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DESIGN, SIMULATION AND COMPARISON OF SINGLE PHASE BIDIRECTIONAL CONVERTERS FOR V2G AND G2V APPLICATIONS

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ABSTRACT

Meeting peak demand is a major challenge faced by our power sector. Electric vehicle penetration, having V2G capability can reduce the impact of this peak deficiency and can facilitate DSM. Bidirectional converters are the most important part of this V2G capable vehicles. So this paper contains the design, simulation and comparison of2 types of single phase bidirectional converters suitable for V2G and G2V applications. Simulations are performed using Matlab – Simulink background.

KEYWORDS: DSM, EV, G2V, Mahindra Reva, PWM, SOC, THD, V2G

INTRODUCTION

Indian peninsula is the world's third largest electric power producer according to 2015 statistics. India has a total of 255 GWas installed capacity for power generation [23]. Studies conducted reveals that Indian Power sector is facing ashortage of 2%to 17.4% during peak hours. By2017India need 135GWmore for its proper operation and a huge investment is required for this[1-3][23,24].Now 28% of peak demand is met by renewable energy resources[24].Electric vehicles,which consists of Battery energy storage systems, can be used as a distributed energy resource. In many developed countries there are many charging stations and parking lots where this concept is implemented. But its charging may sometimes create a peak load in the grid. But still there isa possibility of injecting energy back to the grid by the Vehicle to Grid technology (V2G).But it requires an Independent Source Operator, Aggregator and communication networkto control EVs as distributed generating sources [1-5].

This paper explains the design and simulation ofV2G bidirectional converter suitable for single phase application. Design is based on the EV model, Mahindra Reva and the simulations are done in the Matlab–Simulink platform. Two configurations are simulated and compared for selecting the better configuration. The second section explains the block diagram and the base model details. Third section explains the design of the converters. Then converters are comparedon the basis of THD analysis.

CONFIGURATION

In implementing the concept of V2Gand Grid to vehicle (G2V) bidirectional converters plays an important role.[1-5][15-20] A electric vehicle (Plug-in electric vehicle) cancharge its batteries using AC power or DC power from the charging stations and can give back to grid. Bidirectional converters are required for this purpose.This type of EVscan be used for distributed energy applications like voltage control and regulation, load frequency control, can be used as spinning reserves, and its co-ordinated use facilitatesDemand Side Management (DSM).[3] It helps to implement the concept of peak shaving and valley filling.[2]So the most important part of a V2G capable vehicle is the bidirectional converter system. Figure1 shows the basic block diagram of the required system.

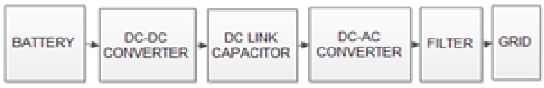


Figure: 1: Block Diagram of the Proposed System

DESIGN

Since most of the people those who owns EV are having single phase charging outlets at their homes, this paper considers the design ofsingle phase converters which are having bidirectional capability.Here we are considering Mahindra Reva as our base model or EV for design and simulation purpose. It uses anarrangement of 8 cells in series; each cell is having a rating of 6volts. The capacity ofeach cell is 200 Ampere hours.

Output Power

Since we are using the vehicle for injecting power to grid,also since we have to use the battery power to drive the motor of the vehicle, which isthe primary purpose, we are limiting the battery power usage by 30% for grid injection.Remaining 70% is for driving purpose. This means that before delivering the power togrid for DSM the SOC of the battery is checked. It should be greater than 70% for gridinjection a we have limited. So the total power that can be delivered can be calculated asfollows:

Battery Voltage = 6V, Number of cells = 8, Ah capacity = 200Ah ;Total capacity of battery bank = 200x6x8 = 9600Wh; Power that can be delivered to grid = (100 - 70)% of SOC= 30% of 9600 = 2880Wh

DC – DC Converter

Battery bank voltage Vin = 48V, DC link voltage V0 =80V; we know thatV_0/ V_{in} = 1 / (1 - D), D = 0.4, Where D is the duty cycle. Maximum current; I_0 = (Wxh) / V_0 = 36A, Take 5 % ripple current = 1.8A; Switching frequency Fs = 10kHz, Load resistance can be calculated as:R = V_o^2 / W = 2.222ohms.

