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POWER QUALITY ENHANCEMENT OF ON GRID SOLAR PV SYSTEM WITH Z SOURCE INVERTER

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Abstract

In this work, the fickleness of solar PV energy can be overcome by using the Maximum Power Point Tracking (MPPT) algorithm. Perturb and Observation (P&O) MPPT algorithm accomplish fast, the maximum power point for a rapid change of environmental conditions such as irradiance intensity and temperature. The MPPT algorithm applied to solar PV system keeps the boost converter output constant. The output from boost converter is taken to three phase Z-source inverter for the grid system. Z-source inverter performs the transformation of the variable DC output of the solar PV system into near sinusoidal AC output. This near sinusoidal AC output consecutively is served to a grid system. The simulation is carried out in Matlab/Simulink platform for grid system and the simulation results are experimentally validated for RL load arrangement only.

Keywords: Maximum Power Point Tracking (MPPT), Solar PV, Z-source inverter.

1. Introduction

Among biomass, geothermal, hydro and solar energy, solar energy is considered to be the most hopeful energy substitute and a potential source for bulk power generation. Unfortunately, solar PV characteristics rely on ecological conditions like irradiance intensity and temperature [1]. The fickleness of solar energy transpires us to find an active method to leverage when it is accessible. The fickleness of solar energy can be overcome using the Maximum Power Point Tracking (MPPT) algorithm.

Perturb and Observation (P&O) MPPT algorithm can execute a maximum power point for rapid change in environmental conditions such as irradiance, intensity and temperature. Therefore, maximum power point tracking based inverter [2] is requisite between the solar PV energy system source and the grid system. Many methods and algorithms for tracking the maximum power from the solar energy system are available. According to Aashoor and Robinson [3], P&O and incremental conductance algorithms are commonly used for the reasons of their appropriateness and ease to realize the solar PV module.

The variable step size P&O has been brought in by Misron et al. [4] and Bounechba et al. [5] to resolve the problem of undulations near the maximum power point under steady-state conditions and poor tracking competency during changeable irradiance traditional P&O algorithms. The various families of power converters have been intended to interface the renewable solar resource for different applications [6]. Owing to the development of power electronics and embedded system techniques, control and implementation of renewable energy systems are made promising.

2. Z-Source Inverter

Z-source inverter shown in Fig. 1 [7] has impedance-network on its DC side. The exclusive impedance network consists of passive components (Inductors and Capacitors) that give single-stage conversion.

A second-order filter, which handles the unwanted voltage sags in a DC voltage source is formed by the impedance network. It reduces the harmonics in the current, due to dual inductors in Z-source network as well as inrush current [8, 9].

The existence of two inductors and capacitors in Z-source network permits both the switches in the same leg in ON state, concurrently named as “shoot through state”. This state provides a boosting ability to the inverter without destructing the switching devices.

In this state, energy is transmitted from capacitor to inductor and hence, Z-source network gains the voltage boosting ability. A diode is mandatory to avoid the discharge of the charged capacitor through the source. The major advantages of Z-source inverter [10, 11] are:

- Can step down (buck) or step up (boost) voltage outputs, which are not possible with voltage source and current source inverters.
- Produce any anticipated voltage outputs, more than the line voltage, irrespective of the voltage input, thus, lessen the ratings of the motor.

- It provides ride-through at the instance of voltage sags minus any additional circuits.
- Less affected by Electro Magnetic Inference (EMI) noise.
- Improves power factor and reduces harmonic current.

