

Implementation of SEPIC Converter for Solar Powered Induction Motor

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Abstract

Solar energy is the most promising non-conventional sources of energy. This paper proposes the working of single phase induction motor using solar arrays and power electronics. The SEPIC converter is taken as dc-dc converter which is designed and DC analysis has been done in CCM. Then inverter is used to convert dc power to ac power. The performance of SEPIC converter and inverter is measured, and different parameters of induction motor are analyzed.

Keywords: Solar array, SEPIC Converter, Single phase inverter, induction motor.

1. Introduction

Conventional energy resources such as coal, oil etc. are getting depleted due to which we are doing more research and exploiting non-conventional resources such as solar energy, wind energy etc. Among non-conventional sources, solar energy is a promising alternative source. It is available to us in abundance and has many advantages such as pollution free and renewability. Solar energy systems are hence in high demand for the production of electricity. We get solar energy from sun which is then converted into electricity by solar panels and using power electronics. Energy from sun is converted into dc voltages by solar cells, which is then regulated by dc-dc converters. Then inverter is used to convert dc power into ac power for home. There is an output power variation from solar arrays which causes a frequency or voltage variations from nominal values in electrical systems, so to remove such problems dc-dc converters are used with MPPT.

Initially, solar array were modeled and implemented with MPPT by wu,chang[1]. SEPIC converters were implemented by Yakov,Adar[2]. And the single phase inverter was used in solar power applications by Katsuya H., Manabu[3].

In this paper Single-Ended Primary Inductance Converter (SEPIC) is proposed as a dc-dc converter which is fed by solar array. Inverter is connected after SEPIC converter to convert dc power into ac power which feed ac voltage to single phase induction motor. The SEPIC converter is designed and MPPT algorithm is used to track the maximum power point from solar array. In this paper performance of dc-dc converter and inverter is calculated.

2. Solar Array

Solar cell is a p-n junction semiconductor device which generates dc current when exposed to a light. Solar cells are connected in series and parallel to form a solar array. Single diode circuit model is used for implementing mathematical modeling in MATLAB. Photovoltaic array is implemented under standard conditions (1kW/m^2 , 1.5 AM, 25°C). Open circuit voltage of 73V, and short circuit current of 4.75A is taken as output. Equivalent circuit model of solar cell is shown in Fig. 1. A bypass diode is included as a single diode.

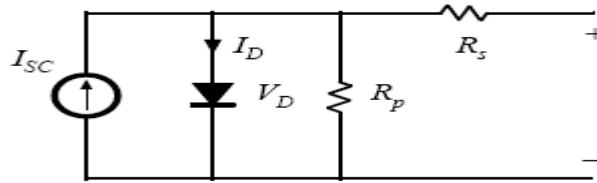


Fig. 1: Equivalent circuit model of solar cell.

Mathematical modeling of the solar cell is implemented on MATLAB using the equations below:

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \quad (1)$$

$$I_D = I_o \left(e^{V_D / V_T} - 1 \right) \quad (2)$$

$$V_{PVcell} = V_D - R_S \times I_{PV} \quad (3)$$

Equation (1) and (3) are obtained by applying KCL and KVL respectively in Fig. 1 and equation (2) is a diode characteristics equation. Then the implementation of these equations is done in MATLAB.

MPPT

Variation in temperature and irradiance leads to the change of maximum power point of the PV array. To overcome such problems different MPPT algorithms are developed, among them Perturb and Observe (P&O) algorithm is used here. It also responds to partial shading and array aging etc. We initialize the reference current (I_{SC}), previous output power of array (P_{old}) and direction. Now new power of PV array is obtained (P_{PV}). If P_{PV} is greater than P_{old} then the direction remains same else it gets

changed. Then current is incremented by the factor of ΔI_{ref} till we achieve maximum power. Flowchart of P&O algorithm is shown in Fig. 2.

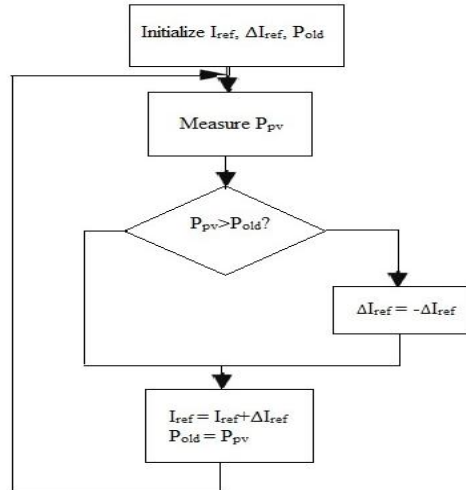


Fig. 2: Flowchart of P&O algorithm.

