International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 3, September 2016, pp. 1012~1022
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v7.i3.pp1012-1022

IRAMY Inverter Control for Solar Electric Vehicle

Rachid Taleb[1], Hemza Saidi[2]
[1] Electrical Engineering Department, Hassiba Benbouali University
Laboratoire Génie Electrique et Energies Renouvelables (LGEER), Chlef, Algeria
[2] Electrical Engineering Department, University of Science and Technology of Oran-Mohamed Boudiaf
Laboratoire d'électronique de puissance d'énergie solaire et d'automatique (LEPESA), Oran, Algeria

Article Info

Article history:

Received Nov 12, 2015
Revised Apr 15, 2016
Accepted May 16, 2016

Keyword:

DSP processor
Induction motor
IRAMY inverter
Solar electric vehicle
SVPWM method
V/F control

ABSTRACT

Solar Electric Vehicles (SEV) are considered the future vehicles to solve the issues of air pollution, global warming, and the rapid decreases of the petroleum resources facing the current transportation technology. However, SEV are still facing important technical obstacles to overcome. They include batteries energy storage capacity, charging times, efficiency of the solar panels and electrical propulsion systems. Solving any of those problems and electric vehicles will compete-complement the internal combustion engines vehicles. In the present work, we propose an electrical propulsion system based on three phase induction motor in order to obtain the desired speed and torque with less power loss. Because of the need to lightweight nature, small volume, low cost, less maintenance and high efficiency system, a three phase squirrel cage induction motor (IM) is selected in the electrical propulsion system. The IM is fed from three phase inverter operated by a constant V/F control method and Space Vector Pulse Width Modulation (SVPWM) algorithm. The proposed control strategy has been implemented on the texas instruments TM320F2812 Digital Signal Processor (DSP) to generate SVPWM signal needed to trigger the gates of IGBT based inverter. The inverter used in this work is a three phase inverter IRAMY20UP60B type. The experimental results show the ability of the proposed control strategy to generate a three-phase sine wave signal with desired frequency. The proposed control strategy is experimented on a locally manufactured EV prototype. The results show that the EV prototype can be propelled to speed up to 60km/h under different road conditions.

Corresponding Author:

Rachid Taleb,
Electrical Engineering Department,
Hassiba Benbouali University,
Laboratoire Génie Electrique et Energies Renouvelables (LGEER),
Hay Salem, Route Nationale No 19, Chlef, Algeria.
Email: r.taleb@univ-chlef.dz

1. INTRODUCTION

Efforts to improve air quality in heavily populated urban communities have rekindled interest in the development of electric vehicle technology. However, the key issues which are challenging in the design of electric vehicles are the electric propulsion system, energy sources and battery management system [1-3]. Solving any of those issues and electric vehicles will compete-complement the conventional internal combustion engines vehicles. This paper will focus in design and performance of electric propulsion system alternative.

Direct Current (DC) and Brushless Direct Current (BLDC) motors drives have been widely applied as propulsion system to EVs because of their technology maturity and control simplicity. However, with the emerging technology in switching semiconductors and digital signal processors at reasonable cost led to more interest in using AC induction motors instead of DC motors [4]. The AC induction motors especially the cage type, have lightweight, small volume, low cost, less maintenance, no commutation, high torque at low speed and high efficiency. These advantages are particularly important for EV applications. In EVs propulsion, an AC induction motor drive is fed from a DC source (battery), which has approximately constant terminal voltage, through a DC/AC inverter [5]. The inverter used in this work is a three phase inverter IRAMY20UP60B type.

Since the output AC voltage of the inverter has high frequency square wave forms, a high speed processor is needed to produce the proper switching sequence. Various switching techniques [6, 7] are used to generate PWM signal which is used to determine the amplitude and the frequency of the output voltage. Among the various PWM techniques, Space Vector PWM (SVPWM) has advantages that made it the most switching techniques suitable for electric vehicles [8, 9]. The interesting features of this type of modulation is that it provides better DC-link utilization, more efficient use of DC supply voltage, produce less ripples and increase life time of drive. Furthermore, it can be easily implemented digitally and hence offers the advantage to perform entire digital processing tasks. The performance of SVPWM depends on the type of processor used for its implementation. Among the various processors available in the market, the most popular are the Texas Instrument DSP which holds about 70% of the market [5]. TMS320F2xxx DSP series are high speed processors which have been developed by Texas Instruments especially for industrial control applications, in particular for implementation of SVPWM algorithm to drive the switches of the inverter.

