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IMPLEMENTATION OF TRIPORT CONVERTER FOR SOLAR-POWERED SRM DRIVE FOR ELECTRICAL VEHICLES WITH FLEXIBLE ENERGY CONTROL FUNCTIONS

[1]A.Malyadri,[2] Y.V. Niranjan kumar,[3]A.Manoj Kumar, [4]G.Manoj Kumar,[5]M.Pallavi,[4]K.Suviraj
[1]Associate Professor ,[2]Assistant Professor,[3,4,5]UG Scholar, Dept. Of E.E.E
[1,2,3,4,5]Sree Venkateswara College Of Engineering, North Rajupalem, Nellore ,A.P

ABSTRACT:

Electric vehicles (EVs) offer a viable solution for reducing greenhouse gas emissions and have thus become a popular research and development topic. Switched reluctance motors (SRMs) are one of the motors that have been promised for EV applications. The use of photovoltaic (PV) panels on the vehicle helps reduce the reliance on vehicle batteries in order to increase the driving range of EVs. This paper proposes a tri-port converter to control the energy flow between the PV panel, battery, and SRM based on the phase winding characteristics of SRMs. Six operating modes are presented, four of which are designed for driving and two for standstill on-board charging. Simulation results based on Matlab/Simulink prove the effectiveness of the proposed tri-port converter, which has potential economic implications to improve the market acceptance of EVs.

I.INTRODUCTION

Electric vehicles have taken a significant leap forward, by advances in motor drives, power converters, batteries and energy management frameworks [1]-[4]. Nonetheless, because of the limitation of current battery technologies, the traveling miles is relatively short that confines the wide application of EVs [5]-[7]. Regarding motor drives, superior performance permanent-magnet (PM) machines are generally utilized while rare-earth materials are required in large quantities, restricting the wide application of EVs [8][9]. To defeat these issues, a photovoltaic panel and a switched reluctance motor (SRM) are acquainted with give power supply and motor drive, individually. Right off the bat, by adding the PV panel on top of the EV, a sustainable energy source is achieved. Nowadays, a typical passenger car has a surface to the point of installing a 250-W PV panel [Ref]. Second, a SRM needs no rare-earth PMs and is also hearty with the goal that it gets increasing attention in EV applications . While PV panels have low power thickness for traction drives, they can be utilized to charge batteries the vast majority of time. Generally, the PV-fed EV has a similar structure to the hybrid electrical vehicle, whose internal combustion engine (ICE) is replaced by the PV panel. The PV-fed EV system is illustrated in Fig. 1. Its key components include an off-board charging station, a PV, batteries and power converters . In order to decrease the energy conversion processes, one approach is to redesign the motor to include some on-board charging functions . For instance, designs a 20-kW split-phase PM motor for EV charging, but it suffers from high harmonic contents in the back electromotive force (EMF). Another arrangement is based on a traditional SRM. Paper achieves on-board charging and power factor revision in a 2.3-kW SRM by utilizing machine windings as the information channel inductor. The idea of modular construction of driving topology is proposed in paper .Based on shrewd power modules (IPM), a four-phase half bridge converter is utilized to achieve driving and matrix charging. Although modularization upholds mass creation, the utilization of half/full bridge topology diminishes the framework reliability (for example shoot-through issues). A straightforward topology for module hybrid electrical vehicle (HEV) that upholds adaptable energy stream. In any case, for gridcharging, the framework ought to be associated with the generator rectifier that increases the energy change cycle and decreases the charging proficiency. In any case, a compelling topology and control strategy for PV-took care of EVs isn't yet evolved. Because the PV has various characteristics to ICEs, the maximum power point tracking (MPPT) and solar energy utilization are the interesting factors for the PV-took care of EVs.

II.SWITCHED RELUCTANCE MOTOR

The SRM or switched reluctance motor is certainly not another innovation; be that as it may, their commercial forms have appeared basically from the past couple of years. The originators of this motor declared that they give high proficiency, better reliability, less cost as well performance as compared with different sorts of motors. The idea of SRM has been perceived in the year 1838. The main advantages of switched reluctance motor mainly incorporate reliability, increased performance, high motor-drive proficiency, the overall framework cost is less, and so forth.This article discusses an overview of the switched reluctance motor.

A.Construction of SRM

In switched reluctance motor, the stator and rotor have projected pole made up of soft iron and silicon stampings. Silicon stamping is used to reduce hysteresis losses.

Stator => Inward projection

Rotor => Outward projection.

The rotor does not have winding and stator only carries main field winding. Each winding in the stator is connected in series with the opposite poles to increase the MMF of the circuit. It is called phase winding. Refer to fig 1.1 AA', BB' and CC'.

