Design and Implementation of Forward-Boost Hybrid Converter for Solar Powered Electric Vehicle Charging Applications

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Abstract

Now a days, charging the Electric vehicle battery is the main concern. To make complete carbon free or emission less transportation, charging the battery using Non-Renewable energy will not suite well. For the development Environment and to withhold the sustainability of the society, we need to preserve the conventional energy resources and use the abundant energy called Renewable energy [1]. Integrating this with EV could be called as complete carbon free transportation. Though renewable energy such as Solar or wind is not stable or stagnant over the time, we could use an Energy storage system at the charging station end. By overcoming this unstable power generation from Solar panel, the designed converter has to feed constant Voltage and current to the energy storage. A well-within magnitude of power should be fed from the converter side. A simple kind of converter could only be used but over the large gain conditions, it results in lower conversion thus efficiency is decreased [2]. This paper will present an intelligent method for charging battery (energy storage) from Forward-Boost hybrid Converter. The gain factor was higher even at very low generation of solar power. A constant 200Volts and 20Ampere is achieved for charging the battery with the overall efficiency of nearly one hundred percent. This was simulated in MATLAB Simulink.

Keywords. EV-Electric vehicle, medium level voltage (level-2), Non-isolated Converter (Boost converter), Isolated Converter (Forward converter), PV-array, Li-ion battery, Environmentally friendly

1. INTRODUCTION

In this Era of revolutionary Technologies, Transportation domain is first in the segment. Having said that, electrifying them stands out from the rest. The very basic why to electrify them is to overcome Emission less transportation and Aid Carbon free, Pollution free, Noise free and Environmentally friendly Transportation [3]. There are many methods to generate this kind of Fuel globally. But, majority of them are Conventional energy generation method. By using the fuel which was produced from conventional method could only be segregated into Noise free and semi environmentally friendly transportation list but still comes under indirect way of carbon emission.

So, to be called Carbon free, Pollution free, Noise free and Full Environmentally friendly Transportation, the fuel has to generated from Non-Conventional energy sources. By integrating the Non-conventional energy produced into EV sector, will overcome the above non- environmentally friendly hurdle [4]. The very next hurdle is charging the battery of EV. Currently there are two types of charging implementations, one with combination of Grid and Non-Conventional energy sources and other is Fully non-conventional way. The only advantage of Grid-Renewable combination is that, there is no requirement of Energy storing devices and the unusable power could be fed back to Grid, which helps in Power factor correction and balances the grid condition. The second, Trendy way is through Fully Renewable (Stand-alone) in which, it overcomes many disadvantages of Grid-Renewable combination and surplus generated power could be stored in the battery [5][6]. The main key element (Technically speaking) to charge the battery is Constant Voltage and Current across it. As we speak, the technology advancement increases the hassle of adopting to it. We all know that power generation through Non-Conventional sources like Solar, wind etc... will not be same at all time and its dependant on Solar Irradiance and Temperature mainly. This Solar Irradiance and Temperature will vary according to Season to season and weather to weather. Same goes with Wind, As the Atmospheric pressure changes with the distance (Pressure gradient) results in High Speed wind generation. During less pressure gradient, wind speed will be less and couldn't meet the generation requirement. So, the produced power from Solar or Wind won't be constant or same over the entire period. The necessary changes to get constant voltage and current can only be done at converter side and not at generation side most of the time. Since, the title deals with Solar powered, we'll be using Solar array or PV array as source of fuel generation to charge the battery [7]. As the converter is receiving input through PV array, the necessary changes have to be made at converter side. Be it in regulating the voltage levels or Amplifying or Attenuating it. Many DC-DC Converters are prominent in this segment for medium to high powered EV. Converter topology has to be chosen based on requirement. During very less power generation, the charging efficiency will decrease drastically in medium and High powered EV due to Converter performance limitation. There are many Chopper topologies available, be it Non-Isolated Chopper like Buck, Boost, Sepic, Cuk converters or Isolated Choppers like Flyback, Forward, Flyback-Forward, or even advanced converters like LLC Resonant or Series resonant DC-DC Converter [8]. The main hurdle is the random generation of power from PV array. Here in this paper, the level-2 voltages and current are been considered. During the peak time, the power generation will be more so at that time it's easy to boost up the voltage levels, so no doubt Boost Converter [9] [10] is most suitable due it its reliability, simple design and Implementation and cost wise. But the real problem comes while choosing the Proper converter which could not only boost up the voltage levels and also maintains the efficiency throughout off peak time. So, for this Forward converter is chosen because of instant conversion of voltage levels and no energy storage and normally way better when the required output current is on higher side. By considering all the parameter like components used, gain factor, overall efficiency, stress on the switches during operation, these two Topologies are best suitable.

