Solar Energy based Hybrid Electric Car: Part 3

Dr. Siva Ganesh Malla[1*], Priyanka Malla[2] **and** ***Rjesh Koilada[3]***

[1]Director, CPGC Pvt. Ltd., Visakhapatnam, Andhra Pradesh, India. Email: mallasivaganesh@gmail.com
[2]Jr. GIS Engineer, Infotech, Cyient Ltd., Vizag, Andhra Pradesh, India, Email: priyamallaece@gmail.com
[3]Det. of Mechanical Engineering, BITS, Vizag, Andhra Pradesh, India, Email: mechkrajesh@gmail.com

Abstract: This paper presents the results with possible practical cases based on MATLAB simulink platform of solar energy based Hybrid Electric Car (HEC). The research has presented in three parts due to restriction on length of the article. The analysis of the solar power based HEC is presented in part-1 and implementation with sizing has discussed in part-2. In present day scenario the world is looking for solar energy as source based electric cars. But solar (Photovoltaic (PV) cells) itself cannot provide sufficient power to the cars for applications of long drive. So, the alternate power source is mandatory. For consideration of economic issues and long drive applications, incorporate battery is integrated to the system with proper controller. So, the system makes hybrid and more reliable. The MPPT (maximum power point tracing) controller is incorporated to the system by using P&O (perturbation and observation) algorithm which can be utilized for PV system to operate at maximum power level. The model used for vector control deign can be obtained by using the space vector modulation technique. The significance of bidirectional DC to DC converter and vector control of induction motor has presented in different possible cases. The extensive results presented with valid explanation of the proposed system. The model can be further extended with eletrolyzer and fuel cell systems to operate the car for long drive application.

Keywords: Hybrid Electric Car, Vector Control, Induction Motor, MPPT, Solar Powered Vehicles, Photovoltaic Cells, Modeling of Battery.

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I. SIMULATION AND BASIC RATINGS WITH ASSUMPTIONS

The simulations have been done by MATLAB simulink software of the proposed system as shown in Fig. 1 (please refer Fig. 3 in Part 1). Using all mathematical equations in both part 1 and part 2, the flux position θ is obtained. It is then used to calculate the quadrature unit vectors cosθ and sinθ. Within the vector controller, the required motor currents are computed with reference to the rotor’s frame of reference, while the three-phase motor currents are referred to the stator’s frame of reference [1-4]. The stator currents are transformed from the stationary to synchronous reference frame by using equations which are presented in previous parts. The inputs to the controller are the command torque and flux current components i_{dse}^* and i_{qse}^* respectively. These are compared with the synchronous frame quadrature and direct axis components of the stator current (i.e. i_{qse} and i_{des}) respectively. The system is tested under different possible conditions. The satisfactory results and analysis is presented for case studies presented in next section. Before going to case studies, the requirements and ratings are mentioned below.

Motor power rating: 10 Hp
Nominal irradiance: 1000 W/m^2
Solar maximum power: 2798 W
System Voltage at maximum power (V_{mpp}): 524 V at nominal irradiance.
Maximum Speed of Car: 50 Kmp
Circumference of car tire: 82 inch=2.08 m
Required RPM of motor: 50*1000/(2.08*60)=400 RPM
Maximum Torque: 178 Nm
Matlab version: R2013a
Batteries Voltage: 300V
Battery Current rating: 100 Ah
Partial Shading: Didn't considered effect of partial shading
Hysteresis current band: 1.5A
The results are carried out by considering below possibilities.

1. Working under maximum power from PV (Change in solar irradiance)
2. Change in Speed (with constant torque)
3. Change in torque (with constant speed)
4. Reverse Speed (required to run a car in reverse direction)

The results are briefly examined and explained by following cases.

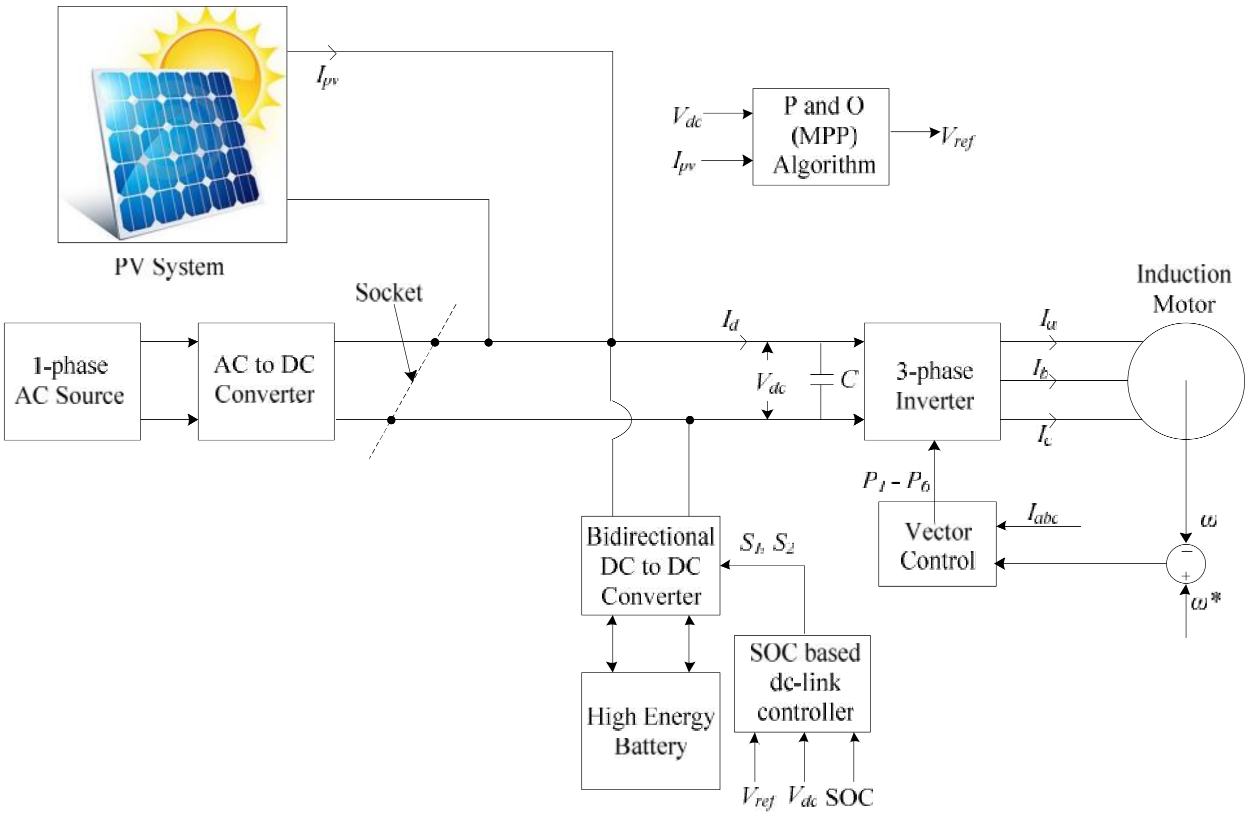

Fig. 1: Proposed System in HEV

II. Results and Discussions

Case-1: System performance under change in solar irradiance:

In this case, we considered a change in irradiance from 1000 W/m^2 to 700 W/m^2 at t=3 sec as shown in Fig. 2. Under this condition, the P and O algorithm will track the voltage at maximum power (V_{mpp}) corresponding to irradiance level 700 W/m^2. The profile of PV curves under various irradiance levels are depicted part 2 (i.e., Fig. 1). The corresponding voltage at maximum power for irradiance 700 W/m2 will be generated by P and O algorithm according to Fig. 1(b) in part 2 and it will be input to the controller of bidirectional DC to DC converter. Hence, the converter will regulate the dc link voltage (V_{dc}) at its reference value (V_{mpp}). The corresponding result for V_{mpp} and V_{dc} as depicted in Fig. 3. The maximum power generated by PV system is shown in Fig. 4 which is also following the reference power of PV. Hence, the controller of DC to DC converter is effectively working as MPPT converter of PV system with association of P and O algorithm.

