Pakistan Journal of Engineering and Technology, PakJET
Multidisciplinary & Peer Reviewed
Volume: 04, Number: 01, Pages: 112- 116, Year: 2021

Modeling and Analysis of FPGA Based PID Controlled DC-DC SEPIC Converter and 3 Phase VSI for Electric Vehicles

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Abstract-: **Renewable energy sources have high demand in recent years. The Power converters are the bridge between renewable sources of energy and electric vehicles. The designing and modeling of the controller for SEPIC and three-phase voltage source inverters (VS) are discussed in this paper. THE FPGA based PID controller is for SEPIC converter while space vector pulse width modulation (SVPWM) technique is implemented for three-phase voltage source inverters (VSI). The SEPIC converter is feed from a solar power panel and regulates the voltage, which again feeds to the three-phase voltage source inverter (VSI). The three-phased induction motor is driven by supplying power from SVPWM based three-phase VSI, which drives the shaft of an electric vehicle.**

Index Terms-- **FPGA, PID, SVPWM, SEPIC.**

I. INTRODUCTION:

Nowadays, great attention has been paid to renewable energy sources because of the disadvantages of fossil fuels [1], [2], [3]. The bridge rectifiers use diodes for rectifications, which are being fed to DC-DC converters to regulate the output voltage. These rectifiers possess more conduction losses so, bridgeless topologies will be preferred [4]. The bridgeless converters can control the voltage at its output in the broader range. Cuk and buck-boost converters give negative polarity at their output, and the zeta converter possesses high EMI issues due to any other switching devices placed near it [5]. Simultaneously, single-ended primary inductance converter (SEPIC) of the same category possess output voltage with positive polarity and have the least EMI issues compared to the above topologies. In literature, the SEPIC converter is used with a PV system using MPPT [6], [7]. In this paper, the SEPIC converter will feed to 3 phase VSI, which drives an electric vehicle's induction motor. The space vector pulse width modulation (SVPWM) technique is widely used to control motors. The Voltage/frequency is the control strategy of the inverter. The SVPWM provides high torque at the higher speed of motors with better efficiency [8].

II. DESIGN OF SEPIC CONVERTER:

The SEPIC converter elements are a MOSFET, a diode, two inductors (L_1, L_2), and two capacitors (C_1, C_2), the circuit topology is shown in figure1. The capacitor C_1 acts as a DC isolation, which isolates input and output [9]. Since the SEPIC converter operates in CCM, two switching modes will be considered, and the circuit of each switching state is shown in figure 2. When S_1 is closed, then inductors L_1 and L_2 will be charged through supply voltage in capacitor voltage V_{C1}. Contrary, when switch S_1 will be opened, the capacitors C_1 and C_2 will be discharged through L_1 [9].

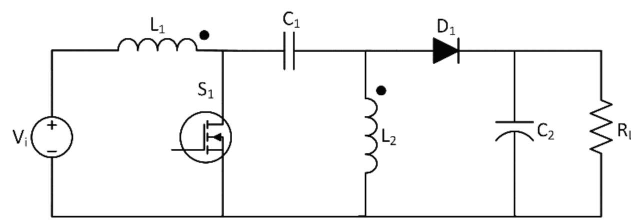

FIGURE 01. Circuit diagram of sepic converter [9]

III. FPGA BASED PI CONTROLLER FOR SEPIC CONVERTER:

The PID is the linear type of controller, which controls the process/ plant. The proportional integral derivative (PID) controller consists of three parameters 1. Proportional (P) 2. Integral (I) and (3) Derivative (D). By tuning the Kp, Ki, and Kd values, any process or plant can be controlled or regulated. There are several tuning methods, and out of them, the conventional one, which is the trial and error method, will be used for tuning Kp, Ki, and Kd values of the PID controller[10].

