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Simulation of Standalone Three-Phase Photovoltaic System with SPWM and SVPWM Techniques

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Abstract: ***Maximum power point tracking is a method employed to produce the utmost power available from the photovoltaic module. To date, many algorithms for maximum power point tracking technique had been stated, every with its own capabilities. In this paper, a Luo converter with high-voltage conversion gain is employed to track photovoltaic panels at maximum power and to step up the voltage to a higher level. This work also aims to validate the performance of the maximum power point tracking system with Luo converter which utilizes incremental conductance techniques. Space vector modulation and sinusoidal pulse width modulations are the control techniques employed to control the three-phase voltage source converter. In order to measure the overall performance indices of the proposed system, a simulation is carried out in MATLAB / Simulink environment.***

Keywords: DC-DC converter, Luo converter, Voltage source converter, Space vector modulations, Sinusoidal pulse width modulations.

I. INTRODUCTION

In this world, no step can be taken without the use of electricity. Electricity is very important for the normal existence of mankind, and human needs for electricity are constantly increasing, therefore, the energy is the object of close public attention; The problems of ensuring its safety and environmental friendliness are now worrying for wide sections of our society. A report by the united nations (UN) secretary-general on commodity trends says that in 2018, renewable energy grew by more than 4 percent and accounted for about a quarter of the development in total power demand [1]. And in the field of electricity, the share of “clean” sources increased by 45 percent. Switching to renewable sources of energy is crucial in order to reduce the share of fossil fuels, the use of which leads to an increase in greenhouse gas emissions. As we know, the concentration of carbon in the atmosphere causes global warming which turns into climate change.

It is known that the disadvantage of the photovoltaic system is the low power output of solar radiation due to changes in environmental conditions. A cheap and virtual solution for converting solar energy is to track the maximum power point (MPP) of the solar photovoltaic (PV) panel and generate the utmost output power from the PV panel [2–6]. Maximum power point tracking (MPPT) technology has become very fashionable in solar-based systems and, in fact, is the standard technology for autonomous or grid-connected inverters. This helps in ensuring that the output of the solar panel or array of the solar cells is at its peak / maximum. This is done using a continuous power tracking methodology in order to settle in the most optimal point of supply from solar panels. The perturb & observe (P&O) and incremental conductance (INC) techniques are frequently reported traditional techniques with certain benefits and pitfalls. P&O procedure has an issue of oscillations around MPP, because of that there is significant loss of electricity [7].

Working on the current / voltage-dependence curve anywhere else than MPP, the power output from the PV panel leads to a decrease in energy conversion efficiency and loss of available energy. Therefore, monitoring the MPP is a necessary function in advanced solar energy source control systems, as this can increase practical efficiency often by 30% or more. The intelligent controller is used to trace the MPP of the PV panel as it has the advent of being robust, relatively easy to model, and does not require the knowledge of an exact model.

In this paper, the modeling of the PV module with incremental conductance algorithm, DC-DC positive output super-lift Luo converter, and a voltage source converter (VSC) are used. In addition, space vector modulation (SVM) is employed for the control of VSC in the PV stand-alone system. Simulations run in Matlab/Simulink are presented with a comparison of sinusoidal pulse width modulation (SPWM).

II. MPPT TECHNIQUE: NECESSITY AND DESCRIPTION

A. Need of MPPT

In practice, the most widely used are photovoltaic systems without batteries. Battery-free photovoltaic systems are very reliable and virtually maintenance-free. In addition, they have maximum energy efficiency from solar panels - from 90 to 98%.

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In such systems, special inverters are used, driven by the network, which uses the network to form the reference voltage for their start-up and synchronization.

To obtain maximum power from photovoltaic panels, regardless of weather conditions, it is necessary to work with the MPPT. To achieve this, inverters used in solar panels must track the MPP, which will be the key to the maximum efficiency of the solar power system. Therefore, the method for checking the effectiveness of the panel-inverter system is MPPT inverter monitoring under any environmental conditions, that is, with changing solar radiation and temperature, which is a very difficult task. In addition, you need to make sure that the inverters used are able to convert the maximum power of solar cells by tracking MPPT.

The algorithms for working with the maximum power point MPPT are complex and testing them on solar panels operating in real conditions, with different lighting and temperature conditions, the process is quite long and expensive. Moreover, comprehensive testing in real conditions of various solar modules is practically impossible, since solar technology is constantly changing. Moreover, it is necessary to provide conditions for monitoring the MPPT point by the inverter. One of the main ways to increase the energy efficiency of photovoltaic plants is to implement the mode of selecting the maximum power at the corresponding point of the volt-ampere characteristic (I–V) of the solar cell. To power various electronic equipments, DC-DC converters (buck, boost, buck-boost type) are very widely used. They are used in computing devices, communication devices, various control and automation circuits, etc. These converters along with inverter or inverter alone as shown in Fig. 1 are employed in between the PV panel and load or grid. These converters use MPPT techniques to assure that the PV cells operate in MPP [8-12].