Since power has decreases due to decreasing in solar irradiance, the discharging power by battery will increase to maintain the constant speed of induction motor. Hence, there will not be any changes in currents drawn by induction motor at t=3 sec due to power balancing by battery. It is highly required in hybrid electrical vehicles because, the speed of the vehicle should not be depends on solar irradiance as well as number of people in car. Hence, speed of the vehicle will be constant at its reference speed with respect to rapid changes in solar irradiance. This can be achieved and possible by only bidirectional DC to DC controller to make power balancing between induction motor, PV and battery. The corresponding battery power, currents and speed of the induction motor as presented in Fig. 5, Fig. 6 and Fig. 7 respectively. Constant load torque is considered in this case. The PV is operating at its maximum power rating corresponding to value of irradiance and obtained satisfactory results of voltage, current, speed and power. Hence, it can be conclude that, the controllers are working effectively under this case study. The satisfactory results are showing that the system and its controllers are working perfectly under both transient and steady state operation. In this case the speed of induction motor is at 400 RPM which is equals to 50 Kmph.

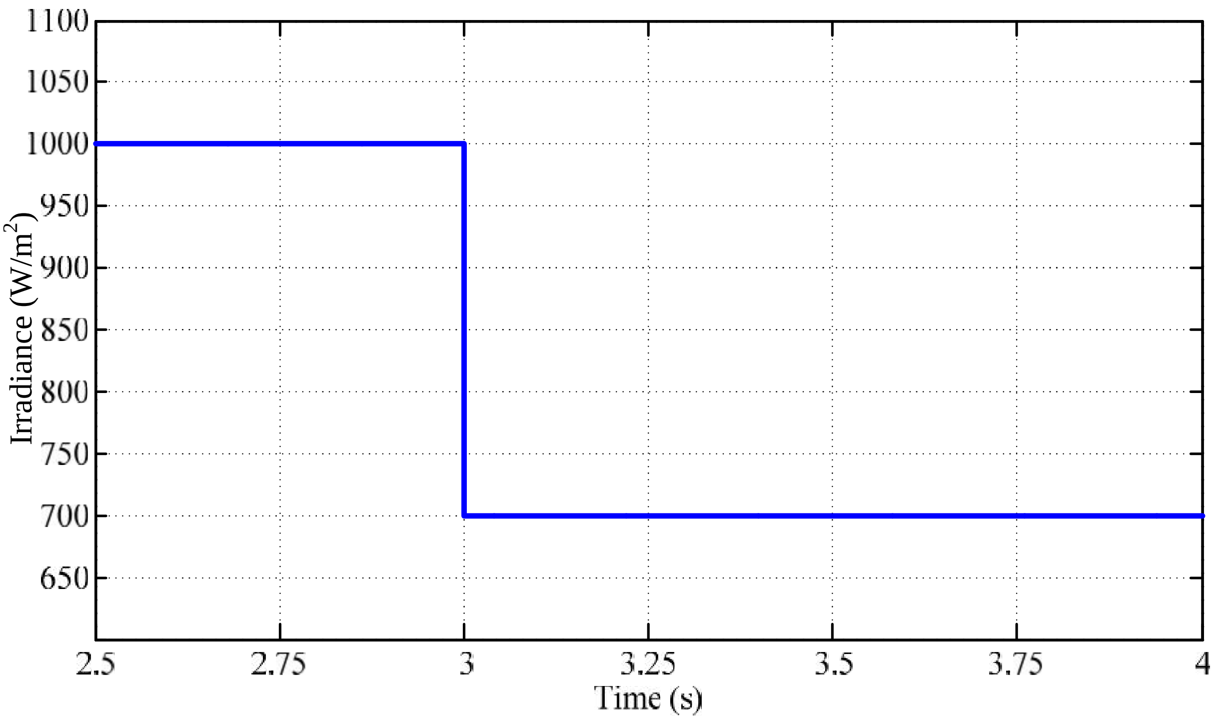

Fig. 2: Change in Solar Irradiance

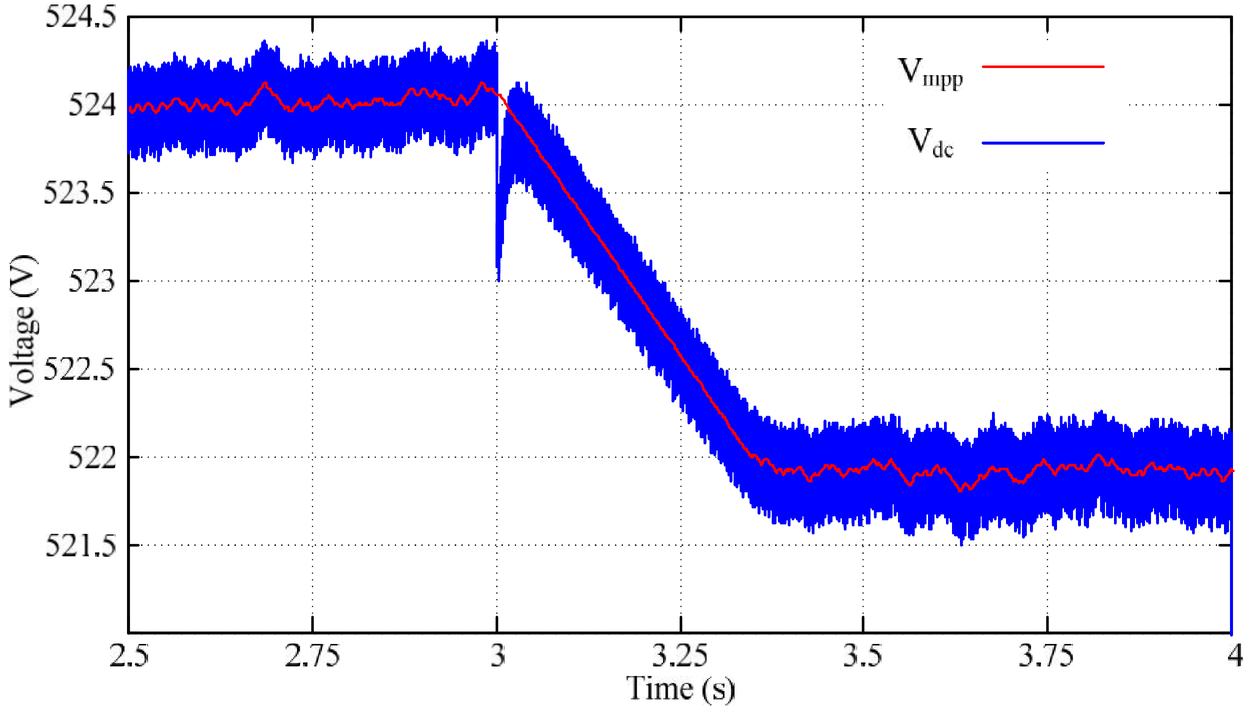

Fig. 3: Response of reference (Vmpp) and dc link voltage (Vdc)

