Design and Performance Evaluation of a Solar Assisted 25kW PMSM Drive for Four Wheeler Electric Car.

Premananda Pany

Abstract: ***This paper presents a complete design and control of solar assisted passenger car electric engine which aims to overcome the disadvantages associated with present E-Rickshaw. Here a permanent magnet synchronous motor (PMSM) drive is considered as main electric engine fed from Battery and Solar PV cell. Generally in VSI fed PMSM drive the dc input voltage to the inverter is kept constant irrespective of the load demand. This leads to more losses in the dc bus and overall efficiency of the system decreases. This paper presents a noble control technique with variable dc link voltage to improve the efficiency of the PMSM drive by minimizing the dc link power losses. An additional separate PI controller is used to control the dc link voltage which adjusts dc- link voltage indirectly. The design of PI controller with basic principles is illustrated and the necessary conditions are analyzed. This control scheme is tested with a 25kW Permanent magnet synchronous motor (PMSM) drive suitable for application in electric vehicle. The effectiveness of the system is verified through simulation using Simulink/ MATLAB.***

Keywords: Solar PV cell, Battery, PMSM, Electric car, DC Bus Voltage.

I. INTRODUCTION

In solar power assisted electric vehicle, improvement of overall performance in terms of millage, increased speed, and reliability is the main concerns [1]. Although EVs are being designed with different types of energy sources, power converters, power management schemes, still it is expected to have cost effective EVs which can be easily affordable by the customers. Three wheeler battery operated passenger rickshaw are becoming popular in cities but are not suitable for intercity long drive [2]. Several technologies are available and they can be implemented in a manner which can lead to achieve a successful design of passenger electric car. Looking at the environmental effect of conventional internal combustion based vehicles and to control the hazardous emission from burning of fossil fuels, different kinds of renewable energy sources have come up as alternative energy sources [3][4]. Many significant improvements are required to integrate these renewable energy sources into electric vehicle are inevitable in near future. Solar power is one of the cleanest natural energy which can be used more effectively in vehicle applications. Different topologies have been proposed in literature to connect solar energy system in EVs[5]. Batteries have always been find the best energy storage device and it is essential to use as power storage in EVs. Different types of batteries can be used for this purpose but among the available batteries Lead acid batteries are widely used and can also be used for solar assisted vehicles. Among the motors permanent magnet synchronous motor (PMSM) is most favorite for vehicular application since they have significant advantages, attracting the interest of researchers and industry for use in many applications [6][7].

II. PMSM Drive Topology

The circuit topology of PMSM drive fed from solar PV panel and battery source is shown in Fig.1. the entire electric drive system consists of three power converters; a unidirectional DC-DC converter for connecting solar PV system, a bidirectional DC-DC converter for connecting battery with DC link and a 3-phase voltage source inverter (VSI) which connects directly to the motor. Both energy sources empowers the DC link to be maintained at desired power level and the bidirectional DC-DC converter facilitates the charging process of batteries from solar cells continuously. Therefore in this configuration, the batteries can perform more efficiently and can supply power to the load intermittently as it charges from solar system continuously. The advantage of this circuit is that it uses minimum number of IGBT switches to complete all the operation of the vehicle. The switching frequency also plays a very vital role as it affects the overall weight and size of the drive system, the size of the inductors also reduce. In this proposed control technique one more voltage sensor is required at the DC link to measure the instantaneous dc bus voltage which is required as input to the controller in order to achieve variable dc link voltage. The initiative of dc bus voltage control can be more useful to obtain higher power conversion efficiency as the practical solar PV cell efficiency is very low as compared to other type of renewable energy sources; typically it's efficiency varies between 16% to 20%.

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The solar PV cell is controlled using maximum power point tracking (MPPT) method so that maximum electrical energy can be extracted from the solar panels [8].

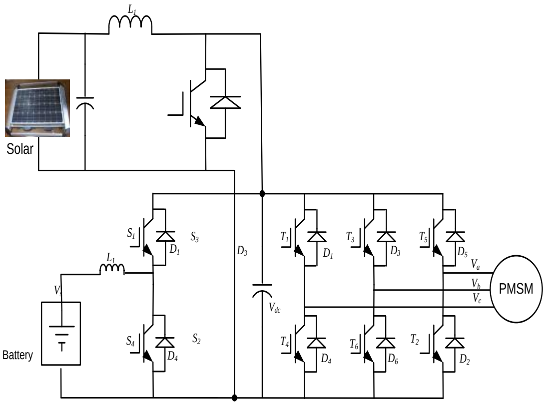

Fig.1. PMSM Drive Topology of 25kW electrical system for passenger car.