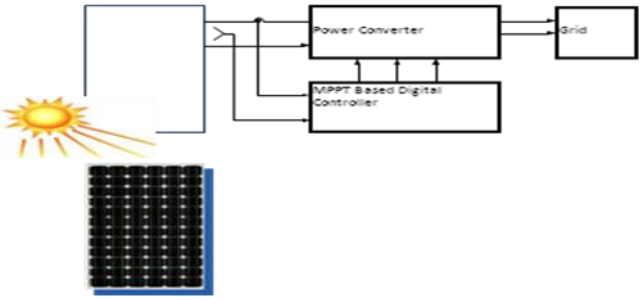


Fig. 1. Block diagram of photovoltaic system with power converter and MPPT controller

A Luo converter (DC-DC) is attached into a solar panel system to improve the output by way of executing an MPPT technique. Due to that, lots of researchers find various processes for MPPT for example P&O, INC, fractional open circuit voltage, fuzzy control, neural system controller and so on. Among all of the strategy, P&O and also INC techniques usually employed as an outcome of simple execution, lesser period to burn up the MPP and many other financial reasons [13,14].

This paper looks at the case of the INC algorithm [15]. The INC MPPT algorithms for finding the maximum power point are often used in converters to select the maximum power from an array of solar panels [16]. The paper provides a brief description of the operation of this algorithm, a description of the testing method based on mathematical modeling in the packages Matlab, Simulink and SimScape. The strengths and weaknesses of algorithm are identified. The results of modeling and comparative analysis of such algorithms are presented.

B. Incremental Conductance Algorithm

INC procedure is a trusted MPPT technique [17–20]. The disadvantage of the P&O procedure, of oscillation of operating purpose across MPP throughout changing environmental requirements can be improved from the INC procedure by assessing the instantaneous PV panel conductance (IPV/VPV) with the incremental PV panel conductance (dIPV/dVPV). The voltage corresponds to max power is monitored to meet dPPV/dVPV=0, and that is MPP. INC established algorithm is more advantageous along with other traditional methods since it's simple to execute, high-speed rate and much better efficiency [20]. Inside this INC MPPT algorithm, both the previous and present values of this solar power voltage and current are felt and therefore are utilised to calculate the worth of dIPV along with dVPV. The algorithm of the INC MPPT technique employed in the proposed PV integrated system is shown in Fig. 2. Fig. 3 shows the P-V relationship in INC MPPT technique.

