A comparative investigation of three-phase stand-alone PV system using Sinusoidal PWM and Space Vector PWM Strategies

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Abstract

This paper proposes a maximum power point tracking (MPPT) systems for photovoltaic (PV) applications. MPPT is necessary for photovoltaic (PV) power system applications to extract the maximum possible power under changing irradiations and temperature conditions. A Luo converter with a high voltage gain is obligatory to track PV at the maximum power and to boost the voltage to a higher level. Sinusoidal pulse width modulations (SPWM) and space vector modulations (SVM) are the control techniques employed for the three-phase voltage source inverter (VSI), to measure the performance indices of the proposed system simulation of the set-up is carried out MATLAB / Simulink environment.

Keywords: DC/DC converter, Luo converter, voltage source inverter, SPWM, SVM, PV, PI controller.

1. INTRODUCTION

Solar energy is clean energy since it fuses hydrogen atoms into helium to radiate light and heat. It has been harnessed by human beings since ancient time using a range of ever-evolving technologies. Solar radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, is accounted for most of the available renewable energy on the Earth. Only a minuscule fraction of the available solar energy is used. Photovoltaic generation is reliable, and its operation and maintenance cost is low. The PV system also provides social and economic benefits to the society where other forms of electricity are unavailable. Renewable energy from solar photovoltaic (PV) is the most ecological type of energy to use. It is based on a clean and efficient modern technology, which offers a glimmer of hope for a future based on sustainable and pollution-free technology. The importance of using renewable energy system, including solar photovoltaic (PV) has been attracted much these days because the electricity demand is growing rapidly all over the world [1]. The solar energy is directly converted into electrical energy by solar PV module. Each type of PV module has its specific characteristic corresponding to the surrounding condition such as irradiation, and temperature and this makes the tracking of maximum power point (MPP) a complicated problem. To overcome this issue, many maximum power point tracking (MPPT) control algorithms have been presented [2-7]. In PV power generation system, other than solar modules, many circuits and devices are required to provide an adequate electricity supply. Many systems implemented in the literature [8–11] have a provision for energy storage to provide electricity at night and during cloudy weather.

The intelligent controller has been used for tracking the MPP of PV modules because it has the advantages of being robust, relatively simple to design and does not require the knowledge of an exact model. In this paper, mathematical models of the PV module with incremental conductance algorithm, DC-DC Positive output super-lift Luo converter and are used. Space Vector Modulation (SVM) is used for the evaluation of proposed Luo converter based PV stand-alone system. Simulations run with Matlab/Simulink are presented with a comparison of Sinusoidal Pulse Width Modulation (SPWM).

2. MAXIMUM POWER POINT TRACKING (MPPT)

Maximum Power Point Tracking referred as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a way that allows the modules to develop all the power they are capable. MPPT is not a mechanical tracking system that "physically moves" the modules to make the point more directly at the sunlight. MPPT is an entirely electronic system that varies the electrical operating point of the modules so that the modules can deliver maximum power. Additional power harvested from the modules formed as the increased battery charge current. MPPT can be utilised in concurrence with a mechanical tracking system, but the two systems are entirely different. Typical solar panel converts only 30 to 40 percent of the incident sunlight into electrical energy. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load resistance. Hence, the problem of tracking the maximum power point reduces to an impedance matching problem [12].

On the source side used, a Luo converter (DC-DC) is linked to a solar panel to enhance the output potential. By changing the duty cycle of the proposed Luo DC-DC converter appropriately to meet the source impedance with the load impedance. Maximum Power Point Tracking Algorithm is necessary to increase the efficiency of the solar panel. In that respect are different techniques for MPPT such as Perturb and Observe, Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network control and so along. Among all the methods Perturb and observe (P&O) and Incremental conductance methods usually employed because of their simple implementation, lesser time to burn through the MPP and several other economic reasons [12-13].