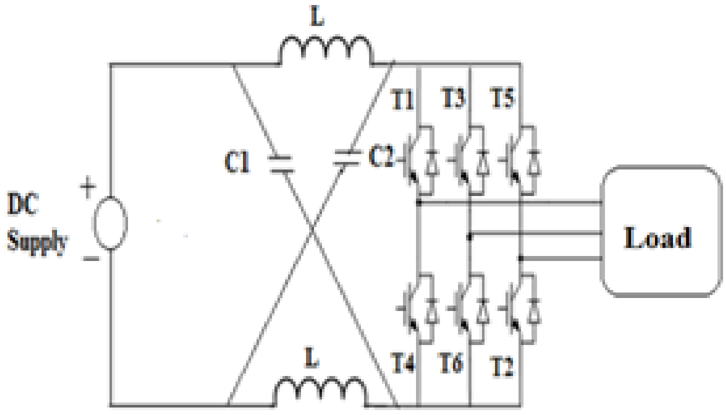

Fig. 1. Schematic of Z-source inverter.

3. Methodology

The output from the solar PV system is fed as an input to boost converter. The MPPT algorithm is applied to a solar PV system in order to keep the boost converter output constant [12]. The output from boost converter is taken first to three phase Z-source inverter with load arrangement and then to the grid system. The three-phase Z -source inverter is operated in closed loop control for voltage and frequency synchronization.

Eventually, three phase Z-source inverter output with LC filters produces a sinusoidal output, which is first fed to the load and then to the grid system. Thus, a control algorithm with a boost converter and three phase Z-source inverter are proposed to utilize the renewable energy resource at their maximum level.

The proposed three-phase Z-source inverter can either buck or boost AC output, a scenario that could not be achieved in conventional Current Source and Voltage Source Inverters [13] (CSI and VSI). Moreover, Z, a network of the three-phase Z-source inverter comprising of a pair of capacitors and inductors forms the second order filter that filters unwanted voltage sags thereby, reducing the current total harmonic distortion and improving the quality of power. Consequently, enhanced power quality without sag and lesser current total harmonic distortion are given to grid system [14, 15].

Among the different controllers, the PID controller is proposed for grid-connected solar PV based Z-source inverter system [16, 17]. PD and PI controllers improve transient and steady-state responses respectively. Henceforth, a combination of both PD and PI controllers improves overall time response of the system. However, it affects both transients as well as the steady-state performance of the system. For effective result, it must be tuned properly. There is no offset error in this controller. It makes the system response faster and reduces the settling time.

4. Results and Discussion

Kamalakkannan and Kirubakaran [18] explained that the Simulink model of the solar system with closed-loop PID controller for the grid system is carried out by means of MATLAB software. The simulation parameters of constructing boost converter and Z-source inverter are tabulated below in Table 1.

The closed-loop Simulink model shown in Fig. 2 comprises of solar PV model, a boost converter, Z-source inverter (Z-filter and three-phase inverter), PID controller, RL Load, grid system, etc., is aimed for a switching frequency of 5 kHz and the outcomes of the same are presented below. The output voltage of 40 V from solar PV panel is given to boost converter where it is boosted to nearly 80 V as shown in Figs. 3 and 4.

Table 1. Simulation parameters of converter and inverter.

Boost converter	Z-filter	Z-source inverter
V_{in} = 40 V		L_1, L_2, L_3= 800 mH
C_1 = 1000 µF	C_1, C_2= 3000 µF	
L_1 = 15 µH		C_1, C_2, C_3=10 µF
C_s = 0.6 mF		
C_{out} = 3000 µF	L_1, L_2= 100 mH	R = 10 Ω
V_o = 80 V		L = 800 mH