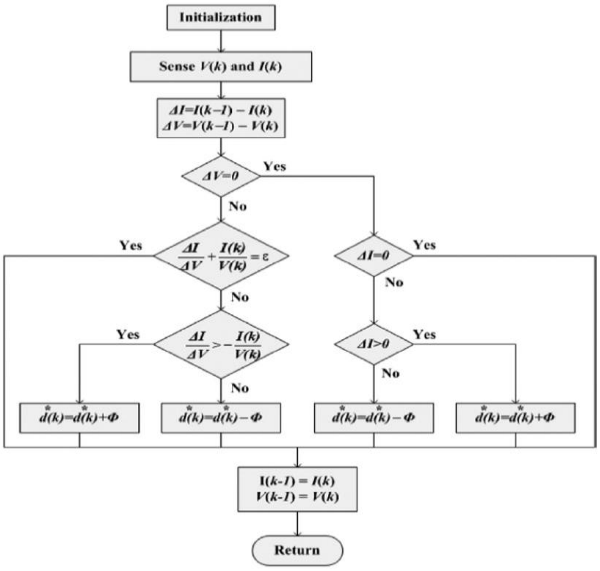


Fig. 2. Flowchart of INC MPPT method

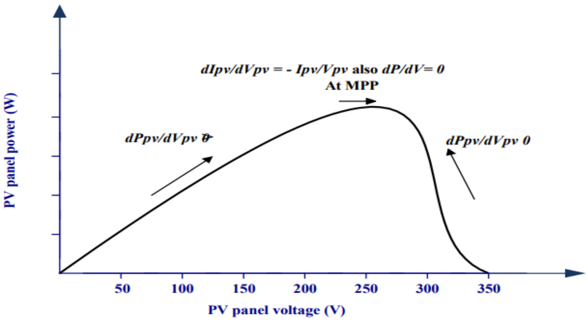


Fig. 3. P–V curve in INC based MPPT Technique

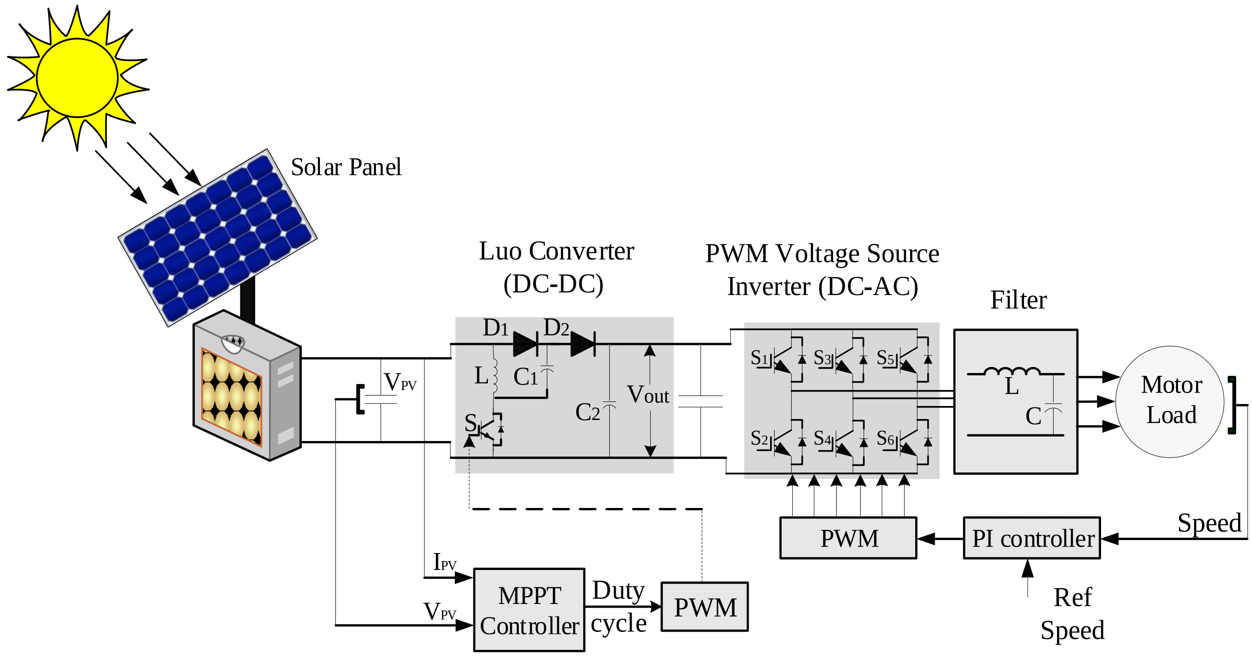


Fig. 4. Block diagram representation of PV system with power converters and INC MPPT tracking

III. PROPOSED PV SYSTEM DESCRIPTION

The proposed system consisting of a PV source, Luo converter, and VSC as depicted in Fig. 4. The PV panel connected with Luo converter. This boost converter tracks the PV panel output voltage and supports to attain the maximum power with the help of the INC MPPT technique. The PWM VSC (DC-AC) converter is converting DC to AC to be connected to either grid or AC load. The price of the PV system is linked to the total operating efficiency of the system defined as follows [21],

$$\eta_{Total} = \eta_{PV} \cdot \eta_{MPPT} \cdot \eta_{Inverter} \qquad (1)$$

$$= \frac{P_{PV}[W]}{G\left[\frac{W}{m^2}\right].A\left[m^2\right]} \cdot \frac{P_{MPPT}[W]}{P_{PV}[W]} \cdot \frac{P_{OUT}[W]}{P_{MPPT}[W]} \qquad (2)$$

where

η_{Total} - Total efficiency of the PV system

η_{MPPT} - Efficiency of the MPPT algorithm

$\eta_{Inverter}$ - Efficiency of the PV inverter

η_{PV} - Efficiency of the PV array

P_{PV} - Maximum power from the PV array

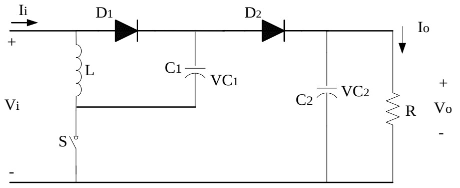
A. Solar Panel (DC Source)

An autonomous solar-powered power supply system seems very simple. This system uses a sun power 305-WHT panel with 96 cells and has a capacity of 100kW at 1000 W/m^2, 25°C.

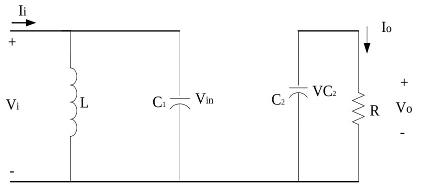
B. Luo Converter (DC-DC Converter)

The INC MPPT technique is implemented to control the Luo converter [22]. Predicated on the speed of modification of current and voltage, the duty ratio is either increased or diminished to achieve maximum capacity having a DC output voltage at the limit.

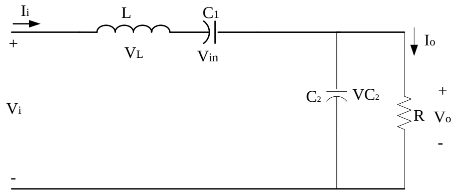
The equivalent circuits of elementary circuit during switch-off and on are shown in Fig. 5. The voltage across the capacitor C_1 is charged to V_{in}.



(a) Circuit diagram



(b) Switching-on



(c) Switching-off

Fig. 5. Positive output super-lift Luo converter

The current i_L passing through inductance L raises with voltage V_{in} during turn-on period kT and reduces with voltage $(V_O - 2V_{in})$ during switch off period (1 – k)T. Therefore, the ripple of the inductor current i_L is given as,

$$\Delta i_{L1} = \frac{V_{in}}{L} kT = \frac{V_o - 2V_{in}}{L}(1-k)T \qquad (3)$$

$$V_o = \frac{2-k}{1-k} V_{in} \tag{4}$$

The voltage transfer gain is,

$$G = \frac{V_o}{V_{in}} = \frac{2-k}{1-k} \tag{5}$$

C. Voltage Source Converter

A VSC is employed for converting direct voltage to alternating voltage and vice versa, which has at least one phase branch configured to connect to opposite poles on the DC voltage side of the converter. It consists of a series configuration of at least two current valves, and the valves contain at least one semiconductor device of the locking type and one rectifying element connected to it in string-parallel, and the midpoint of the series connection of the valves forming the phase output is configured to connect to the AC side of the converter. A three-phase VSC has been widely utilized in commercial adjustable speed AC motor drives, and a typical one is shown in Fig. 6.