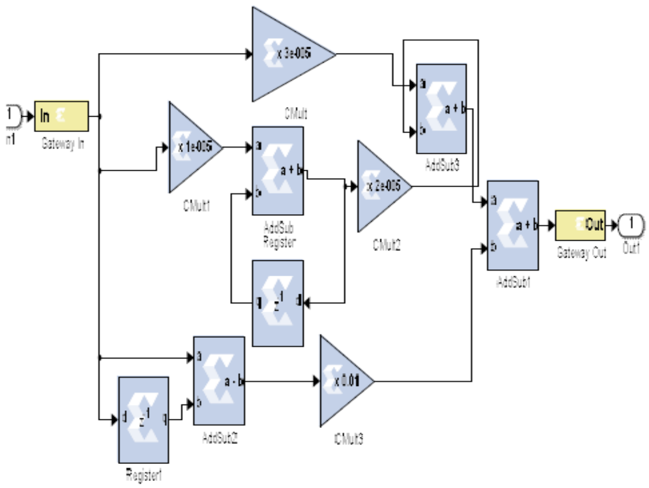

FIGURE 2. PID controller design using Xilinx system generator MATLAB toolbox [10]

IV. DESIGN OF 3 PHASES VSI:

The three phases VSI is shown in the figure contain 6 MOSFETs with three legs, and each leg includes two switches. The upper three switches and lower three switches are complementary to each other, as shown in figure

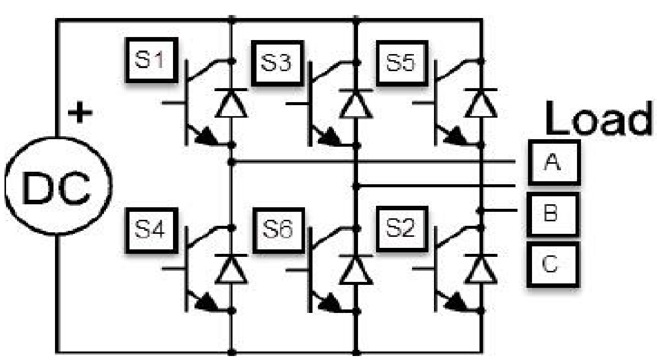

FIGURE 3. Conventional Three Phase Inverter [9]

V. CONTROLLER DESIGN FOR 3 PHASES VSI:

The 3 phase quantities can be converted into 2 phase quantities like into alpha-beta frame or DQ frame. From these stationary or synchronously rotating frames [11], the reference vectors of voltage and current can be calculated.

The three-phase vector components can be:

$$V_a = V_m \sin wt \qquad 1$$

$$V_b = V_m \sin\left(wt - \frac{2\pi}{3}\right) \qquad 2$$

$$V_c = V_m \sin\left(wt - \frac{4\pi}{3}\right) \qquad 3$$

The interchange of switching vector [a, b, c] and line-line voltage [Vab, Vbc, Vca] can be done by:

$$K_s = \frac{2}{3}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{-\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

The 3 phase voltage vectors [a, b, c] can be calculated from phase voltage vectors by using the formula:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$$

For the upper switches of each three-phase leg, there are eight switching combinations, while for the lower three switches, their switching pattern is opposite to that of the upper switches. Hence, if the switching pattern of upper switches is known then lower switches pattern can be easily calculated.

TABLE 1. Switching pattern, Line to line voltage, Line to ground voltage

Vectors Of Voltage	Switching Vectors			Phase Voltage			Line Voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_{-0}	*Low*	*Low*	*Low*	0	0	0	0	0	0
V_{-1}	*High*	*Low*	*Low*	0.66	-0.33	-0.33	1	0	−1
V_{-2}	*Low*	*High*	*Low*	0.33	0.33	-0.66	0	1	−1
V_{-3}	*Low*	*High*	*Low*	-0.33	0.66	-0.33	−1	1	0
V_{-4}	*Low*	*High*	*High*	-0.66	0.33	0.33	−1	1	1
V_{-5}	*Low*	*High*	*High*	-0.33	0.33	0.66	0	−1	1
V_{-6}	*Low*	*Low*	*High*	0.33	-0.66	0.33	1	−1	0
V_{-7}	*High*	*Low*	*High*	0	0	0	0	0	0

VI. DESIGN AND IMPLEMENTATION OF SVPWM

The SVPWM technique can be implemented in MATLAB by following steps:

1. Calculation of V_d, V_q, V_{ref} and alpha angle.
2. Calculation of time duration of T_1, T_2 and $T_{0.}$
3. Calculation of switching time Ts.