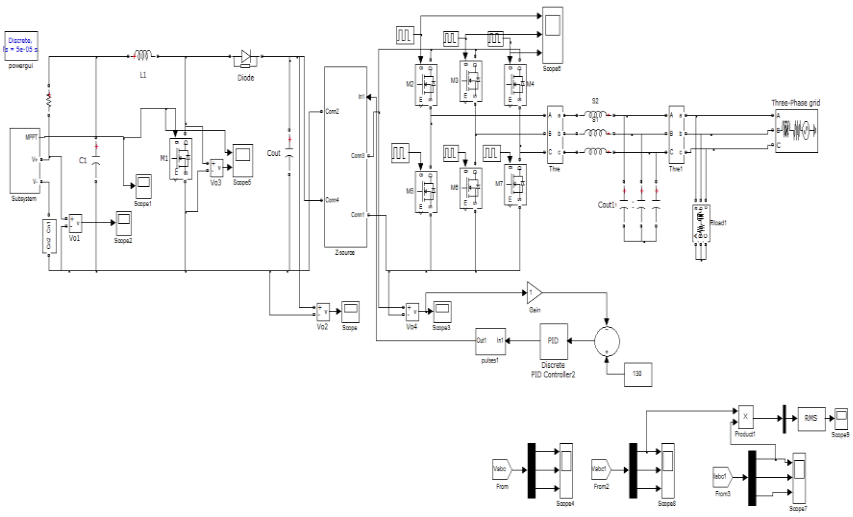

Fig. 2. Simulink model-solar system with closed-loop PID controller for grid system.

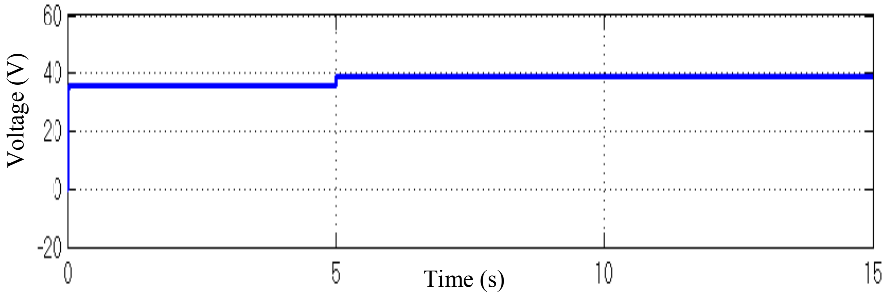

Fig. 3. Output voltage of solar PV panel.

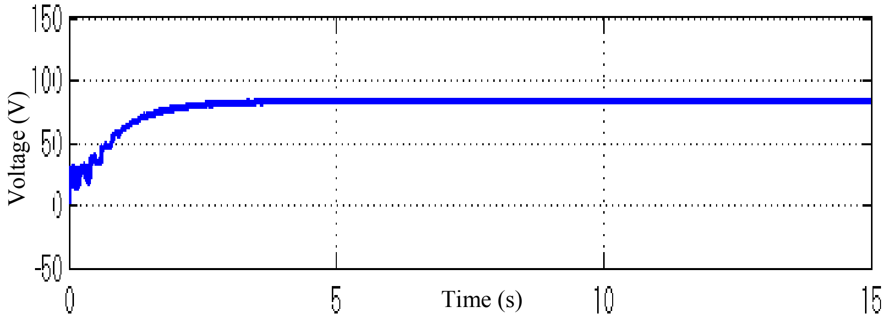

Fig. 4. Output voltage of boost converter.

The firing pulses for three MOSFET switches viz. M_1, M_3 and M_5 of the three-phase inverter, a part of Z-source inverter are shown in Fig. 5. The three output voltages displaced by a certain degree of the three-phase inverter is shown in Fig. 6. The output voltage across the connected grid and output current through the connected grid are shown in Figs. 7 and 8.

The FFT analysis is obtained as in Fig. 9 for a solar PV system with closed-loop PID controller for the grid system. The current total harmonic distortion with the PID controller is 3.05%, which is within an acceptable level.

Figure 10 is a prototype hardware model of Z-source inverter for solar PV energy system. It consists of a solar PV panel, a boost converter, Z-source inverter (Z-filter and three-phase inverter), control circuitry and RL load arrangement.

The PIC controller circuitry is preferred for this solar PV energy system for the creation of all control signals to boost converter and Z-source inverter. These signals are amplified by driver ICs. The input voltage required both by driver and controller circuitries is provided by the voltage regulator. The output voltage across RL load is shown in Fig. 11.