D. Sinusoidal Pulse-Width Modulation

Pulse-width modulation (PWM) of voltages or currents in power electronic AC devices has a slightly different definition than in DC converters, taken into account the peculiarities of PWM when solving problems of converting electricity to alternating current. According to the definition of IEC 551-16-30, pulse-width modulation is called pulse control, in which the width or frequency of the pulses, or both, are modulated within the period of the fundamental frequency in order to create a certain shape of the output voltage curve. In most cases, PWM is carried out in order to ensure a sinusoidal voltage or current, i.e. lowering the level of higher harmonics relative to the fundamental (first) harmonic, and is called sinusoidal.

A sinusoidal PWM (SPWM) is changing the width of the pulses that form the output voltage or current by comparing a signal of a given shape, called a reference or reference, with a triangular waveform having a higher frequency and called a carrier. The reference signal is modulating and determines the desired shape of the output voltage (current). In the case under consideration, this signal has a sinusoidal shape, and its frequency is equal to the frequency of the fundamental (first) harmonic of the generated voltage or current. There are many modifications to this method in which modulating signals are special functions other than sinusoidal. But at the same time, goals to reduce the level of certain harmonics are successfully achieved.

E. Space Vector Modulation

This work presents a control algorithm for VSC based on the SVM technique, which allows you to obtain a sinusoidal shape of the curves at the input and output with a unit input power factor. The vector modulation approach has the following advantages relative to the traditional modulation technique,

- Instant coverage of required switching processes;
- Simplified control algorithm;
- Maximum voltage transfer coefficient without adding third harmonic components;
- No synchronization requirement with input voltage.

In addition, the proposed switching algorithm can reduce the number of switching devices involved in the switching process relative to conventional switching strategies [1], [2]. It should be noted that since the modulation strategy is defined directly in terms of the amplitude and phase angle of the output, this method is applicable to highly efficient drive systems.

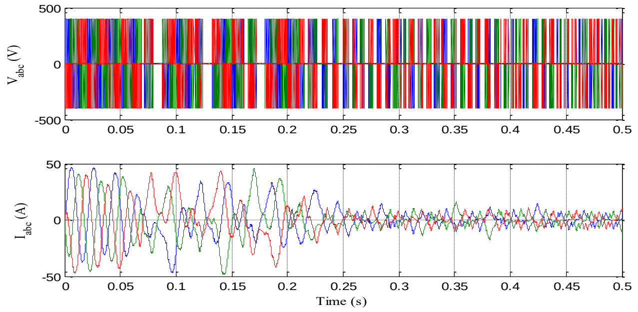
The analyzed control circuit requires that the measurement of two input line voltages determines the ratio of the on-time to the modulation period of the allowed switching combinations. In addition, the measurement of two linear load currents allows for safe switching. Table 1 shows the magnitude of phase and line voltage output of VSC in the SVM technique with seven switching vectors.

IV. SIMULATION RESULTS AND DISCUSSION

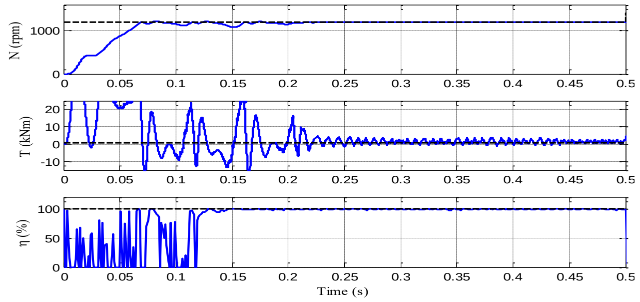
Simulation is performed with MATLAB/Simulink applications. Simulink version consists of a PV panel standalone system working with the MPPT manner of this type INC technique. MPPT is an entirely electronic system which changes the electrical functioning stage of the modules in order that modules may deliver maximum ability.

Table 1. Phase and output line to line voltages in SVM technique

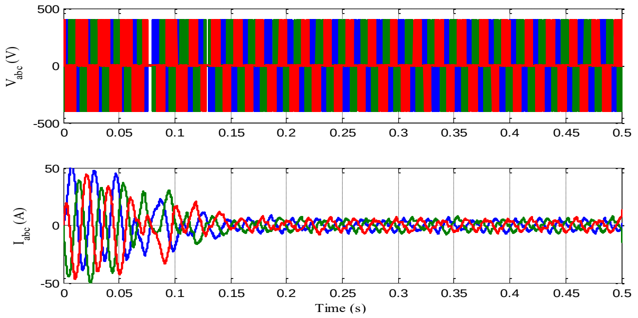
Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	a	b	c	Van	Vbn	Vcn	Vab	Vbc	Vca
Vo	0	0	0	0	0	0	0	0	0
V1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V2	1	1	0	1/3	1/3	-2/3	0	1	-1
V3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V4	0	1	1	-2/3	1/3	1/3	-1	0	1
V5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V6	1	0	1	1/3	-2/3	1/3	1	-1	0
V7	1	1	1	0	0	0	0	0	0