In the present paper an electric propulsion system is investigated. The propulsion system constitutes of a three phase squirrel cage induction motor, IGBT based three phase inverter and advanced processor, such as DSP, implementing SVPWM algorithm for open loop speed control using V/F method of electric vehicle. The V/F is selected because it tries to achieve some features which are suitable for electric vehicles. These include wide speed span with constant motor torque, low starting current, acceleration and deceleration of the vehicle. The paper is organized as follows: first SVPWM technique along with V/F method is discussed, second the mechanical parts of the vehicle are presented, and third the electrical propulsion system is described and finally practical results obtained are presented along with conclusions.

2. SPACE VECTOR PULSE WIDTH MODULATION TECHNIQUE

A number of Pulse Width Modulation (PWM) schemes are used to control the magnitude and frequency of AC output voltage of the inverter. The most widely used PWM schemes for three phase voltage source inverters are sine wave Sinusoidal PWM (SPWM) [8, 10] and Space Vector PWM (SVPWM) [8, 11]. Since SVPWM is easily implement digitally, enable more efficient utilization of DC bus voltage, and generate sine wave with lower Total Harmonic Distortion (THD), it is most frequently preferable technique used in modern AC machines drives fed by inverters.

The performance of an induction motor is improved when SVPWM technique is applied. Details explanation of the SVPWM and SPWM techniques can be found in [12]. Although SVPWM is more complicated than sinusoidal PWM, it is easily implemented using modern DSP based control systems. The SVPWM technique implemented into the existing TI Digital Motor Control (DMC) library reduces computation time and the number of transistor commutations [13]. It therefore improves Electro Magnetic Interference (EMI) behavior.

3. V/F CONTROL METHOD

The best way to vary the speed of the induction motor is by varying the supply frequency and voltage level simultaneously. It can be shown that the torque developed by the induction motor is directly proportional to the ratio of the applied voltage and the frequency of the supply. By varying the voltage and frequency, but keeping their ratio constant, the maximum torque developed can be kept constant throughout the speed range. In summary, using the V/F control method the following can be achieved: 1) the induction motor can be run typically from 5% of the synchronous speed up to the base speed (maximum vehicle speed), and the maximum torque generated by the motor can be kept constant throughout this range, 2) the starting current is lower, 3) the acceleration and deceleration can be controlled by controlling the change of the supply frequency [14, 15].

4. DESIGN OBJECTIVES

The mechanical structure of the electric vehicle prototype manufactured locally and used in this study is shown in Figure 1. The weight, volume and aerodynamic drag and rolling resistance effects have been carefully considered in the design of the body of the vehicle [5]. The design objectives are to attain maximum speed of 60km/h with a total weight of 500kg and acceleration time 0 to 60km/h below 30sec.

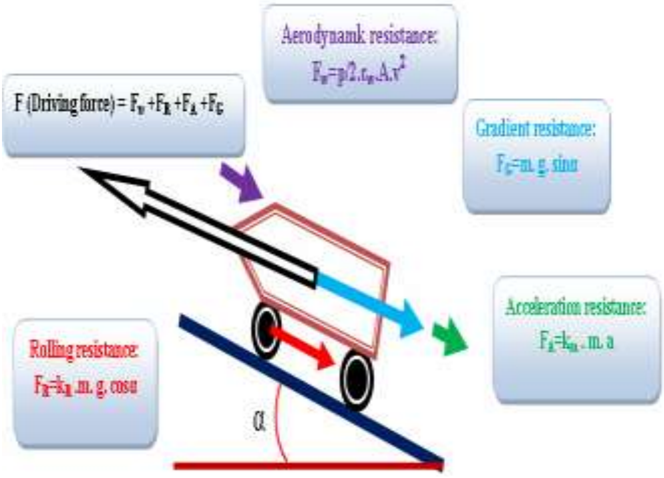

Figure 1. Representation of all forces acting on EV

The road slope torque T is defined by:

$$T = T_w + T_R + T_A + T_G \tag{1}$$

where

a. $T_w = p/2.c_w.A.v^2$: Aerodynamic torque
b. $T_R = k_R.m.g.\cos(\alpha)$: Rolling torque
c. $T_A = k_m.m.a$: Acceleration torque
d. $T_G = m.g.\sin(\alpha)$: Gradient torque
e. m, α : Vehicle mass and road angle

Torque evaluation of the power flow occurring into a vehicle is in strong relation with its mass and a total torque will be expressed as:

$$C_t = T_A + T_p \tag{2}$$

For this study, we selected for the EVs propulsion a cage three phase induction motor of 4.7kW, 220/380V, 11/19A, 4 poles with maximum speed of 1500rpm.