For step No.01, the Vd and Vq and Vref can be calculated as:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}.$$

And Vref as:

$$\therefore |\overline{V}_{ref}| = \sqrt{(V_d^2 + V_q^2)}.$$

In step No.02, T1, T2, and T_o can be calculated as:

$$Tz.|\overline{\nabla}_{ref}| * \begin{bmatrix} \cos(\alpha). \\ \sin(\alpha). \end{bmatrix} = T_1 * \frac{2.}{3.} * V_{dc} \begin{bmatrix} 1. \\ 0. \end{bmatrix} + T_2 * \frac{2.}{3.} * V_{dc} \begin{bmatrix} \cos\left(\frac{\pi}{3}\right). \\ \sin\left(\frac{\pi}{3}\right). \end{bmatrix}$$

$$\therefore T_1 = T_z.a.\frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \qquad (where, 0 \le \alpha \le 60^0)$$

$$\therefore T_2 = T_z.a.\frac{\sin\left(\frac{\pi}{3}\right)}{\sin\left(\frac{\pi}{3}\right)}$$

$$\therefore T_0 = T_z - (T_1 + T_2)\left(where, T_z = \frac{1}{f_z} \; and \; a = \frac{|\overline{\nabla}_{ref}|}{\frac{2}{3}.V_{dc}}\right)$$

[12], [13], [14]

In step No.03 switching time of each switch

Sector.1: In the first sector, the switch S1 is closed but switches S3 and S5 will remain open. But lower three switches will act as complementary to the above switches

Sector.2: In the second sector, the switch S3 is closed, but S1 and S5 will be opened. The lower three switches will acts as opposed to the above switches.

Sector.3: In the third sector, the switch S1 and S3 will be closed, and switch S5 will be opened. But the lower half of the three switches will operate as opposed to the upper switches

Sector.4: In the fourth sector, the switch S5 is closed while switch S1 and S3 will remain open. But the lower half of the three switches will act as complementary to the upper switches

Sector.5: In the fifth sector, the switch S1 and S5 will be closed while switch S3 will remain open. But lower three switches will act as complementary to the above switches.

Sector.6: In the sixth sector, the switch S1 is opened while switch S3 and S5 will be closed. But lower three switches will act as complementary to the above switches.

VII. SIMULATION RESULTS AND DISCUSSIONS:

The model of the complete system is detailed here by the following statement and also shown in fig. 09. The DC-DC SEPIC converter takes power from a solar panel as input sources of energy; it then regulates out voltage at the desired output voltage. The controller for SEPIC converters is FPGA based PID controller. Again the output SEPIC is fed to a three-phase voltage source inverter (VSI), which is being controlled by the most popular control technique for motors speed control is the Space vector pulse width modulation technique. The 3 phase VSI will supply energy to the three-phase induction motor to drive any application.

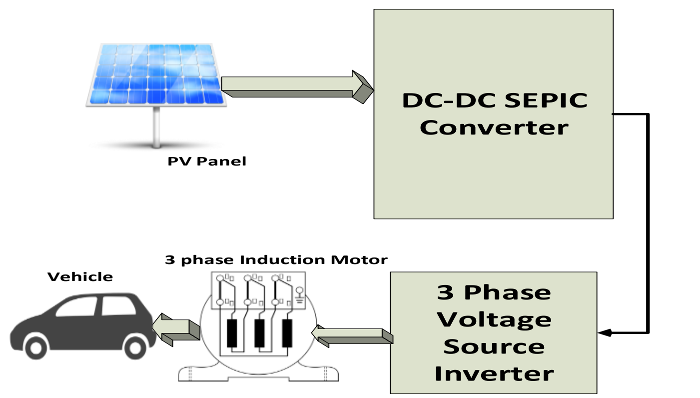

FIGURE 4. Flow of the Whole system.

