designed in MATLAB/SIMULINK to demonstrate the system configuration and the expected yield is calculated using PV SYST software. It is found that, ideally the 10 kW solar PV system will generate 21290 kWh energy per year, considering 7 units a day per kW and total 300 sunny days in a year. But the actual energy generated by the system after considering the losses is 17400 kWh per year. The rest 3890 kWh of energy per year is lost due to environmental and electrical losses. The paper reviews the components of the single phase PV system so as to develop a new modified system which is cost effective and efficient. It also helps other researches and professionals for developing new topologies in single phase grid connected PV system.

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