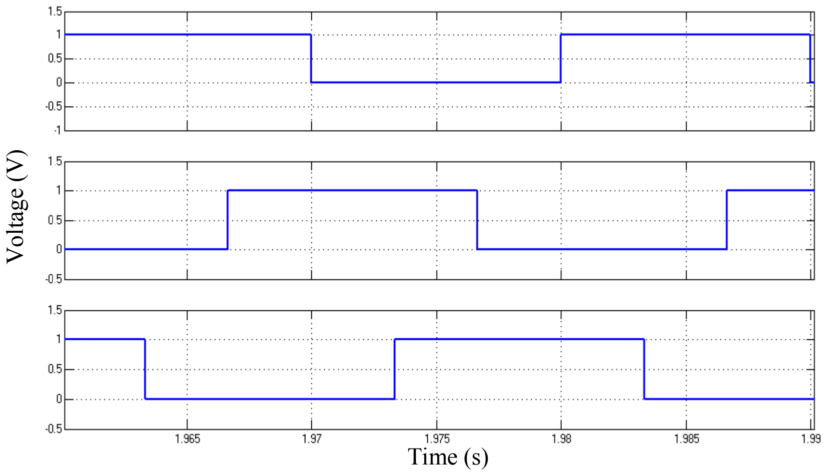

Fig. 5. Firing pulses for three-phase inverter (M_1, M_3 and M_5).

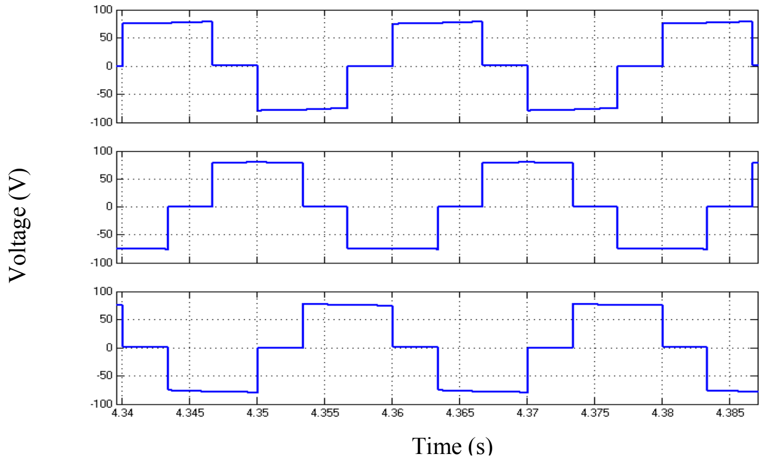

Fig. 6. Output voltage of three-phase inverter.

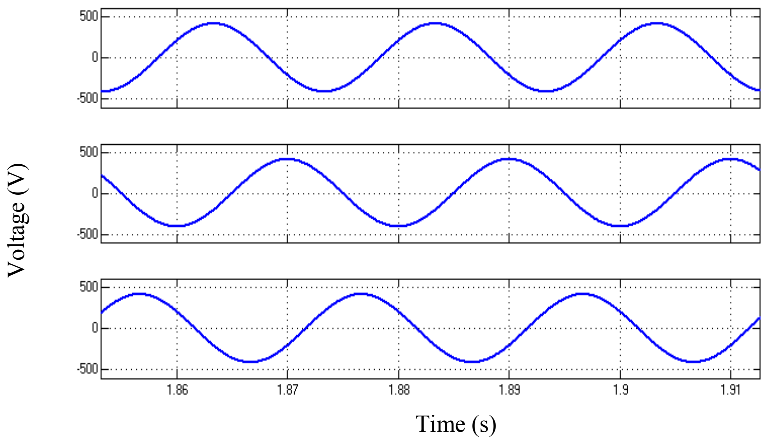

Fig. 7. Output voltage across grid system.

