



Control for Grid Connected Electric Vehicles in Single- And Three-Phase Networks with On- Board Battery Charging

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Abstract: Due to the increased rate of depleting fossil fuels, air pollution and global warming, the conventional vehicles using internal combustion engines (ICE) are replaced by electric vehicles (EV). It recaptures the regenerative braking energy, thus eliminating engine idling time. The bidirectional flow capability of vehicle is controlled by using a unified control methodology. It also reduces cost, weight and size of on board chargers in electric vehicles, thus enhancing dual usage of converters for charging and propulsion. The control is eminent in that it can be executed for four quadrant operation when connected in single-phase or three-phase network. The operation and grid management are spontaneously adjusted depending on specified terminal voltage and current measurements without the need for additional status signals. The proposed system is validated via detailed simulation.

Keywords: Electric vehicle, internal combustion engine, charging, global warming, voltage source inverter.

I. INTRODUCTION

The transportation has a most important role in day-to-day existence. Finding of ecological fuel energy with the lowest emission is highly preferred nowadays due to shortage in fossil fuels. As the penetration of plug-in hybrid electric (PHEVs) and plug-in electric vehicles (EVs) continues to increase, uncoordinated and uncontrolled charging of these vehicles considerably affect the distribution grid [1], [2]. Within the smart grid initiative, the need to accommodate for the impact of a large number of EVs performing charging and vehicle to grid (V2G) calls for intelligent control methodologies [3]-[5]. Several EV modeling and control strategies have recently been reported in literature [6]-[11], including reactive power compensation [12]-[14]. But the shortage of standards in the locomotive industry has led to various circuits and control structure.

Fig. 1 describes the conventional method of grid connected electric vehicle system. When the system is connected to three-phase network, an inverter and dc/dc converter operates, thus charging the battery. For single phase charging, electric vehicle supply equipment (EVSE)

is to be installed in a region to charge the battery and separate inverter is used. Fast charging is done by using three phase network installed in bulk stations.

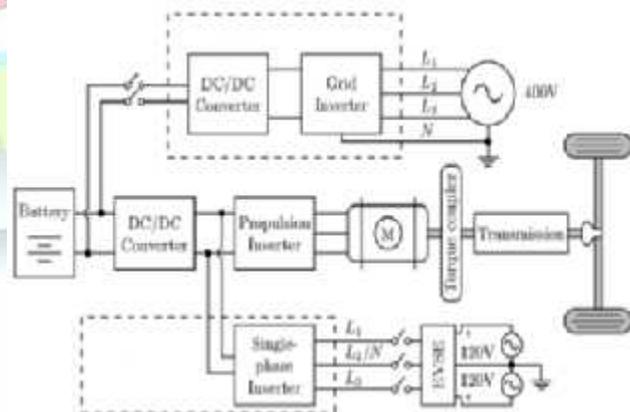


Fig.1. Conventional grid connected electric vehicle system

Fig. 2 describes proposed grid connected electric vehicle system that uses a single dc/dc converter and



inverter that can be controlled both in single and three phase networks with bidirectional power flow capability. It includes a battery bank connected to a dc bus via bi-directional dc-dc converter and Voltage Source Inverter which serves as the interface to the ac system. It uses the same converter for multiple functionalities like single-phase charging, three-phase charging and for propulsion. The electrification of transportation systems would enable increased electricity generation from carbon-free and renewable energy sources such as wind, solar, and hydro resources. The cost for installation of Electric vehicle supply equipment in residential areas is eliminated.

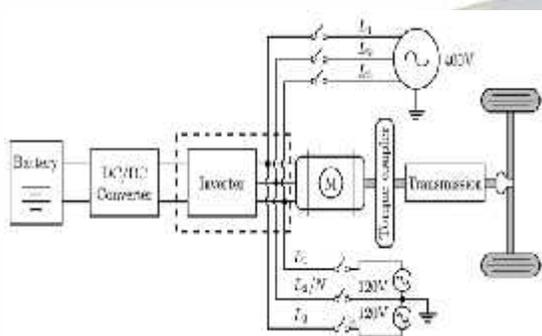


Fig. 2. Proposed grid connected electric vehicle system

II. PROPOSED ELECTRIC VEHICLE SYSTEM

A. THEVENIN-BASED BATTERY MODEL

A battery is a device that can store electrical energy and release it by chemical reaction when it is needed. From Electric drive vehicles perspectives, a battery system is used to store the electric energy by vehicle regenerative braking or charged from external source. Because of complex charging and discharging characteristics and relative damageable feature of battery, it is necessary reliably. Therefore electrical equivalent models known as circuit-oriented battery models are used to design a battery model.

Here the battery is modeled through Thevenin-equivalent circuit including its transient behaviour. In its most simple form, a Thevenin-based model shown in Fig.3 consists of a voltage source in series with a resistor and a parallel combination of a capacitor and resistor to predict battery response to transient load events at a particular SOC [15].