3. SEPIC Converter

There are different types of dc-dc converters or switched mode converters which use switch to change the one level of dc voltage to another level of voltage. PWM switching is used by keeping switching frequency of MOSFET constant with PID controller to control its switching. Among all dc-dc converters, SEPIC converter is used in continuous current conduction (CCM) mode. In this PWM switching is done at switching frequency of 50 kHz, where reference current obtained from MPPT algorithm is compared with inductor current. Then the error signal is treated as control signal which is compared by repetitive waveform and the switching pulse is obtained. Fig. 3. shows the circuit diagram of SEPIC converter.

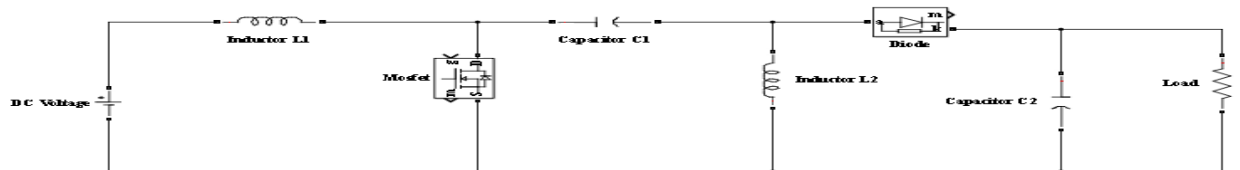


Fig. 3: Circuit diagram of SEPIC Converter.

4. Operation

SEPIC is a non-inverting converter which can be used in boost mode as well as in buck mode. In this when MOSFET is turned on, input voltage V_{in} charges the inductor L_1 . Capacitor C_1 discharges and give energy to inductor L_2 . In this mode diode gets reverse biased, capacitor C_2 cannot discharge to the load. But when MOSFET is turned off, L_1 gets discharge and charges C_1 . Here $i_{L1} + i_{L2}$ flows through the diode and charges C_2 and supply to the load. Fig. 4. shows the on and off topology of SEPIC converter.

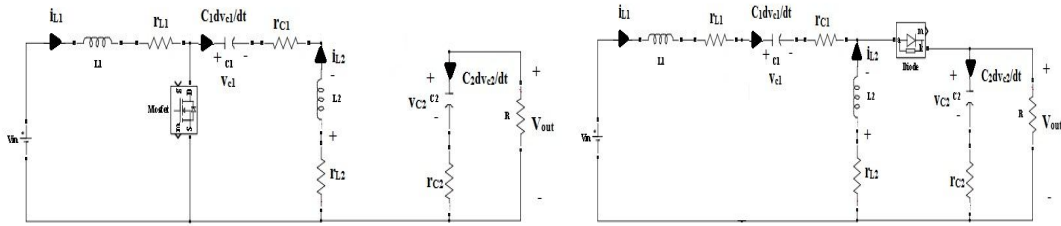


Fig. 4(a) on topology (b) off-topology of SEPIC Converter

5. DC Analysis of SEPIC Converter in CCM

SEPIC converter has two switching stages per cycle in CCM operation. DC resistance of L_1 is r_{L1} , L_2 is r_{L2} , C_1 is r_{C1} and capacitor C_2 has r_{C2} .

The state space equations of the first switching topology when the MOSFET is on.

$$\frac{d}{dt} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} = \begin{bmatrix} -\frac{r_{L1}}{L_1} & 0 & 0 & 0 \\ 0 & \frac{-r_{L2} + r_{C1}C_1}{L_2} & \frac{1}{L_2} & 0 \\ 0 & -\frac{1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{(r_{C2} + R)C_2} \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} V_{in} \quad (4)$$

$$v_{out} = \begin{bmatrix} 0 & 0 & 0 & \frac{R}{R + r_{C2}} \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} \quad (5)$$

State-space equations describing second switching topology when the MOSFET is off.