5. SYSTEM DESIGN

The structure of the electro-solar vehicle is a strong evaluating manner because of the more or less rapid but steady evolution of the components technology and performance. As electric vehicles, the different parts are an emerging industry, it is necessary to set time constraints and objectives to be achieved at the level of performance cars, like to improve the acceleration performance of the vehicle. There have been remarkable developments in the area of solar cells and in the development of ultra light weight solar charging battery powered cars. The photovoltaic array can provide a large current in a short time, delivering extra energy to meet the energy requirement when it is needed. In addition, the electronics itself is an important constraint in terms of the shape of the car. AutoCAD software is used to design the vehicle shape (Figures 2 and 3) in order to choose the best frame vehicle shape and determines the weak points of the vehicle.

The front consists a suspension system coupled with the vehicle steering system. The suspensions is considered double wishbone, they consist two triangles, each of them is bound by two hinges one to the frame and the other ball to knuckle. These suspensions are similar to McPherson, often fitted to luxury vehicles or competition one, as they allow an infinite number of settings positions. Figure 4 is used to derive the desired driving power to ensure vehicle operation.

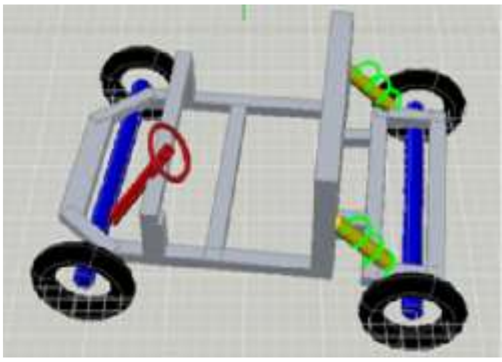

Figure 2. Structure supposed of the car

Figure 3. Mechanical structure design

Figure 4. Photo of the vehicle manufactured

6. ELECTRICAL PROPULSION SYSTEM

Figure 5 shows the block diagram of the open loop control system used to adjust the speed of the vehicle. The hardware includes squirrel cage induction motor, bridge inverter, isolation card, Digital Signal Processor (DSP), speed sensor, potentiometer for desired speed adjustment, and switches for user interface. The desired speed is entered by the user via the potentiometer and then entered to DSP via analog to digital converter (ADC). The speed of the motor (i.e. vehicle) is monitored using a tachometer setup. The inverter used in this work is a three phase inverter IRAMY20UP60B type (Figure 6).

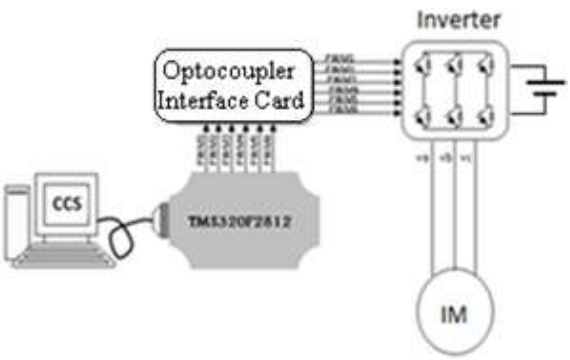

Figure 5. The block diagram of the open loop control system

Figure 6. Three phase inverter IRAMY20UP60B

It is a iMOTION series 20A, 600V integrated power hybrid IC with internal shunt resistor for appliance motor drives applications and compressor drivers. It offers an extremely compact, high performance AC motor driver in a single isolated package to simplify design. This advanced HIC is a combination of low $V_{CE(on)}$ non punch through IGBT technology and the industry benchmark 3 phase high voltage, high speed driver in a fully isolated thermally enhanced package. A built in temperature monitor and over current and over temperature protections, along with the short circuit rated IGBTs and integrated under voltage lockout function, deliver high level of protection and failsafe operation. Using a newly developed single in line package (SiP3) with heat spreader for the power die along with full transfer mould structure minimizes PCB space and resolves isolation problems to heat sink. The internal electric schematic and the typical application connection of IRAMY20UP60B are presented by Figures 7 and 8.