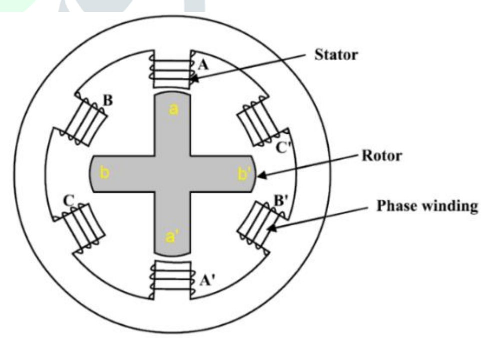


Fig 1: Linear SRM

Pole concern, the quantity of poles in the stator will associate with 6 to 8 numbers. Be that as it may, the rotor carries less number of poles concerning the stator. The rotor poles will be 4 to 8 numbers.

By increasing the quantity of poles we can get a low angle of rotation from the motor. The rotor's shaft is mounted with a position sensor. The position sensor is utilized to decide the place of the rotor by a control circuit.

The control circuit always gathers the information of the rotor position and based on that the regulator gives the contribution to the motor.

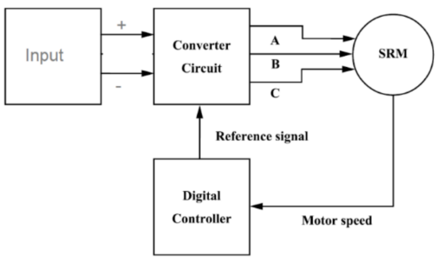


Fig 2:Block Diagram of SRM

The DC input is connected to the driver/converter circuit and the output is connected to the motor. The rotor sensor's feedback wire is connected to the controller circuit and it provides the position of the rotor with reference to the reference axis.

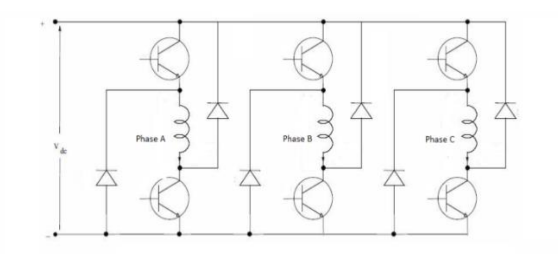


Fig 3: Converter circuit

Finally, the controller collects all information and based on that, reference will be given to the stator. Also, the controller monitors the motor current to protect the motor from internal and external faults.

III.PROPOSED SYSTEM

A. Proposed topology and working modes

The proposed Tri-port topology has three energy terminals, PV, battery and SRM. They are connected by a power converter which comprises of four exchanging gadgets (S0~S3), four diodes (D0~D3) and two relays, as displayed in Fig. 2. By controlling relays J1 and J2, the six operation modes are upheld, as displayed in Fig. 4; the comparing relay actions are illustrated in Table I. In mode 1, PV is the energy source to drive the SRM and to charge the battery. In mode 2, the PV and battery are both the energy sources to drive the SRM. In mode 3, the PV is the source and the battery is inactive. In mode 4, the battery is the driving source and the PV is inactive. In mode 5, the battery is charged by a solitary phase matrix while both the PV and SRM are inactive. In mode 6, the battery is charged by the PV and the SRM is inactive.

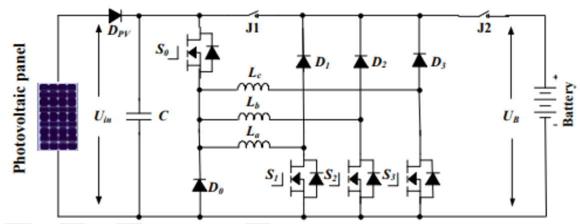


Fig. 4: The proposed Tri-port topology for PV-powered SRM drive.

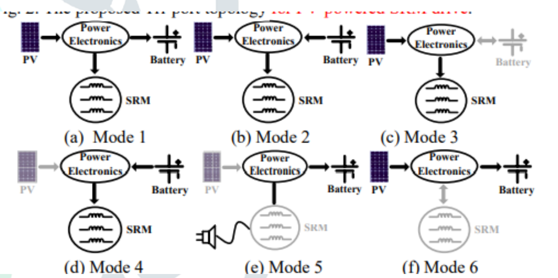


Fig. 5. Six operation modes of the proposed Tri-port topology.

TABLE I J1 and J2 Actions under Different Modes

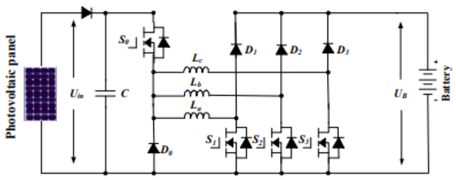
Mode	J1 and J2
1	J1 turn-off; J2 turn-on
2	J1 and J2 turn-on
3	J1 turn-on; J2 turn-off
4	J1 and J2 turn-on
5	J1 and J2 turn-on
6	J1 turn-off; J2 turn-on

B. Driving modes

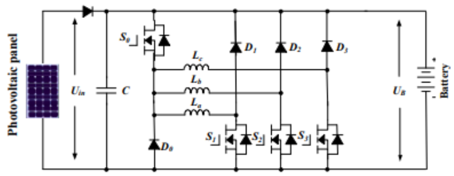
Operating modes 1~4 are the driving modes to provide traction drive to the vehicle.