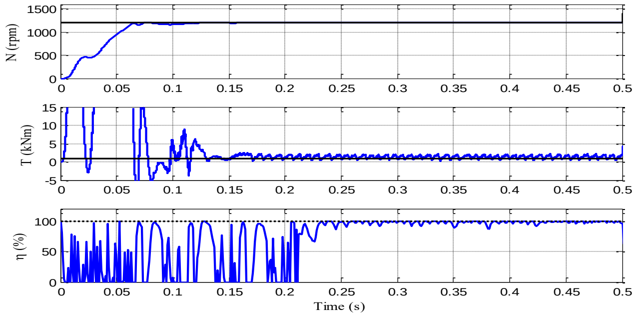
(a) Output voltage and current using SPWM



(b) Speed-torque and efficiency using SPWM



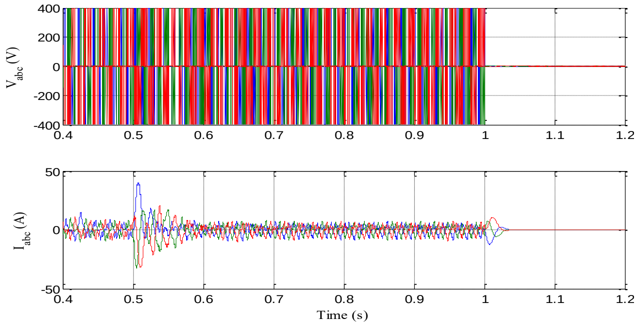
(c) Output voltage and current using SVPWM



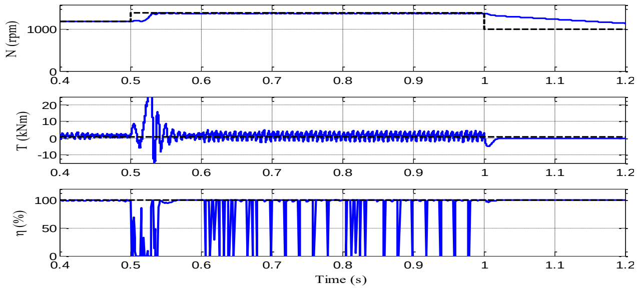
(d) Speed-torque and efficiency using SVPWM

Fig. 6. Startup-transient response of three-phase standalone PV system

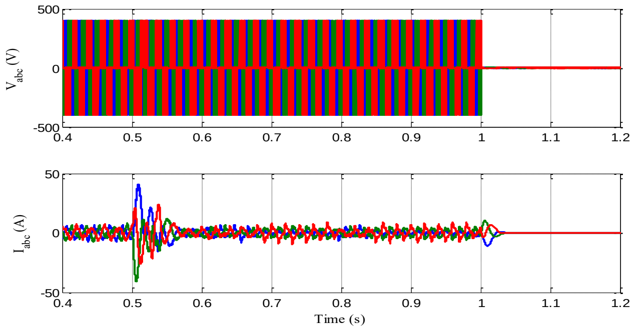
Fig. 6(a) and 4(b) shows the three-phase output voltage and current and speed-torque and efficiency during startup-transient mode using SPWM. Fig. 6(c) and 4(d) shows the three-phase output voltage and current and speed-torque and efficiency during startup-transient mode using SVPWM. It is observed that the SPWM technique speed is not settled, the torque response getting oscillated more due to oscillation voltage. The speed response settled at 0.364 secs with a torque of 4.127 N-m and efficiency of 95.84 %, but the SVPWM technique speed response is settled at 0.1232 secs with a torque of 1.5 N-m and improved efficiency of 98.46 % compared to SPWM.



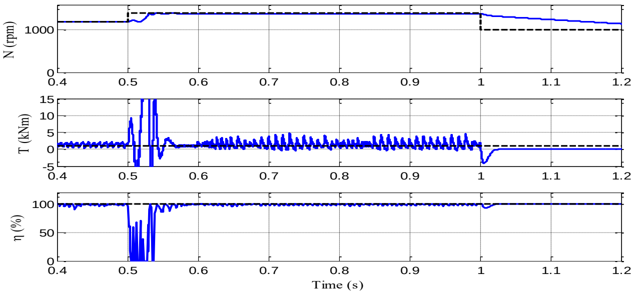
(a) Output voltage and current using SPWM



(b) Speed-torque and efficiency using SPWM



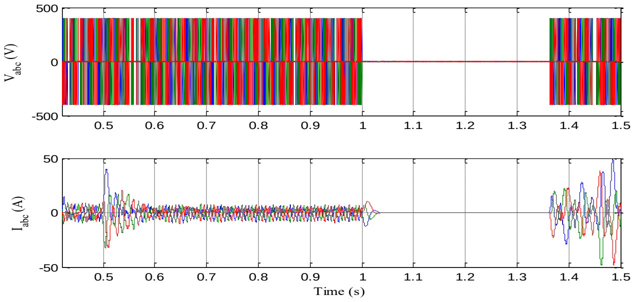
(c) Output voltage and current using SVPWM



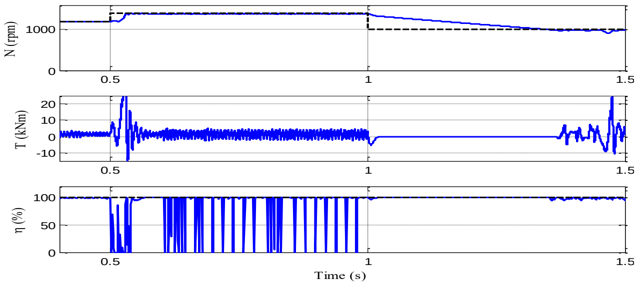
(d) Speed-torque and efficiency using SVPWM