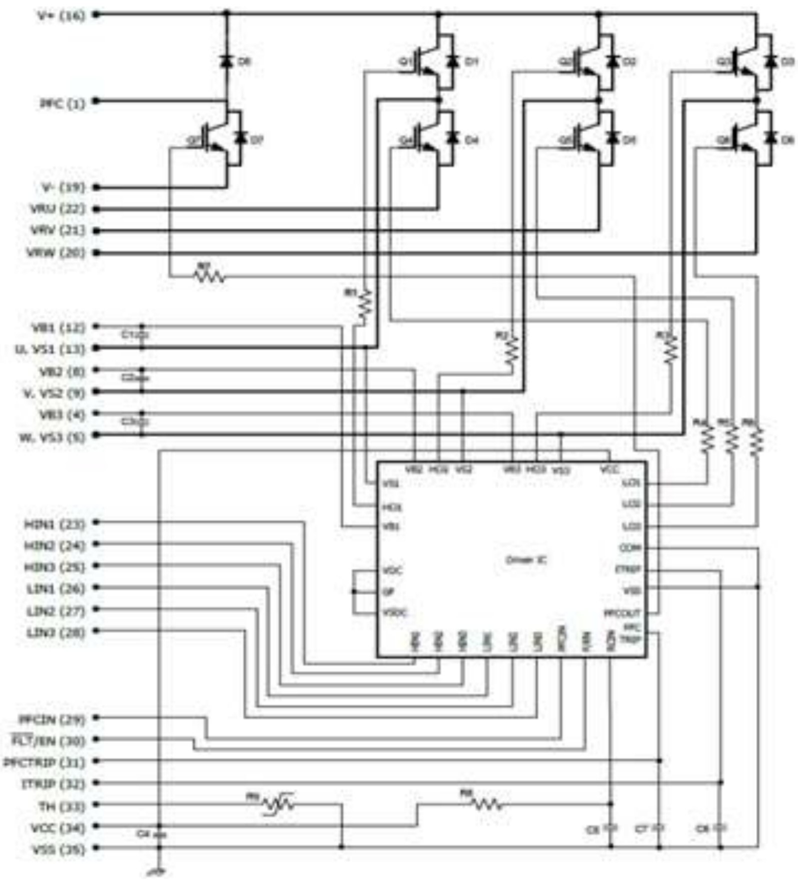

Figure 7. Internal electric schematic of IRAMY20UP60B

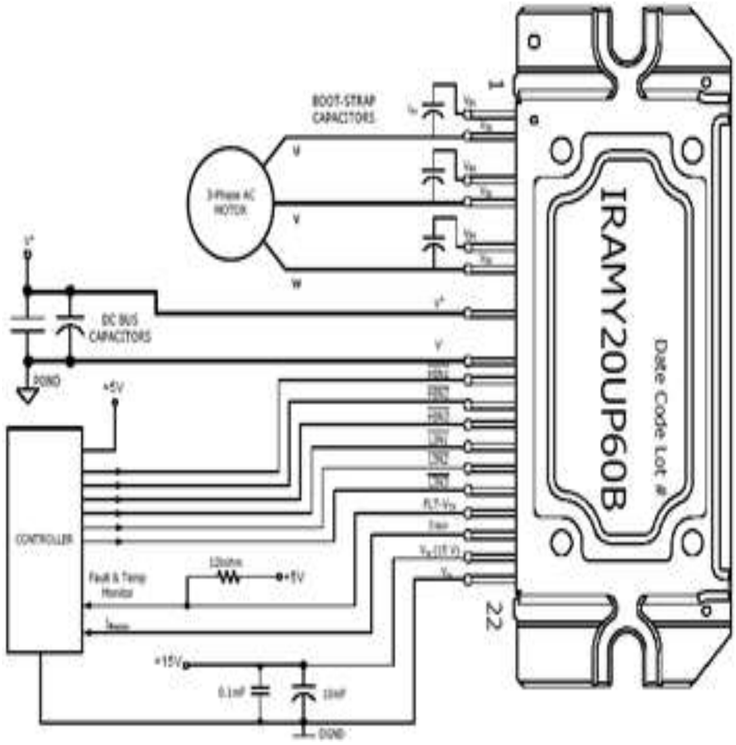

Figure 8. Typical application connection of IRAMY20UP60B

7. OPEN LOOP CONTROL STRATEGY

The user adjusts the desired speed using a potentiometer and this latter converts it to its analogous voltage. The output of the potentiometer is sensed by the ADC which is integrated on the DSP and then converted to desired frequency f_s. The open loop control program consists of several stages as shown in the flow chart depicted in Figure 9. Based on the figure, the open loop system can be summarized as follows:

a. Initialization DMC modules and declare variables;
b. Determine V_s voltages with constant V/F profile based on desired frequency (f_s) using VHz_PROF module;
c. Determine the time durations T_a, T_b and T_c based on V_s and f_s using SVGEN_MF module;
d. Generate the signal PWM based on the time durations T_a, T_b and T_c using PWMGEN module.

