Switched Reluctance Motor Drive for Electric Vehicle using Artificial Neural Network Control Strategy

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***Abstract*— Hybrid electric vehicle is a topic where most of the researches are taking place. It is a viable solution to oil crises and air pollution. Electric vehicle(EV) with switched reluctance motor(SRM) are more predominant than those with permanent magnetic motor. Hybridization of different energy sources can be used to extend the driving miles of EV. Installing a PV panel on the EV will reduce the dependence2 on battery supply. In this paper switched reluctance motor (SRM) with PV panel and battery as energy source is used .An advanced tri-port converter is proposed here to control the energy flow between SRM ,PV panel and battery. Artificial neural network (ANN)is used here instead of conventional PI controller.Circuit with ANN controller has less total harmonic distortion in the SRM phase current compared to that of PI controller The proposed converter can be operated in six different modes. In which four modes are used for driving and other two modes are used for stand–still onboard charging. In the driving mode speed control of SRM motor is obtained. In the charging mode ,battery charging is accomplished without the use of any external hardware. For efficient charging of battery maximum power point tracking of PV panel also can be done .Simulation is done on Matlab/Simulink**

Keywords*— *Switched Reluctance Motor (SRM), Photovoltaic panel(PV), Tri-port converter, Electric vehicle (EV)

I. INTRODUCTION

Electric vehicle uses a motor for traction and their corresponding energy sources. Electric vehicle have many advantageous compared to that of conventional internal combustion engine. It includes high efficiency ,less pollution ,independence of fuel. Conventionally permanent magnetic(PM) machine is used as motor drive but large quantities of rare earth materials are used in PMs which in turn increase the cost of the motor.The current battery technology is not enough to provide sufficient energy supply for the motor, this will reduce the driving miles of the EV.

In order to overcome all this problem permanent magnetic motor are replaced with highly efficient switched reluctance motor, which does not use any permanent magnetic material[1-5]. PV panel is used as a sustainable energy source to drive the motor which will reduce the dependence on battery for energy ,thereby the life period of the battery can be extended. When the motor load is low or energy generated by the PV panel is more ,PV panel can be used to charge the battery.

A typical PV fed EV consist of an off board charging station, ,PV panel, batteries, power converter and motor[6-8] A multiport converter obtained by integrating full bridge converter and DC-DC converter is used to couple two energy sources and motor. Both the phase shift angle and duty cycle are used as control variables to decouple the energy sources and control the output .Zero voltage switching of mosfet and zero current switching of diodes are main advantage of the circuit. This converter is not suitable for grid connected charging for battery so additional converters are required .This will increases the power conversion stages and thereby the loss. Also this type of converter is suitable only for dc motor. Power conversion stages for grid charging can be eliminated by redesigning the motor for including some online charging capability. But this will introduce high harmonic content in the system. Another way is to use SRM .Paper [9] compares the performance of 50 KW switched reluctance motor with that of a permanent magnetic synchronous motor. The test result shows that SRM has an efficiency and maximum output power similar to that of an permanent magnetic synchronous motor. The rotor of SRM does not contain any winding or permanent magnetic material, therefore it has high efficiency ,low cost and can be used for wide range of speed control. The main issue for achieving best performance of SRM is choosing the Suitable power converter. Several converters are available for SRM among this modified miller converter is the best option considering it's switch number and control of switches. But for EV application high performance charging circuit is also needed. Paper [10] four phase half bridge converter based on intelligent power module is used for driving and grid charging of electric vehicle but the use of bridge topology will reduce the reliability of the system.

For efficient charging of battery and low cost operation of EV a new tri-port converter for SRM is introduced here, Which can effectively co-ordinate the PV panel, SRM and battery. This converter can be operated in six modes and thereby achieving the energy flow control between the three ports. Artificial neural network controller(ANN) is used instead of conventional PI controller.ANN controller has lesser harmonic distortion in the motor current than the conventional PI controller.

