Simulation and Analysis of Solar Powered Induction Motor Drive with V/f Control for Electric Vehicle Applications

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Abstract. Induction Motor (IM) drive with V/f control for electric vehicle application is presented in this paper. The DC-AC converter of induction motor drive is supplied by a Solar PV system. The complete system model consists of solar PV array, DC/DC converter and three phase Inverter with V/f control is developed in MATLAB/Simulink. A 4 kW Induction motor is selected as drive. The simulation model developed in MATLAB is operated under different conditions, the results are obtained. The results are presented and discussed.

1. Introduction

Photovoltaic (PV) based power systems had significant developments during the last few decades. There is a noticeable progress solar PV based power generation around the world due to its advantages such as low maintenance, easy installation, zero pollution. Total capacity of first solar PV power station “Arco Solar” installed in California in 1982 is 1 MWp[1]. At present, “Tengger Desert Solar Park” in China is the world’s largest PV station with the installed capacity of 1547 MW[2]. The solar power plant with a capacity 648MW at Kamudhi, Tamilnadu is largest solar PV installation of its kind in India. The total worldwide PV capacity has increased by 95 GW, with a 34% growth in 2017 and the cumulative installed capacity of Solar PV exceeded 401 GW by the end of the year 2017. This is sufficient to supply 2.1 percent of the world's total electricity consumption [3].

Electric vehicles have a century long history back from 19th century. Introduction of Internal Combustion (IC) engines suppressed the electric vehicle industry. But, in 21st century, the technological developments and the environmental concerns due to the usage of fossil fuels have turned the focus towards EVs and Renewable energy [4,5].

Automobile Industry has been migrating into electric powered vehicle and this revolution has received positive impact worldwide. The legends in automobile industry like Tesla, Mercedes Benz, Toyota and Chevrolet have already launched their variants into the market. Tesla’s EV is driven by Induction Motor. One of the major limitations in the developing countries which restrict the promotion of electric vehicle is the charging stations. Charging Stations are the important requirements for the electric vehicle industry since, the vehicle need to be charged in a regular interval.
Solar Powered charging stations are emerging along with EV industry [6,7]. India’s first solar powered charging station has recently installed in Mumbai. The charging station is the associated project of Magenta Power and Exicom Power Solution. A solar powered charging station at Netherlands is equipped with 20 charging points. The charging points are connected to a solar PV system consists of 200-panel solar array and a 400kW/800kWh Tesla Power pack battery system.

In this paper, solar powered induction motor drive for electric vehicle application is attempted. The Induction motor drive system is directly fed by the power generated using solar PV system. The paper is organized as follows; Section 2 describes the structure of the complete system. Functionality of each component in the system is also explained. The simulation model and the results are presented and discussed in Section 3. The presented work is concluded in section 4.

2. Structure of Induction Motor Drive System

Figure 1 shows the block diagram of the proposed solar powered electric drive system for electric vehicle. The main components of the system are PV array, DC-DC Converter with MPPT Controller, 3 phase Induction Motor drive.

![Figure 1. Structure of Induction Motor Drive System](image)

Photovoltaic (PV) modules convert sun light into DC electricity. Solar PV has non-linear characteristics and the output power of PV mainly depends on the weather conditions such as irradiation and temperature of light falling on the cells [8-9]. DC-DC converters are used in PV systems to regulate the voltage generated by the PV modules [10-11]. DC-DC boost converters are used in grid connected applications to step up the module voltage. The MPPT algorithms are used to control the duty cycle of the converter or power conditioning circuit connected in between the PV and load to extract the maximum power from the source and to feed it into the load. The P&O and InC algorithm are widely used algorithms among the MPPT algorithms. Some of the other MPPT algorithms are soft computing MPPT techniques such as Fuzzy, ANFIS based MPPT algorithms and hybrid MPPT algorithms are also proposed [12-16]. Soft computing technique based control provide efficient computation with minimum effort [19], [20]. The P&O algorithm is simple and easy to implement and hence, P&O MPPT algorithm is used in this work. The MPPT controller continuously tracks the output voltage and output current of the PV module, the change in output power (ΔP) is calculated from them. The duty cycle of the converter switch is adjusted according to the change in output power after each perturbation. The MPPT controller continuously adjusts the duty cycle of the converter until the Maximum power is attained.

Induction motors are widely used in Electric vehicle applications and in many other domestic and industrial applications due to its low cost, less maintenance and robustness. To achieve desired performance IM should work under rated stator flux. This can be achieved by maintaining the voltage
to frequency ratio constant [17]. To control the voltage and frequency independently, Inverters are used in AC drive applications with V/f control strategy [18]. Hence, Induction Motor with V/f controlled inverter is adopted for the system development.