(1) Mode 1 At light loads of operation, the energy generated from the PV is an overabundance; the framework operates in mode 1. The relating operation circuit is displayed in Fig.6 (a), in which relay J1 switches off and relay J2 turns on. The PV panel energy feed the energy to SRM and charge the battery; so in this mode, the battery is charged in EV operation

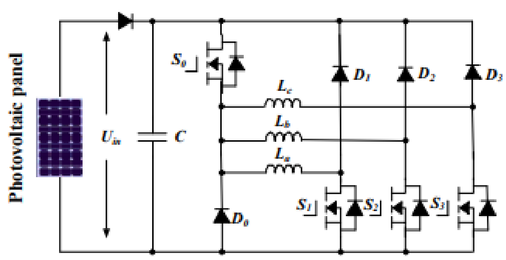
condition.



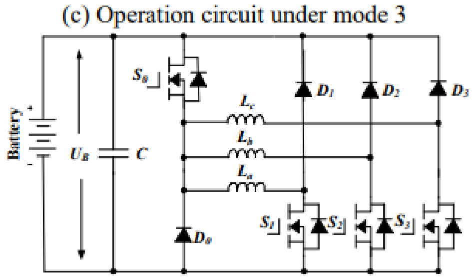
(a) Operation circuit under mode 1



(b) Operation circuit under mode 2



(c) Operation circuit under mode 3



(d) Operation circuit under mode 4

Fig. 6: The equivalent circuits under driving modes.

(2) Mode 2 :When the SRM operates in heavy load such as uphill driving or acceleration, both the PV panel and battery supply power to the SRM. The corresponding operation circuit is shown in Fig. 6(b), in which relay J1 and J2 are turned on.

(3) Mode 3 When the battery is out of power, the PV panel is the only energy source to drive the vehicle. The corresponding circuit is shown in Fig. 6(c). J1 turns on and J2 turns off.

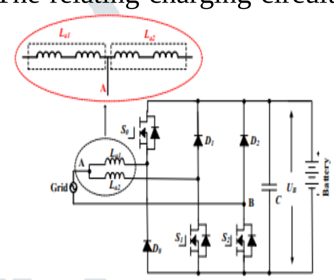
(4) Mode 4 At the point when the PV cannot generate electricity because of low solar irradiation, the battery supplies power to the SRM. The relating topology is illustrated in Fig. 6(d). In this mode, relay J1 and J2 are both directing.

C. Battery charging modes

Operating modes 5 and 6 are the battery charging modes.

(5) Mode 5 At the point when PV cannot generate electricity, an external power source is expected to charge the battery, like AC matrix. The comparing circuit is displayed in Fig. 7(a). J1 and J2 turns on. Point An is central tapped of phase windings that can be easily achieved without changing the motor design. Three phase windings are parted and their midpoints are pulled out, as displayed in Fig. 7(a). The central tapped hub can be got without changing body construction of motor. Phase windings La1 and La2 are utilized as information channel inductors. These inductors are part of the drive circuit to frame an AC-DC rectifier for network charging.

(6) Mode 6 At the point when the EV is parked under the sun, the PV can charge the battery. J1 switches off; J2 turns on. The relating charging circuit is displayed in Fig. 7(b).



(a) External grid-connected charging mode

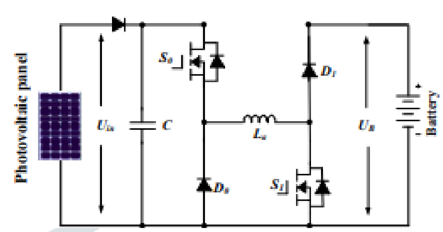


Fig. 7:Equivalent circuits of charging condition modes

III. CONTROL STRATEGY UNDER DIFFERENT MODES

To make the best utilization of solar energy for driving the EV, a control strategy under various modes is planned.

A. Single source driving mode

According to the difference in the power sources, there are PV-driving; battery-driving and PV and battery parallel fed source. In a heavy load condition, the PV power cannot support the EV, mode 2 can be adopted to support enough energy and make full use of solar energy.

In single source driving mode, the voltage-PWM control is employed as the basic scheme, as illustrated in Fig. 8. According to the given speed ω*, the voltage-PWM control is activated at speed control

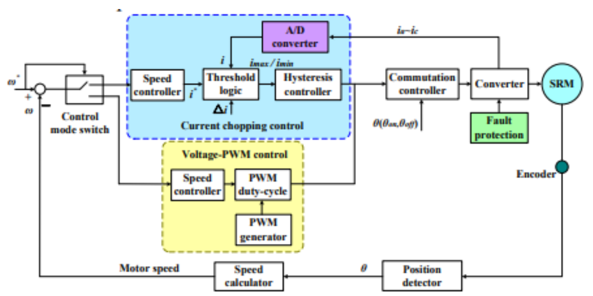


Fig. 8. SRM control strategy under single source driving mode.