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II.PROPOSED CONVERTER TOPOLOGY AND OPERATING MODES

The proposed tri-port converter shown in fig1 is used to coordinate three energy terminal ,SRM, battery, PV panel. The converter consist of four switches(S_0~S_3),four diodes(D_0~D_3) and two relay. The converter can be operated in six different modes by operating the relay switchesJ_1 and J_2. Fig.2 shows six modes of operation

In mode 1.PV panel will act as the source to drive the motor. In this mode the energy supplied by the PV is more than motor needed, the excess energy in the PV is used to charge the battery. In mode 2 when the vehicle is running under heavy load condition , both battery and PV will supply the motor.In mode3, PV panel will drive the motor and battery is inactive.In mode4 ,battery will drive the motor. The last two modes are battery charging mode.In mode 5 the battery is charged directly connecting to grid.In mode6 battery is charged using PV panel and the motor is inactive

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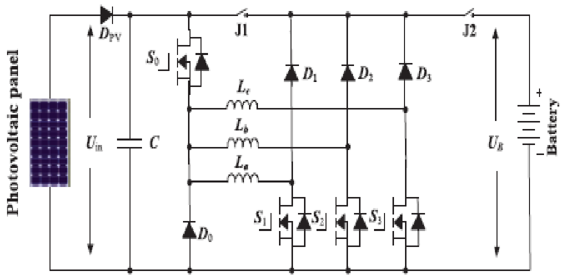

Fig 1 proposed tri-port converter

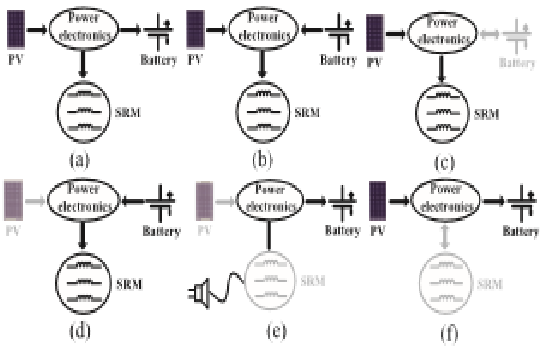

Fig 2 Six modes of operation

A .Driving Mode

The first four modes are called driving mode. Because in this four mode the SRM is under working condition.

(1)Mode 1

If the vehicle is running under low load condition and there is enough solar irradiation the energy supplied by the PV panel will be more than that of motor required. In this condition the system will operate in mode1.The equivalent operation circuit is shown in fig 3.Here switch J_1 turn off and switch J_2 turn on. The energy produced from the PV panel is used to drive the motor as well as to charge the battery. This mode is called as driving charging mode because the battery will be charged when the motor is in operating condition.

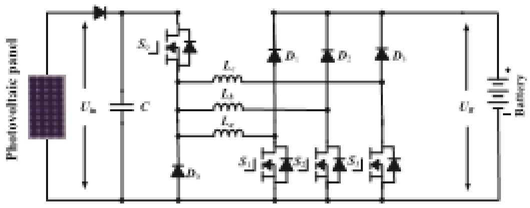

Figure 3 Circuit configuration for mode1

(2) Mode 2

The system will operate in this mode when the load is heavy and energy produced by the PV panel is not enough to meet the load. Both the PV and battery will deliver power to the load. Fig 4 shows the equivalent circuit of operation, in which both the switches are turned on.

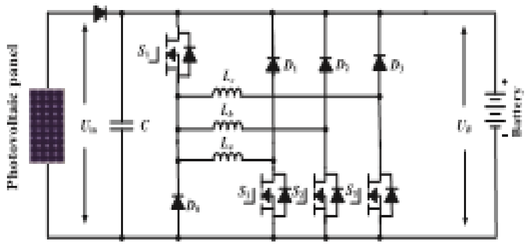

Fig 4 circuit configuration for mode 2

(3) Mode 3

Vehicle will operate in this mode when battery is unable to supply the power , PV panel will drive the motor. The relay switch J1 is turned on and J_2 is turned off. Equivalent circuit of operation is shown in fig 5