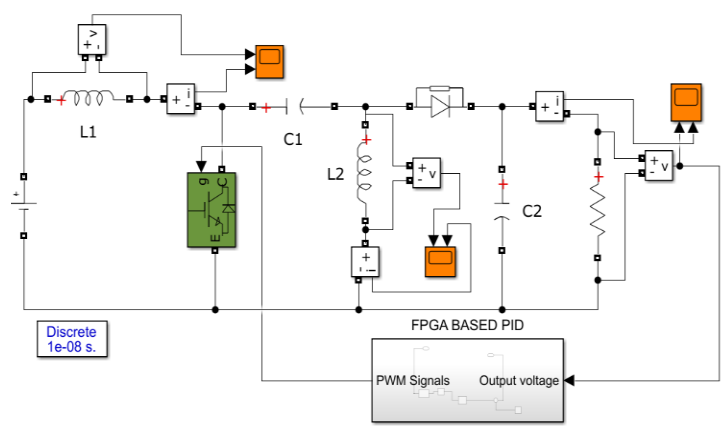

FIGURE 5. MATLAB simulation of FPGA based SEPIC converter

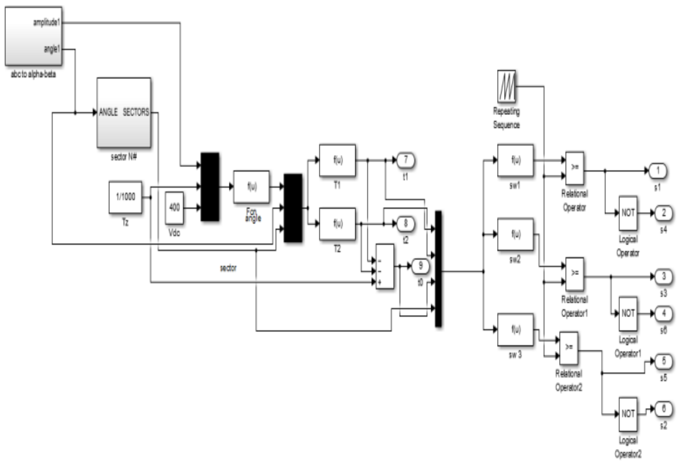

FIGURE 6. SVPWM complete design system

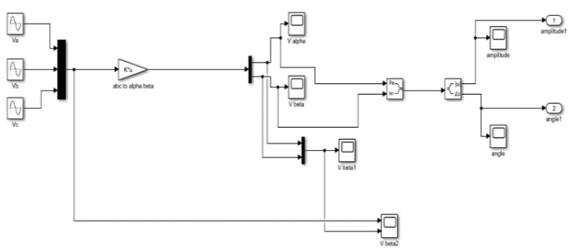

FIGURE 7. Step 01: conversion from three-phase into two-phase using MATLAB Simulink

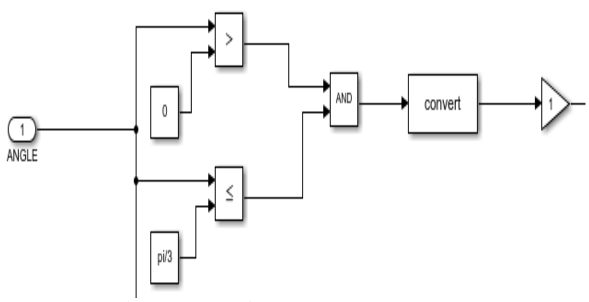

FIGURE 8. Step02: Design of a Sector using MATLAB Simulink

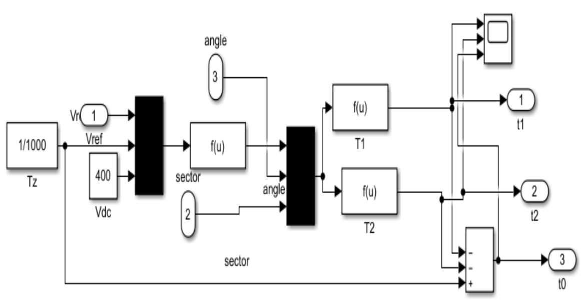

FIGURE 9. Step 04: Switches operation in different sectors.