$$\frac{d}{dt} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} = \begin{bmatrix} \frac{-(r_{L1} + r_{C1} + R)}{L_1} & \frac{R}{L_1} & \frac{1}{L_1} & 0 \\ -\frac{R}{L_2} & \frac{-(R + r_{L2})}{L_2} & 0 & 0 \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{R}{(R + r_{C2})C_2} & \frac{R}{(R + r_{C2})C_2} & 0 & \frac{-1}{(R + r_{C2})C_2} \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} V_{in} \quad (6)$$

$$v_{out} = \begin{bmatrix} \frac{R(1 - R)}{r_{C2}} & \frac{R(1 - R)}{r_{C2}} & 0 & \frac{1}{r_{C2}} \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ v_{C1} \\ v_{C2} \end{bmatrix} \quad (7)$$

6. Designing of SEPIC Converter

To design the passive components of SEPIC converter following calculation is done. Where D is the duty cycle, Δi_L is the inductor ripple current, f_s is the switching frequency, i_{out} is the output current and Δv_{out} is the output ripple voltage.

$$D = \frac{V_{out}}{V_{in} + V_{out}} \quad (8)$$

$$L_1 = \frac{V_{in} \times D}{\Delta i_{L1} \times f_s} \quad (9)$$

$$L_2 = \frac{V_{in} \times D}{\Delta i_{L2} \times f_s} \quad (10)$$

$$C_1 > \frac{D \times i_{out}}{\Delta v_{C1} \times f_s} \quad (11)$$

$$C_2 > \frac{D \times i_{out}}{\Delta v_{C2} \times f_s} \quad (12)$$

7. Simulation Results

Solar array produce 73 V as output voltage, which is then fed to SEPIC converter. It worked in boost mode and increased the input voltage to 110 V. MPPT algorithm is used to track maximum power point. The value of the passive components are obtained through equations from (8-12). Table I shows the values of components of SEPIC converter. V_{in} is 73 V, V_{out} is 110 V, switching frequency f_s is taken as 50 kHz.

Table I: Values of passive components of SEPIC converter

Inductor [L_1 (H)]	Inductor [L_2 (H)]	Capacitor [C_1 (F)]	Capacitor [C_2 (F)]
2.19×10^{-4}	2.19×10^{-4}	1.14×10^{-4}	1.456×10^{-3}

The output of SEPIC Converter is shown in Fig. 5. Its efficiency is about 90%.

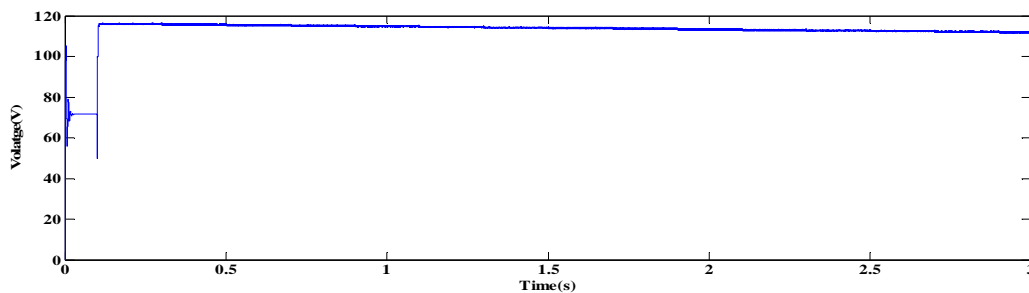


Fig. 5: Output voltage of SEPIC Converter.

Inverter is then used to convert 110 V dc to 110 V ac, which leads to some harmonic distortion. Fig. 6. shows the current THD. The current THD of inverter is 2.05%.

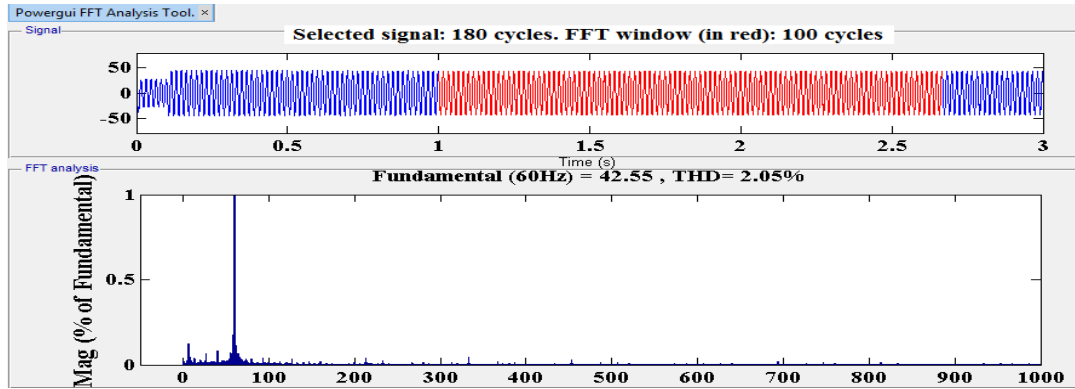


Fig. 6: Current THD of inverter.