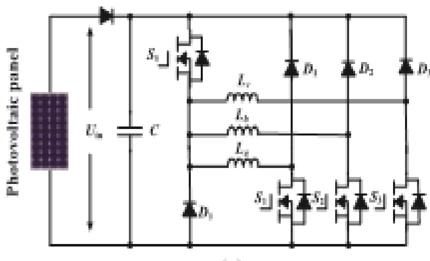

Fig 5 circuit configuration for mode3

(4) Mode 4

EV will operate in this mode when there have no sufficient solar irradiation and PV panel is out of power, battery will supply the power.in this mode both the relays are conducting. The corresponding operation circuit is shown in fig6

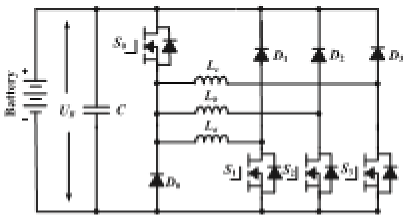

Fig 6circuit configuration for mode 4

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B.BATTERY CHARGING MODE

Mode 5 and mode 6 are called battery charging mode.

(5) Mode 5

When PV cannot charge the battery ,the battery is charged by connecting it with external Ac grid. In this mode battery charging is achieved without an external AC-DC converter. One of the phase winding of the motor is pulled out and it will act as an input filter. The corresponding circuit is shown in fig 7 in which winding corresponding to phase A is pulled out, winding $L_{a1}$and L_{a2} will act as input filter. Both the switches are conducting here

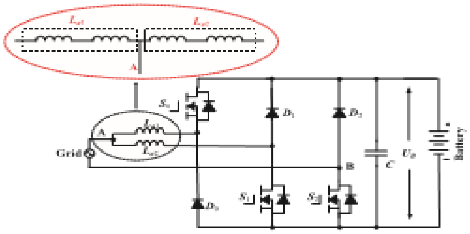


Fig 7 Equivalent circuit for mode 5

(6) Mode 6

In this mode., when the electric vehicle is parked under the sun PV panel will charges the battery. Fig 8 shows the corresponding circuit configuration in which J_1 turn off and J_2 turn on.

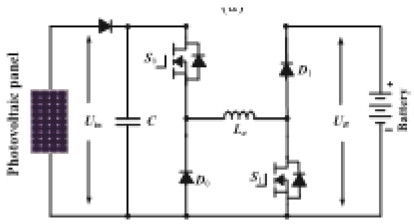


Fig 8 Equivalent circuit for mode 6

III.CONTROL STRATEGY FOR DIFFERENT MODES

A.Control strategy for mode one(Driving –charging mode)

In driving-charging mode PV panel will drive the SRM and charge the battery.The battery is charged by freewheeling current. Maximum power point tracking of PV panel and speed regulation of SRM are the main objectives here. Maximum power tracking of PV panel is obtained by controlling the turn off angle and speed of SRM is controlled by regulating the turn on angle. Turn off angle controls the charging current of the battery. Control strategy for this driving charging mode is shown in fig 9 in which θ_{off} is turn off angle of SRM and θ_{on} is turn on angle of SRM.

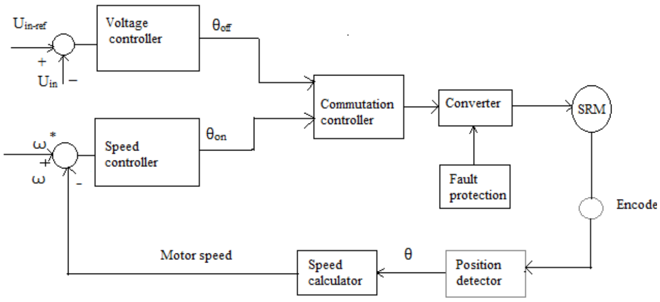


Fig 9.Mode 1 control strategy

B. Driving mode control strategy(mode2,mode3,mode4)

Battery driving and PV driving are the single source driving mode. When the load is heavy ,PV panel alone cannot support the load so the system switches to mode 2 in which the PV panel is connected in parallel with the battery so that there will be maximum utilization of solar power. Since the PV panel is connected in parallel with the battery ,the PV panel voltage will be clamped to the battery voltage.

