Design of Transformerless Single Stage Double Switch Step Down PLL Derived Inverter using Single Phase Grid Connected PV Module with MPP Tracking

A Vijayaprabhu\(^1\) K B Bhaskar\(^2\) M Rajavelu\(^3\) N jehan\(^4\)
\(^1\)Assistant Professor, Department of Electronics and Communication, Sri Venkateswara College of Engineering and Technology, India
\(^2,3,4\)Department of Electrical and Electronics Engineering, Adhi College of Engineering and Technology, India

Vijayabrabhu85@gmail.com\(^1\), jaibhaskar15@gmail.com\(^2\)

Abstract. Here we propose a single stage double switch (SSDS) converter for single phase grid connected photovoltaic inverter step-down module, the structure is designed and modelled to a highly reliable step-down buck DC-DC converter and robust from the input derived from the PV module. The proposed PV module uses perturb and observe algorithm reference voltage to gain the maximum power in different changing climatic conditions. The grid is designed for 110 V/50 Hz, since it’s a low frequency, the utilization of heavy and expensive transformer is avoided. In a grid connected systems usually transformer is employed in the power conversion stage to provide sudden isolation between the PV system and the grid, and also ensures that no continuous current is injected into the grid by avoiding leakage currents between the PV module and the ground. As a choice to the grid connected module with line transformer, a transformer less inverter topology is proposed to avoid the leakage currents possibly occurring due to the capacitance between the PV array and ground, an inverter topology with PLL is proposed to avoid common mode voltage and the increase in electromagnetic emissions. This paper provides a highly efficient transformer less photovoltaic grid topology with reduced switches and has been validated by simulation.

Keywords: Step-down converter, grid interface, transformer less, PLL, MPP Tracking.

1. Introduction

Striving over the decades, the requirement for fossil fuels have keep on increasing as it cannot fulfil the requirement for day to day energy demand. They are getting compensated by the renewable energy generation systems are connected to the grid in a reliable way [1]. This began to rise in semiconductor power devices in power system. 1 phase photo voltaic grid connected inverter systems gains an optimal solution for low frequency systems [2,3].
Considering any one of the PV topology systems from standalone and grid-connected, In the grid connected systems the power semiconductor converter topology plays a vital role in transporting the available photo voltaic dc output in to the grid [4,5]. One more classification of standalone photo voltaic systems required a converter setup to convert produced DC in to AC for the end users. Power semiconductor switching devices are necessary in making interaction with the produced DC output with the AC load applications [6].

The switching device made the converter should always keep in track of photo voltaic module produces maximum VI in spite of the variation in the climatic changes and load variations[7]. This is taken in consideration by MPP tracking, the converted continuous AC voltage fed to the loads from the generated PV modules[8], the produced output must match the parameters of the grid such as alternating nature of output, frequency and amplitude[9].

In power inverters based grid to maintain the level of synchronism in order to produce an instantaneous alternating voltage to provide the VI to the loads, To synchronize the photovoltaic tracking output and the AC grid a PLL (Phase-locked loop) was proposed[10], [11], which performs the angle detection in the grid, the grid stability has to be maintained perfectly therefore the controlling to the inverter should be modified from the grid to the leading grid nature[12], this type of grid-forming arrangement where semiconductor inverters can able to produce AC with correct amplitude and stipulated frequency at the point of common coupling[13].

The paper proposes a SSDS 1-phase grid connected inverter, mainly concentrates on voltage source inverter grid-forming control for low frequency applications, the proposed controlling to the PI controller gains improves the stability of the system and approached to operate at unity power factor to enable efficient utilization of the full inverter capacity. Since, operation at any random power factor is possible in cases of availability of flexible inverter capacity due to possible drop in the available solar power, therefore the system adopts the MPP tracking with the incremental conductance method and without difficulty it can track any variations in insulation without oscillation. The system is designed in matlab/Simulink to verify its proposed characteristics.

Up to this, a system elaboration is made in the first section, Further, this paper elaborates as, in the next section II describes the system model, PV modelling with characteristics, MPP tracking methodology, Proposed Double switch step down DC-DC converter module in section III. The output simulation model are discussed, conclusions are done in section [IV, V].