In this paper, the hassle of Charging efficiency for medium and High powered EV is achieved nearly one hundred percent by proposing an Intelligent Forward-Boost Hybrid converter. The proposed converter is chosen so that one converter will overcome the performance limitation of the other and vice versa. The proposed converter is Design and Implemented for Medium Level (Level 2) which has voltage between 200-240Volts and current from 20-32Amperes. Here a Constant 200V & 20A is achieved to charge the Li-ion Battery. By this, losses at low power generation is minimised and switching stress of both the switches of converter is minimised thus improving converter life span.

2. BLOCK DIAGRAM OF PROPOSED MODEL:

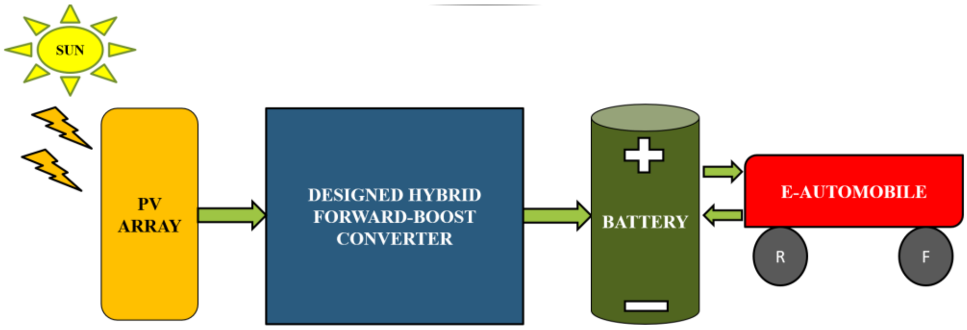

Figure 1: Block Diagram

The above figure gives an overall glimpse of the Proposed model. The radiation delivered from the sun will be captured by Solar Panel or an PV-Array. This intern will produce the massive amount of power in terms of voltage and current which completely depend on the Solar Irradiance and temperature on any particular day. Now, the generated power is completely not constant and varies depend on Irradiances and temperature. This is fed as an input to the Forward-Boost hybrid Converter, based upon the generated power, one of them is will carry the fuel to charge the battery while other won't. From this there will be constant DC voltage which is required for the battery to charge. Finally, the charged battery will be discharged or can also be charged (regenerative action) as the input fed into electric motor of the Automobile. The design and implementation concept of Forward-Boost converter is the heart of the model, along with PV-array, Battery. Here instead of Electric automobile, a simple Resistance load is considered to verify the charging and discharging period of the battery. The detailed flow flow-chart how exactly the flow (power flow) goes is discussed below.

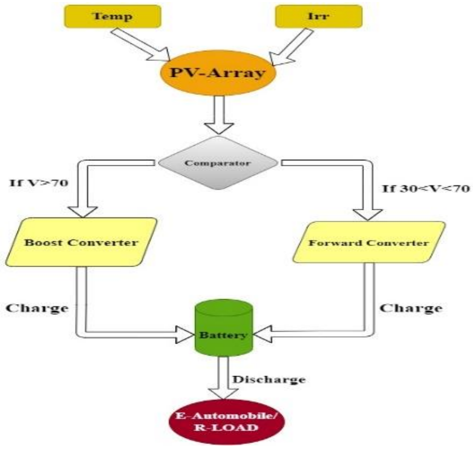

Figure 2: Flow chart of Proposed Model

3. METHODOLOGY:

3.1. *Mode 1: Forward Converter =Activated, Boost Converter = De-activated*

In this mode, Forward converter will be activated and Boost converter will be in off mode. This mode will be activated when the power generated from PV-array is anywhere in between 30V to 70V. For this a suitable design of Forward converter has been done with less switching loss and stress and greater efficiency. The switching frequency is high of 100kHz to reduce the compactness of the circuit by limiting the lesser values of Passive components like Inductor, capacitor and Resistor. A closed loop design is implemented to get the better results, accuracy and very less ripple while charging and dis-charging of battery through Isolated converter. (Forward converter)