Fig. 7. Output voltage and current during servo response (increment of speed at 15%) using SPWM

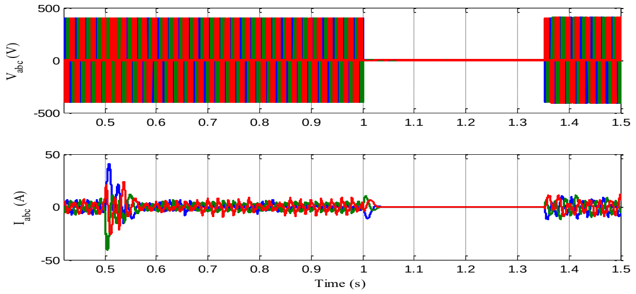
Fig. 7(a) and 7(b) shows the output voltage and current during servo response with an increment of speed at 15% using SPWM and Fig. 7(c) and 7(d) shows the output voltage and current during servo response with an increment of speed at 15% using SVPWM. The speed is incremented from 1200 rpm to 1400 rpm at t=0.5 sec. The speed reaches its steady-state value of 1400 rpm at 0.086 sec with torque and efficiency of 1.875 N-m and 98.64 for SPWM technique, and the speed is settled at 0.053 sec with torque and efficiency of 1 N-m and 99.47 for SVPWM.



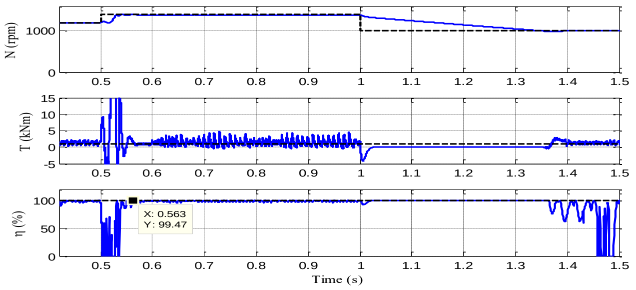
(a) Output voltage and current using SPWM



(b) Speed-torque and efficiency using SPWM



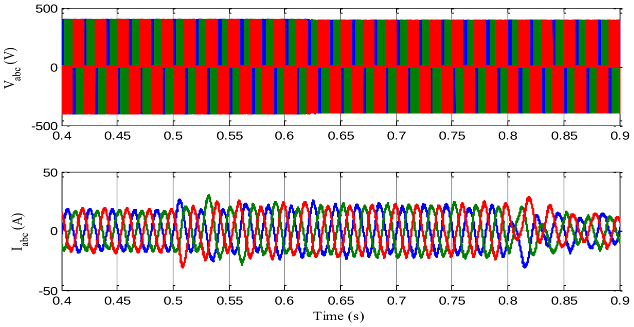
(c) Output voltage and current using SVPWM



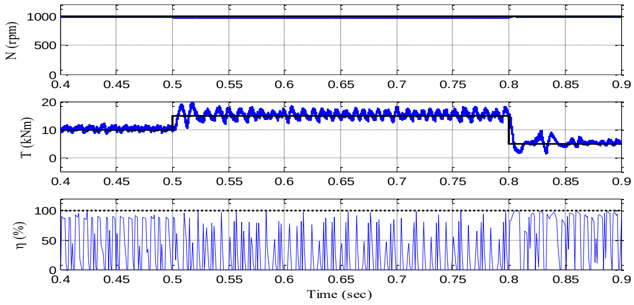
(d) Speed-torque and efficiency using SVPWM

Fig. 8. Speed-torque and efficiency of servo response with decrement of speed 30% using SPWM

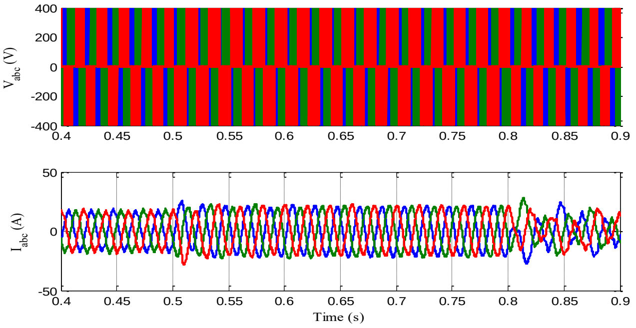
Similarly, Fig. 8(a) and 8(b) shows the output voltage and current during servo response with a decrement of speed at 30% using SPWM and Fig. 8(c) and 8(d) shows the output voltage and current during servo response with a decrement of speed at 30% using SVPWM. The speed is decremented from 1400 rpm to 1000 rpm at t=1.5 sec. Using SPWM technique the torque reaches 0.7 N-m with efficiency obtained is 98.45% and the torque reaches zero with efficiency obtained is 100% using SVPWM technique. SVPWM technique produced better results compared to sine PWM for servo responses.