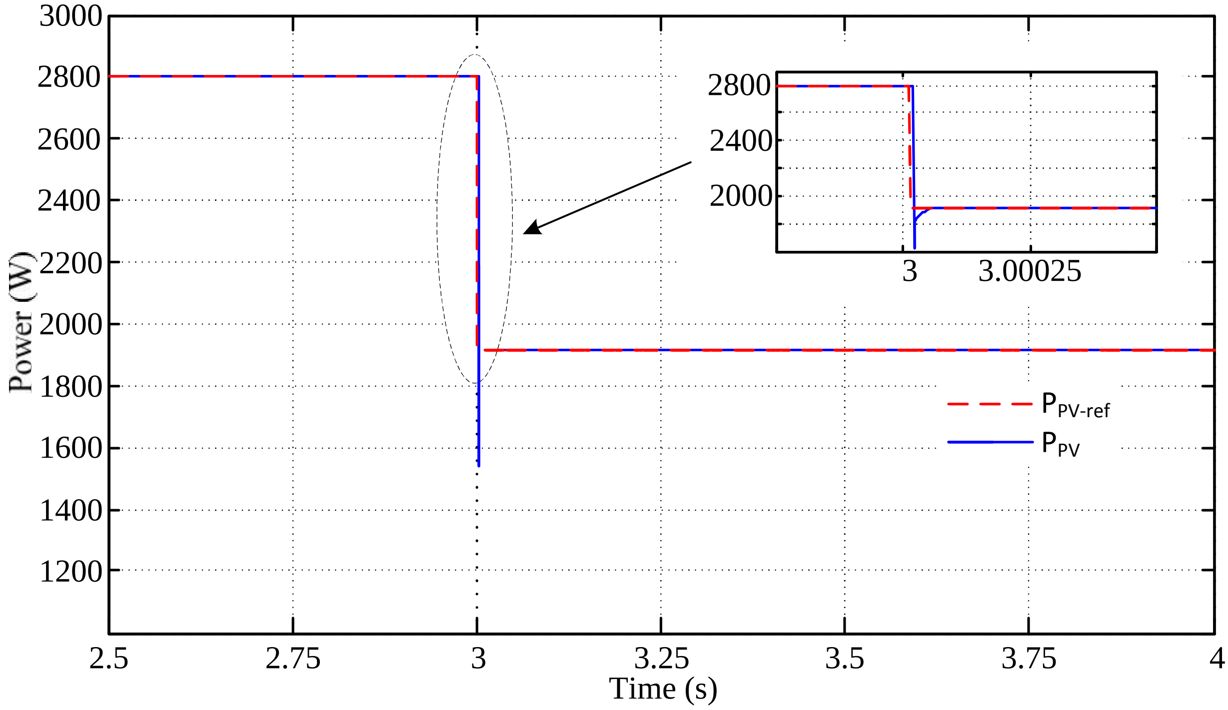

Fig. 4: Output power of PV system

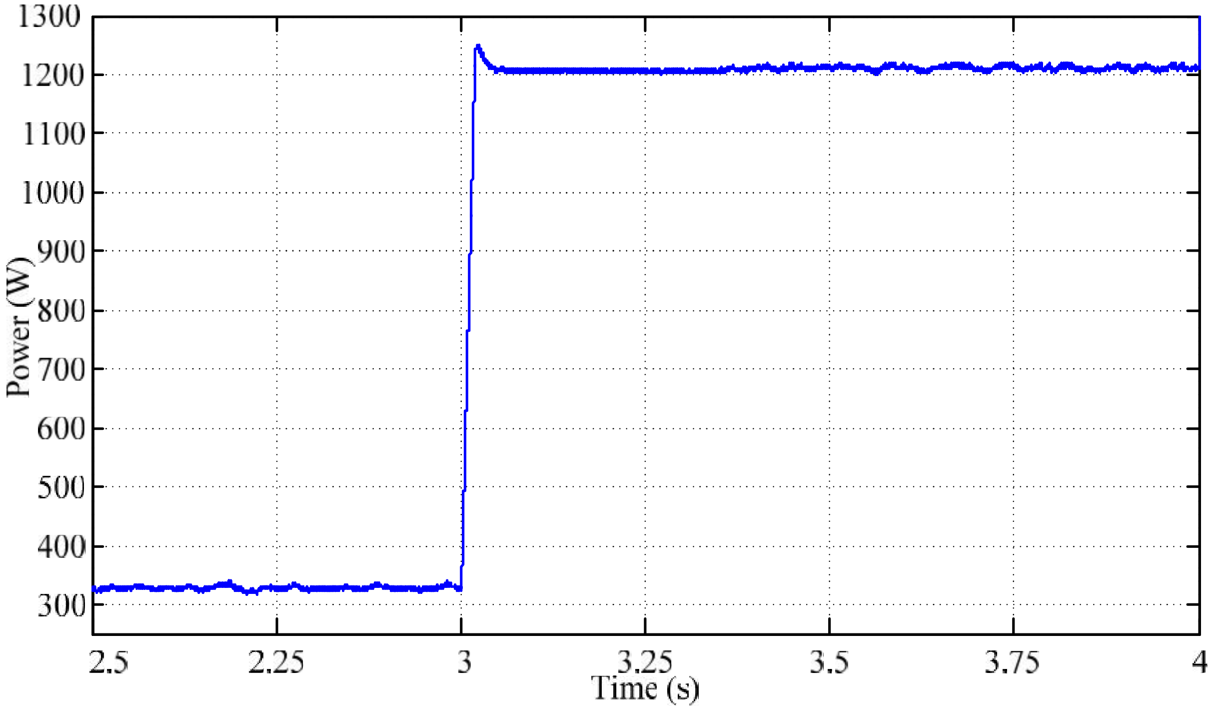

Fig. 5: Battery power (Discharging mode)