DC - AC Converter

It includes an inverter, control and a filter circuit. IGBT based H-bridge configuration is used.Design equations are given in the reference. [25]. To eliminate harmonics,filter circuit is included at the output side of the converter. Srated is the kVA rating ofthe converter. T is the time period corresponding to the grid frequency. Δr is the powervariation in watts. Δx is the allowable dc bus voltge change.Mathe inverter modulationindex and RAF the Ripple Attenuation Factor.

Boost converter inductance, L_{dc} = (RD $(1 – D)^2$) / (2Fs)

Take S_{rated} = 2.880kVA, T = 20ms, Δr = 2880W, Power factor = 0.95,

V_{dc} = 80V, Δx = 8, M_a = 0.9,

DC link capacitor C_{dc} =(Srated x 2n x Δr x pf)/(Vdc2 x Δx) = 2137uF

Inverter side inductor L_{source}

= (Vgrid2 / (THD x Srated x 2∏ x Fs))√((∏2 /18)(1.5 – (4√3 / 11)Ma +(9 Ma 2/8)))

= 0.7073mH

Filter capacitor C_{filter}= 71uF, Filter inductor L_{source}= 0.13449mH, R_{filter}= 0.42527ohms

SIMULATION

Boost Converter

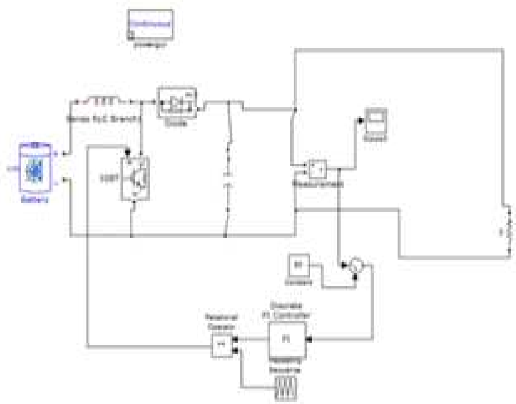


Figure2: Boost converter

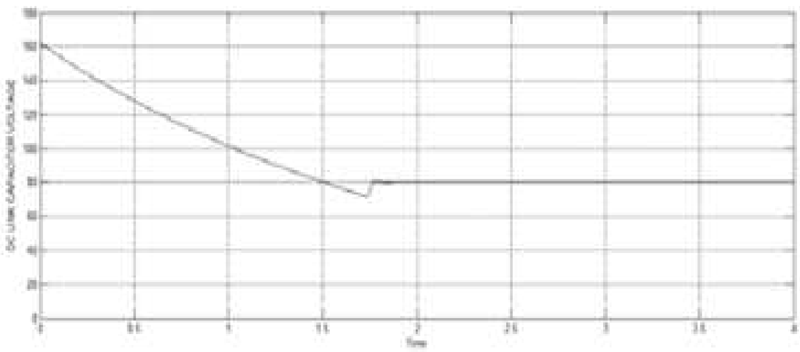


Figure3: Output Voltage of Boost Converter

Figure2 and Figure3 shows the MATLAB model for dc-dc converter andits output waveform respectively. The DC link voltage become steady after 1.8 seconds

4DC - AC Converter

Table 1: Circuit Parameters

Parameters	Values	Parameters	Values
V_{in}	48V	L_{inv}	0.7073mH
L_{dc}	46uH	L_{source}	0.1344mH
C_{dc}	2137.5uF	C_{filter}	71uF
V_o	80V	R_{filter}	0.42527ohms
Kp	0.01	AC source voltage(through transformer)	75V
Ki	1	Load	5kW,80V,50Hz

Two types of converters are compared in this paper,type-1 which is based on the zero crossings and on off control and the type-2 is based on the Pulse Width Modulation (PWM). Table 1 summarizes all the design and simulation parameters.