In PV and battery parallel fed driving mode there are three different working state: winding excitation ,energy recycling and freewheeling state.as shown in fig10

. Phase voltage by ignoring the voltage drop across switches and diode

$$u_{in} = R_k * i_k + \frac{d\Psi(i_k,\theta_r)}{dt}(1)$$

$$= R_k i_k + L_k \frac{di_k}{dt} + i_k \omega_r \frac{dL_k}{d\theta_r}, k = a,b,c \qquad (1)$$

U_{in} is the dc link voltage ,$R_k$is phase resistance ,i_k phase current ,L_k phase inductance, θ_r is the rotor position,$\Psi(i_k,\theta_r)$ is the flux linkage

Back electromotive force

$$e_k = i_k \omega_r \frac{dL_k}{d\theta_r} \qquad (2)$$

Phase voltage

$$U_k = R_k i_k + L_k \frac{di_k}{dt} + e_k \qquad (3)$$

When S_0 and S_1 turned on in excitation region, a positive voltage will apply to phase a winding

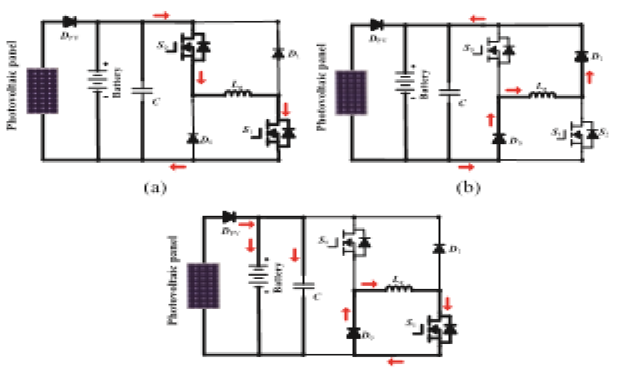
$$+U_{in} = R_k i_k + L_k \frac{di_k}{dt} + e_k \qquad (4)$$

When S_0 is off and S_1 is on , current will be in freewheel as shown in figure(b) . Hence the phase voltage is zero

$$0 = R_K\, i_K + L_k \frac{di_k}{dt} + e_k \qquad (5)$$

When S_0 and S_1 both are turned off ,Phase current will flow back to the source as shown in figure (b)in this state a positive voltage is applied to phase winding

$$-U_{in} = R_k i_k + L_k \frac{di_k}{dt} + e_k \qquad (6)$$



(c)

Fig 10 Different working state for mode2 (a) Winding excitation state (b) Energy recycling state (c) Freewheeling state.

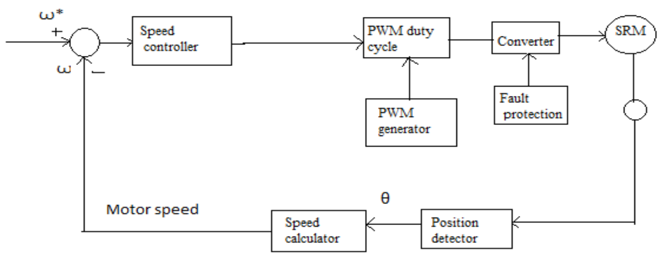


Fig 11 control strategy for driving modes

Control strategy for driving modes are shown in fig 11. Voltage pwm control strategy is used here.

C .Grid charging mode control strategy

The suggested topology can charge the battery without an external converter. There are mainly four battery charging states. Fig12(a)and 12(b) illustrate the two charging states if the grid voltage is greater than zero, In fig 12(a)When the switches S_1 and S_2 is on, grid voltage will charge the winding L_{a2} .Equation for grid voltage is