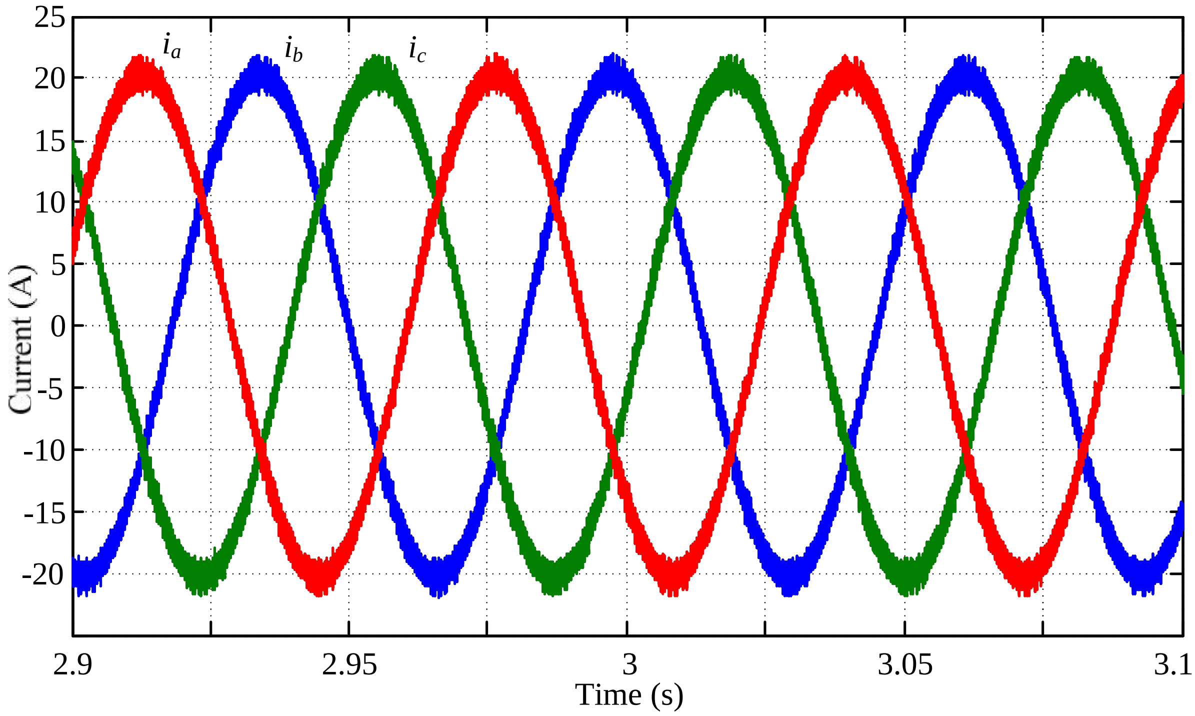

Fig. 6: line currents of Induction motor

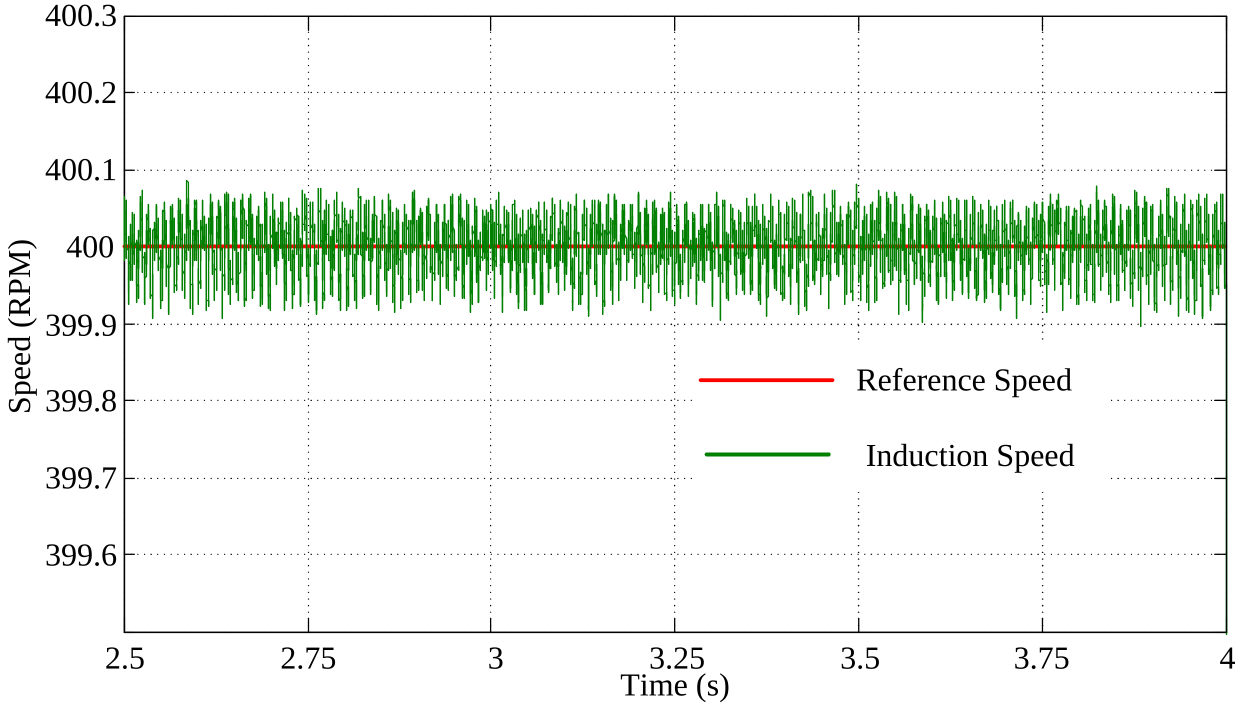

Fig. 7: Speed of the Induction motor

Case-2: Change in Load Torque:

Let us considered there is no change in irradiance and kept at 1000 W/m^2 during this case. The load torque is applied at t=1.5 sec. before that just nominal load torque (T_L=5 Nm) is applied on motor and its increase to Nm at t=3 sec. Hence, the battery needs to supply the required power to motor or will reduced the charging power by battery depends on availability of power and consumed by motor. The vector control will helps to generate the electromagnetic torque to reach or driven the load torque (i.e., reference torque) without any changes in speed (under steady state). The corresponding torque and speed responses are shown in Fig. 8 and Fig. 9 respectively. From Fig. 9, there is no change in speed at steady state even significant increment in torque applied on the motor. However, the speed has decreased during transient time due to action on overcome the electromagnetic torque over the load torque. But the vector control helps to run the motor at its reference speed with respect to changes in torque. The corresponding currents and battery power diagram as soon n Fig. 10 and Fig. 11.