Type-1 Configuration

In the type-1 converter, the grid voltage is fed back to the switching sub system. Zero Crossing Detectors(ZCD) decides whether to turn on or turn off the IGBT switches by generating pulses.

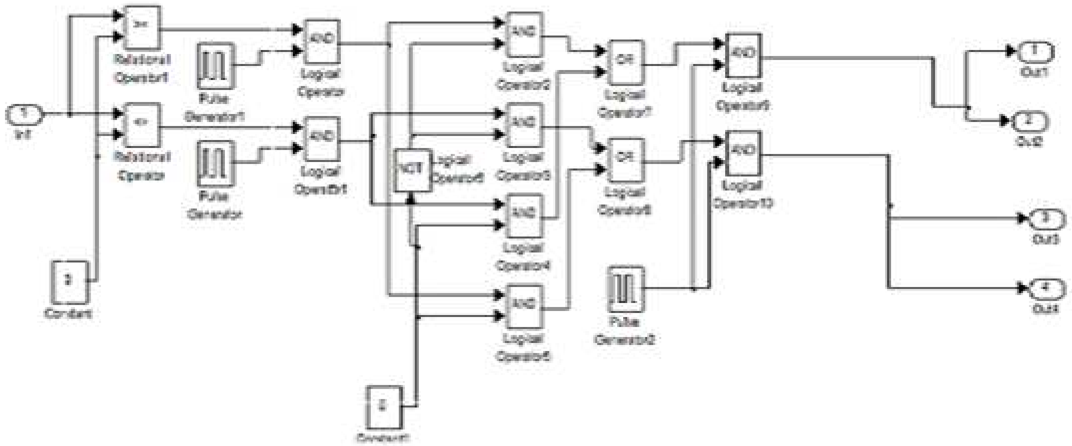
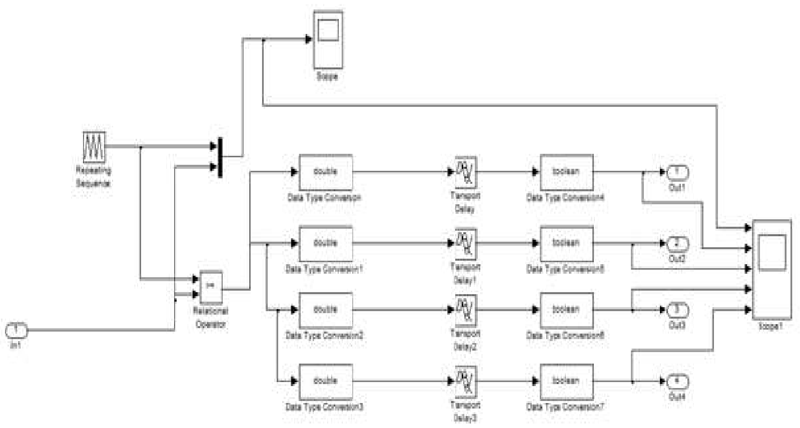


Figure4: Type-1 Configuration– Switchingsubsystem for Inverter

The output of ZCDs are again compared with carrier pulses generated by the pulse generators and are used to trigger the IGBT gates.. H – bridge inverter configuration with 4 IGBTs are used. The main advantage of this converter scheme is that, as the pulses from the ZCDs are used, the converter can easily follow up the frequency changes in the grid in a co-ordinated manner without any controller aid. Figure 4 shows the Subsystem for Inverter switching using type-1 configuration.

Type-2 Configuration

In order to reduce the THD further and to make the waveform shapes moresinusoidal we can make use of the Pulse Width Modulation in the type-2 configuration.