III. CONTROL PHILOSOPHY OF THE DRIVE SYSTEM

As shown in the schematic in Fig.1, the most suitable PMSM drive for a passenger car which is fed from solar PV cell and storage Lithium Ion battery driven through a current controlled PWM voltage source inverter. The main control circuit of this drive associated with the inverter includes a speed control loop, which is designated as outer loop requires the measurement of actual motor speed and speed command. The rotor position "θ" is used to derive the motor speed and also to control the switching of inverter. The output of the speed control loop is considered to be the requisite load torque. The internal current control loop depends directly on the output of the speed controller. The speed controllers as well as the current controllers are designed using proportional- integral (PI) controller. This control scheme helps to achieve variable dc bus voltage at the inverter input terminal as per the load power requirement, which leads to minimize the dc link power losses hence increases the overall efficiency of the system. is the rated voltage of the motor.
The voltage equations of PMSM in rotor reference frame are given by

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \begin{bmatrix} r_s + pL_d & -\omega_e L_q \\ \omega_e L_d & r_s + pL_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} 0 \\ \omega_e \lambda \end{bmatrix}$$

Where 'r_s' is the stator winding resistance, ω_e is the electrical rotor speed, p is the number of poles; λ_d, λ_q are the d-q components of the stator flux linkage. λ is the rotor flux linkage generated by the permanent magnets; i_d and i_q are d-q components of the stator winding currents, v_d and v_q are the d-q components of the stator winding voltage. T_e is the electromagnet torque. L_d, L_q are components of stator winding inductance.
λ_d and λ_q can be expressed as

$$\lambda_q = L_q i_q \qquad (1)$$

$$\lambda_d = L_d i_d + \lambda \qquad (2)$$

$$\frac{d\theta_m}{dt} = \omega_m = \frac{2}{P}\omega_e \qquad (3)$$

$$\frac{d\omega_m}{dt} = \frac{1}{J}\left(T_e - B\omega_m - T_L\right) \qquad (4)$$

The generated torque of the rotor in *dq* variable is

$$T_e = \frac{3}{2}\frac{P}{2}\lambda i_q \qquad (5)$$

To maximize the torque generation, the reference value of the *d*-axis current can set to zero.
The *q*-axis current can be written as

$$i_d^* = 0 \qquad (6)$$

$$i_q^* = \frac{T_m^*}{\lambda_m}\cdot\frac{2}{3}\cdot\frac{2}{P} \qquad (7)$$

The reference current for each current of the motor can be derived by using following equation

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{1}{3}V_{DC}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} a \\ b \\ c \end{bmatrix} \qquad (8)$$

Where v_a,v_b and v_c, are 3-phase stator phase voltages in *abc* coordinate system. By using the Clark transform, voltages in the α-β coordinate system can be obtained as

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (9)$$

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ \cos\left\langle\theta - \frac{2\pi}{3}\right\rangle & \sin\left\langle\theta - \frac{2\pi}{3}\right\rangle \\ \cos\left\langle\theta + \frac{2\pi}{3}\right\rangle & \sin\left\langle\theta + \frac{2\pi}{3}\right\rangle \end{pmatrix}\begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} \qquad (10)$$

The two front end converters are controlled using Variable dc bus voltage control method to maintain the required dc bus voltage at desired value which depends on load power requirement and the dc link reference voltage is determined by operational parameters of PMSM drive.

(1)

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Basically the voltage control at dc link relies on the input voltage of the voltage source inverter. The magnitude of dc link voltage is controlled in a closed loop manner. However due to continuous long drive operation the battery SOC level decreases resulting voltage drop at the output of the battery, under such circumstances the recharging of the battery is done from the solar energy at the same time controller operates the bidirectional dc-dc converter in buck mode, thereby fast charging of the battery bank can be achieved by supplying high charging current. The control block diagram is shown in Fig 3. In this configuration the battery can be at healthy condition at all time for maintaining desirable SOC level, thus adequate and uninterruptible power can be delivered to the motor to meet the load demand with desired torque controllability during transient and steady state operation.

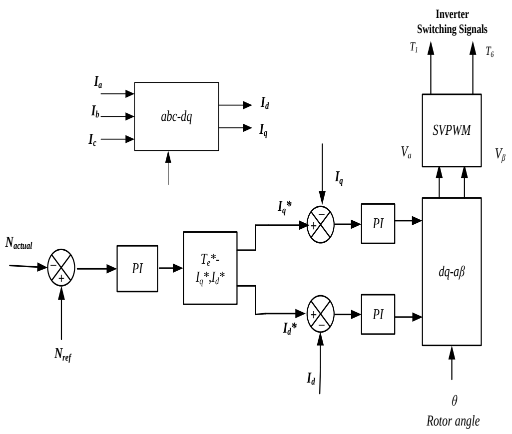

Fig. 2. VSI and PMSM Control.