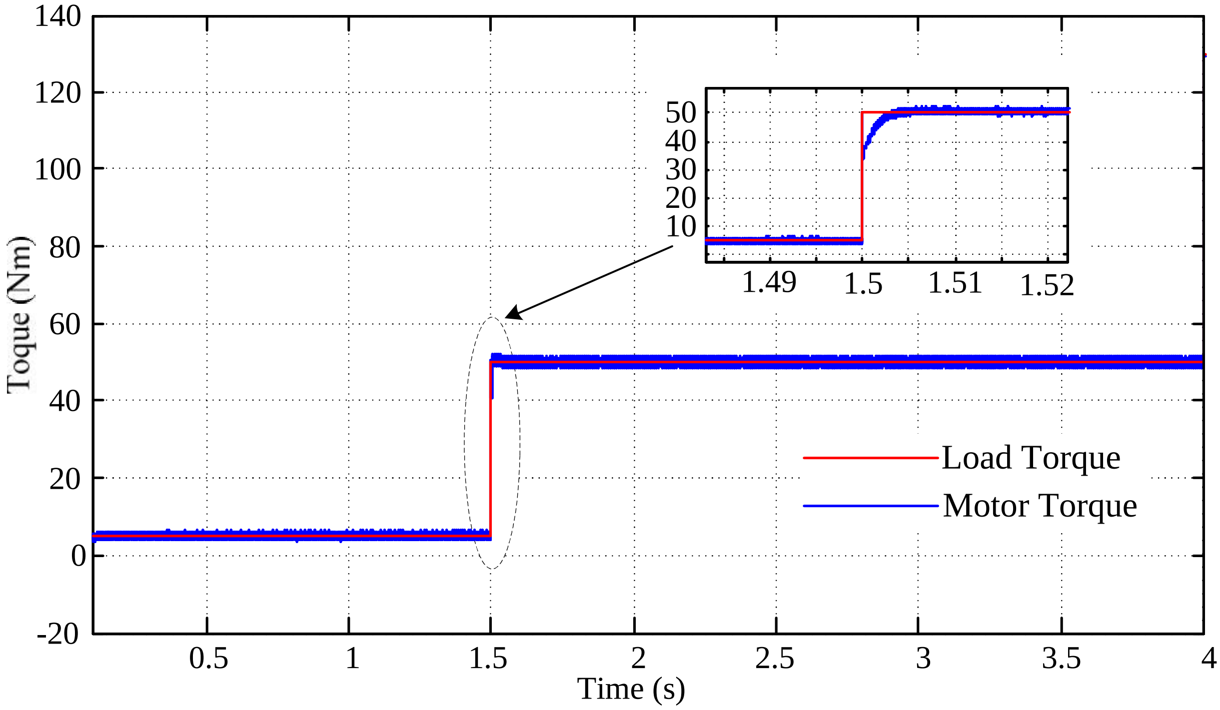

Fig. 8: Load and electromagnetic torque generated by Induction Motor

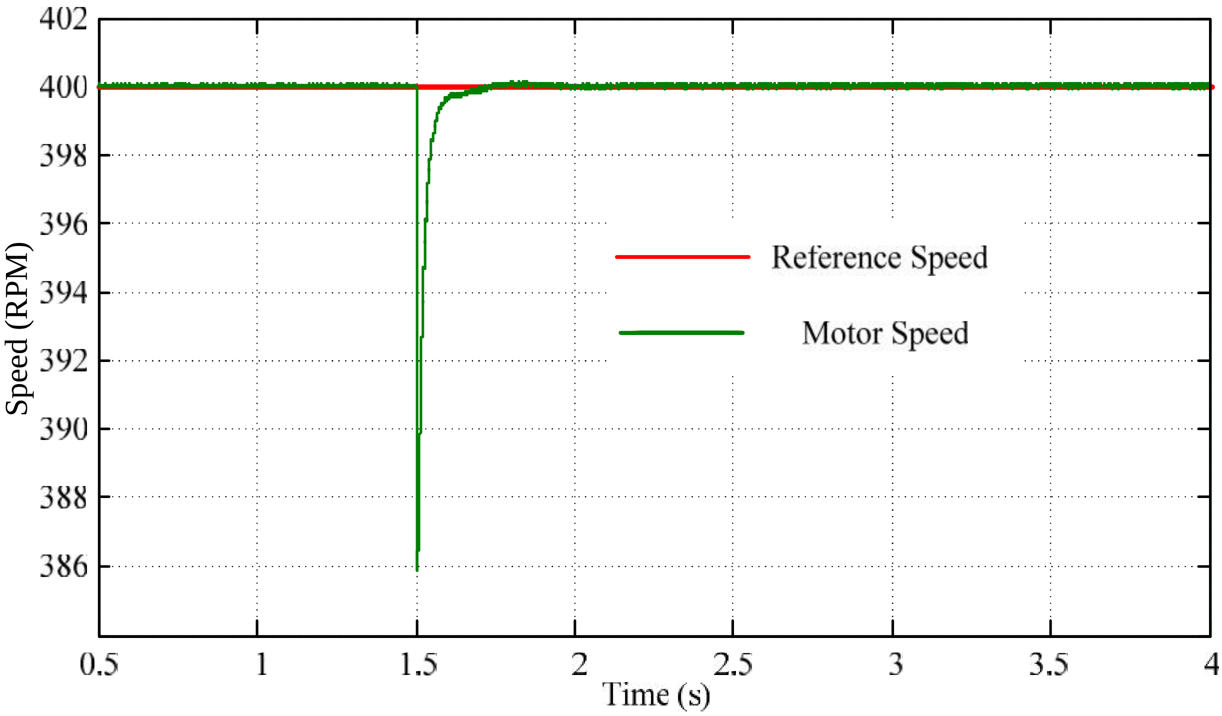

Fig. 9: Response of Speed under Increasing Load Torque

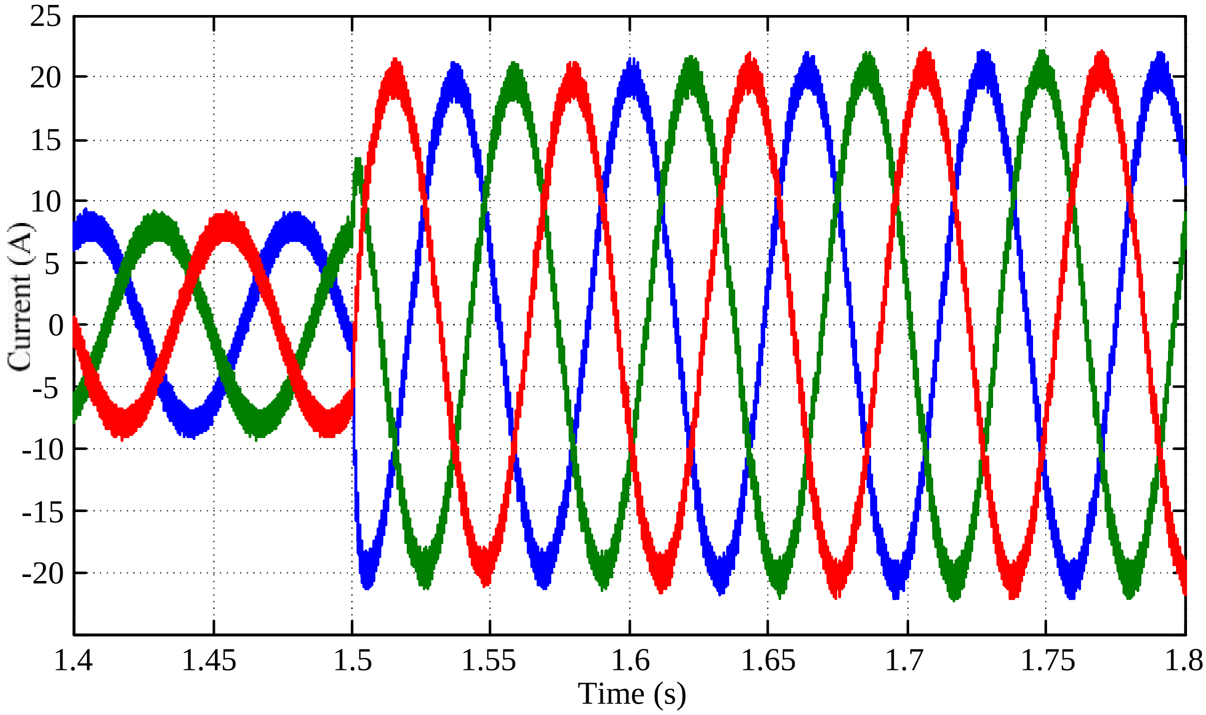

Fig. 10: Line currents of Induction motor under change in torque.

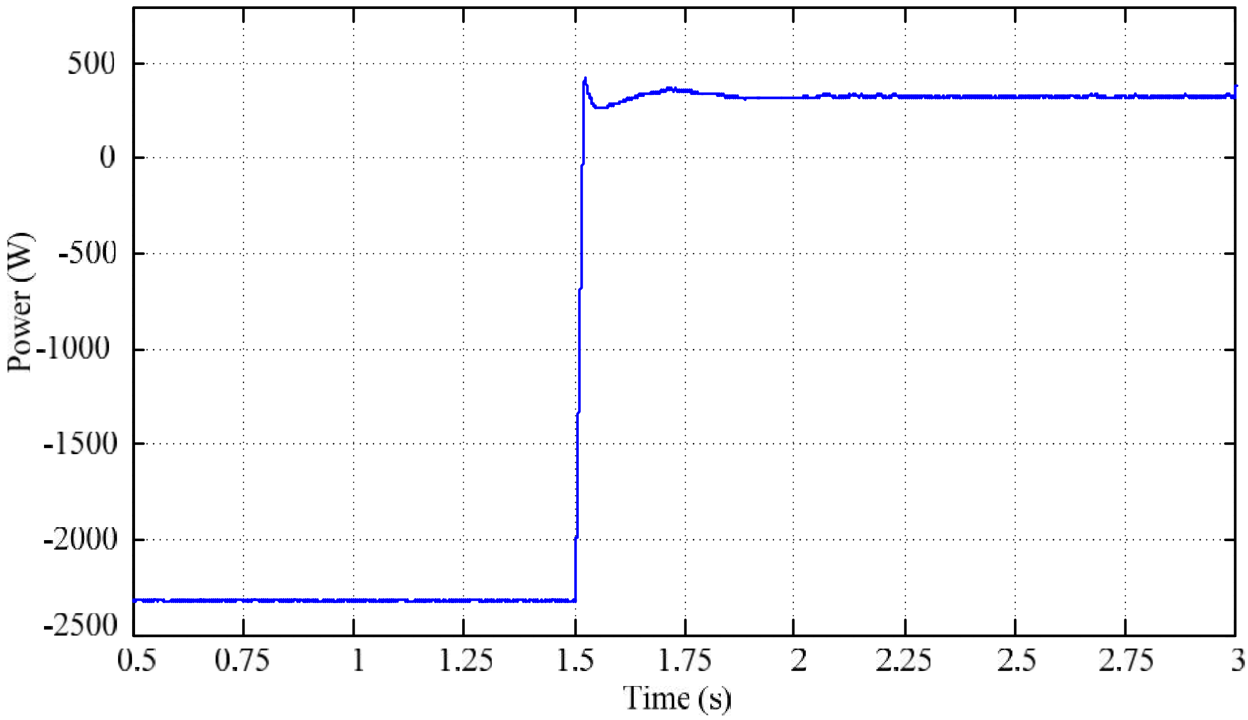

Fig. 11: Battery power under charging and discharging mode for changing in load torque

Case-3: Changes in speed of the vehicle:

In electrical vehicles, the rapid changes are required in speed of the vehicle. Hence, the response has to be studied under the changes along with variations in the speed. In this study, the reference speed on the vehicle is changed from 40 kmph to 50 kmph which is equals to 320 RPM to 400 RPM on the motor. So, the speed has changed from 320 RPM to 400 RPM at t=4 sec. The vector control helps to operate the motor at its reference speed even changes which are mentioned above. The speed response of the motor is shown in Fig. 12. The speed needs to be increased; hence, the electromagnetic torque produced by motor will increase during the transient time period. The generated torque by the motor will follows the load torque (reference) which is not changed in this case as shown in Fig. 13. There will be no change in V_{mpp} due to considering constant irradiances during the case study. The dc link voltage will fall and rise in permissible value due to sudden changes in speed. But the power generated by PV systems remains at maximum available power level since the dc link voltage is following the V_{mpp} during steady state. The corresponding voltage on dc side as depicted in Fig. 14. The currents on stator of the induction motor are soon in Fig. 15.