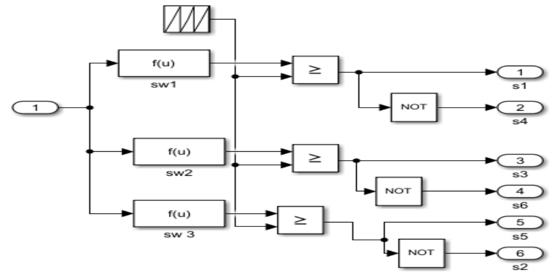

FIGURE 10. PWM signals generations

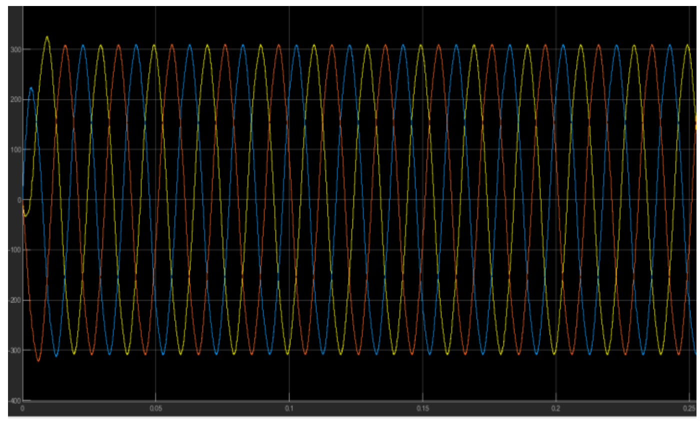

FIGURE 11. Waveform of voltage at 3 phase (Ø) VSI

Three Phase Induction Motor performances:
The three-phase induction motor is operated feed from three-phase VSI and tested on five different loading conditions. In the first instance, there is no load, no motor, on second instant load increases and in third and fourth instants further load is shaded, and in a fifth instant, there will be no load again. These five instants are tested on the MATLAB simulations as shown in fig.16 and fig.17.