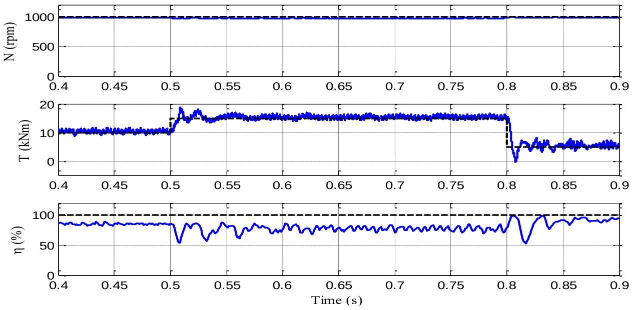
(a) Output voltage and current using SPWM



(b) Speed-torque and efficiency using SPWM



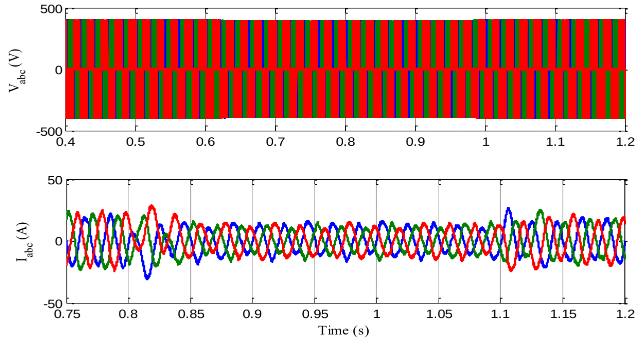
(c) Output voltage and current using SVPWM



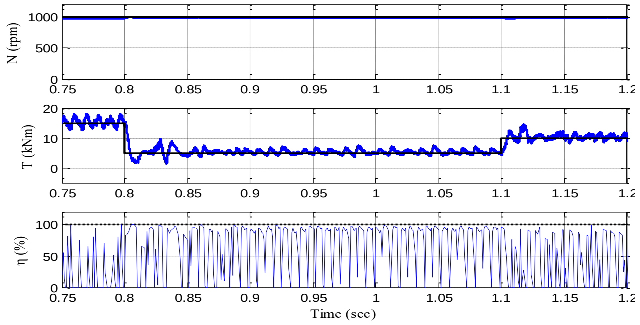
(d) Speed-torque and efficiency using SVPWM

Fig. 9. Speed-torque and efficiency of regulatory with load increment of 50% using SPWM

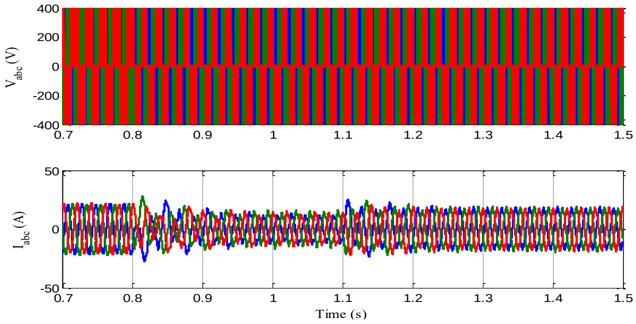
Fig. 9(a) and 9(b) shows the output voltage and current during regulatory response with an increment of a load of 50% using SPWM and Fig. 9(c) and 9(d) shows the output voltage and current using SVPWM. The torque is increased from 10 N-m to 15 N-m at 0.5 secs due to the load increment. The efficiency of the system also reduced at this period. The speed response at this mode is 961.1 rpm with the efficiency of 81.13% using SPWM technique, and the system efficiency is increased to 87.55% using SVPWM.



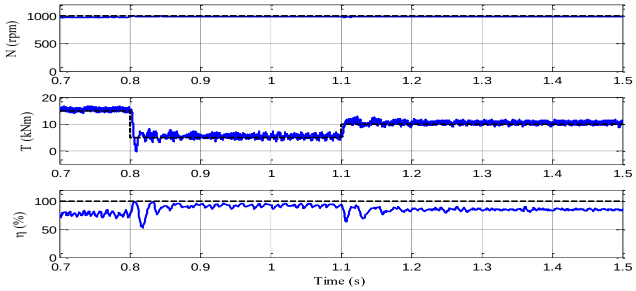
(a) Output voltage and current using SPWM



(b) Speed-torque and efficiency using SPWM



(c) Output voltage and current using SVPWM



(d) Speed-torque and efficiency using SVPWM

Fig. 10. Speed-torque and efficiency of regulatory response to load change of 75% decrement using SPWM

Similarly, Fig. 10(a) and 10(b) shows the output voltage and current during regulatory response with a decrement of a load of 75% using SPWM and Fig. 10(c) and 10(d) shows the output voltage and current using SVPWM. The torque is reduced to boost the speed of the induction motor. The efficiency of the system is 94.24%, and the speed increased to 983 rpm using SPWM technique, and the efficiency of the system is 96.45%, and the speed is increased to 996 rpm. SVPWM technique produced better results compared to sine PWM for regulatory responses.

V. CONCLUSION

This paper presented a corporative simulation study of a three-phase stand-alone Photovoltaic (PV) system with the implementation of positive output super-left two DC-DC Converter the acceptable results for the proposed system are obtained. From Tables 2-4, it is concluded that the voltage, current, speed, torque, and efficiency are improved by the implementation SVM technique compared with SPWM. The speed and efficiency are improved during load disturbances using the SVM technique than SPWM as shown in Table 4. Similarly, the Torque and efficiency are better improved in the SVM technique when compared with SPWM. The overall comparison has been analyzed with these two PWM strategies. Finally, SVM is superior for all performance evaluation of the proposed system is concluded.