B. Driving-charging hybrid control strategy

In the driving-charging hybrid control, the PV is the driving source and the battery is charged with the freewheeling current, as illustrated in drive mode 1. There are two control targets: maximum power point tracking (MPPT) of the PV panel and speed control of the SRM. The dual-source condition is switched from a PV-driving mode. First and foremost, the motor speed is controlled at a given speed in mode 3. Then, J2 is tuned on and J1 is set for change to mode 1. By controlling the mood killer angle, the maximum power of PV panel can be tracked

Fig.9 is the control strategy under driving-charging mode. In Fig.9, θon is the turn on angle of SRM; θoff is the turn-off angle of SRM. By adjusting turn-on angle, the speed of SRM can be controlled; the maximum power point tracking of PV panel can be achieved by adjusting turn-off angle, which can control the charging current to the battery.

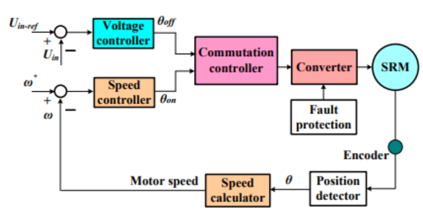


Fig. 9. Control strategy under driving-charging mode (mode 1)

C. Grid-connected charging control

In Fig. 10, Ugrid is the grid voltage; by the phase lock loop (PLL), the phase information can be got; Iref_grid is the given amplitude of the grid current. Combining sinθ and Iref_grid, the instantaneous grid current reference iref_grid can be calculated. In this mode, when Ugrid > 0, the inductance is La2; when Ugrid < 0, the inductance is paralleled La1 and La2; in order to adopt the change in the inductance, hysteresis control is employed to realize grid current regulation. Furthermore, hysteresis control has excellent loop performance, global stability and small phase lag that makes grid connected control stable.

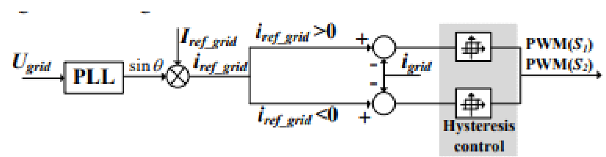
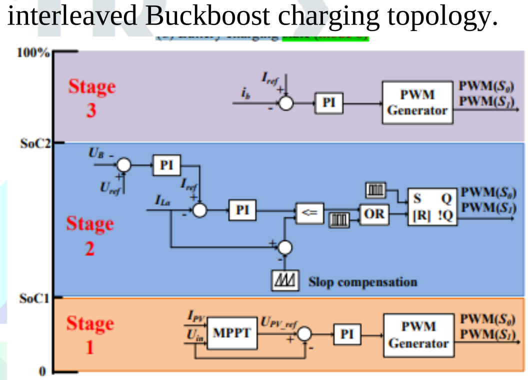


Fig. 10 Grid-connected charging control (Mode 5).

D. PV-fed charging control strategy

In this mode, the PV panel charges the battery straight by the driving topology. The phase windings are utilized as inductor; and the driving topology can be worked as interleaved Buckboost charging topology.



c) Mode 6 charging control strategy.

Fig. 11 Mode 6 charging states and control strategy.

IV.SIMULATION RESULTS

A 12/8 SRM is first modeled in Matlab/Simulink using parameters in Table II. Fig. 14(a) presents the simulation results at mode 1. The load torque is set as 35 Nm, the PV panel voltage is controlled at the MPP. The freewheeling current is used to charge the battery. Fig. 14(b) shows the simulation results of the single-source driving modes (modes 2-4).

TABLE III Motor Parameters

Parameter	Value
Phase number	3
Stator poles	12
Rotor poles	8
Rated speed (r/min)	1500
Rated power (W)	750
Minimum phase inductance (mH)	27.2
Maximum phase inductance (mH)	256.7
Rotor outer diameter (mm)	55
Rotor inner diameter (mm)	30
Stator outer diameter (mm)	102.5
Stator inner diameter (mm)	55.5
Core length (mm)	80
Stator arc angle (deg)	14