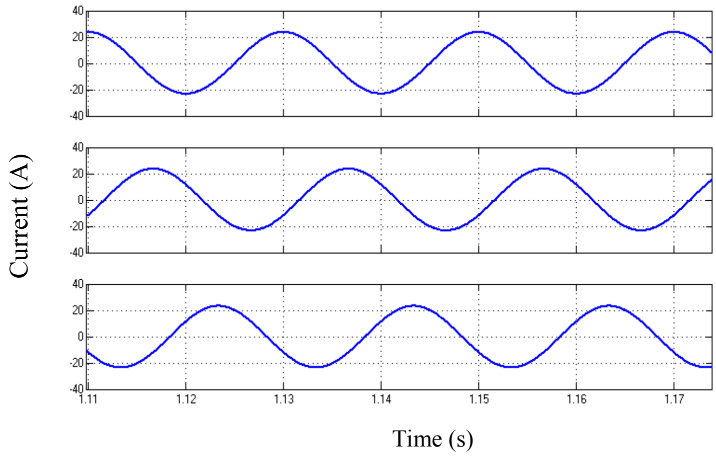

Fig. 8. Output current through grid system.

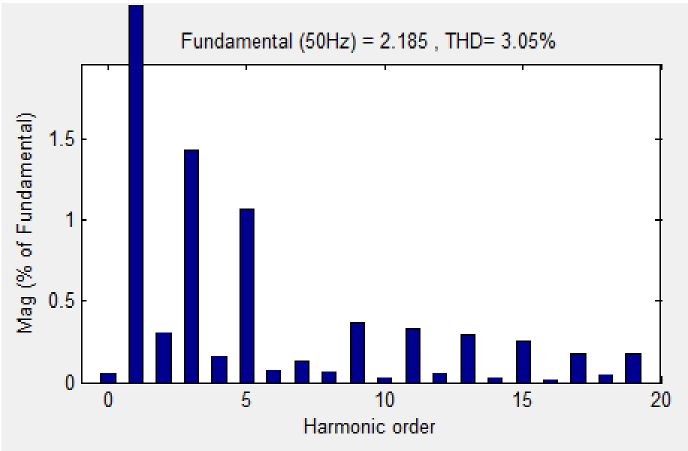

Fig. 9. Analysis of current THD.

Fig. 10. Prototype hardware model-
Z-source inverter for solar energy system.

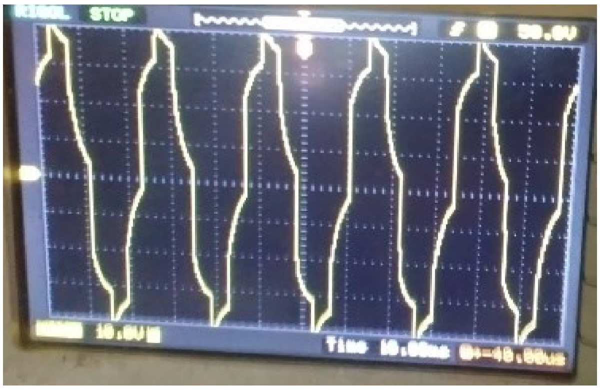

Fig. 11. Output voltage across RL load.

5. Conclusions

A solar PV based Z-source inverter with a PID controller for a grid system is analysed. The accomplishment demonstrates that the current total harmonic distortion of the system was within an acceptable level. Digital simulation and prototype hardware modelling of solar PV based Z-source inverter with PID controllers is established and the outputs are obtained under transient and steady state conditions. The future enhancement of this work is to simulate the wind energy conversion system of the system proposed.