2.1 Operation of the System

The output of PV array is supplied to the load through DC-DC Converter. The DC-DC converter is controlled by P&O MPPT controller based on the output of PV module. The duty cycle of DC-DC converter switches are adjusted by P&O MPPT controller. The DC-DC boost converter output is fed into the load.

In this case, the load is an Inverter which drives the induction motor. The DC input is converted into 3 phase AC and fed to the induction motor. Inverter switches are controlled by V/f method to maintain the stator flux constant. The reference speed is set by the user and the V/f controller generates the control signal based on the reference value. The PWM controller provides switching pulses to the inverter switches. The speed of IM is controlled under different load torques.

3. Simulation and Analysis

The simulation model developed in MATLAB/Simulink is presented in figure 2. A 4 kW induction motor is selected as drive. Hence, Solar PV system for 4kW is designed. A solar PV string consists 16 solar PV panels of 250 W (ASW-250P) is built. The electrical specification of solar PV module is given in Table 1. The DC-DC converter is designed to produce DC output of 816V at 4kW. The design procedure presented in [8] is followed to design the converter. The switching frequency $f_s$ of DC-DC Boost converter is 10 kHz. The components values are calculated as follows $L=8.1$ mH, $C=10\mu F$.

Table 1. Electrical Specification of Solar PV Module

| Parameters                      | Unit | Value |
|---------------------------------|------|-------|
| Power at STC                    | W    | 250   |
| Power at PTC                    | W    | 227.8 |
| Vmp: Voltage at Max Power       | V    | 35.2  |
| Imp: Current at Max Power       | A    | 7.1   |
| Voc: Open Circuit Voltage       | V    | 43.22 |
| Isc: Short Circuit Current      | A    | 7.76  |
| Nominal Operating Cell Temp     | °C   | 43.5  |
| Open Circuit Voltage Temp Coefficient | % / °C | -0.303 |
| Short Circuit Current Temp Coefficient | % / °C | 0.035 |

PV panels has non-linear characteristics and the power generated by PV varies depends on the change in weather conditions [9]. Figure 3 and Figure 4 shows the V-I and V-P characteristics of 4kW PV string under different irradiation level respectively. The power output of PV string is 4000W at 25 °C and 1000 W/m².
Figure 2. Simulink model of proposed system

Figure 3. V-I characteristics of 4 kW PV String

Figure 4. V-P characteristics of 4 kW PV String

Figure 5.1 Output Voltage of 4 kW PV String

Figure 5.2 Output Current of 4 kW PV String
Figure 6.1 DC-DC Boost Converter Output Voltage

Figure 6.2 DC-DC Boost Converter Output Current

Figure 5.1 and Figure 5.2 shows the output voltage and output current of PV string respectively under standard test conditions of PV module. The PV output is fed as input to the DC-DC Boost Converter. The maximum power output voltage ($V_{mp}$) of the string is 563.2V and the current at maximum power ($I_{mp}$) is 7.1A. The DC-DC boost converter is designed for the output voltage of 804 V and the current output of the converter is 4.9 A. The output voltage and current waveforms shown in figure 6.1 and 6.2 respectively confirms that the converter outputs has very close match with the designed values.

Figure 7.1 Speed of Induction Motor at starting condition

Figure 7.2 Torque of Induction Motor at starting condition

Figure 8.1 Speed of Induction Motor at running condition

Figure 8.2 Torque of Induction Motor at running condition

Electric vehicle requires high torque at low speed during starting condition and the torque gradually decreases with increase in speed. Figure 7.1 shows the speed on induction motor drive under starting condition and the stating torque of the motor drive is depicted in figure 7.2. From the figures, it can be noticed that the speed of the drops at starting condition and the torque is high. Similarly, under running condition, speed increases until it reaches the rated speed (figure 8.1) and the torque is lower than that of the starting torque (figure 8.2).
4. Conclusion

A V/f controlled induction motor drive for electric vehicle application is presented in this paper. A 4kW induction motor drive with Solar PV system is designed and modelled in MATLAB/Simulink. The MATLAB simulation model is simulated under different conditions and the speed, torque of the drive motor is obtained in addition to the output of PV string and DC-DC Boost converter. The results are presented and discussed. The V/f controlled IM drive maintains the speed based on the reference set by the user and the torque of the motor is adjusted accordingly.

5. References

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