This paper looks at the case of Incremental Conductance algorithm [14]. The Incremental Conductance (INC) MPPT algorithm design based on the incremental and the instantaneous conductance value of the PV array has not the inclination to vary from the MPP due to rapidly changing the atmospheric conditions [15].

2.1 Incremental Conductance algorithm

The Incremental conductance algorithm is an advanced version of the P&O algorithm. The Incremental Conductance (IC) method had taken to overcome the drawbacks of the PO algorithm when subjected to fast-changing environmental conditions. With the help of voltage and current measurements, the conductance I/V and incremental conductance dI/dV are determined so that the decision can be made to increase or decrease the operating voltage according to the operating point on the left or the right of the MPP respectively.

The incremental conductance (IC) algorithm provides enough information to locate the MPP. This is made possible by the respective measurement and comparison of, dI/dV and I/V. V_{MPP} is the set point reference voltage corresponding to the MPP at which the PV module is needed to run. The specific operating principle of the IC algorithm can be viewed by the accompanying flowchart shown in Fig.1 [13], [16]. The current and voltage is to be valued, then a test is conducted to assess on one side if the deviation in voltage and current is equal to zero respectively, and on the other end if the variation of potential difference is equal to zero and the balancing condition $dI/dV + I/V = 0$ at MPP is obtained. If so, no changes take place in the operation's process. If not, the IC method acts to increase or decrease the voltage according to the difference in the current or the condition $dI/dV + I/V$ superior or inferior to zero respectively.