8. PRACTICAL RESULTS

Figure 10 shows a snapshot of PWM signals generated by the SVPWM module after the execution of the program implemented in the DSP. Figure 11 illustrates the two PWM pulses which are complementary and used to trigger the gates of one leg of the IGBT Bridge of the inverter. As shown in Figure 11, in order to avoid the short circuit of inverter power supply, we introduced a time delay of 0.5µs between the two complementary pulses.

Figure 12 shows PWM signals before and after the optocoupler card which ensures galvanic isolation between DSP and Inverter. As shown in Figure 12, the PWM signals of magnitude 3.3 volts generated at the DSP output are inverted and amplified to 5 volts by the optocoupler card before inputting them to the inverter.

To check the switching behavior and the reliability of the inverter (i.e. IRAMY20UP60B module), the operation of one of its cell during commutation is investigated. Figure 13 illustrates the waveforms of current and voltage of one IGBT cell under *RL* inductive load (R=8.4Ω and L=4.75mH) during commutation. The switching frequency of the IGBTs transistors and DC power supply voltage are 10kHz and 160V respectively. As shown in Figure 13, the current increases in continuous form from 0 to 5A during switching off (Switch Open) and then decreases back to 0A during switching on (Switch Close). The voltage across the switch is equal to the DC power supply. Figure 13 shows small currents pikes and voltage ringing during switching which are probably due to the IGBTs internal parameters effects.