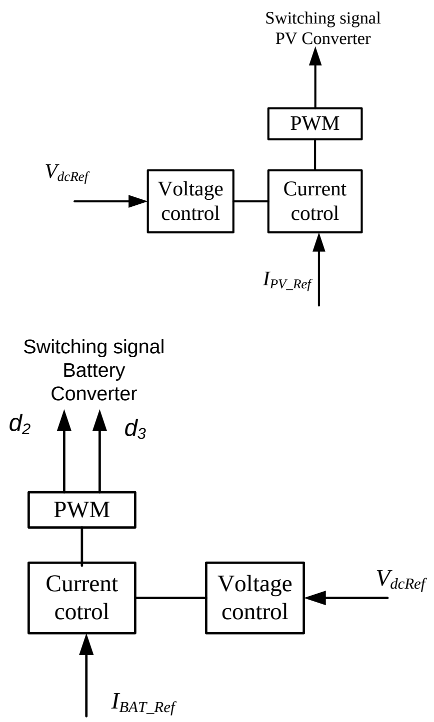

Fig.3. (a) solar power control and (b) Battery power control

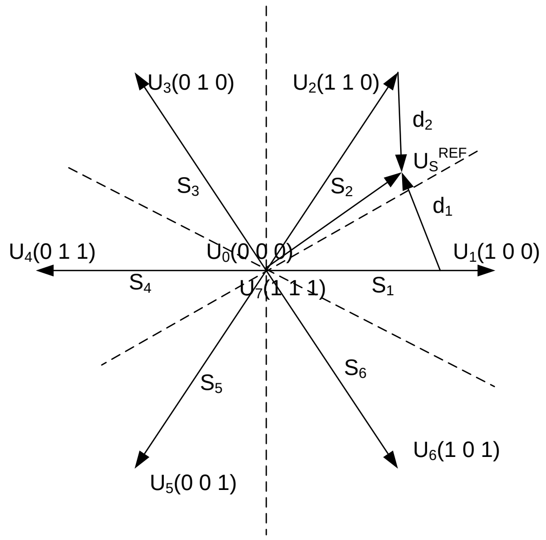

Fig. 4 Space Vector VSI.

For the control of Voltage Source Inverter used in electric drive application generally Vector control methods are employed. In space vector modulation technique, in any sector of the space vector, the adjacent two active vectors V_i and V_j of sectors and the zero vector is V_z.

It can be known from the space vector synthesis principle that

$$D_i.V_{dc} = \sqrt{3}.V_{ph}.\sin\left(\frac{\pi.i}{3} - \theta\right) \qquad (11)$$

$$D_j.V_{dc} = \sqrt{3}.V_{ph}.\sin\left(\theta - \frac{\pi.i}{3} + \frac{\pi}{3}\right) \qquad (12)$$

Where V_{ph} inverter output phase voltage, V_{dc} is the DC bus voltage and angle *‘θ’* is the angle between V_S^{Ref} .

$$V_{dc} = \left[\frac{1 - D_{rth}}{1 - 2D_{rth}}\right].V_{in} \qquad (12)$$

TABLE-1

SI. No	Components	Parameters
1	Battery	Lead Acid, 220 V, 90 Ah, SOC = 100%.
2	Solar PV Cell	5 kW
3	Solar Power converter	DC/DC Boost Converter
4	Battery Converter	DC/DC Bidirectional Converter
5	Inverter	3-ph VSI, IGBT switch..
6	Switching Frequency	f_{SW} =30 kHz
7	Motor	25kW, 6200RPM, IPMSM.

IV. SIMULATION RESULTS AND VERIFICATION.

The feasibility study of the PMSM drive system is presented in this section. The controller performance proves to be very satisfactory from this simulation study. Fig.5 shows the motor speed reaches its desired speed smoothly within 2 seconds without any glitches during starting of the drive. Fig. 6 depicts the nature of torque characteristic, at time t=0, during starting the torque is maximum and the corresponding speed at the same time is zero. As the speed increases the torque decreases. The torque even decreases when motor speed is controlled in field weakening mode to reach beyond the rated speed which is a common phenomenon in electric vehicle drive system. Therefore the controller allows the motor to operate from standstill to maximum speed, thus the proposed drive can be used efficiently as it allows the motor vehicle to operate at higher speed which is highly desirable feature in such application. Fig.7 shows the power utilization by the motor and it can receive uninterruptible power from the source as the vehicle's battery charges from solar PV cells mounted in the vehicle during the whole day hour. Fig.8 demonstrates the battery state of charge (SOC) which decreases as motor draws power for its operation during starting and steady state operation.