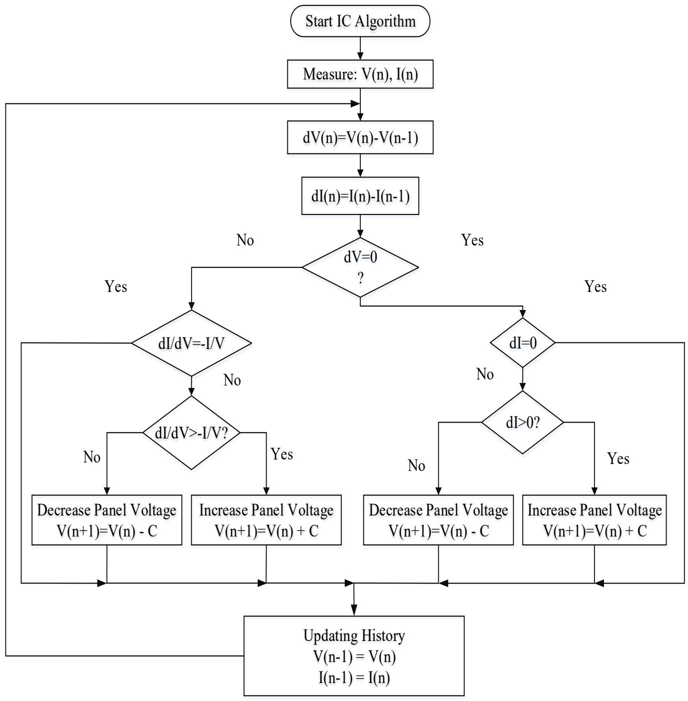


Fig.1. Flowchart of Incremental Conductance Algorithm

3. PROPOSED PV SYSTEM DESCRIPTION

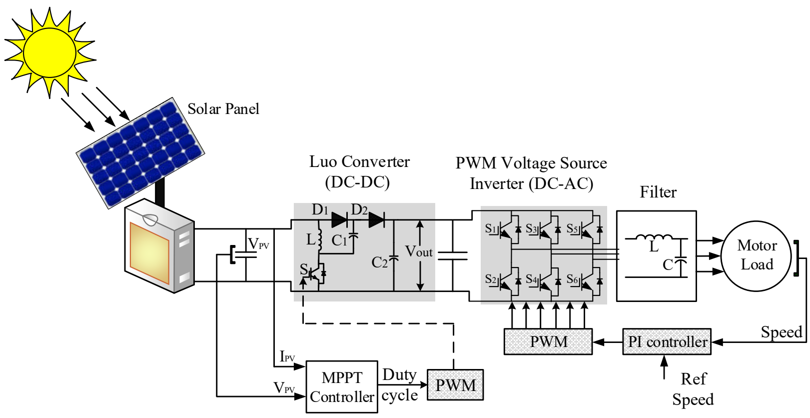


Fig.2. Block diagram representation of PV system with INC MPPT tracking

Fig.2 consists of three divisions such as DC source, DC-DC converter, and DC-AC converter. A DC power source (PV panel) connected in series with the Luo converter. Luo converter (DC/DC) which regulates the output voltage of PV panel and helps to attain the maximum power. PWM Voltage Source Inverter (DC-AC) 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 [17],

$$\eta_{Total} = \eta_{PV} . \eta_{MPPT} . \eta_{Inverter} \tag{4}$$

$$= \frac{P_{PV}[W]}{G\left[\frac{W}{m^2}\right] . A[m^2]} . \frac{P_{MPPT}[W]}{P_{PV}[W]} . \frac{P_{OUT}[W]}{P_{MPPT}[W]} \tag{5}$$

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

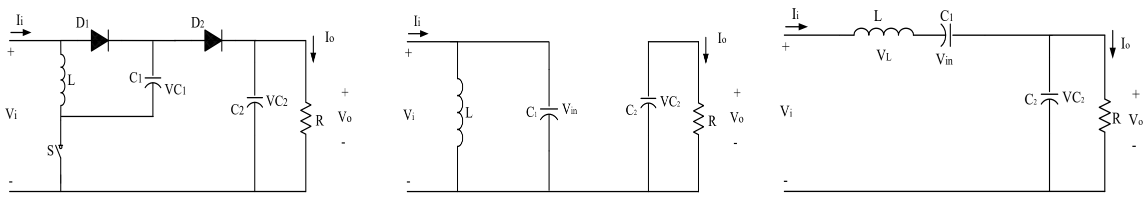
P_{PV} - Maximum power from the PV array

3.1 Solar panel (DC source)

A sun power 305-WHT panel is modelled on the proposed system, which consists of 96 cells, and have the capacity of 100kW at 1000 W/m^2, 25°C.

3.2 Luo converter (DC-DC converter)

Maximum power point algorithm (incremental conductance) is implemented here to control the duty ratio of Luo converter (18). Based on the rate of change of voltage and current, either the duty ratio is increased or decreased to attain maximum power with a DC output voltage in the acceptable limit. A PI controller is used to regulate the duty ratio of the incremental algorithm. The elementary circuit and its equivalent circuits during switch-on and off are shown in Fig.3. The voltage across capacitor C_1 is charged to V_{in}.



(a) Circuit diagram (b) Switching-on (c) Switching-off

Fig. 3. Positive output super-lift Luo (DC-DC) converter

The current i_L flowing through inductor L increases with voltage Vin during switch-on period kT and decreases with voltage $-(V_O - 2V_{in})$ during switch off period (1 –k)T. Therefore, the ripple of the inductor current i_L is

$$\Delta i_{L1} = \frac{V_{in}}{L} kT = \frac{V_o - 2V_{in}}{L}(1-k)T \tag{6}$$

$$V_o = \frac{2-k}{1-k} V_{in} \tag{7}$$

The voltage transfer gain is,

$$G = \frac{V_o}{V_{in}} = \frac{2-k}{1-k} \tag{8}$$

3.3 Voltage source inverter

A three-phase voltage source inverter has been widely utilised in commercial adjustable speed AC motor drives, and a typical one is shown in Fig.6. To generate three-phase balanced voltages, gating signals should be pulled ahead or delayed by 120° [17]. Switching sequence is modified at every 60° of the interval to obtain a three-phase balanced output voltage. The resulting output line voltage is in the quasi-square form. In this control strategy, switching is kept constant. For the modification of the output voltage, it is necessary to set the DC input voltage to the inverter.