$$U_{grid} = L_{a2}.\frac{di_{grid}}{dt} \qquad (7)$$

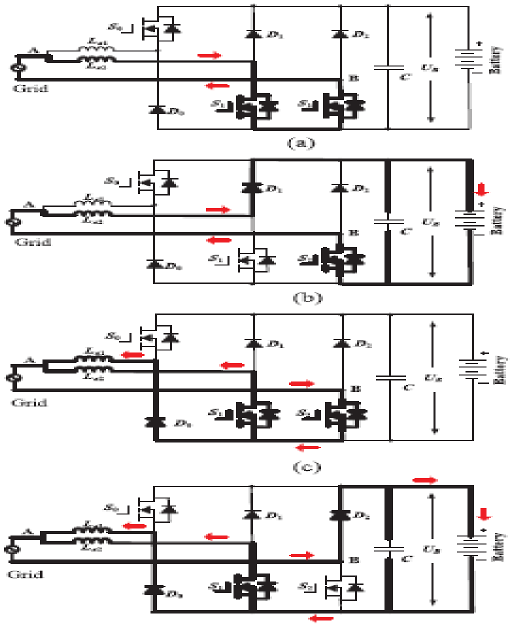
If the switch S_1 turn off and S_2 conduct as shown in fig 12(b),grid and phase winding will be series connected to charge the battery

$$U_B - U_{grid} = L_{a2}.\frac{di_{grid}}{dt} \qquad (8)$$

If the grid voltage is less than zero, two working states are shown in fig 12(c) and12(d).When the switches S_1 and S_2 conduct ,the grid voltage charges the winding and if S_1 keeps conducting and S_2 turns off the grid will be connected in series with phase winding L_{a1} and L_{a2} to charge the battery

$$U_{grid} = \frac{L_{a1}+L_{a2}}{L_{a1}.L_{a2}}\frac{di_{grid}}{dt} \qquad (9)$$

The control circuit used for grid charging is shown in fig 13. The instantaneous grid current reference is calculated by multiplying Grid current with sinθ. The inductance value is more for grid voltage greater than zero compared to that of grid voltage less than zero.



(d)
Fig 12 Charging state of mode 5

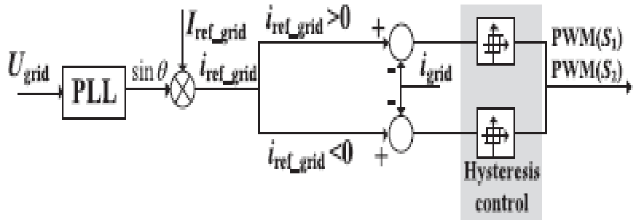
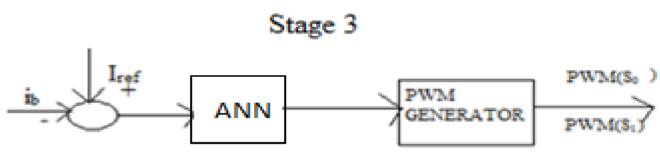


Fig13 control strategy for mode 5

D. Battery charging using PV

During this mode PV panel will directly charges the battery. In order to make full consumption of solar energy there are three stages of charging depending up on battery SOC level.Fig14 illustrate different control strategy adopted depending up on battery SOC. During stage1 battery energy level is very low(0-SOC_1) MPPT control is used for fast charging of battery. In stage2 battery SOC lies between SOC1 and SOC_2., Constant voltage control is used for this stage. During stage3 battery SOC lies between SOC_1-1,micro current control strategy is adopted here.