Mode-1

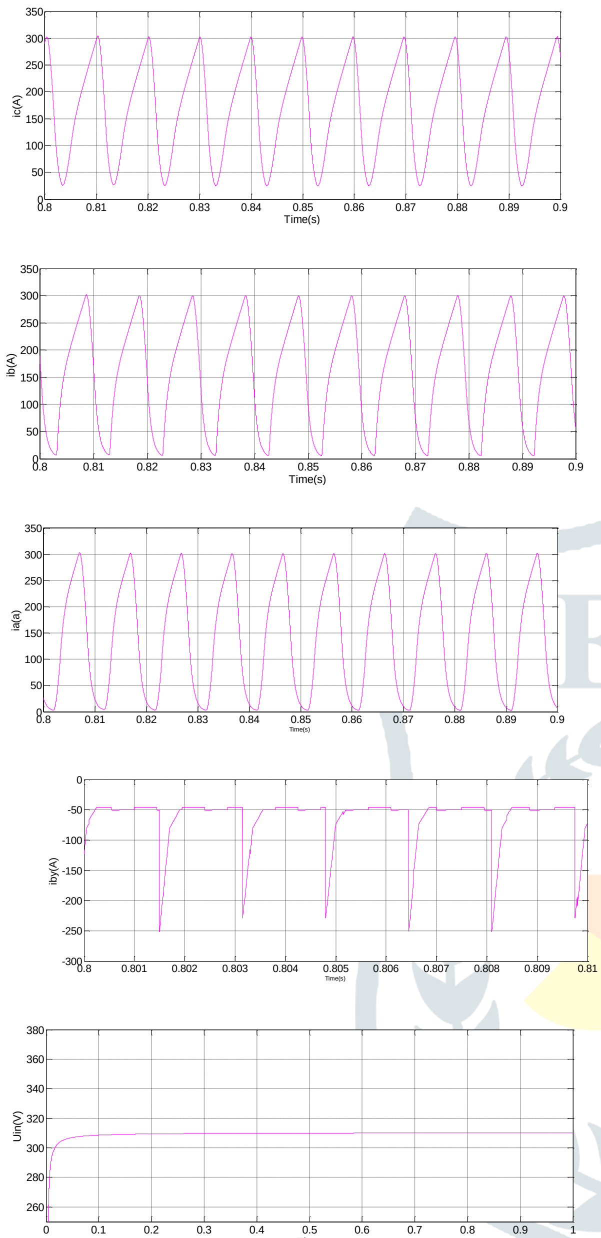
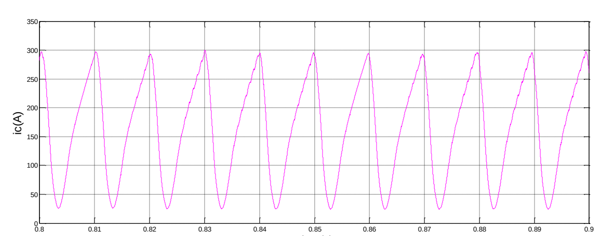


Fig 12: Simulation results of driving-charging mode (mode 1)

Mode-2



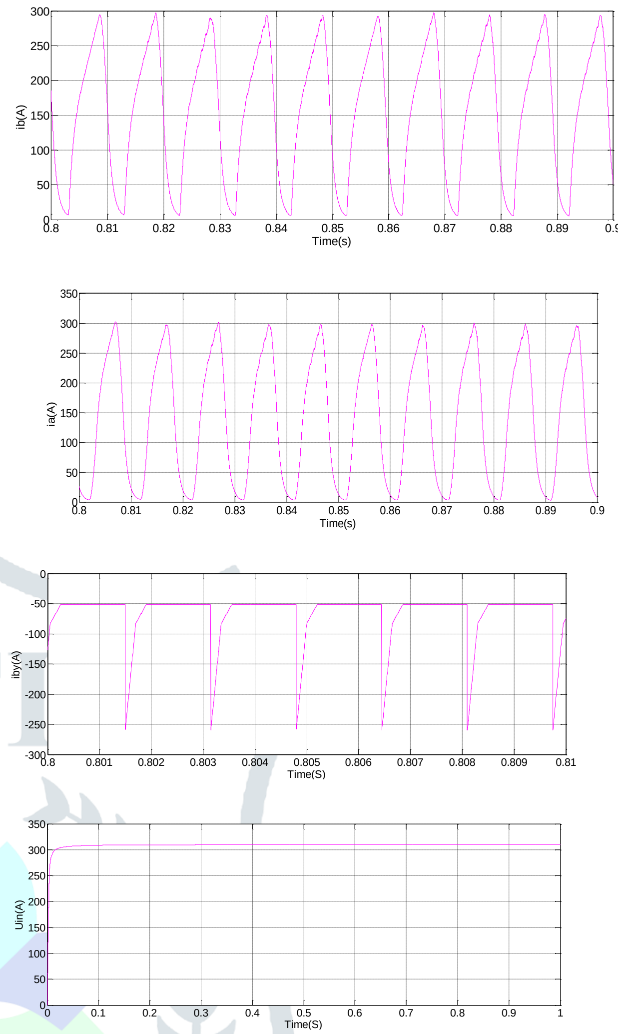


Fig 13: Simulation results of driving-charging mode (mode 2)