3.2. *Mode 2: Boost Converter = Activated, Forward Converter =De-activated*

In this mode, Boost converter will be activated and Forward converter will be in off mode. This mode will be activated when the power generated from PV-array is above 70-80Volts. For this a suitable design of Boost converter has been done with less switching loss and stress and greater efficiency. The switching frequency is high of 100kHz to reduce the compactness of the circuit by limiting the lesser values of Passive components like Inductor, capacitor and Resistor. A closed loop design is implemented to get the better results, accuracy and very less ripple while charging and dis-charging of battery through Non-Isolated converter. (Boost converter)

3.3. *Converter Design parameters:*

3.3.1. *Boost Converter:*

$V_o = \frac{Vin}{(1-D)}$ ⇒ gives D, Duty ratio (1)

$L_{min} = \frac{\mathrm{D}(1-D)^2\mathrm{R}}{2f}$ ⇒L=1.25 L_{min} & C=$\frac{D}{Rf\left(\frac{\Delta Vo}{Vo}\right)}$ ⇒ C

gives L & C value for Continuous conduction of current (2)

3.3.2. *Forward Converter:*

$V_o = \mathrm{VinD}(\frac{\mathrm{N2}}{\mathrm{N1}})$ ⇒D, Duty ratio (3)

By Assuming, 40% variation in Inductor Current

$iL_x = \frac{Vo}{R}$ (4)

$L_x = \frac{Vo(1-D)T}{\Delta iLx}$ & C =$\frac{(1-\mathrm{D})\,V_o}{8\Delta V_o\, L_x f^2}$ (5)

gives L & C value for Continuous conduction of current

Solving equations 1 to 5 and with some assumptions, converters parameter is designed.

Parameters	Forward Converter	Boost Converter
Input Voltage, Vin	30-70v	≥70v
Output Voltage, $Vout$	300v	300v
Output Current, Iout	20A	20A
Output ripple, $\frac{\Delta v_0.}{v_0}$	5%	5%
Frequency, f	100KHz	100KHz
Transformer ratio, N1:N2		1:10
Duty ratio, D	0.9-0.76%	42.85%
Inductor, L	2.76µH	$L_{x=}$0.4mH
Capacitor, C	15.µF	100µF
Load, R	10-15Ω	10-15Ω

The above table, represents the designed parameters which is implemented for Boost and Forward converters. Frequency of 100KHz is considered so that the size of the apparatus could be compact enough. All the Passive components designed are with respect to the continuous conduction mode of the current. The output ripple is will not be more than 5%.

At low power generation from PV-array, comparator will confirm whether the voltage generated is well within 30-70v, then Forward converter will be responsible for boosting up voltage to 300v. Later this voltage will be again stepped down from the switching actions and fed to the battery with constant 200v 20A rating. Similarly, when the comparator founds that voltage is above 70v, then boost converter will be responsible to produce 300v output voltage, this voltage is stepped down and fed into battery with constant 200v 20A rating in the designed MATLAB Simulink model and results were shown in section 4 & 5.