3.4 Sinusoidal pulse-width modulation

This technique has been used since 1965s [18], and now it can be practised for real-time on-line microprocessor applications. The pulse durations in the sinusoidal or natural PWM scheme are changed so that they are about the amplitude of the modulating signal. The intersection points of the carrier signal and the reference signal considered as switching instants.

3.5 Space Vector Modulation

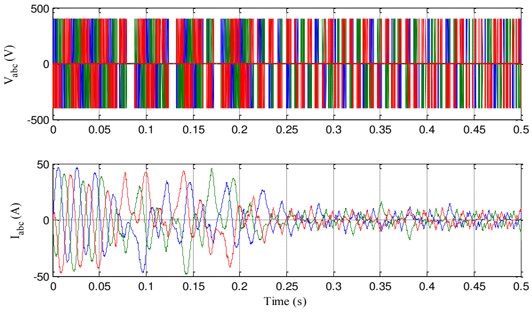
Space-vector (SV) pulse width modulation (PWM) technique has become a popular PWM technique for three-phase voltage source inverters (VSI) in applications such as control of AC induction and permanent magnet synchronous motors. Space Vector Modulation (SVM) was initially developed as vector approach to Pulse Width Modulation (PWM) for three-phase inverters. It is a more sophisticated technique for generating a sine wave that provides a higher voltage to the motor with lower total harmonic distortion. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application. SVPWM is a different approach from PWM modulation. In this modulation technique, the three-phase quantities can be transformed to their equivalent two-phase quantity either in synchronously rotating frame (or) stationary frame. From these two-phase components, the reference vector magnitude can be found and used for modulating the inverter output.

Table-1 Phase and output line to line voltages in SVPWM

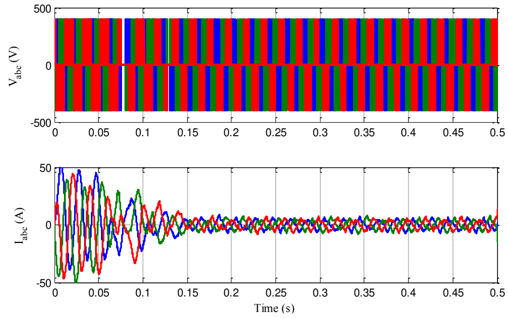
Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	a	b	c	Van	Vbn	Vcn	Vab	Vbc	Vca
Vo	0	0	0	0	0	0	0	0	0
V1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V2	1	1	0	1/3	1/3	-2/3	0	1	-1
V3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V4	0	1	1	-2/3	1/3	1/3	-1	0	1
V5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V6	1	0	1	1/3	-2/3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

4. SIMULATION RESULTS AND DISCUSSION

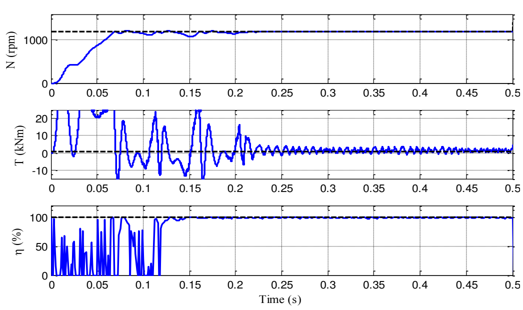
Simulation is carried out using MATLAB/ Simulink software. The Simulink model arrangement of PV array stand-alone system using the MPPT technique of the type Incremental Conductance method. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules can deliver maximum power.