Mode-3

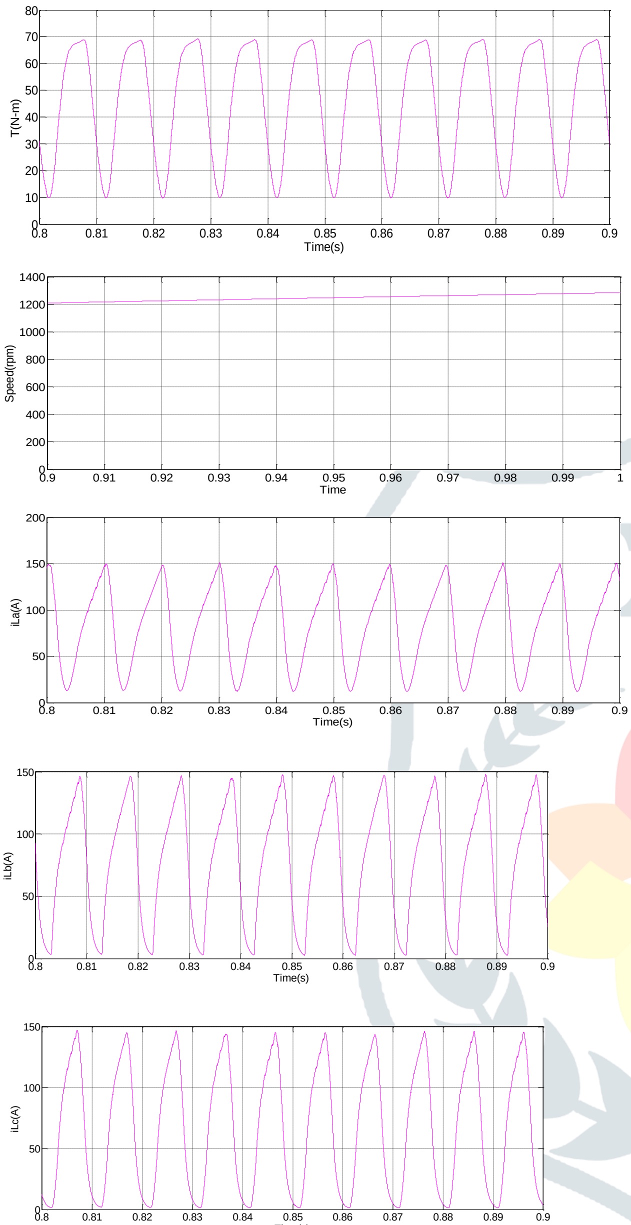
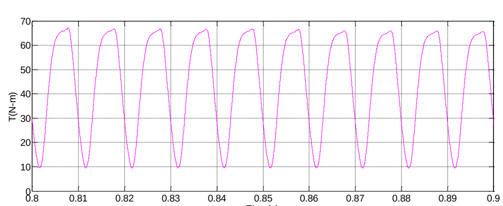


Fig 14: Simulation results of Single Source mode (mode 3)

Mode-4



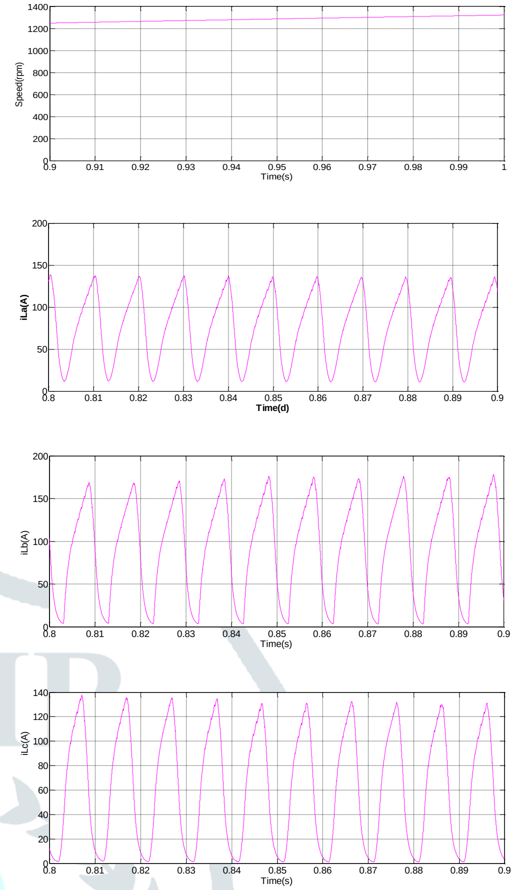
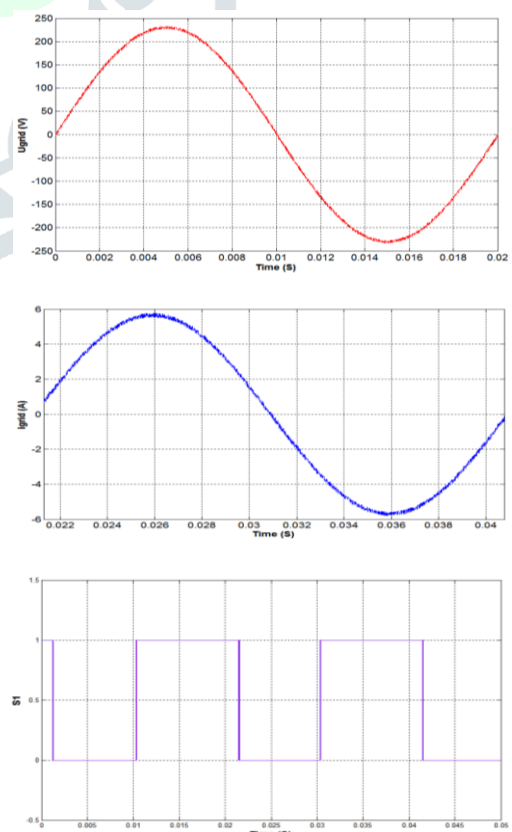