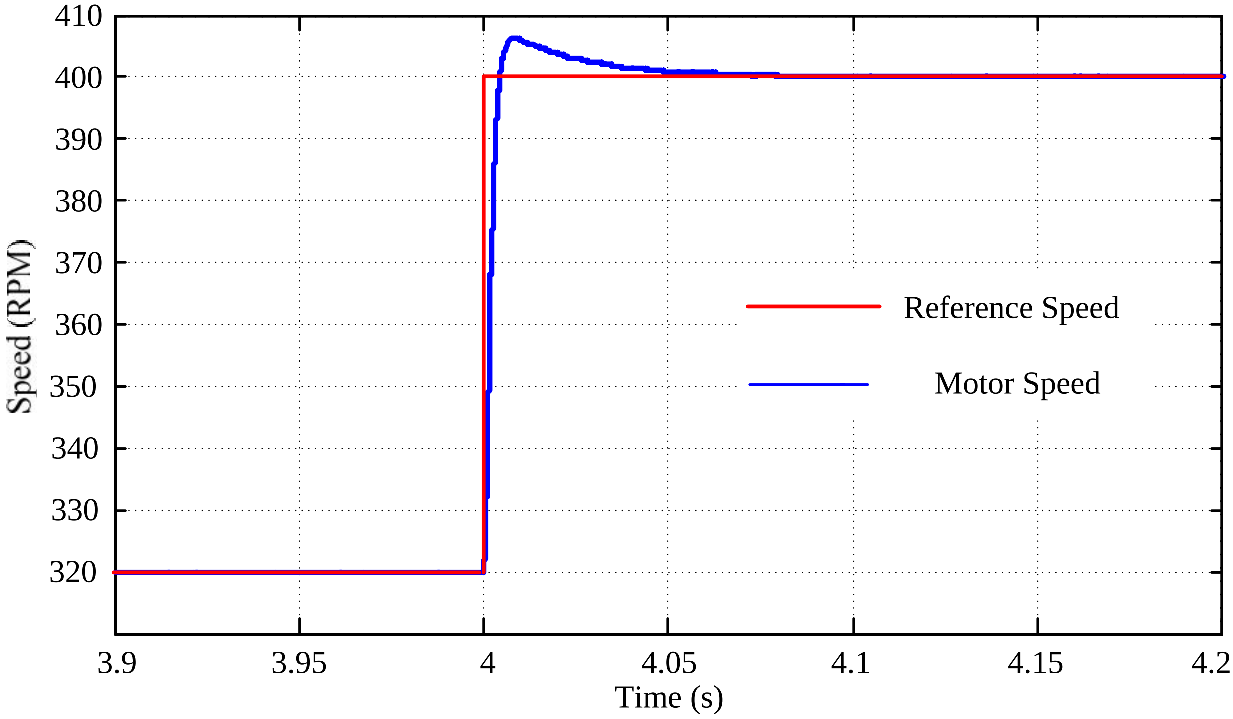

Fig. 12: Speed response under increasing speed

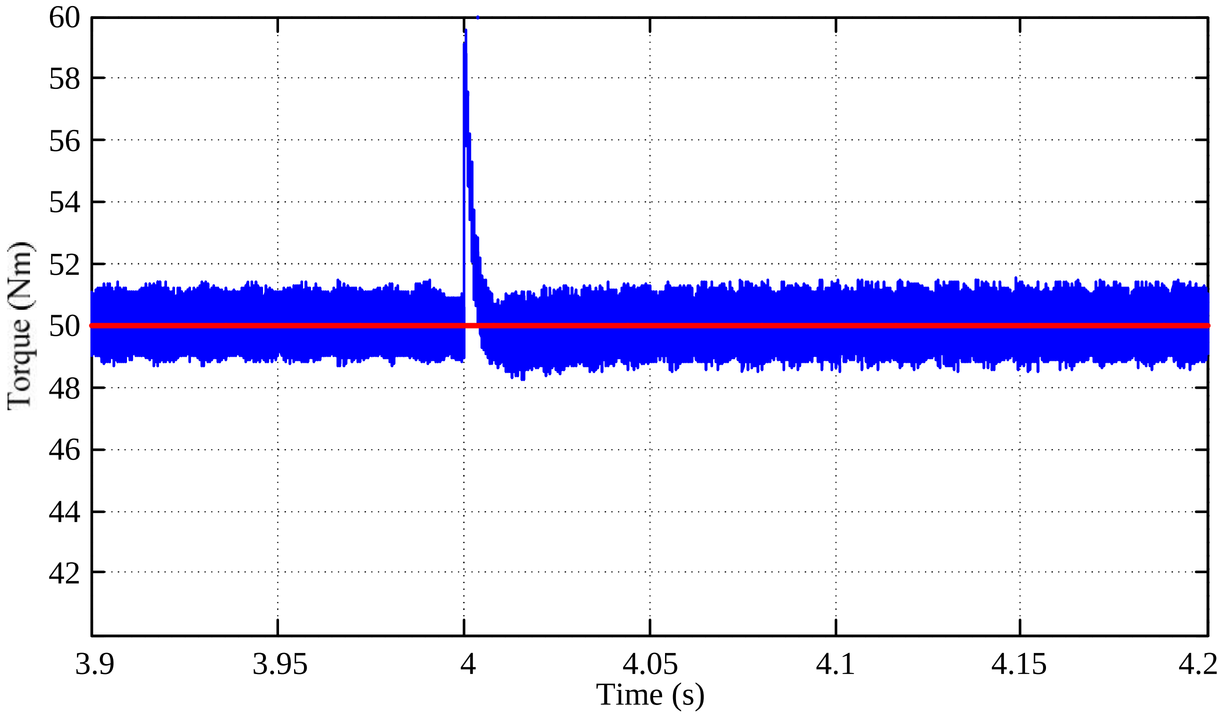

Fig. 13: Response of torque

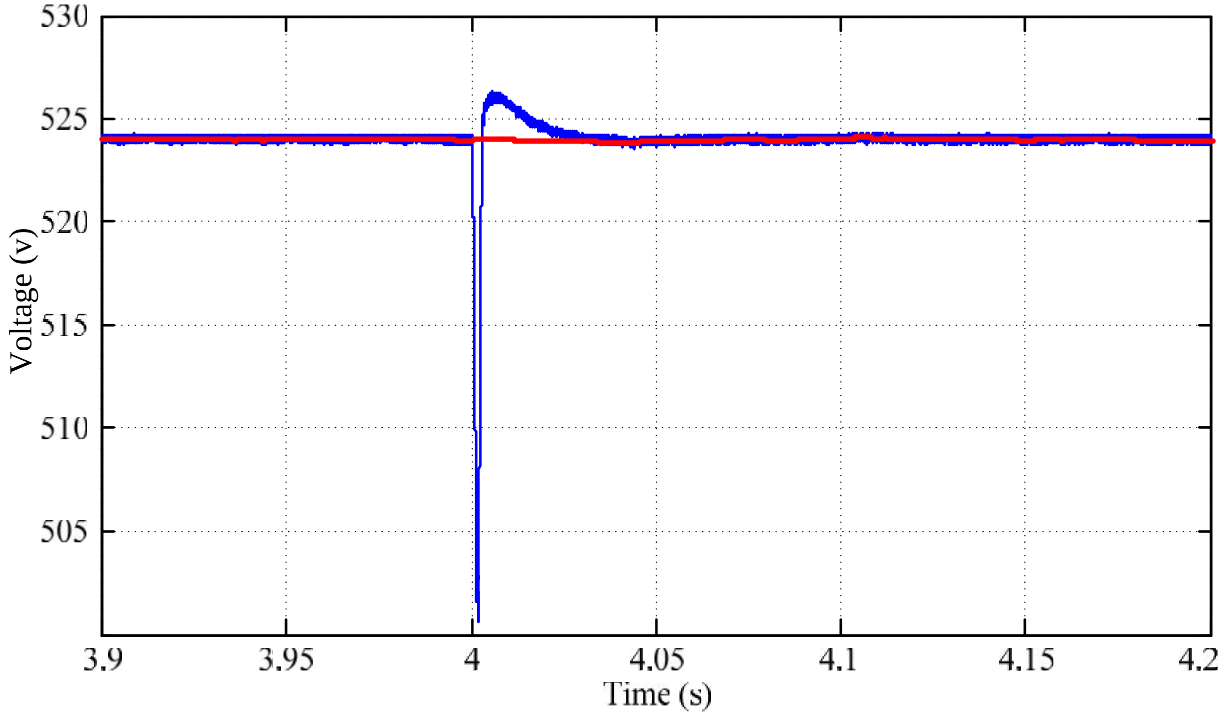

Fig. 14: V_{mpp} and dc link voltage

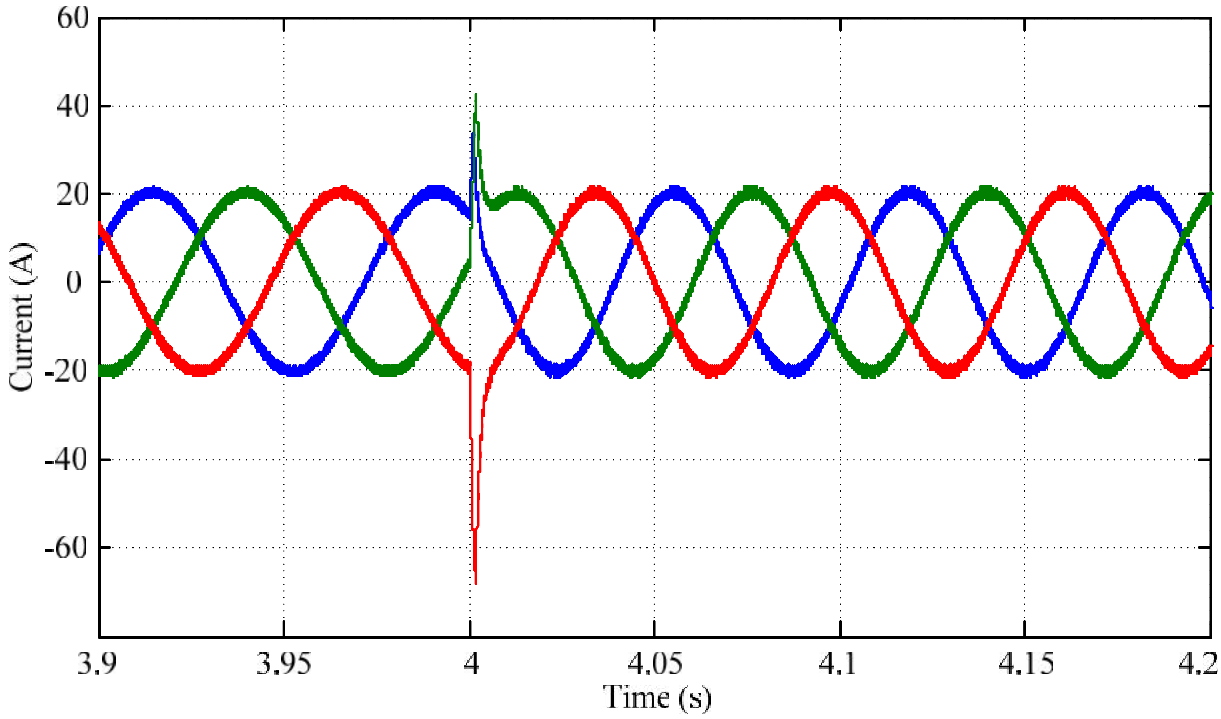

Fig. 15: Line currents under change in Speed

Case-4: Reverse driving of the Vehicle:

Generally in any four wheeler vehicle the reverse driving plays a vital role. Consciously it is difficult to drive the 4 wheeler vehicles in backward direction through manually like 2 wheelers. The reverse driving is possible in electrical vehicle by operating the motor in reverse motoring mode. Usually the pulses of any two phases will be interchanged automatically by vector control method to run the motor in reverse direction. Let us consider the vehicle to run in reverse direction with 10 kmph which is equals to 80 RPM of the motor. It is done by changing the reference speed of the motor from 80 RPM to -80 RPM at t=4 sec. The vector control makes the speed direction as reverse in motor automatically. It is shown in Fig. 16. Due to sudden change in the direction, the dc link voltage will fluctuate for few seconds and maintains at its reference value. This is represented in Fig. 17. However, in order to run motor in reverse direction, the electromagnetic torque needs to decrease suddenly and vector control will helps to maintain electromagnetic torque at its reference value during steady state time period as soon in Fig. 18. There is no change in solar irradiance during this operation hence the power generated by the PV system will remains constant under steady state. However, small disturbance is occurred due to change in dc link voltage due to sudden changes in direction of the speed. The power obtained by PV system is represented in Fig. 19.