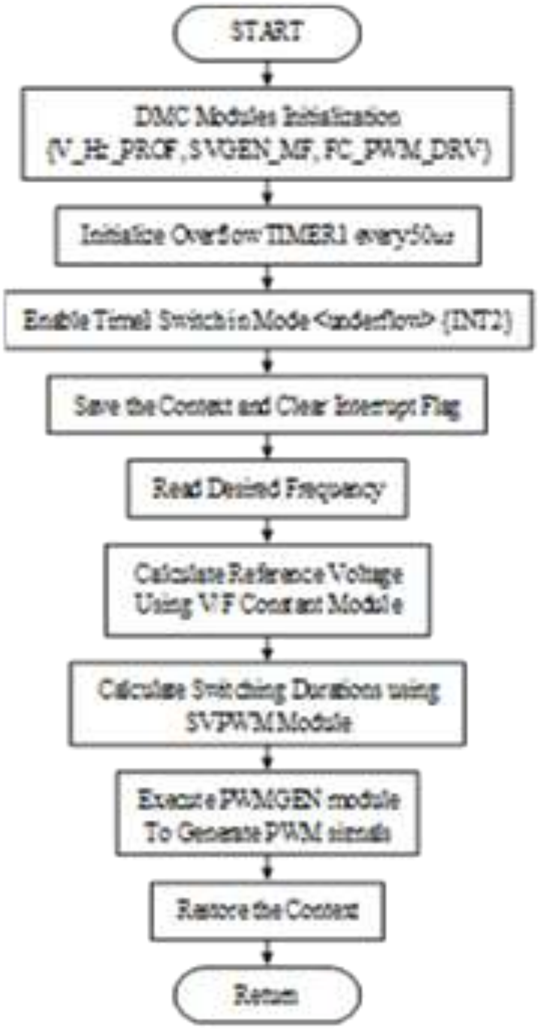

Figure 9. Program Flowchart

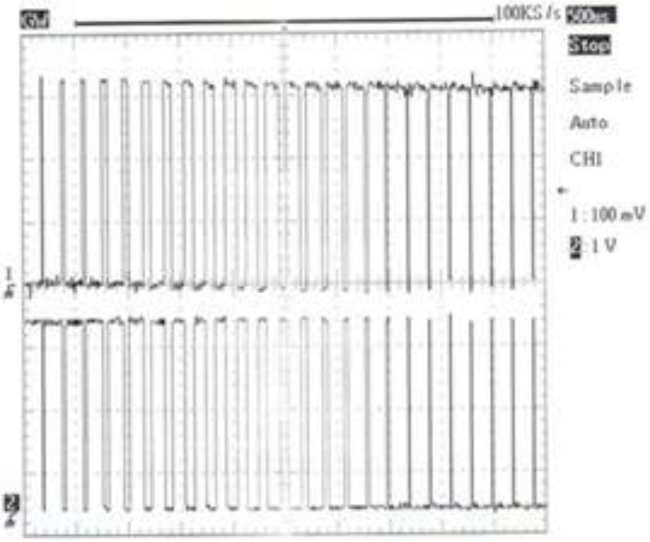

Figure 10. PWM signal and its complement

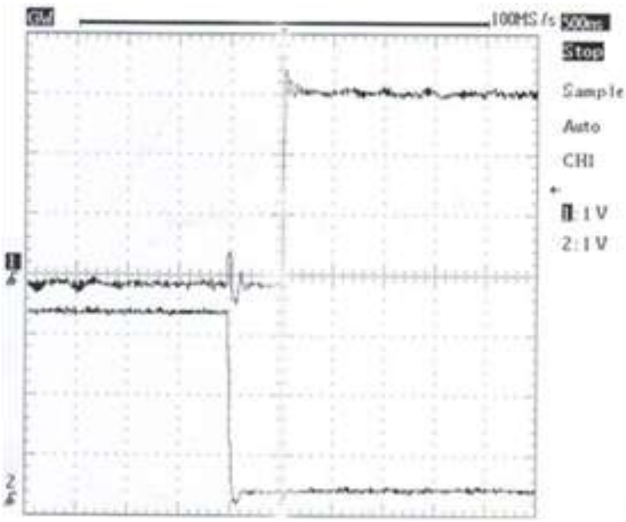

Figure 11. Dead time between two complementary pulses

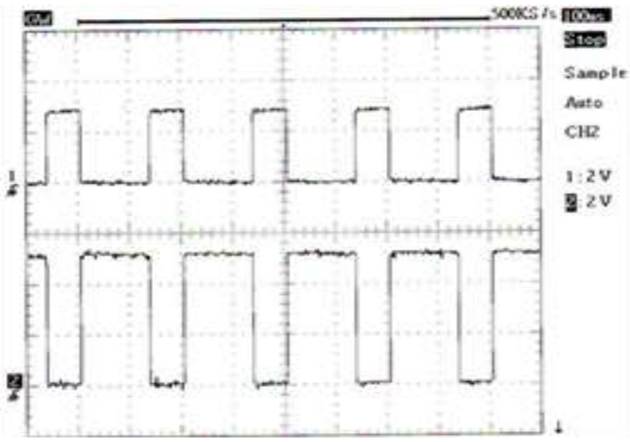

Figure 12. PWM signals before and after optocouplers

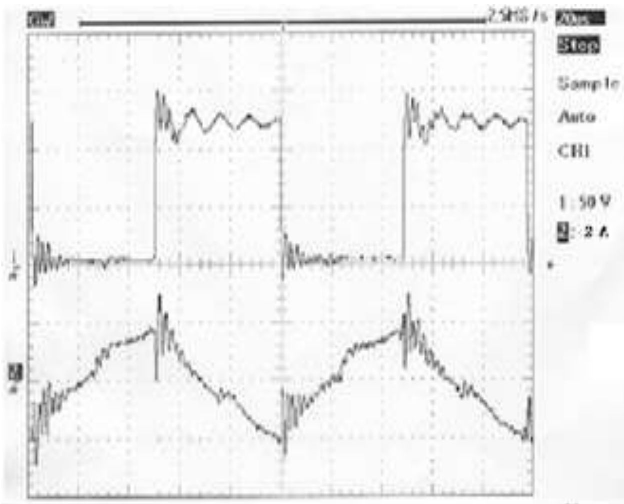

Figure 13. Voltage and current waveforms for one IGBT cell

The inverter is tested to supply induction motor with rating 4.7kW with and without load. This motor is the one selected to be used in the propulsion system designed. The switching frequency of the IGBTs transistors and DC power supply voltage are 10kHz and 200V respectively. Results illustrated in Figures 14 and 15 shows the line to neutral voltage and current at the inverter output when supplying the motor. As can be noticed, the results are very satisfactory and the current wave is almost sinusoidal. Figures 14 and 15 also show the ability of the inverter changing speed of the motor (i.e. vehicle) by generating sinusoidal voltage for different desired frequencies (i.e. 25Hz and 50Hz).

Finally, the practical performance of the electric propulsion system designed operating under road load conditions is investigated. The vehicle has been operated on a flat road and started changing its speed at different stages. The results obtained are very satisfactory as shown in Figure 16. The speed is increased progressively by the driver and the maximum speed reached is more than 60km/h (i.e. 19.5m/s) and the current required at this speed is 3.5A. The results show that the vehicle can reach speed up to 90km/h. However, driving at this speed resulted in lot of vibrations of the vehicle. This is probably due to the incomplete design requirements of the vehicle body.