Fig 15: Simulation results of Single Source mode (mode 4)

Mode-5



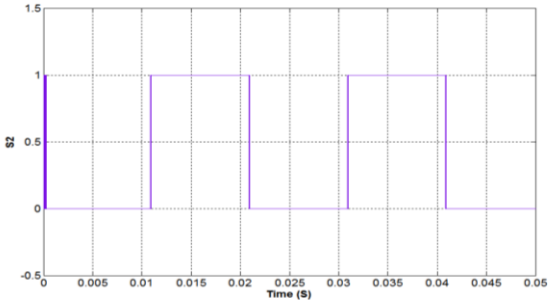


Fig 16: Simulation results of grid charging mode (mode 5)

Mode-6 stage 1

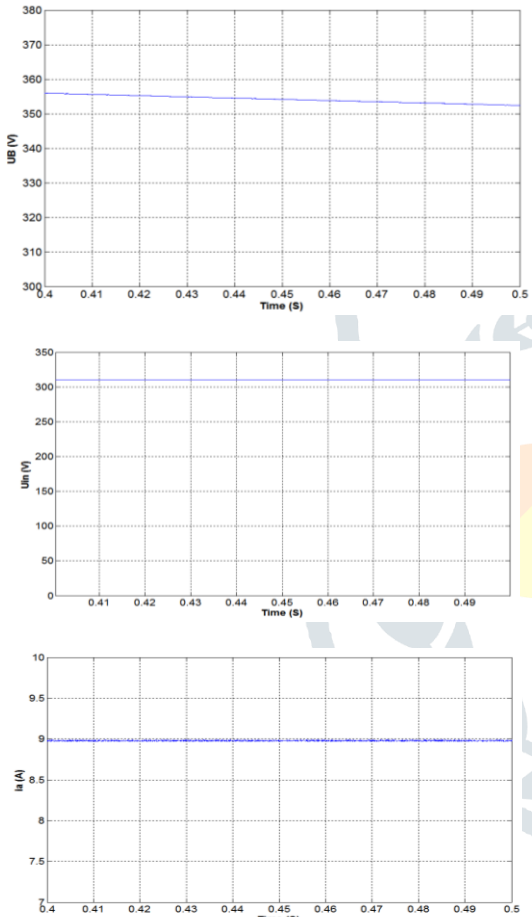
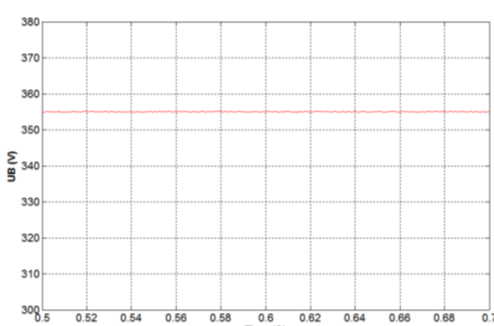


Fig 17: Simulation results of PV charging mode (mode 6,Stage-1)