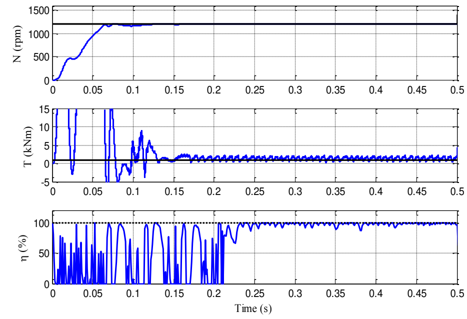
(a) Output voltage and current using SPWM



(c) Output voltage and current using SVPWM

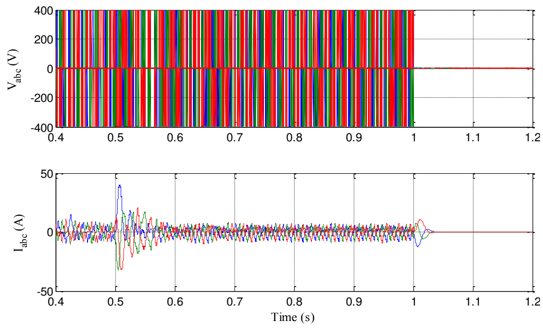


(b) Speed-torque and efficiency using SPWM

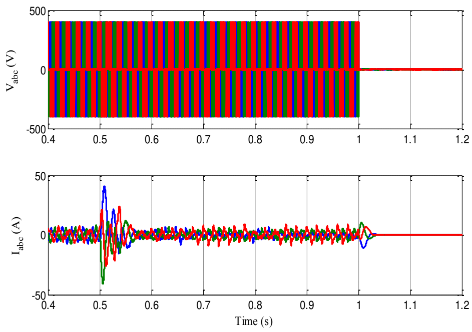


(d) Speed-torque and efficiency using SVPWM

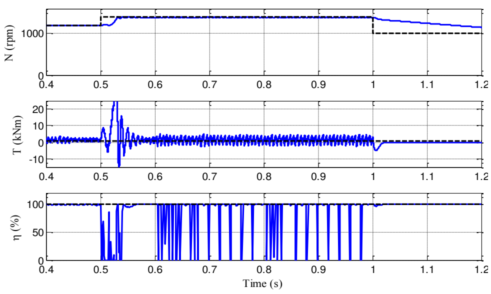
Fig. 4. Startup-transient response of three-phase standalone PV system



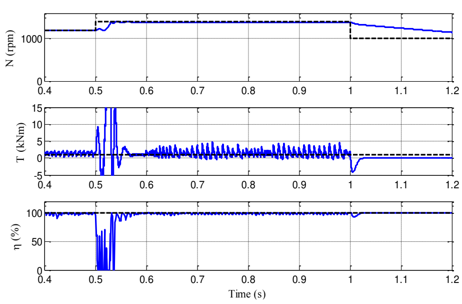
(a) Output voltage and current using SPWM



(c) Output voltage and current using SVPWM

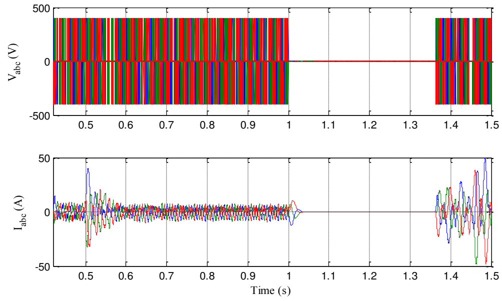


(b) Speed-torque and efficiency using SPWM

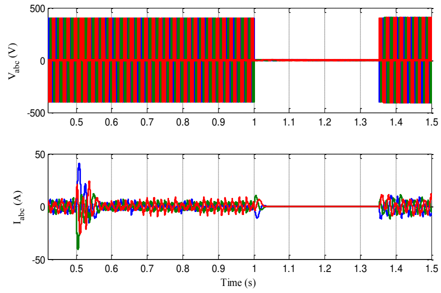


(d) Speed-torque and efficiency using SVPWM

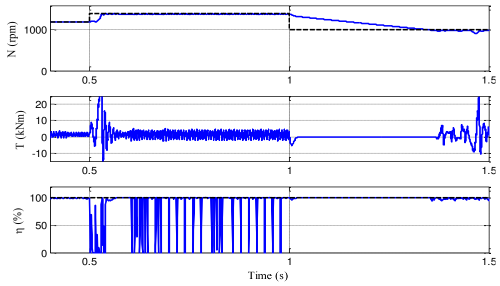
Fig. 5. Output voltage and current during servo response (increment of speed at 15%) using SPWM