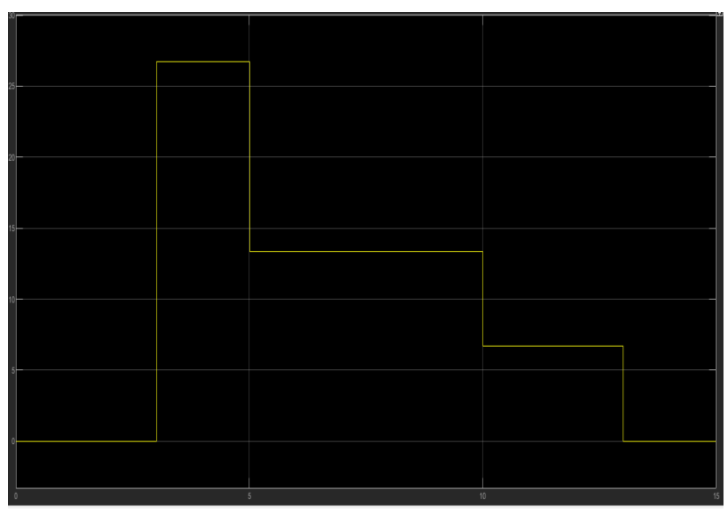

FIGURE 12. loading instants on the motors

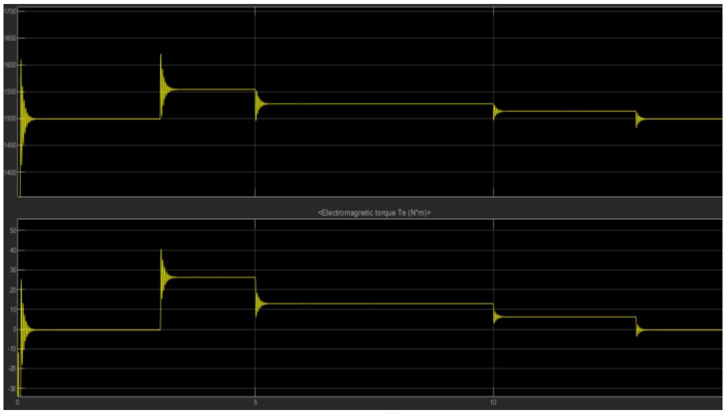

FIGURE 13. Speed Vs. torque on different loading conditions

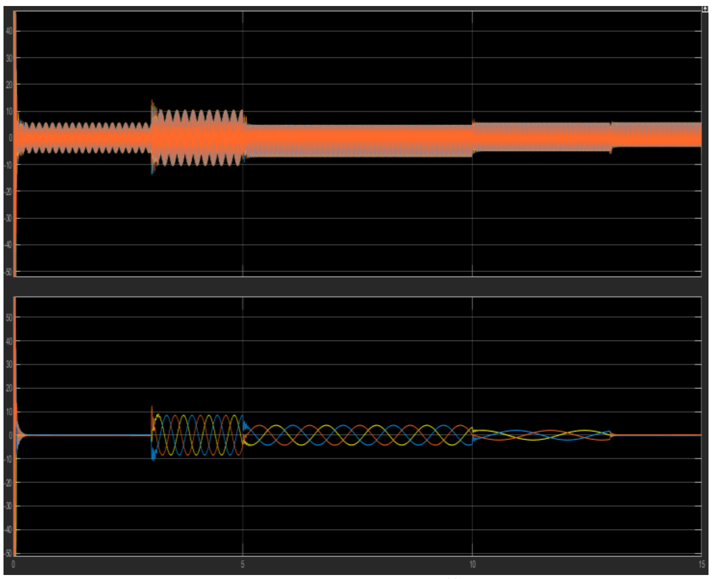

FIGURE 14. Stator current and rotor current on different loading conditions

VIII. CONCLUSION:

The PV system supplies power to the SEPIC converter, regulating the output voltage and providing it to the three-phase voltage source inverter. In turn, the three-phase VSC feeds to the three-phase induction motor, which can turn the shaft of the vehicle. The results of different parts have shown step by step. The Induction motor is tested on multiple loading conditions, and its torque increases as the load increases while speed decreases. The stator and rotor current also increases as the load increase, and they decrease as the load on the motor decreases.

REFERENCES:

[1] C. Schuss, T. Fabritius, B. Eichberger and T. Rahkonen, “Impacts on the Output Power of Photovoltaics on Top of Electric and Hybrid Electric Vehicles,” in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 5, pp. 2449-2458, May 2020, DOI: 10.1109/TIM.2019.2962850.

[2] Z. Q. Zhu and S. Cai, “Hybrid excited permanent magnet machines for electric and hybrid electric vehicles,” in CES Transactions on Electrical Machines and Systems, vol. 3, no. 3, pp. 233-247, Sept. 2019, DOI: 10.30941/CESTEMS.2019.00032.

[3] Y. Zhao, X. Xiang, W. Li, X. He, and C. Xia, “Advanced symmetrical voltage quadrupler rectifiers for high step-up and high output-voltage converters,” *IEEE Trans. Power Electron.*, vol. 28, no. 4, pp. 1622– 1631, 2013.