4. DESIGN & IMPLEMENTED MATLAB SIMULINK MODEL:

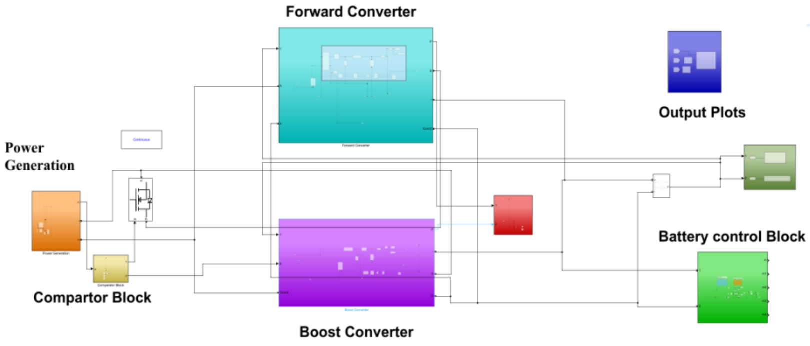

Figure 3: Forward-Boost Hybrid Converter

4.1. Battery Control Block:

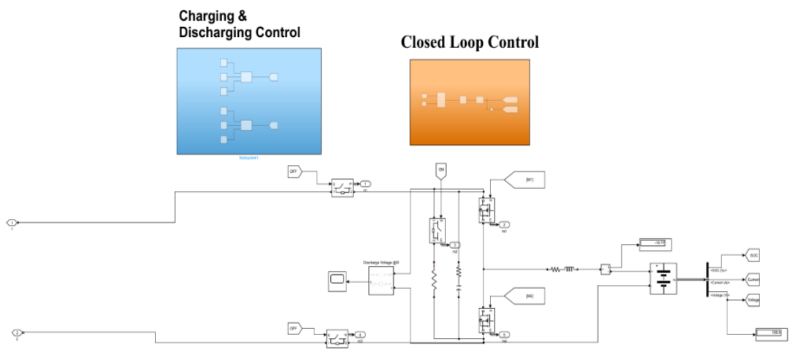

Figure 4: Battery Control Block

5. RESULTS:

5.1. Forward mode results:

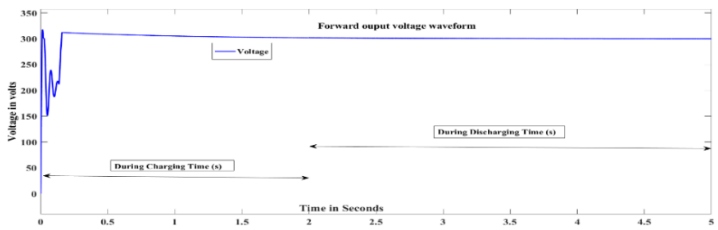

Figure 5: Forward Operated Output Voltage, 300V

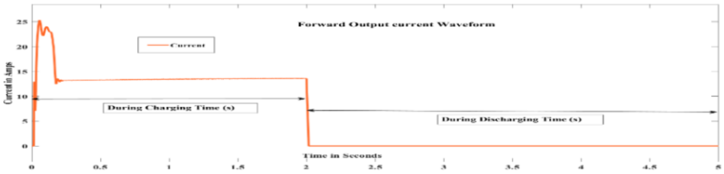

Figure 6: Forward Operated Output Current, $Iavg$ =15-20A, 0-2s=Charging & 3-5s=Discharging