The capability of the electric propulsion system under overload was also investigated by operating the vehicle on graded road condition where the road grade angle is about 45 degree. The results are shown in Figure 17. The speed reached in this case is about 12.7m/s (i.e. 45km/h) and the current required is 5.8A.

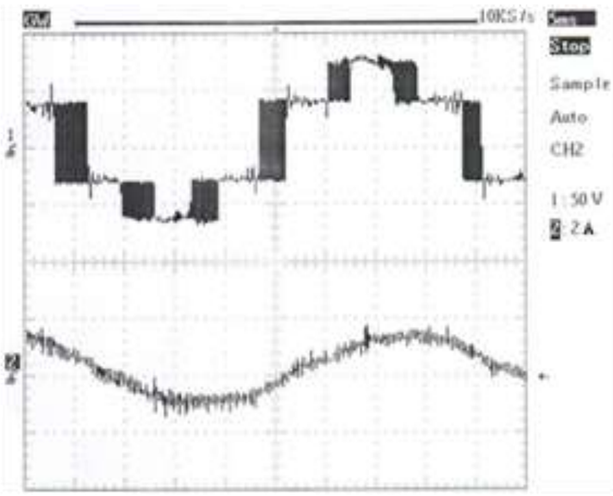

Figure 14. Wave form of the phase voltage and current for *f* = 25Hz with a load torque

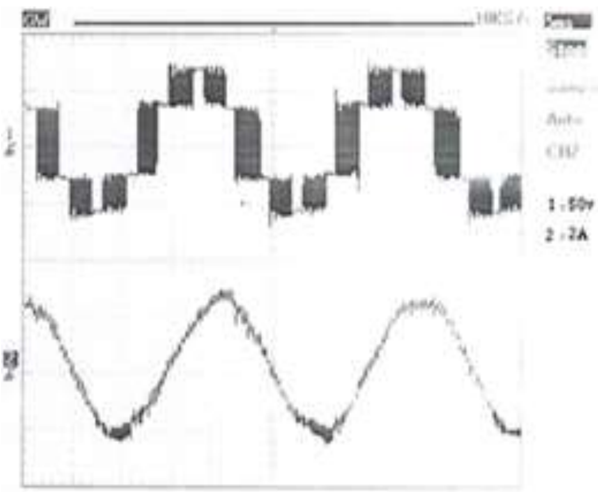

Figure 15. Wave form of the phase voltage and current for *f* =50Hz with a load torque

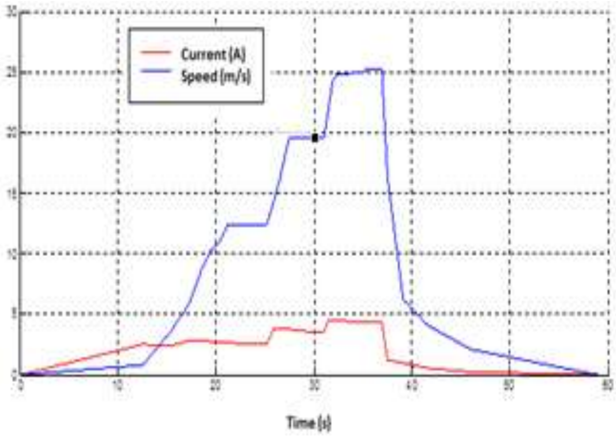

Figure 16. Running the vehicle in flat road

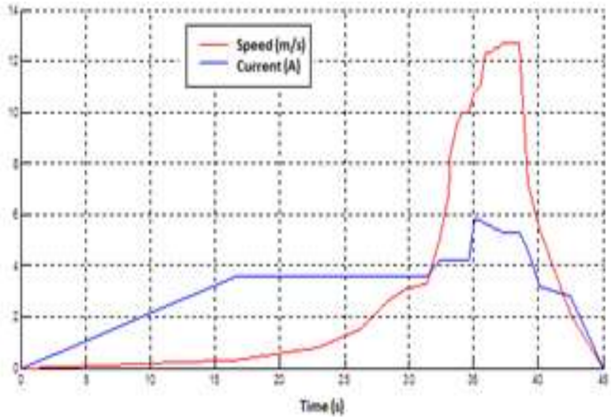

Figure 17. Running the vehicle in a graded road

9. CONCLUSION

This paper presented design of a certain part of an electric vehicle. The electric vehicle is propelled by three phase cage induction motor and powered by batteries which are charged by solar energy station. After several experiment performed, the DSP based control system proposed and developed in this paper is able to operate the vehicle at different speeds under flat and uphill road conditions. However, during uphill condition the current required was quite high compared to current supplied to DC motor used on the same vehicle under the same condition. Therefore, to be comparable to DC motor, more research work is required on control strategies in order to improve the performance of induction motor used in EV.