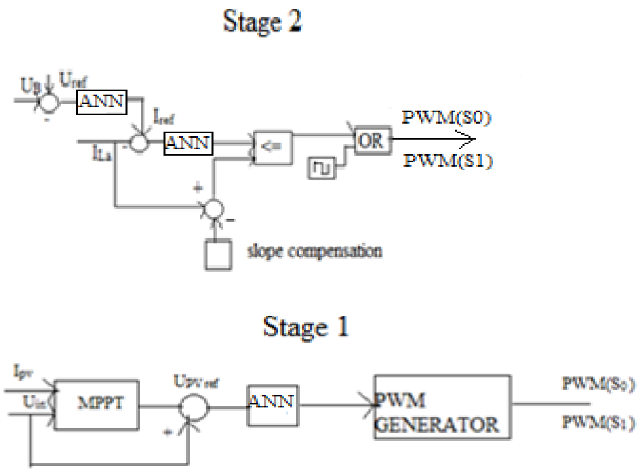
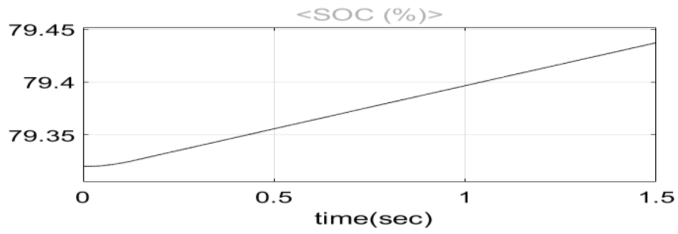
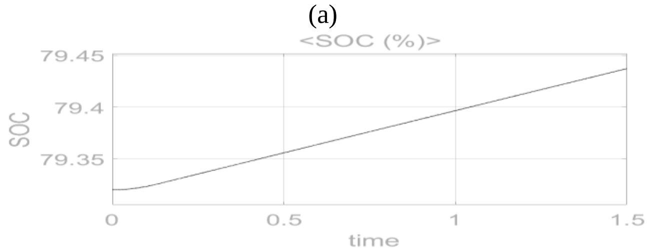


Fig14.Chargingcontrol of battery for mode 6



(a)



(b)

Fig 15.simulation result for mode 1and mode2
(a)simulation result for mode1,(b)Simulation result for mode 2

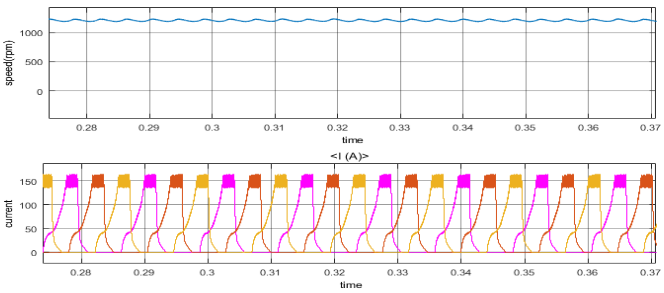
IV.SIMULTION RESULT

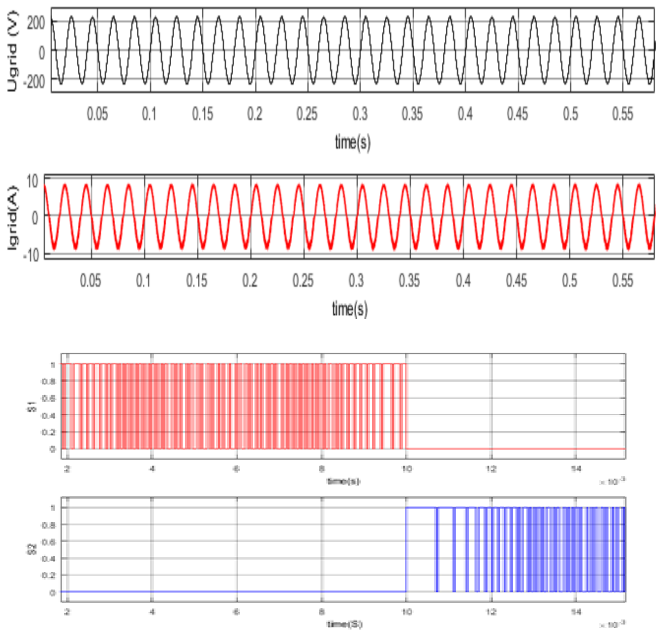
Using Matlab/Simulink Simulation of 12/8 switched reluctance motor is done first.The load torque is given as 35 Nm. Simulation parameters are shown in table I

TABLE I
Simulation parameter

Parameter	Value
SRM	12/8
PV panel Voltage	310V
Battery voltage	355V
Voltagecontrol reference	355V
Current reference	100A
Driving speed	1250 rpm
Load torque	35Nm