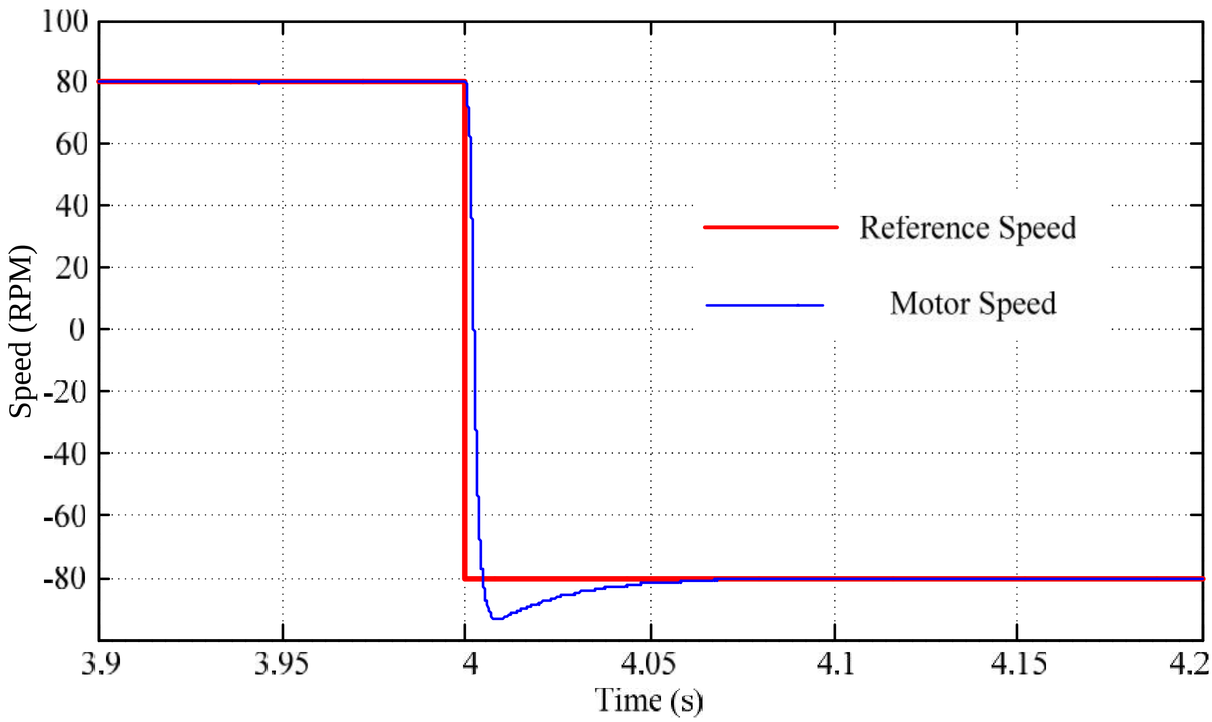

Fig. 16: Reference and motor speed in reverse direction

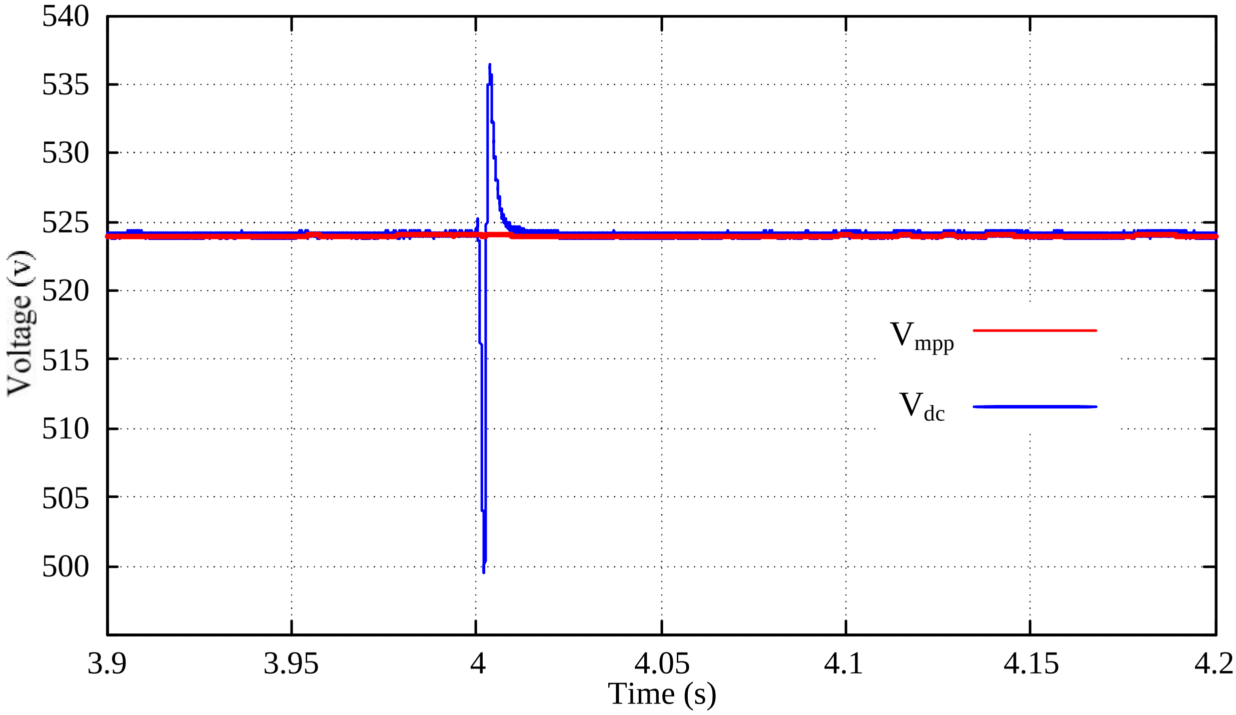

Fig. 17: V_{mpp} and dc link voltage under change in direction

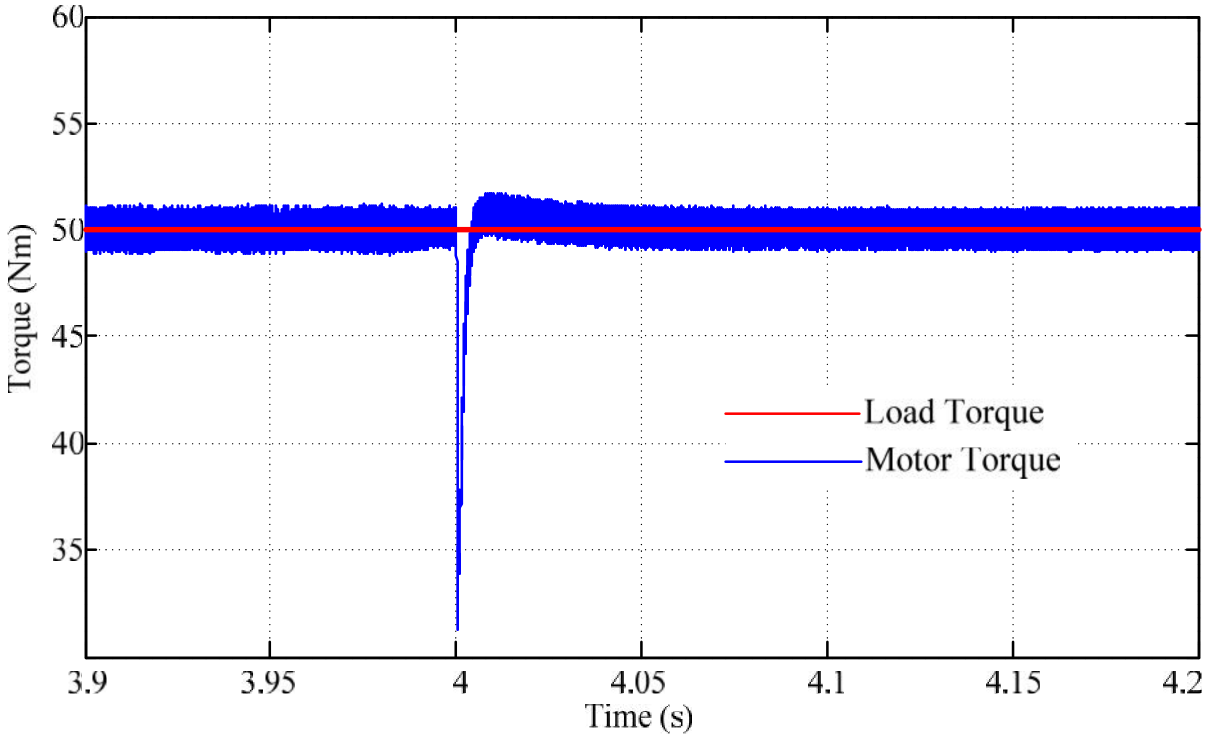

Fig. 18: Response of load torque and electromagnetic torque under change in speed

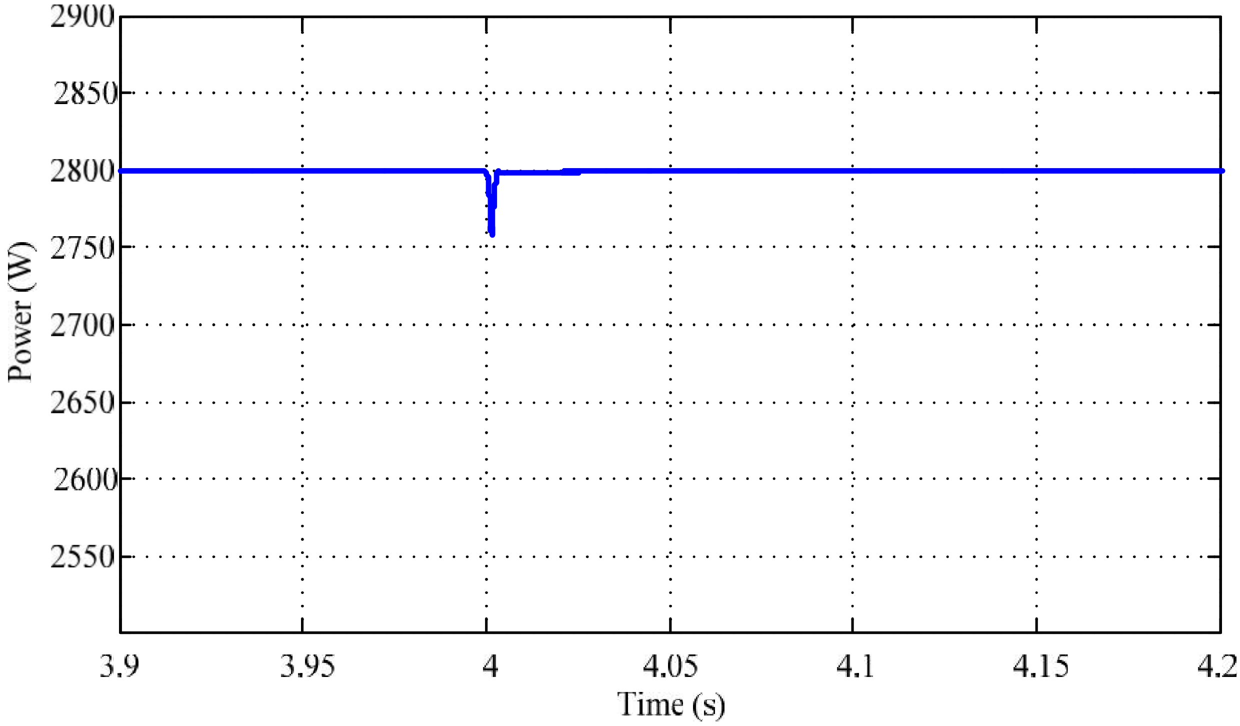

Fig. 19: PV output power under change in speed

From the above case studies, the vector controller and dc side controllers are performed very well in both steady state as well as transient state conditions. Due to hardware constraints, we tested the system performance in MATLAB Simulink package. The proposed controllers are providing smooth operation on driving, it can be observed from above case studies.

III. CONCLUSION

The analysis of solar powered based HEV has presented in part 1 and the continuous research on controllers of the proposed system is described in part 2. The results carried out by MATLAB are presented in this paper under possible conditions. The discussions over results are briefly presented. Results are discussed in four cases and included reverse motoring operation, since it will be required in electric car to run the car in reverse direction when it's needed. From the results, the MPPT is working perfectly to achieve the maximum power from PV system in all the conditions with the help of integration of perturbed and observe algorithm and bidirectional DC to DC converter controller. The regulation of dc link voltage is achieved by controlling of DC to DC converter.