2. Modeling & Tracking
2.1. System Model

The SSDS proposed converter model presents a 1 Phase grid interface photo voltaic model, in the below Figure1 shows the system consists of PV array with MPP tracking fed the input to the proposed step-down converter which will reduce the supply voltage for low level applications and PLL is used for grid side integration to the inverter.
2.2. **PV modelling with characteristics**

The PV cells are arranged in a bunch units are called PV panels which are collectively modelled in a parallel-series to give the PV arrays. The general voltage and current equation of PV array with respect to efficiency is very sensitive to cell series resistance $R_s$. and irrespective to changes in cell shunt resistance $R_{sh}$, the simplified equation is as,

$$I_{pv} = N_p I_{ph} - N_p I_0 (e^{\frac{V_{pv}}{N_p R_{sh}}} - 1)$$

![Figure 1. Block diagram of the proposed model](image)

![Figure 2. PV Current (A) and Power (W) output Vs voltage (V)](image)
2.3. MPP tracking of the Solar panel

From the photovoltaic modelled in the above equation the maximum power and the output voltage are depend on irradiation and cell temperature to produce a maximal power and maintains the output voltage at a constant value despite of the variations in the temperature a MPP tracking must be used. The MPPT techniques approaches to incremental conductance and P and O process is used and implementation is simple.

Incremental conductance is based as:

\[ P_{pv} = V_{pv} \times I_{pv} \quad \text{(2)} \]

Maximum power flows from the PV array when,

\[ \frac{dp_{pv}}{dv_{pv}} = 0 \quad \text{(3)} \]

By applying differentiation to equ (2), we have,

\[ \frac{dI_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}} \quad \text{(4)} \]
From the equation (4), the error signal resulting from the inequality is integrated to generate the reference value of the capacitor voltage that minimizes the error signal and ensures the flow of maximum power from the PV array.

3. Proposed SSDS- step down converter

The proposed SSDS step down converter exits in between the power generation and the inverter, the converter topology is buck type unidirectional process flow, the IGBT Q1 and Q2 produces a switching for a certain period based on frequency depends on load current requirement. The inductor ‘L’ and ‘C’ acts as a filter and averages the switched voltage.

In the first operating mode shown in Figure 4, IGBT switch Q1 and Q2 is at ON condition, the capacitor(C) charges through it, and the current flows through the path Vs-Q1-Q2-C. The variable pulse width oscillator controls On/OFF periods for Q1 and Q2.

![Figure 4. Operating mode 1](image)

In the second operating mode shown in figure, IGBT switch Q1 and Q2 is at OFF condition, the stored energy in the capacitor (C) discharges the energy to the load, the process flow is as L-C-D2-Load.
When the ON switching time is more compared to OFF time, the capacitor charges more, increasing the output voltage, in parallel when OFF time is more than ON time for Q1 and Q2 the output voltage decreases, here in this case the above mentioned second approach is modelled to produce the buck output from the tracking control to the switches the PWM pulses to the switches is shown in the below Figure 6.

4. Simulated circuit design and output waveforms

The proposed single stage double switch in single phase grid connected inverter is simulated using MATLAB/SIMULINK is shown in the Figure 7. The system elaborates the input side PV generation is fed in to the proposed SSDS buck converter and the step down voltage is interfaced with the grid using the inverter topology and the isolation is corrected by PLL technique, and through the inverter AC output is obtained.
Figure 7. Overall Simulink model for the proposed design

Figure 8. Shows the waveform of the generated power from PV (1Soltech 1STH-215-P) module, Figure 8(i) refer the input voltage of 363V, and 8(ii) & 8(iii) represents the current and power waveforms.

Figure 8. Generated input (i) Voltage (ii) Current (iii) Power
Figure 9. DC Link (i) voltage (ii) Current (iii) Power

Figure 9. Shows the graph of DC capacitor link parameters of PV and Grid side, in that Figure 9. (i) Shows the voltage waveforms which has maintained constant for interfacing to grid, Figure 9. (ii) & Figure 9. (iii) Waveform outputs the link current and power.

Figure 10. Phase Locked Loop (PLL) pulse

Figure 11. Active power and Reactive power at the output
Figure 10. Shows the PLL Pulse waveforms which controls the grid interface inverter and makes synchronization between the generation and grid side, Figure 11. Shows the active and reactive power at the inverter side and Figure 12. (i) Shows the inverter output produced at positive peak of 150V which is a step-down output from the input side, Figure 12. (ii) Inverter output current.

5. Conclusions

In the above proceedings, a single phase grid connected photovoltaic inverter with single stage double switch converter is presented. This system had a non-isolated DC-DC step down and a single phase inverter for DC to AC conversion. The control algorithm of MPP tracking were implemented in order to produce maximum input by performing the controlling of frequency of input switches. The advantage of designing using transformer less circuit avoided the leakage current, In the grid side the Phase Locked Loop (PLL) technique is implemented to provide the synchronization by estimating phase angle for the voltage grid reference. The simulation results shows that the input rated voltage generated by PV is 363V and by using the converter the voltage is step-down to 150 V AC at the output end, the output inverter and input solar radiance is always in phase with the grid.