References

1. Patel, M.R. (2005). *Wind and solar power systems. Design, analysis and operation* (2nd ed.). Boca Raton, Florida, United States of America: CRC Press.
2. Gules, R.; Pacheco, J.D.P.; Hey, H.L.; and Imhoff, J. (2008). A maximum power point tracking system with parallel connection for PV stand-alone applications. *IEEE Transactions on Industrial Electronics,* 55(7), 2674-2683.
3. Aashoor, F.A.O.; and Robinson, F.V.P. (2012). A variable step size perturb and observe algorithm for photovoltaic maximum power point tracking. *Proceedings of the 47th International Universities Power Engineering Conference (UPEC).* London, United Kingdom, 1-6.
4. Misron, N.; Vaithilingam, C.A.; Mailah, N.F.; Masaya, K.; and Hanamoto, T. (2016). A new maximum power point estimator (MPPT) control strategy to maximise output power of the double stator permanent magnet generator. *Journal of Applied Sciences,* 6(8), 12 pages.
5. Bounechba, H.; Bouzid, A; Nabti, K.; and Benalla, H. (2014). Comparison of perturb and observe and fuzzy logic in maximum power point tracker for PV systems. *Energy Procedia*, 50, 677-684.
6. Hajibeigy, M.T.; Vaithilingam, C.A.; Al-Atabi, M.; and Hoole, P. (2017). Heat response model for phase layered topology in a photovoltaic thermal system. *Indonesian Journal of Electrical Engineering and Computer Science*, 7(1), 52-60.
7. Peng, F.Z. (2003). Z-source inverter. *IEEE Transactions on Industry Applications,* 39(2), 504-510.

8. Gao, Z.; Shen, K.; Wang, J.; and Chen, Q. (2010). An improved control method for inductive load of Z-source inverter. *Proceedings of the Asia-Pacific Power and Energy Engineering Conference.* Chengdu, China, 1-4.
9. Sedaghati, F.; and Babaei, E. (2011). Double input Z-source DC-DC converter. *Proceedings of the 2nd Power Electronics, Drive Systems and Technologies Conference.* Tehran, Iran, 581-586.
10. Gharakhany, R.; Mohamadian, M.; and Varjani, A.Y. (2009). Reactive power compensation using Z-source based PV system. *Proceedings of the IEEE Power and Energy Society General Meeting*. Calgary, Canada, 1-7.
11. Rabi, B.J.; and Arumugam, R. (2005). Harmonics study and comparison of Z-source inverter with traditional inverters. *American Journal of Applied Sciences*, 2(10), 1418-1426.
12. Hajibeigy, M.T.; Aravind, C.V.; and Walveka, R.G. (2018). Proposed framework of hybrid photovoltaic thermal systems to ecotourism in Malaysia. *Proceedings of the 9th Eureca International Engineering Research Conference*. Selangor, Malaysia, 11 pages.
13. Marshal, J.; and Deepa, K. (2012). Single input DC-DC converter for hybrid distributed energy generators with maximum utilization using DSP controller. *International Journal of Engineering Research and Applications* (IJERA)*,* 2(4), 989-993.
14. Yang, S.; Feng, F.Z.; Lei, Q.; Inoshita, R.; and Qian, Z. (2010). Current-fed quasi-Z-source inverter with voltage buck-boost and regeneration capability. *IEEE Energy Conversion Congress and Exposition.* San Jose, California, United States of America, 3675-3682.
15. Aravind, C.V.; Al-Atabi, M.; Ravishankar, J.; Malik, A.; Arkar; and Ambikairajah, E. (2013). Eco-tourism sustainability through PV technology: A comprehensive review. *Journal of Engineering Science and Technology* (JESTEC), 8(6), 654-669.
16. Chen, Y.-M.; Liu, Y.-C.; Hung, S.-C.; and Cheng, C.-S. (2007). Multi-input inverter for grid connected hybrid PV/wind power system. *IEEE Transactions on Power Electronics*, 22(3), 1070-1077.
17. Aravind, C.V.; Al-Atabi, M.; Arasan; and Ramesh, G.P. (2014). The case of the energy solution to the eco-tourism model for sustainable development using PV/T technology. *International Journal of Scientific and Engineering Research* (IJSER), 5(4), 174-177.
18. Kamalakkannan, S.; and Kirubakaran, D. (2015): Comparative analysis of grid connected photovoltaic based Z-source inverter with PI and PID controllers. *Journal of Computational and Theoretical Nanoscience*, 14(1), 577-584.