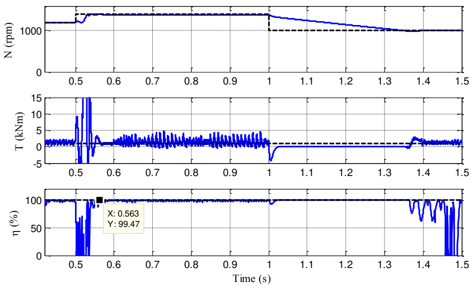
(a) Output voltage and current using SPWM



(c) Output voltage and current using SVPWM

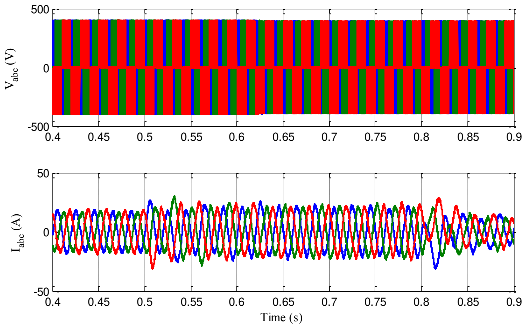


(b) Speed-torque and efficiency using SPWM

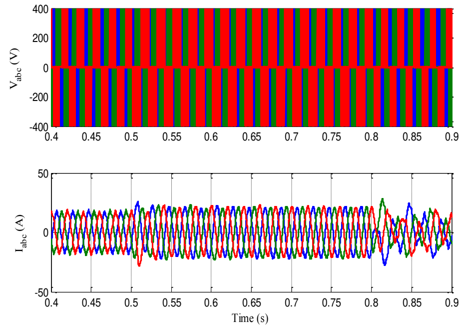


(d) Speed-torque and efficiency using SVPWM

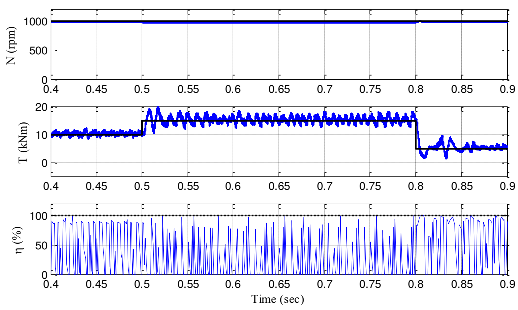
Fig. 6. Speed-torque and efficiency of servo response with decrement of speed 30% using SPWM



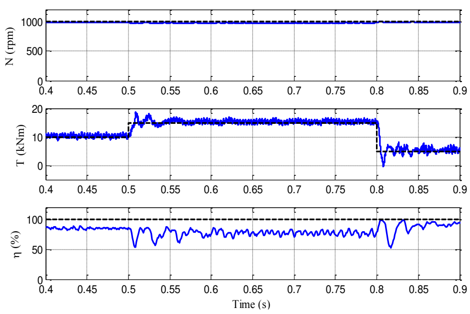
(a) Output voltage and current using SPWM