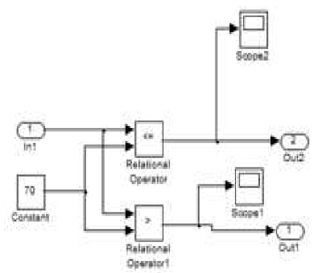


Figure 5: Type-2 SwitchingsubsystemFigure 6: Charging Discharging Control Block

The sinusoidal voltage wave form from the source, which is taken through a voltage feedback loop, is compared with a carrier waveform of triangular shape havinga higher carrier frequency and the resultant pulses are used for triggering the converterswitches. Here the carrier frequency is again 10kHz.

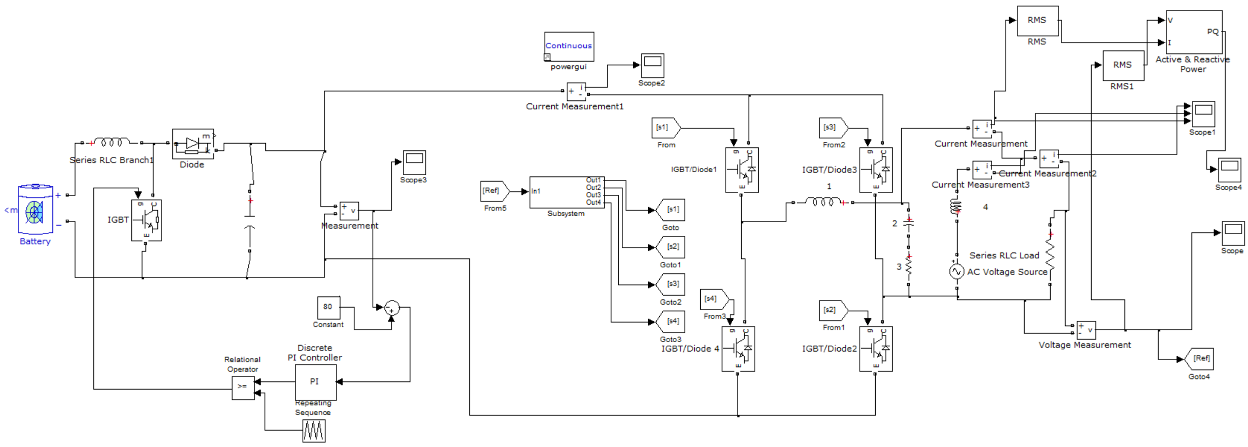


Figure7: Type 1 Converter – Matlab-Simulink Model

When the amplitude of the voltage feedback become greater than the triangular carrier, corresponding IGBT pair in the H-bridge inverter is triggered ON. Other pair is turned ON after a delay of 10mS which corresponds to the time delay of 1 half cycle.Figure 5 shows the Subsystem for Inverter switching using type-2 configuration. Main drawback is that, delay must be adjusted according to the change in grid frequency dynamically. Otherwise synchronism will be lost.

Figure 6show the arrangement to control the charging and discharging selection. It monitors frequently the SOC (State Of Charge) of the EV battery and the two anti-parallel thyristors are turned on accordingly as per the requirement.