Due to its low cost, robustness, high reliability and free from maintenance, automobile industry will certainly select cage induction motor as the most appropriate candidate for EVs. Hence, it is believed that the work carried out will contribute in development of future electric vehicles based on the use of squirrel cage induction motor.

REFERENCES

[1] T. Wei, T. Kim, S. Park, Q. Zhu, "*Battery management and application for energy-efficient buildings*", 51st ACM/EDAC/IEEE Design Automation Conference (DAC), pp. 1-6, San Francisco, USA, 1-5 June, 2014.
[2] G. Oriti, A.L. Julian, N.J. Peck, "Power Electronics Based Energy Management System with Storage", *IEEE Transactions on Power Electronics*, vol. PP, no. 99, pp. 1-1, 26 February, 2015.
[3] D. Ganesh, S. Moorthi, H. Sudheer, "A Voltage Controller in Photo-Voltaic System with Battery Storage for Stand-Alone Applications", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 2, no. 1, pp. 9-18, March 2012.
[4] H. Cheng, X. Gong, Y.F. Hu, Q.F. Liu, B.Z. Gao, H.Y. Guo, "Automotive Control: the State of the Art and Perspective", *Acta Automatica Sinica*, vol. 39, no. 4, pp. 322-346, 26 April, 2013.

[5] H. Saidi, "Etude et réalisation d'un véhicule solaire (in french)", *Master thesis*, University of Science and Technology of Oran-Mohamed Boudiaf, Algeria, 2010.
[6] C. Bharatiraja, S. Raghu, P. Rao, K.R.S. Paliniamy, "Comparative Analysis of Different PWM Techniques to Reduce the Common Mode Voltage in Three-Level Neutral-Point-Clamped Inverters for Variable Speed Induction Drives", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 3, no. 1, pp. 105-116, March 2013.
[7] Z.B. Ibrahim, M.L. Hossain, I.B. Bugis, J.M. Lazi, N.M. Yaakop, "Comparative Analysis of PWM Techniques for Three Level Diode Clamped Voltage Source Inverter", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 5, no. 1, pp. 15-23, 2014.
[8] Z.B. Ibrahim, M.L. Hossain, I.B. Bugis, N.M.N. Mahadi, A.S.A. Hasim, "Simulation Investigation of SPWM, THIPWM and SVPWM Techniques for Three Phase Voltage Source Inverter", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 4, no. 2, pp. 223-232, June 2014.
[9] C. Wang, Y. Tian, L. Ge, "A novel algorithm of space vector pulse width without sector calculation", *IEEE International Conference on Mechatronics and Automation (ICMA)*, pp. 1475-1480, Tianjin, 3-6 August, 2014.
[10] J. Lyu, W. Hu, F. Wu, K. Yao, "Variable Modulation Offset SPWM Control to Balance the Neutral-point Voltage for Three-level Inverters", *IEEE Transactions on Power Electronics*, vol. PP, no. 99, pp. 1-1, 15 January, 2015.
[11] C. Sarath, A. Antony, *"Implementation of SVM to improve the performance of a nine level inverter with reduced number of switches"*, IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), pp. 1-5, Kozhikode, 19-21 February, 2015.
[12] G. Brando, A. Dannier, A.D. Pizzo, D. Iannuzzi, "*Voltage fluctuation smoothing in the half-bridge cells of MMC for induction motor drives using recirculation currents SVM control*", IEEE International Energy Conference (ENERGYCON), pp. 94-100, Cavtat, 13-16 May, 2014.
[13] D.A. Morales, K. Findlater, V. Chandran, "*A motor controller using field oriented control and Hall effect rotor position sensors: Simulation and implementation"*, 6th European Embedded Design in Education and Research Conference (EDERC), pp. 235-239, Milano, 11-12 September, 2014.
[14] D. Amudhavalli, L. Narendran, "*Speed control of an induction motor by V/F method using an improved Z source inverter"*, International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM), pp. 436-440, Chennai, 13-15 December, 2012.
[15] P. Elangovan, N.K. Mohanty, "FPGA Based V/f Control of Three Phase Induction Motor Drives Integrating Super-Lift Luo Converter", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol. 5, no. 3, pp. 393-403, February 2014.