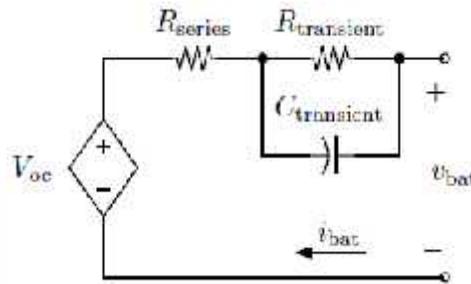


Fig.3. Thevenin Battery Model

A. BATTERY CHARGER AND CONTROL

The bidirectional dc-dc converter regulates the battery charge and discharge processes. In Buck, Boost and Buck-boost dc-dc converters, the implementation of the switching power-pole by one diode dictates the instantaneous current flow to be unidirectional. As shown in Fig.4, by combining the switching power-pole implementations of Buck and Boost converters, where two transistors are switched by complimentary signals, allows a continuous bi-directional power and current capability [16].

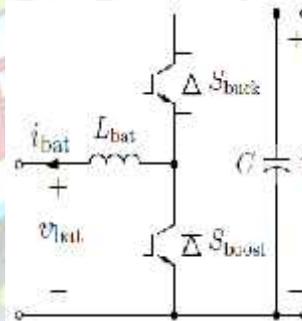


Fig.4. Battery charger configuration

The battery charger control has a DC-link voltage control loop in cascaded with current control loop as shown in Fig.5. The battery duty ratio (d_{bat}) is processed with the carrier signal to generate pulse for buck and boost transistor switches.

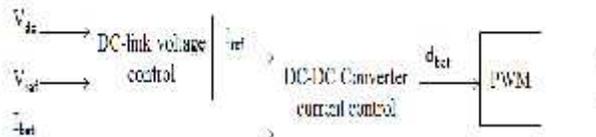


Fig.5. Battery charger control



B. INTEGRATED INVERTER AND CONTROL

The inverter has six thyristor switches in antiparallel with a diode as shown in Fig.6. The DC link voltage is kept constant and the inverter acts as an interface between the grid and the charger. The ac grid is modelled by an ideal voltage source behind impedance and may correspond to a single- or three-phase network. VSI connects to the grid through a standard LCL filter to comply with power quality requirements [17]. A LCL grid filter is equipped to minimize the overshoot and high frequency oscillation.

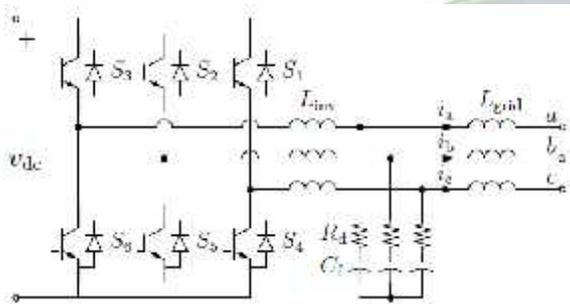


Fig.6. Three phase inverter with LCL filter

The inverter control shown in Fig.7 consists of PLL block, current signal preprocessing block, and PWM block. The Phase locked loop(PLL) block can autonomously track single- and three-phase signals. The current signal preprocessing stage allows for the use of the same control strategy for single- or three-phase nature of the network that is connected to and Pulse width modulation (PWM) strategy for a three-leg two-level voltage source inverter can operate as a single-phase H-bridge or a three-phase VSI.

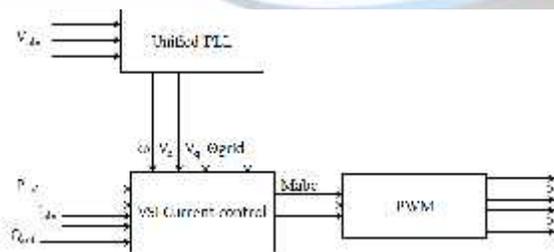


Fig.7. Inverter control

The inverter control is made by converting three phase stationary coordinate system into a two phase rotating coordinate system. The phase to phase transformation is done by using Clarke and park transformation. The main advantage of the PWM is a very low power loss for the switching devices. Especially, in the digital control mission,

it is easy to set needed duty cycle by PWM. Design guidelines for properly sizing LCL filter is obtained from the literature [18].

III. SIMULATION RESULTS

To verify the proposed schemes, a simulation model for single phase and three phase networks was modeled and implemented by using MATLAB/Simulink. The necessary are tabulated in Table.1

Table.1. Parameters for simulation

Parameters	values
Battery voltage	350V
Battery current	32A
Dc link voltage	700V
Open circuit voltage	400V
Switching frequency	5KHZ
Grid frequency	50HZ
Battery inductance	1mH

The Thevenin based circuit oriented battery model output with voltage value of 350V is shown in Fig.8. The pulse produced for Battery charger control is shown in fig.9. The current and voltage measurement waveforms are shown in Fig.10 and fig.11. The inverter control pulse is shown in Fig.12.