REFERENCES

1. Global Energy & CO2 Status Report “The latest trends in energy and emissions in 2018” https://www.iea.org/geco/renewables/
2. Huang, Chao, et al. "A Novel Spline Model Guided Maximum Power Point Tracking Method for Photovoltaic Systems." IEEE Transactions on Sustainable Energy (2019).
3. Sarniak, Mariusz T., Jacek Wernik, and Krzysztof J. Wołosz. "Application of the Double Diode Model of Photovoltaic Cells for Simulation Studies on the Impact of Partial Shading of Silicon Photovoltaic Modules on the Waveforms of Their Current–Voltage Characteristic." Energies 12.12 (2019): 2421.
4. Santhosh, K., and R. Neela. "Optimal Placement of Distribution Generation in Micro-Grid Using Eagle Strategy with Particle Swarm Optimizer." International Journal of Pure and Applied Mathematics 118.18 (2018): 3819-3825.
5. Henri, Gonzague, and Ning Lu. "A Supervised Machine Learning Approach to Control Energy Storage Devices." IEEE Transactions on Smart Grid (2019).
6. Huang, Chao, et al. "A Novel Spline Model Guided Maximum Power Point Tracking Method for Photovoltaic Systems." IEEE Transactions on Sustainable Energy (2019).
7. Jana, Baishyanar, et al. "A Study of DC–DC Converters with MPPT for Standalone Solar Water-Pumping System." Recent Developments in Machine Learning and Data Analytics. Springer, Singapore, 2019. 373-381.
8. Ballaji, Adithya, et al. "Energy Efficient Perturb and Observe Maximum Power Point Algorithm with Moving Average Filter for Photovoltaic Systems." International Journal of Renewable Energy Research 9.1 (2019).
9. Sharma, Gourav Kant, and Ashish Kumar Singhal. "Solar Energy Conversion System with Maximum Power Point Tracking." Journal of Instrumentation Technology and Innovations 8.3 (2019): 15-20.
10. Hassan, Md Sabir, et al. "A Comparative Analysis of Different Maximum Power Point Tracking Algorithms of Solar Photovoltaic System." Applications of Computing, Automation and Wireless Systems in Electrical Engineering. Springer, Singapore, 2019. 217-229.
11. Awad, Khalid, Omar Abdel-Rahim, and Mohamed Orabi. "Modified Maximum Power Point Tracking Technique Based on One Cycle Control for PV Applications." 2019 International Conference on Innovative Trends in Computer Engineering (ITCE). IEEE, 2019.
12. Hammami, Manel. "Basic RCC-MPPT Scheme in Single-Phase H-Bridge Grid-Connected PV Systems." Level Doubling Network and Ripple Correlation Control MPPT Algorithm for Grid-Connected Photovoltaic Systems. Springer, Cham, 2019. 9-26.
13. Farzaneh, Javad, Reza Keypour, and Ali Karsaz. "A novel fast maximum power point tracking for a PV system using hybrid PSO-ANFIS algorithm under partial shading conditions." International Journal of Industrial Electronics, Control and Optimization 2.1 (2019): 47-58.
14. WeiFeng, You, and Cui Yan. "Maximum Power Point Tracking of PV Systems Based On a Novel Adaptive Variable Step Size INC MPPT Method." Journal of Physics: Conference Series. Vol. 1213. No. 4. IOP Publishing, 2019.

15. Belkaid, Abdelhakim, et al. "Design and Implementation of a Cuk Converter Controlled by a Direct Duty Cycle INC-MPPT in PV Battery System." International Journal of Smart Grid-ijSmartGrid 3.1 (2019): 19-25.
16. Choudhary, Nitin, and Onkar Singh Nishant. "Power Quality Assessment of Photovoltaic System." (2019).
17. Li, Jiyong, and Honghua Wang. "A novel stand-alone PV generation system based on variable step size INC MPPT and SVPWM control." 2009 IEEE 6th International Power Electronics and Motion Control Conference. IEEE, 2009.
18. Rouibah, N., et al. "A low-cost monitoring system for maximum power point of a photovoltaic system using IoT technique." 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS). IEEE, 2019.
19. Loukriz, Abdelhamid, Sabir Messalti, and Abdelghani Harrag. "Design, simulation, and hardware implementation of novel optimum operating point tracker of PV system using adaptive step size." The International Journal of Advanced Manufacturing Technology 101.5-8 (2019): 1671-1680.
20. Hashim, Norazlan, and Zainal Salam. "Critical evaluation of soft computing methods for maximum power point tracking algorithms of photovoltaic systems." International Journal of Power Electronics and Drive Systems 10.1 (2019): 548.
21. Ahmad, Jawad. "A Unified Approach to Maximum Power Point Tracking and IV Curve Determination of Photovoltaic Arrays from Real-time Measurements." (2019).
22. Siddharthan, Niranjana, and Baskaran Balasubramanian. "Performance evaluation of SEPIC, Luo and ZETA converter." International Journal of Power Electronics and Drive Systems 10.1 (2019): 374.

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