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Dr. Siva Ganesh Malla was born on 1986 in Nagulapalli, Anakapalli, Visakhapatnam, Andhra Pradesh, India. He received the award of Ph. D from School of Electrical Sciences, Indian Institute of Technology (IIT) Bhubaneswar, Odissa, India in 2014. He got his B. Tech degree in Electrical Deportment from Jawaharlal Nehru Technological University Hyderabad in 2007 and M. Tech in Power Electronics and Electric Drives in Electrical Deportment from Jawaharlal Nehru Technological University Kakinada in 2010. Now he is working as a director of CPGC Pvt. Ltd, Visakhapatnam, Andhra Pradesh, India. His research interests are renewable energy sources, microgrid, power quality, electrical vehicles, biomedical signal processing, converters, power electronics, drives, optimization techniques and FACTS.

Priyanka Malla was born on 1996 in Anakapalli, Visakhapatnam, Andhra Pradesh, India. She received her B. Tech in Electronics and Communication Engineering from Jawaharlal Nehru Technological University, Kakinada, India, in 2017. Presently she is working as Jr. GIS Engineer, Infotech, Cyient Ltd., Vizag, Andhra Pradesh, India. Her research interests are included in renewable energy sources, electrical vehicles, biomedical signal processing, optical communication and digital electronics.

Rajesh Koilada was born on 2000 in Venkupallem, Anakapalli, Visakhapatnam, Andhra Pradesh, India. Presently he is working towards his bachelor degree in Mechanical Engineering Department, Baba Institute of Technology and Sciences, affiliated to Jawaharlal Nehru Technological University, Kakinada, India. His research interests are included in renewable energy sources, electrical vehicles, robotics, thermal engineering, fluid dynamics and machine designing.