Comparison of Single Stage & Two Stage Conversion of PV System for VSI Fed Induction Motor Drive under Varying Temperature and Irradiance using LabVIEW

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ABSTRACT
In this paper, the comparison of the single stage and two stage conversion of PV system under varying the temperature and irradiance using labview are proposed. Due to clean energy and less impact on the environment, now a day’s solar energy is preferred most and represented by PV (photo voltaic) cell. PV cell, inverter and induction motor have been designed using labview and the converter is designed using NI multisim. The simulated result shows the characteristics like torque, speed, current and flux by varying temperatures and irradiance. These results are presented and validated.

Keywords—PV cell, converter, inverter, IM modelling.

I. INTRODUCTION
The non-renewable energy sources are depleting day by day so the need is to concentrate and focus on the renewable energy sources like solar, tidal, wind etc., as the solar energy is clean and more abundant, much concentration is on the PV cell. It has some advantages like less maintenance, long life time and ease of installation. When a photovoltaic cell is illuminated by sunlight or artificial light, electric power is generated. A Photovoltaic directly converts the solar energy into electrical energy since there is no conversion to thermal energy; it is a direct conversion process. Though the energy potential of the sun is immense, the efficiency of solar cells is quite low. It works on the principle of PN junction. If doped with P type gives excess of holes and if doped with N type gives excess of electrons. Average energy of electrons is nothing but Fermi level; it is nearer to valence band for P type and nearer to conduction band for N type. Whenever a P type and N type materials are sandwiched a PN junction is formed, this junction is blocked by the electrons and holes. This is nothing but the band gap. Whenever the sunlight has energy more than the band gap then the junction breaks and the electrons flow and the movement of electrons is termed as the current. So the PV cell is represented by a current source rather than voltage source. Manufacturing of PV cells is mainly of 3 types they are
1. Single crystalline cell where the cell is made by only one crystal and it has good efficiency around 20-25% but it costs high.
2. Poly crystalline cell where the efficiency is quite less than single crystalline but the cost is less compared to single crystalline.
3. Amorphous crystalline cell has the least efficiency when compared to both but it is very economical. Usually found this type of solar cells in calculators.

II. PV CELL MODEL AND MATHEMATICAL ANALYSIS
Basically PV cell is modeled as single diode model and two diode model mostly. The equivalent of single diode model is shown below.

Using the Kirchhoff’s current law for the single diode circuit model as shown

\[ I = I_{ph} - I_d - I_{sh} \]  

(1)

The current through the diode \( I_d \) is given by

\[ I_d = I_o \left[ \exp \left( \frac{V_d}{nKT_C} \right) - 1 \right] \]  

(2)

The Current-Voltage (I-V) equation of the single diode equivalent circuit for the PV cell is,
When the terminals of the PV cell are open circuited the voltage produced is maximum and is called open circuit voltage $V_{oc}$ given by

$$V_{oc} = \ln\left(\frac{I_{sc}}{I_o} + 1\right) \left(\frac{nKT_C}{q}\right)$$

The reverse saturation current $I_{or}$ at reference temperature is given by,

$$I_{or} = \exp\left(\frac{qV_{oc}}{nKT_r}\right) - 1$$

Increase in temperature results in the decrease in the band gap of the semiconductor material. The parameter most affected is the open-circuit voltage ($V_{oc}$) because of its dependence on saturation current ($I_o$).

$$I_o = I_{sc} \left(\frac{T_C}{T_r}\right)^3 \exp\left(\frac{qE_g}{nK}\left(\frac{1}{T_r} - \frac{1}{T_C}\right)\right)$$

There is a direct relationship between the output power of solar cell and solar irradiation. This is because the light generated current $I_{ph}$ is directly dependent on the solar irradiation and hence $I_{sc}$ increases with the increase in the incident irradiation.