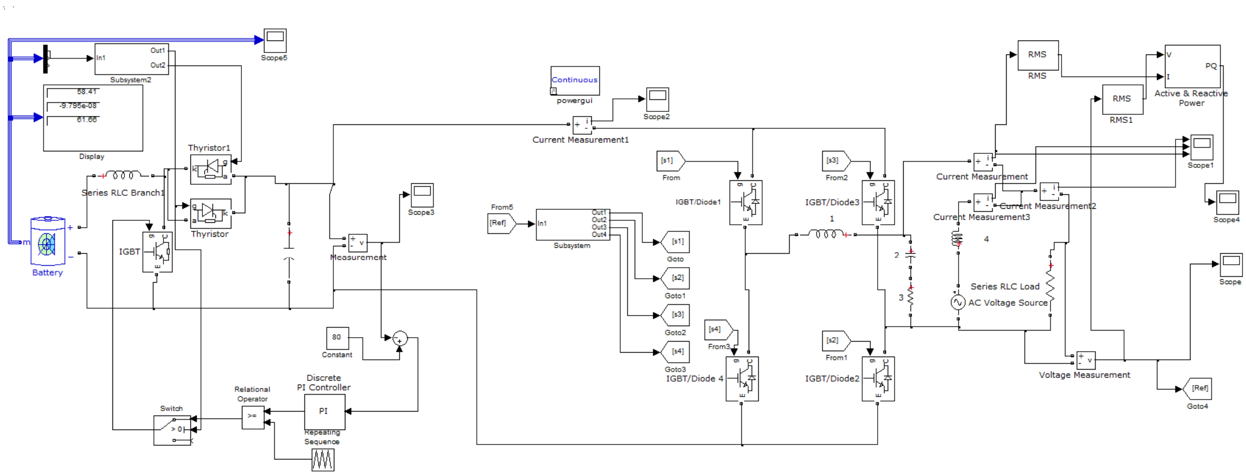


Figure8: Type 2 Converter Matlab-Simulink Model

COMPARISON

Figure7 and 8 shows the Matlab–simulink models for type 1 and 2 converters respectively. Comparisons are made on the basis of current THD analysis, ease of synchronization and charging discharging control. Figuresbelow shows the current waveforms of both type of converters. Type -1 configuration has more distorted current waveforms and greater THD than Type -2 configuration. Table 2 shows the THD analysis results and also compares the both types of converters. In type -1, since the pulses generated by pulse generator and ZCD outputare the only factors that governs the switching mechanism, it is not possible to control the charge/discharge rate directly. But in case of PWM, current control schemes can be easily done.It must be noted that in both types, mode selection (ie: charging/discharging) can be easily inco-orporated. Also as power injected increases, THD is also found to be increasing in the case of Type-1 converter to drastic level, which cannot be allowed as per standards. Also in Type -2, as feedback is taken from the grid voltage, distortions in grid voltages can lead to higher THD which is not allowable. In case of Type- 1, grid voltage distortions, noises and spikes can lead to false triggering of ZCDs which further increases the THD.

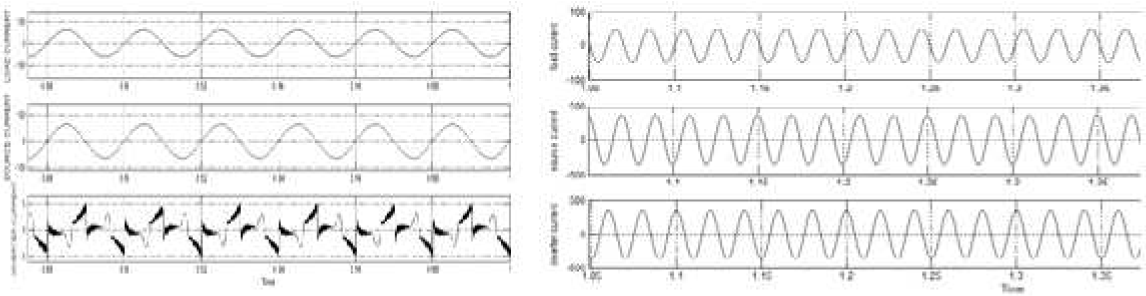


Figure 9: Current Waveforms for Load,Source and Inverter in Type 1 & Type 2 Converter

Table 2:Comparison at Aglance

Criterion	Type-1	Type2
THD (source current)	0.99%	0.33%
THD (load current)	3.33%	0.22%
THD (inverter current)	44.33%	0.34%
Synchronization	Automatic	Delay adjustment
Charge/discharge rate control	Not possible	Possible
Charge/discharge mode selection	Possible	Possible
Effect of distortions in grid voltage	False triggering	THD increases

CONCLUSIONS

Two types of single phase bidirectional converters suitable for V2G and G2V applications were designed and simulated using Matlab – Simulink platform. It was found that type-2 PWM converter currentis having less THD, better wave form andsmoother controls than type-1 converter based on ZCD and pulses. But synchronization is easier in case of type-1 converter.

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