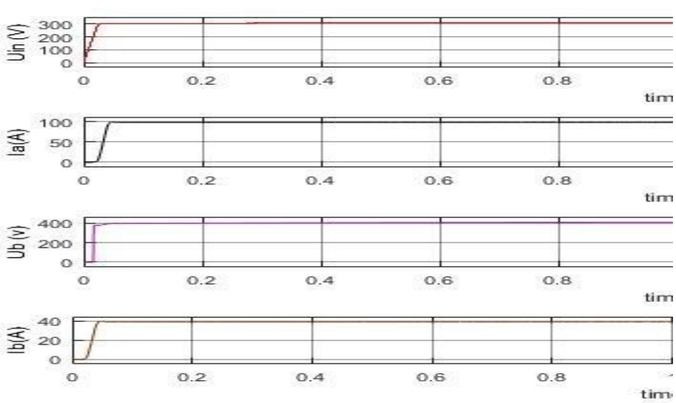
Fig15(a)shows simulation result for mode1 .The speed of SRM is controlled at 1250 rpm,batterySOC is increasing which implies that the pv panel is charging the battery. Fig15(b) shows battery SOC for mode2. The battery SOC is deacreasing which implies that the battery is supplying load. Fig16shows simulation result for charging mode.In which 16(a)represents grid charing .The quality of positive half cycle of current wave form is superior to negative half cycle this is because of the variation in the inductance value.



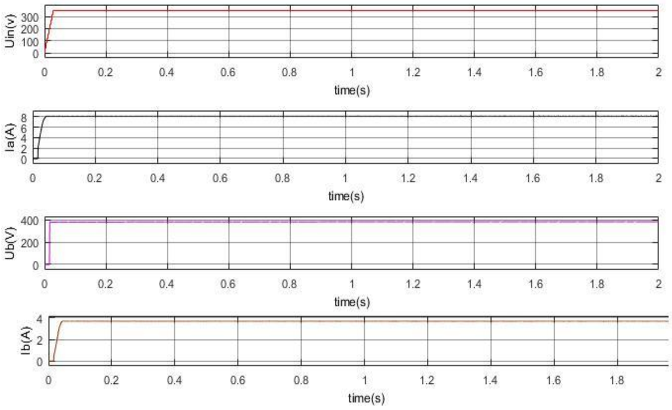


(a)

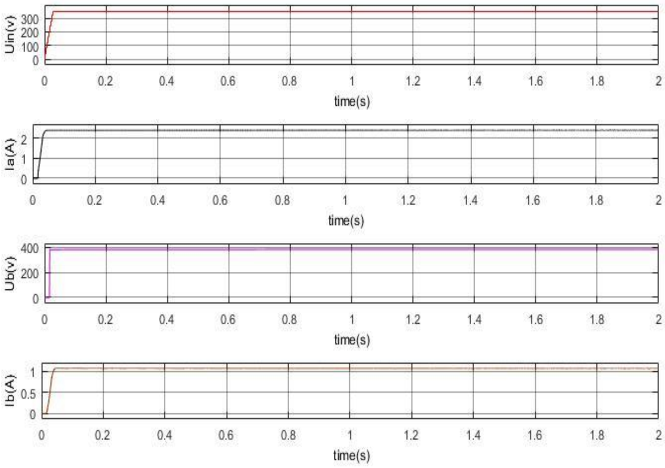
Fig 16(b) represents waveform corresponding tostage 1 constant voltage control is used to achieve MPPT of PV panel.Fig(c) shows waveform corresponding to stage 2 , in which the charging current is less compared to stage1



(b)



(c)



(d)

Fig16.Simulation result for charging mode.(a)grid charging ,(b)PVcharging(stage1),(c)PVcharging mode(stage2)(d) PV charging (stage 3)

V. CONCLUSION

Electric vehicle is a good solution to the increasing energy demand. By incorporating a renewable energy source along with battery we can increase the driving miles of electric vehicle. The proposed tri-port converter have three terminal which can effectively coordinate battery ,solar panel and switched reluctance motor. This can be operated in different mode depending up on the load demand of motor. Thereby a flexible energy flow is obtained. The same topology can be applied to fuel cell powered electric vehicle.Total harmonic distortion of motor phase current is less for ANN controller compared to conventional PI controller

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