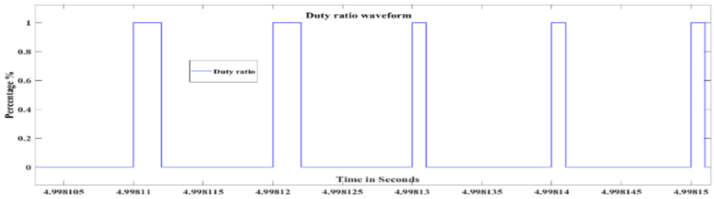

Figure 7: PID Generated Duty ratio during charging

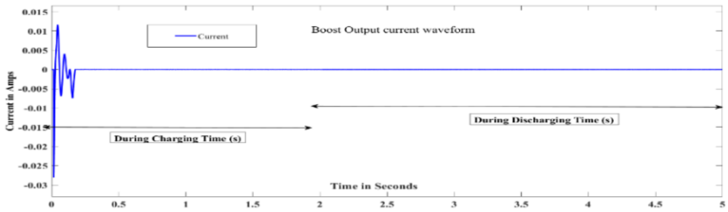

Figure 8: Boost Generated Current, 0A

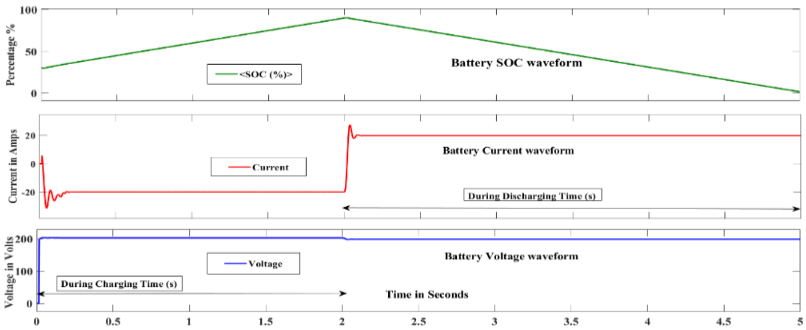

Figure 9: Battery Charging & Discharging Cycle, 0-2s=Charging & 3-5s=Discharging

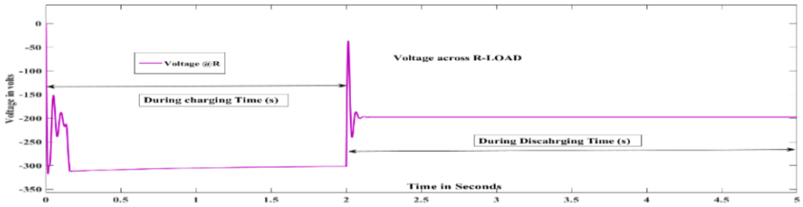

Figure 10:Output Voltage Across R-Load during charging=300v & discharging=200v

5.2. Boost mode results:

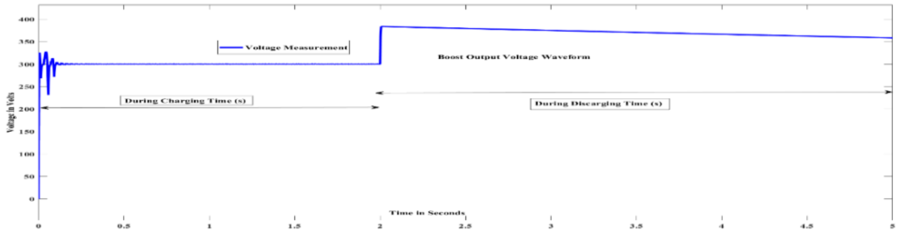

Figure 11: Boost Operated Output Voltage, 300V

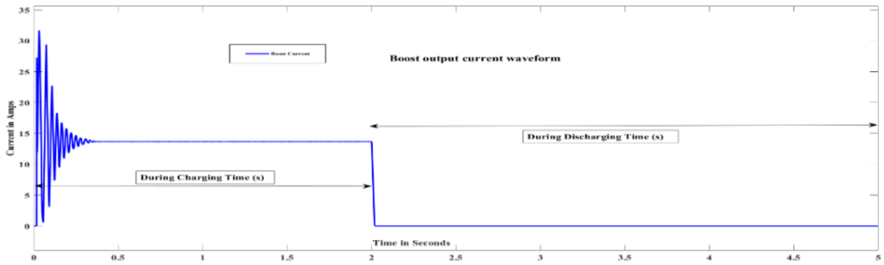

Figure 12: Boost Operated Output Current, $\boldsymbol{Iavg}$ =15-20A, 0-2s=Charging & 3-5s=Discharging