(c) Output voltage and current using SVPWM

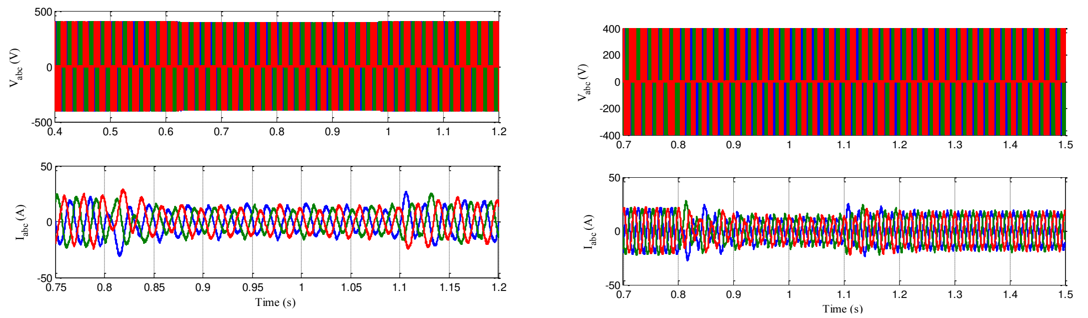


(b) Speed-torque and efficiency using SPWM

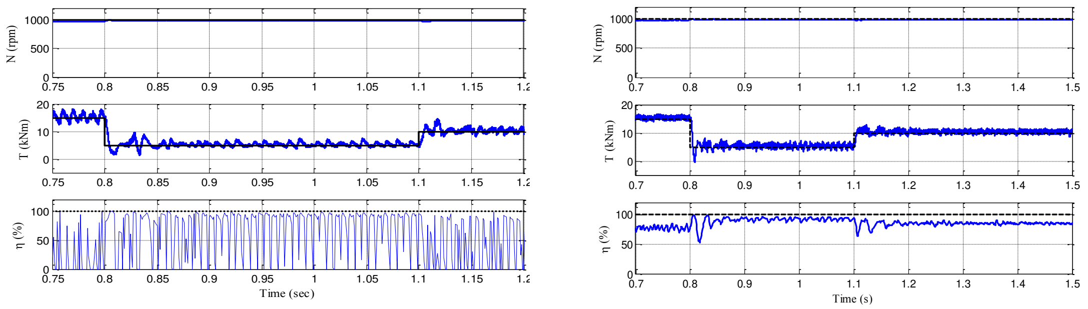


(d) Speed-torque and efficiency using SVPWM

Fig. 7. Speed-torque and efficiency of regulatory with load increment of 50% using SPWM



(a) Output voltage and current using SPWM (c) Output voltage and current using SVPWM



(b) Speed-torque and efficiency using SPWM (d) Speed-torque and efficiency using SVPWM

Fig. 8. Speed-torque and efficiency of regulatory response to load change of 75% decrement using SPWM

Fig. 4(a) and 4(b) shows the three-phase output voltage and current and speed-torque and efficiency during startup-transient mode using SPWM. Fig. 4(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.

Fig. 5(a) and 5(b) shows the output voltage and current during servo response with an increment of speed at 15% using SPWM and Fig. 5(c) and 5(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. Similarly, Fig. 6(a) and 6(b) shows the output voltage and current during servo response with a decrement of speed at 30% using SPWM and Fig. 6(c) and 6(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.

Fig. 7(a) and 7(b) shows the output voltage and current during regulatory response with an increment of a load of 50% using SPWM and Fig. 7(c) and 7(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. Similarly, Fig. 8(a) and 8(b) shows the output voltage and current during regulatory response with a decrement of a load of 75% using SPWM and Fig. 8(c) and 8(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.

Table 2. Simulated responses of PV source standalone system

Control Technique	Start – up Transients			Servo response				Regulatory response			
				Increment with 15%		Decrement by 30%		Increment with 50%		Decrement by 75%	
	Rise time (Sec)	Settling time (Sec)	Efficiency (%)	Settling time (Sec)	Efficiency (%)	Settling time (Sec)	Efficiency (%)	Settling time (Sec)	Efficiency (%)	Settling time (Sec)	Efficiency (%)
SPWM	0.5	0.364	95.84	0.086	98.64	0.285	98.45	0.137	81.13	0.158	94.24
SVM	0.0445	0.1232	98.46	0.053	99.47	0.168	100	0.0634	87.55	0.152	96.45

5. CONCLUSION

This paper presented a corporative investigation of 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 implementation SVM technique compared with SPWM. The speed and efficiency are improved during load disturbances using SVM technique than SPWM as shown in Table 4. Similarly, the Torque and efficiency are better improved in SVM technique only. Compared with SPWM. The overall comparison has been analysed with these two PWM strategies. Finally, SVM is superior for all performance evaluation of the proposed system is concluded.

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