[4] M. V. Mosconi Ewerling, T. Brunelli Lazzarin, and C. H. Illa Font, “Proposal of an Isolated Two-Switch DC-DC SEPIC Converter,” 2019 IEEE 15th Brazilian Power Electronics Conference and 5th IEEE Southern Power Electronics Conference (COBEP/SPEC), Santos, Brazil, 2019, pp. 1-6, DOI: 10.1109/COBEP/SPEC44138.2019.9065718.

[5] C. Muranda, E. Ozsoy, S. Padmanaban, M. S. Bhaskar, V. Fedák and V. K. Ramachandaramurthy, “Modified SEPIC DC-to-DC boost converter with high output-gain configuration for renewable applications,” 2017 IEEE Conference on Energy Conversion (CENCON), Kuala Lumpur, 2017, pp. 317-322, DOI: 10.1109/CENCON.2017.8262505.

[6] Mahajan Sagar Bhaskar Ranjana, Nandyala SreeramulaReddy and Repalle Kusala Pavan Kumar, “A novel sepic based dual output DC-DC converter for solar applications,” 2014 POWER AND ENERGY SYSTEMS: TOWARDS SUSTAINABLE ENERGY, Bangalore, 2014, pp. 1-5, DOI: 10.1109/PESTSE.2014.6805309.

[7] T. Ajith Bosco Raj, R. Ramesh, J. R. Maglin, M. Vaigundamoorthi, I. William Christopher, C. Gopinath, C. Yaashuwanth, “Grid Connected Solar PV System with SEPIC Converter Compared with Parallel Boost Converter Based MPPT,” International Journal of Photoenergy, vol. 2014, Article ID 385720, 12 pages, 2014. https://doi.org/10.1155/2014/385720.

[8] H. Chen et al., “A Novel Hybrid SVPWM Modulation Algorithm for Five-Level Active Neutral-Point-Clamped Converter,” 2019 IEEE Applied Power Electronics Conference and Exposition (APEC), Anaheim, CA, USA, 2019, pp. 2494-2498, DOI: 10.1109/APEC.2019.8722112.

[9] O. Kircioğlu, M. Ünlü and S. Çamur, “Modeling and analysis of DC-DC SEPIC converter with coupled inductors,” 2016 International Symposium on Industrial Electronics (INDEL), Banja Luka, 2016, pp. 1-5, DOI: 10.1109/INDEL.2016.7797807.

[10] Bhellar, S., Memon, Z., Memon, T., simulation, Y. B.-Comparative Analysis of PID and Fuzzy Logic Controller for Buck Converter. Estirj.Com, vol. 2, no. 1, pp.1–6, 2018.

[11] Y. Huang, Y. Xu, W. Zhang and J. Zou, “Modified Single-Edge SVPWM Technique to Reduce the Switching Losses and Increase PWM Harmonics Frequency for Three-Phase VSIs,” in IEEE Transactions on Power Electronics, vol. 35, no. 10, pp. 10643-10653, Oct. 2020, DOI: 10.1109/TPEL.2020.2975626.

[12] Y. Han, P. Shen, and J. M. Guerrero, “Stationary frame current control evaluations for three-phase grid-connected inverters with PVR-based active damped LCL filters,” J. Power Electron., vol. 16, no. 1, pp. 297–309, 2016, DOI: 10.6113/JPE.2016.16.1.297.

[13] S. Wang, J. Ma, B. Liu, N. Jiao, T. Liu and Y. Wang, “Unified SVPWM Algorithm and Optimization for Single-Phase Three-Level NPC Converters,” in IEEE Transactions on Power Electronics, vol. 35, no. 7, pp. 7702-7712, July 2020, DOI: 10.1109/TPEL.2019.2960208.

[14] S. Hussain, W. Ahmed, A. Khan, M. Shahanawaz, and R. Ali, “Simulative Analysis of Power Conversion System for Hybrid Electric Vehicles Based on Dual Input Sources Including Charging From Solar Panel ”, Pakistan J Engg & Tech, vol. 3, no. 03, pp. 14-19, Dec. 2020