Appendix

PV array parameters

PV Type: 1 Soltech 1STH-215-P
Parallel Strings: 40
Series-connected modules per string: 10
Maximum power: 213.15 W
Cell per module (N cell): 60

Open circuit voltage Voc (V): 36.3 V

Short-circuit current Isc (A): 7.84 A

Voltage at maximum power point Vmp (V): 29 V

Current at maximum power point Imp (A): 7.35 A

Temperature coefficient of Voc (%/deg.C): -0.36099 %/deg.C

Temperature coefficient of Isc (%/deg.C): 0.102 %/deg.C

Model Parameters

Light-generated current IL (A): 7.8649 A

Diode saturation current I0 (A): 2.9259 e-10

Diode ideality factor: 0.98117

Shunt resistance Rsh (ohms): 313.3991 ohms

Series resistance Rs (ohms): 0.39383

References

[1] M. A. Eltawil and Z. Zhao, “Grid-connected photovoltaic power systems: Technical and potential problems-A review,” Renewable and Sustainable Energy Reviews, 2010, doi: 10.1016/j.rser.2009.07.015.

[2] S. V. Araújo, P. Zacharias, and R. Mallwitz, “Highly efficient single-phase transformerless inverters for grid-connected photovoltaic systems,” IEEE Trans. Ind. Electron., 2010, doi: 10.1109/TIE.2009.2037654.

[3] N. F. Guerrero-Rodríguez and A. B. Rey-Boué, “Modelling, simulation and experimental verification for renewable agents connected to a distorted utility grid using a Real-Time Digital Simulation Platform,” Energy Convers. Manag., 2014, doi: 10.1016/j.enconman.2014.04.020.

[4] K.B. Bhaskar and T.S. Sivakumar 'Implimentation of 11 level cascaded multilevel inverter using level shifting pulse with modulation technique with different loads', International journal of electrical engineering(IPASJ),volume 2,issue 10 Nov 2014

[5] D. Debnath and K. Chatterjee, “A buck-boost integrated full bridge inverter for solar photovoltaic based standalone system,” 2013, doi: 10.1109/PVSC.2013.6745069.

[6] Bhaskar, K. B., &Alagumariappan, P. (2020). Energy Channeling Led Driver Technology to achieve Flicker Free Operation with Zeta Converter for Power Quality Improvement. International Journal of Automation and Smart Technology, 10(1), 401-407.

[7] P. Vivek, R. Ayshwarya, S. J. Amali, and A. S. N. Sree, “A novel approach on MPPT algorithm for solar panel using buck boost converter,” 2016, doi: 10.1109/ICEETS.2016.7583787.

[8] Paramasivam A., Bhaskar K.B., Madhanakkumar N., Vanchinathan C. (2020) Analysis of an Enhanced Positive Output Super-Lift Luo Converter for Renewable Energy Applications. In: Siano P., Jamuna K. (eds) Advances in Smart Grid Technology. Lecture
Notes in Electrical Engineering, vol 687. Springer, Singapore. https://doi.org/10.1007/978-981-15-7245-6_11

[9] Z. M. Yasin, N. Ashida Salim, and N. F. Ab Aziz, “Harmonic Distortion Prediction Model of a Grid-Connected Photovoltaic Using Grey Wolf Optimizer - Least Square Support Vector Machine,” 2019, doi: 10.1109/ICPES47639.2019.9105398.

[10] Alagumariappan, Paramasivam, Najumnissa Jamal Dewan, GughanNarasimhanMuthukrishnan, Bhaskar K. Bojji Raju, Ramzan Ali Arshad Bilal, and VijayalakshmiSankaran. 2020. "Intelligent Plant Disease Identification System Using Machine Learning" Engineering Proceedings 2, no. 1: 49. https://doi.org/10.3390/ecsa-7-08160

[11] K. Biju and R. Ramchand, “Control of a novel single phase grid connected solar PV/battery hybrid energy system,” 2015, doi: 10.1109/ASCC.2015.7244436.

[12] H. Zhao, Q. Zheng, Y. Li, and D. Li, “Study on the Fast Phase-locked Technology Applied in Three-phase Grid-connected System,” Gaodianya Jishu/High Volt. Eng., 2018, doi: 10.13336/j.1003-6520.hve.20171227038.

[13] B. Perera, P. Ciufu, and S. Perera, “Advanced point of common coupling voltage controllers for grid-connected solar photovoltaic (PV) systems,” Renew. Energy, 2016, doi: 10.1016/j.renene.2015.09.028.