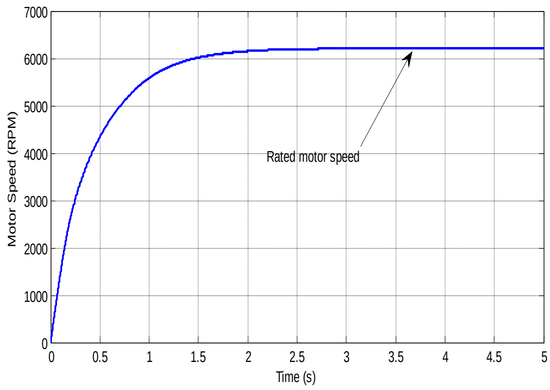

Fig. 5. Motor speed in RPM.

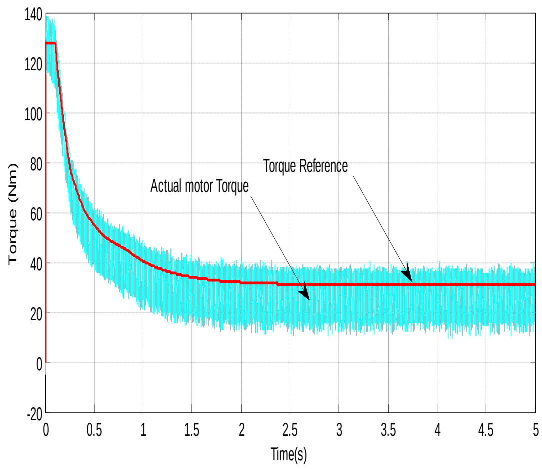

Fig. 6. Motor Torque (Nm).

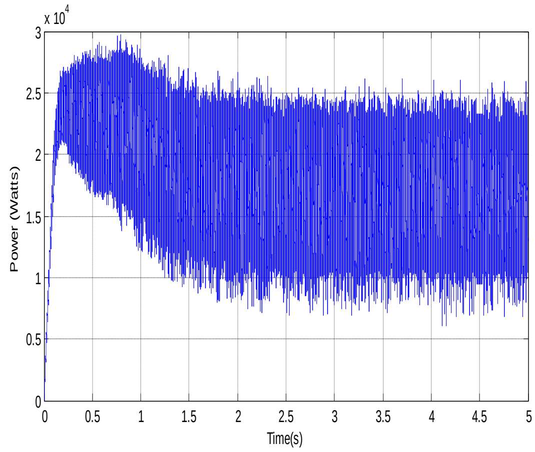

Fig. 6. Motor Power.

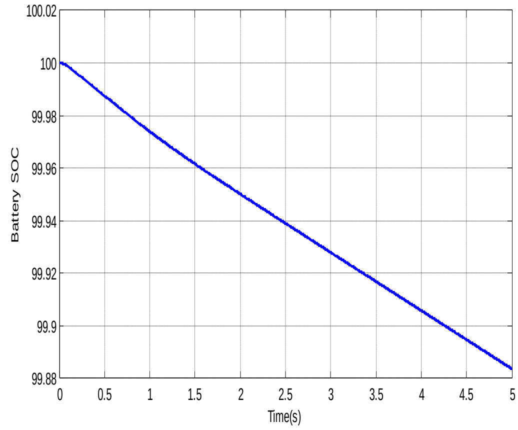

Fig. 7. Battery SOC.

V. CONCLUSION

The work presented in this paper demonstrates the utilization of a PMSM drive in electric vehicles in order to achieve higher millage and speed. It fulfills all the necessary requisite at par of conventional IC engine based motor vehicles. The performance has been improved by proper integration and control of the solar PV system and battery power management system. The next generation electric vehicle on road demands highly reliable electric drive system which can be replaced the conventional fossil fuel based engines which causes serious environ mental issues. This proposed drive system can be replaced in EVs to overcome the demerits associated with the present battery operated electric vehicles.

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Ph.D in Electrical Engineering with specialization Power electronics & drives from MNNIT, Allahabad. Currently working as Associate Professor in EEE Department at Sharda University. Have 17 years of experience in the field of Teaching, Research & Industry. Published research papers in the area of Power Electronics, Electric vehicle in various international journals and conferences.