Then induction motor is fed at 110 V ac at 60 Hz. This motor starts at no load and at 2 seconds, step of 1 Nm torque is applied. Graph with rotor speed and electromagnetic torque of induction motor in capacitor start and capacitor start-run mode is shown in Fig. 7.

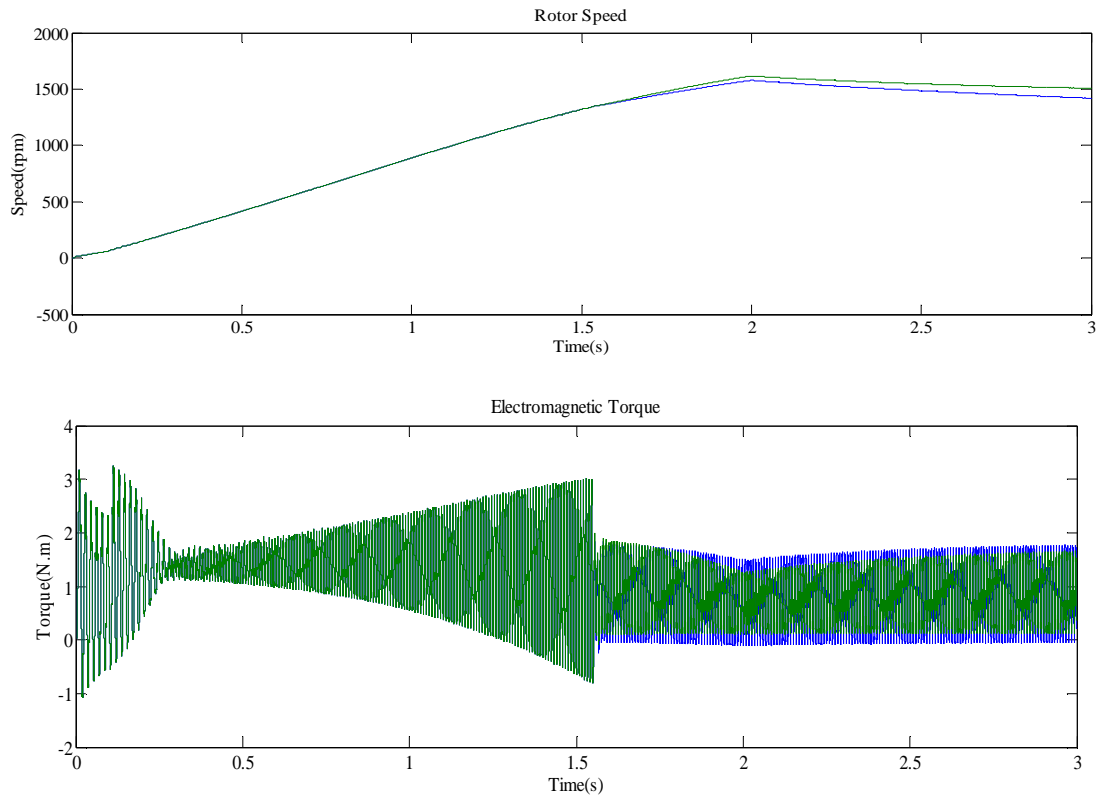


Fig. 7: Rotor speed and Electromagnetic Torque of induction motor.

8. Conclusion

The voltage obtained from solar array is stepped up from 73 V dc to 110 V dc using SEPIC converter. SEPIC converter dc analysis equations have been derived and the passive components are also designed with the efficiency of about 90 %. 110 V dc is converted into 110 V ac using single phase inverter having total current harmonics of 2.05%. In induction motor the rotor speed is about 1600 rpm and the electromagnetic torque in capacitor start run is more pulsating. So capacitor start run motor shows the better operation mode as at the steady state magnitude of torque ripple is only 3% of the load torque.

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