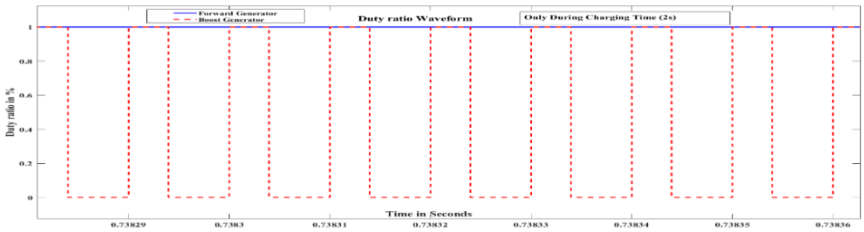

Figure 13: PID Generated Duty ratio during charging

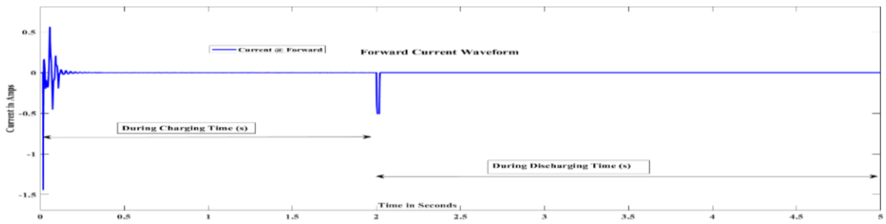

Figure 14: Forward Generated Current, 0A

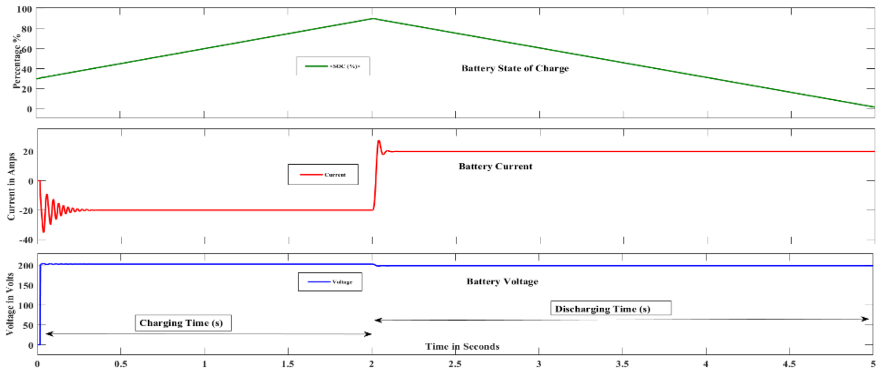

Figure 15: Battery Charging & Discharging Cycle, 0-2s=Charging & 3-5s=Discharging

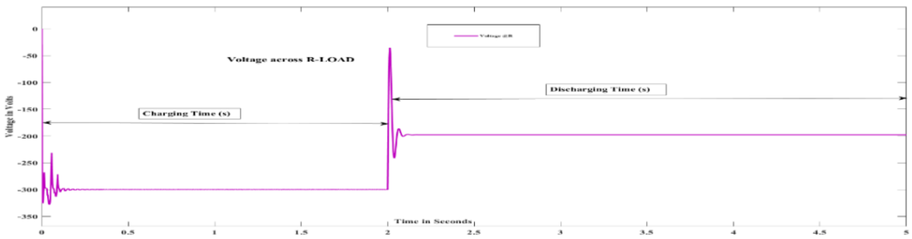

Figure 16: Output Voltage Across R-Load during charging=300v & discharging=200v

The Figure 5 & 11 shows the constant 300V during Charging & Discharging mode both from Forward and Boost converter. The figure 6 & 12 shows the 15-20A current during charging (0-2s) time and no current during discharging (3-5s) time in both the converters. Figure 7 & 13 represents the Duty ratio which is generated by PID controller in closed loop to trigger the Forward & Boost converter switches. The current across the other converter while one converter is feeding the load is shown in figure 8 & 14 respectively. This entire time, the voltage & current across the battery is 200V, 20A (both during charging & discharging) & Battery is charged till 90% of SOC in 2sec & discharges in 3sec from 90% to initial SOC value of 30% which could be seen in figure 9 & 15. Finally, the voltage across the R-load during charging (0-2s) is the voltage which is feeding the battery from converters that is 300V and while discharging time (3-5s) the voltage is found to be 200V which is fed from battery is shown in figure 10 & 16 respectively.

6. CONCLUSION:

By all means of experimentation, the best suitable Forward-Boost converter has been designed and implemented. The hassle of charging the battery with non-conventional energy sources is overcome. With this irrespective of power generated from PV-array a constant output producing of Hybrid converter is been implemented and verified in MATLAB Simulink. So, A Constant uninterrupted DC output voltage and Current of 200V, 20A is achieved to charge the Electric Vehicle Battery irrespective of Power generated from the PV-Array. When the voltage from the solar PV-array lies between 30V to 70V, forward converter is operational and Boost converter is in an idle state. On the other hand, when the input voltage from the solar PV-array is greater than 70V, Boost converter is operational and Forward converter is in an idle state. The Study, Analysis and Simulation of this hybrid converter topology has proven to be a reliable candidate for battery charging applications. By considering overall performance, we can say it's best suited for medium power EV charging applications, perfectly suitable for standalone solar powered charging stations for EV.

7. REFERENCES

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