$$I_o = \frac{G}{1000} \left[I_{scr} + K(T_C-T_R)\right]$$

Where
- $T_R$=Reference temperature, 298.15 Kelvin
- $I_{ph}$=short circuit current at $T_C$ and irradiance
- $I_{sh}$=Current through shunt resistance $R_{sh}$
- $I_{or}$=Reverse saturation current at $T_R$ in Amperes
- $K$=Boltzmann’s constant=1.38*10^-23 Joules/Kelvin
- $q$=Electron charge=1.60*10^-19 Coloumb
- $n$=Diode ideality factor (between 1 and 2)

By using the above equations carefully, designed the PV cell model in labview [1] and check the simulated results for varying temperature and irradiance and also plot the P-V and I-V characteristics.

III. SINGLE STAGE & TWO STAGE CONVERSION

PVs can be interfaced either through a single-stage dc/ac converter or through a two-stage dc/dc converter followed by a dc/ac converter [3]. First in single stage process direct conversion of the dc voltage from PV cell to ac by using an inverter is done, the efficiency is more in this type of conversion since it has only one stage for conversion so the name.

Inverter takes DC voltage at input side and converts it to AC voltage. Voltage fed inverter is used more for AC motor drive, induction heating, etc. In voltage fed inverters, transistor family devices are used because of self-commutation and high switching frequency. In this paper a simple simulation block diagram for a three-phase, two-level PWM inverter is used. Each leg of the inverter is represented by a “switch” which has three input terminals and one output terminal. The output of switch is connected to upper terminal when control signal is positive and to negative terminal when the control signal is negative. The phase voltages are calculated by the following equations.

$$V_{An} = \frac{2V_{Ao} - V_{Bo} - V_{Co}}{3}$$

$$V_{Bn} = \frac{2V_{Bo} - V_{Co} - V_{Ao}}{3}$$

$$V_{Cn} = \frac{2V_{Co} - V_{Ao} - V_{Bo}}{3}$$

In the above circuit, the upper and lower limits are supplied from the PV system. It is designed in the control and simulation loop block of labview.

After getting the phase voltages, these 3 phase quantities should be converted into 2 phases. Why the need to convert means? For dynamic control of induction motor, parc transformation is used. It is explained in the induction motor modelling concept.
In single stage conversion the disadvantages are flexibility of control and also it needed so many pv cells that should be connected in series or parallel to form as a panel at the input side so the number of pv cells required are high then the cost of equipment increases naturally. So the use of converter is needed, so focus on the boost converter.

By using boost converter the number of cells to be used at input side is reduced and can increase the voltage also to our comfort level by varying the duty cycle. Boost converter has two controls namely open loop and also closed loop control. Whenever the temperature and irradiance are maintained constant then open loop control is best one. The pulses to the switch are supplied directly and by varying the duty cycle for the switch, required output is desired. For simulation point of view the temperature and irradiance are maintained constant but in practical cases it is not possible so closed loop control is used, the actual output is compared with the desired output and the error that is generated is given to pwm generator where it compares with a ramp signal and generates required pwm signals. This process continues until the actual value and desired value are equal which gives zero error.

The Boost converter is designed in NI multisim and is shown below.

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IV. INDUCTION MOTOR MODELLING

The induction motor (IM) is largely used in many industrial applications due to low cost, good torque density and robustness. In general, the mathematical model of any Induction Motor can be modelled by various methods, like, space vector phase theory or the two-axis theory of electrical machines. Main drawback of the space vector phase is coupling effect in the control of SCIMs, it gives a highly over damped plant response, thus making the system very slow and sluggish. Thus an IM model was developed using the concept of rotating d–q field reference frame concept. The most popular representation for ac machines for transient simulation is the so-called qd model based on a series of mathematical transformations [2]. The direct and quadrature axis model based on the space phase theory is widely used to study the dynamic behaviour of three -phase inductor motor. Rotating reference frame, e.g. stationary, rotor or synchronous are used to transform physical (abc)variable s of the machine into fictitious (qd) variable. By having the voltage and current quantities in qd frame, it is possible to control the speed of the machine by controlling the flux and torque independently.