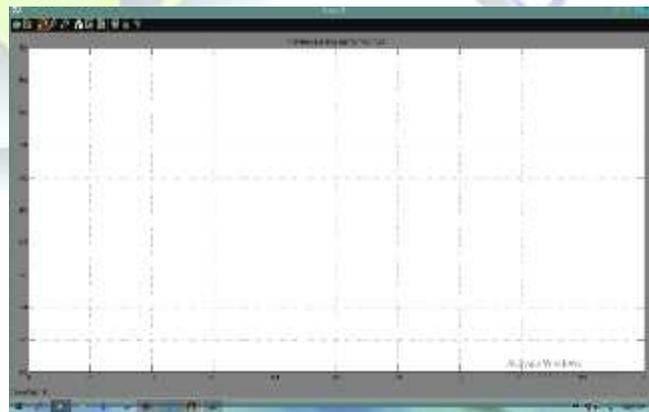


Fig.8. Battery output voltage

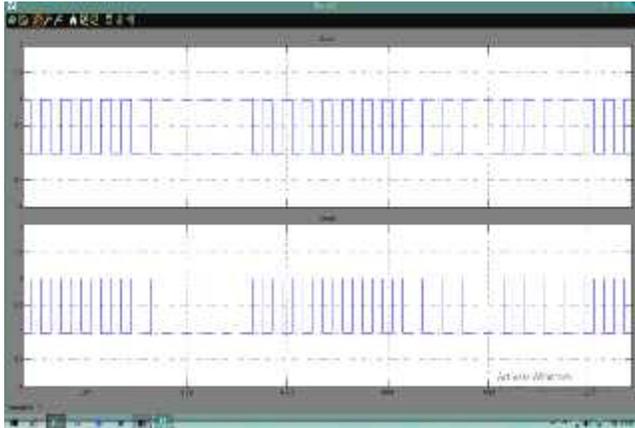


Fig.9. Battery charger control pulse

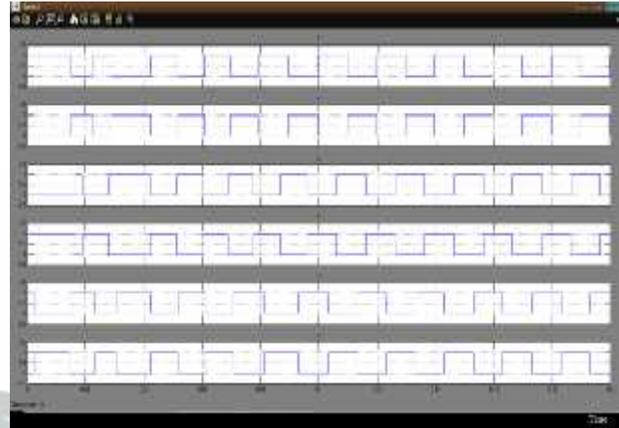


Fig.12. Inverter control pulse

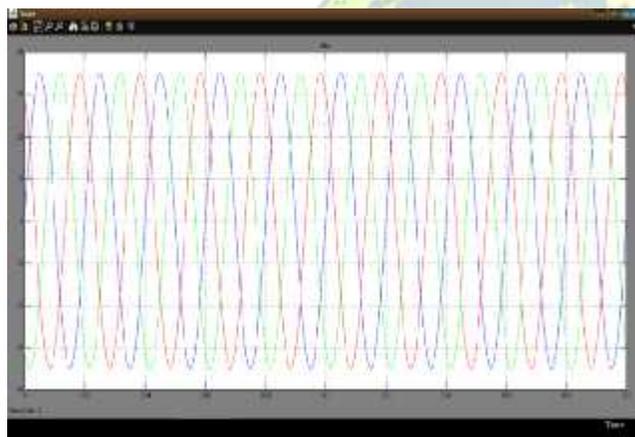


Fig.10. Current waveform



Fig.11. Voltage waveform

IV. CONCLUSION

The combination of on-board charging converters with converters for propulsion into a single unit symbolizes a smart substitute for the electric vehicle power conversion system. For such a combined converter, a new unified control structure was developed which allows for the operation of a three-leg VSI as either a single- or a three-phase inverter. The flexibility provided by this control is desirable for EVs to have single- and three-phase connection capabilities for slow and fast charging, respectively. The transformation matrices introduced in the PLL and in the current control allow for autonomous transition from single- to three-phase networks and vice versa with the same power electronic converter and without need to switch between different control schemes. The effectiveness of the unified control scheme was successfully validated via detailed computer simulations. Since the integrating of all these components in a drive train configuration could be a challenge for the manufacturer, computer simulation and modeling before prototyping could be really beneficial in terms of cost, safety and design performance.

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