Mode-6 stage 2



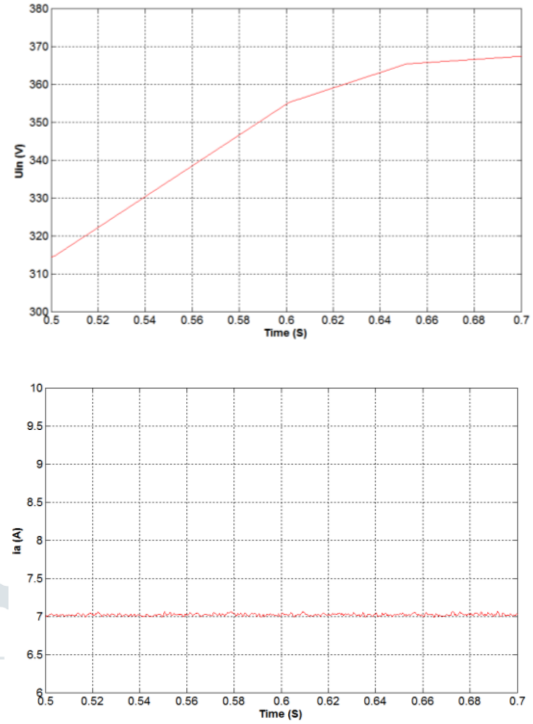
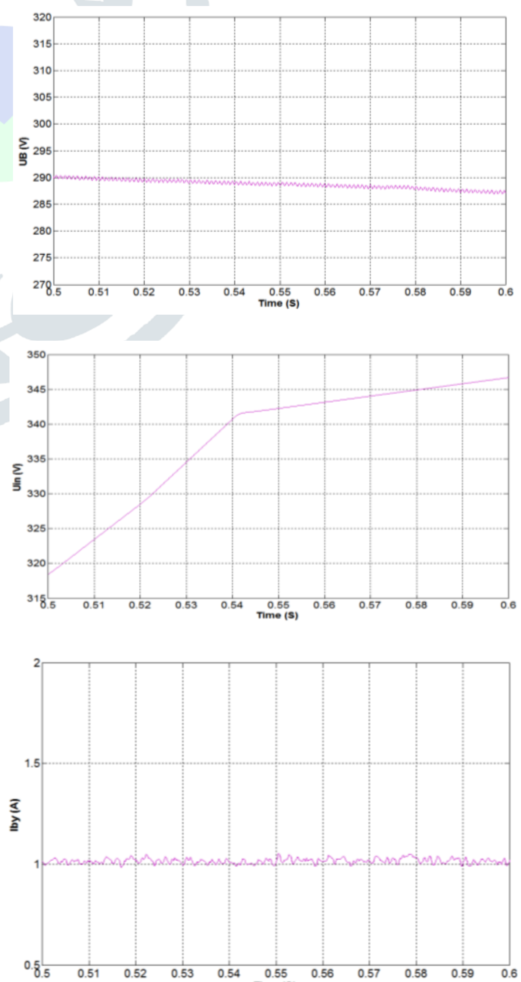


Fig 18: Simulation results of PV charging mode (mode 6,Stage-1)

Mode-6 stage 3



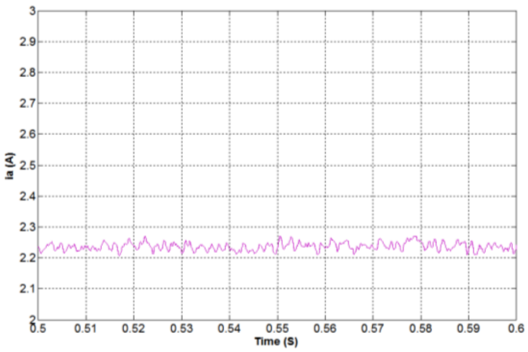


Fig 19: Simulation results of PV charging mode (mode 6,Stage-3)

V.CONCLUSION

In order to tackle the range anxiety of using EVs and decrease the system cost, a combination of the PV panel and SRM is proposed as the EV driving system. The main contributions of this paper are: (i) A tri-port converter is used to coordinate the PV panel, battery and SRM. (ii) Six working modes are developed to achieve flexible energy flow for driving control, driving/charging hybrid control and charging control. (iii) A novel grid-charging topology is formed without a need for external power electronics devices. (iv) A PV-fed battery charging control scheme is developed to improve the solar energy utilization. Since PV-fed EVs are a greener and more sustainable technology than conventional ICE vehicles, this work will provide a feasible solution to reducing the total costs and CO2 emissions of electrified vehicles. Furthermore, the proposed technology may also be applied to similar applications such as fuel cell powered EVs fuel cells have a much higher power density and are thus better suited for EV applications. The proposed topology gives one of the low cost solutions for fuel cell powered EV.

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Author's Profile:

Mr. M.Malyadri received B. Tech Degree in Electrical & Electronics Engineering from Mekapati Rajamohana Reddy Institute of Technology and Science, udayagiri, Nellore Affiliated to JNTU and M. Tech Degree in Electrical Power Engineering, Narayana Engineering College, Nellore affiliated to JNTUA, Anantapur. Currently working as Associate Professor at Sree Venkateswara College of Engineering, North Rajupalem, Nellore, A.P.

Mr.Y.V.Niranjan Kumar, received B. Tech Degree in Electrical & Electronics Engineering from JNTU Anantapur, M.Tech Degree in Electrical Power Engineering from JNTU Anantapur. Currently he is a Research Scholar from National Institute of Technology , Mizoram & Working as Assistant Professor in the Dept of EEE, Sree Venkateswara College of Engineering, Nellore.

A. Manoj Kumar, is currently pursuing B. Tech Degree in Electrical & Electronics Engineering from Sree Venkateswara College Of Engineering, North Rajupalem, Nellore,A.P.

G. Manoj Kumar, is currently pursuing B. Tech Degree in Electrical & Electronics Engineering from Sree Venkateswara College of Engineering, North Rajupalem, Nellore, A.P.

M. Pallavi is currently pursuing B. Tech Degree in Electrical & Electronics Engineering from Sree Venkateswara College of Engineering, North Rajupalem, Nellore, A.P.

K. Suviraj is currently pursuing B. Tech Degree in Electrical & Electronics Engineering from Sree Venkateswara College of Engineering, North Rajupalem, Nellore, A.P