The three phase output (abc) from the inverter is converted into 2 phase (d-q) quantities by the following equations.

\[
\begin{bmatrix}
 v_d \\
 v_q \\
 v_b
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
 1 & -1 & 0 \\
 \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & -\frac{2}{\sqrt{3}} \\
 \frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix} \begin{bmatrix}
 v_a \\
 v_b \\
 v_c
\end{bmatrix}
\]

\[ (11) \]

The stator and rotor equations are used for the modeling of induction motor.

Stator equations

\[
v_a = i_a R_a + \frac{d q}{dt}
\]

\[ (12) \]

\[
v_b = i_b R_b + \frac{d q}{dt}
\]

\[ (13) \]

\[
v_c = i_c R_c + \frac{d q}{dt}
\]

When converted to two phase quantities the voltage equations are

\[
v_{ab} = R_i i_d + \frac{d \lambda_b}{dt} \Rightarrow \lambda_{ds} = \int(v_{ds} - R_s i_{ds})
\]

\[ (14) \]

\[
v_{qr} = R_i i_q + \frac{d \lambda_q}{dt} \Rightarrow \lambda_{qr} = \int(v_{qr} - R_i i_{qr})
\]

0 = \frac{d \lambda_d}{dt} = \frac{d \lambda_q}{dt}

\[
\Rightarrow \lambda_{dr} = \int(- R_i i_d - \omega_r \lambda_{qr})
\]

0 = \frac{d \lambda_q}{dt}

\[
\Rightarrow \lambda_{dq} = \int(R_i i_q - \omega_r \lambda_{dr})
\]
Here stator reference frame is taken so the $V_{dr}$ and $V_{qr}$ are zeroes.
The stator and rotor flux linkages in the stator reference frame are defined as

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds}$$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2} \left( \frac{P}{2} \right) \left( \lambda_{ds} i_{qs} - \lambda_{qs} i_{ds} \right)$$

These equations are mathematically designed in the math script block of labview and the respective torque, speed, flux, current waveforms are simulated.

V. SIMULATED RESULTS

(A) Fixed Temperature and Variable Irradiance: $T_c=25^\circ$C & $G=1000$(W/m$^2$)
The torque, speed, flux and also voltage waveforms of two phases are shown. $S_\alpha$ and $I_\alpha$ are flux and current waveforms. These can be simulated by using either single stage or two stage conversion process. Remember one point that steady state torque occurred at 5.5(time) and speed at 5.48(time).

(B) Variable Temperature and fixed Irradiance
1. $T_c=-5^\circ C$ & $G=1000(W/m^2)$

The wave forms are presented similar as by varying the temperature and keeping the irradiance constant. The temperature in varied form -5$^\circ$C to 85$^\circ$C in steps of 15$^\circ$C. Here steady state torque occurs at 4.25(time) and speed at 4.3(time). The main difference observed is that as temperature is increased the output voltage PV cell decreases and also the torque and speed waveforms also takes more time to attain steady state speed. Once reached the steady state then apply the load.

2. $T_c=10^\circ C$ & $G=1000(W/m^2)$

3. $T_c=40^\circ C$ & $G=1000(W/m^2)$

4. $T_c=55^\circ C$ & $G=1000(W/m^2)$
The observation clearly shows that whenever the temperature is increased then output of pv system decreases and also it takes more time to reach steady state torque and speed and vice versa but whenever the irradiance is increased then output of pv increases and takes less time to reach steady state since irradiance has direct effect on output of pv system. For single stage more pv cells are required and for two stage less number are required and control complexity problem is avoided.

VI. CONCLUSION & FUTURE SCOPE

In this paper a clear study and comparison is conducted on PV system for single stage and two stage conversion by using labview. The models are constructed using simple VI’s and math script. In future by using two diode model for PV cell design and also if included the velocity of air and its effect then the exact output of PV Cell is derived.

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