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Renewable Energy Sources Based EV/HEV for Bi-Directional Operation in AC and DC Grid

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Abstract:

The concept bidirectional dc-dc converters (BDC) have recently received a lot of attention due to increasing the systems capability of bidirectional energy transfer between two dc buses. Apart from traditional application in dc motor drives, new applications of BDC include energy storage in renewable energy systems, fuel cell energy systems, hybrid electric vehicles (HEV) and uninterruptible power supplies (UPS). Under the requirements of reducing emissions, air pollution and achieving higher fuel economy. Most of the companies are developing electric, hybrid electric and plug-in hybrid electric vehicles. However, the high cost of these technologies and the low autonomy are very restrictive. Different DC to DC converter structures can be organized from the inverter semiconductor elements.

This project represents an integrated traction machine and converter topology that has bidirectional power flow capability between an electric vehicle and the dc or ac supply or grid. The dc grid voltage provides more stable voltage to counteract the rate of change of inductor current and the current ripple is controlled in a better fashion in a dc grid connected mode. The inductances of the traction motor windings are used for bidirectional converter operation to transfer power eliminating the extra needed inductors for the charging and vehicle-to-grid converter operations. Finally these operations are implementing in vehicle traction mode operation with help of using PV/Fuel cell based instead of battery supply & simulation results are obtained for electric motor characteristics by using MATLAB/SIMULINK software.

Index terms:

Grid, Electric Vehicles, Battery Chargers, Motor Drive, PWM control, Power Quality, PV converters.

I.INTRODUCTION:

Several distributed energy (DE) systems are expected to have a significant impact on the California energy market in near future. These DE systems include, but are not limited to: photovoltaic (PV), wind, micro turbine, fuel cells. In addition, several energy storage systems such as batteries and flywheels are under consideration for DE to harness excess electricity produced by the most efficient generators during low loading. This harvested energy can be released onto the grid, when needed, to eliminate the need for high-cost generators. There are a number of applications for DC-to-DC systems. These systems are used to convert the DC voltage magnitude from one level to another with or without galvanic isolation. They take an uncontrolled, unregulated input DC voltage and condition it for the specific load application. An example for such topology can be found in PV applications, where the dedicated DC-DC units are often designed to extract the maximum power output of the PV array. Photovoltaic (PV) technology involves converting solar energy directly into electrical energy by means of a solar cell. A solar cell is typically made of semiconductor materials such as crystalline silicon and absorbs sunlight and produces electricity through a process called the photovoltaic effect. The efficiency of a solar cell is determined by its ability to convert available sunlight into usable electrical energy and is typically around 10%-15%. Therefore, to produce significant amount of electrical energy, the solar cells must have large surface areas

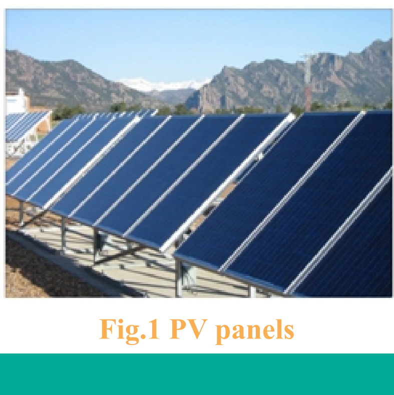

Fig.1 PV panels

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Figure 1 show typical PV panels configured into arrays. For a PV system, the voltage output is a constant DC whose magnitude depends on the configuration in which the solar cells/modules are connected. On the other hand, the current output from the PV system primarily depends on the available solar irradiance. The main requirement of power electronic interfaces for the PV systems is to convert the generated DC voltage into a suitable AC for consumer use and utility connection. Generally, the DC voltage magnitude of the PV array is required to be boosted to a higher value by using DC-DC converters before converting them to the utility compatible AC. The DC-AC inverters are then utilized to convert the voltage to 50 Hz AC.An integrated motor converter is proposed that can be used as the traction motor drive, a battery charger, and a power converter to transfer energy from vehicle-to-grid (V2G) through reconfiguration of the inverter topology using relays or contactors.

The traction inverter with the proposed reconfiguration method can also transfer power from the vehicle to a dc grid and from a dc grid to the vehicle using the traction motor windings with the appropriate relay settings. The three phase machine windings and the three inverter phase legs can be utilized with an interleaved configuration to distribute the current and reduce the converter switching stresses. The battery voltage is increased in the boost mode to an output reference voltage level within the limits of the machine ratings. A soft starter method using PWM control has been used to reduce the starting current overshot when connecting to a dc grid. In a dc grid connected mode, the voltage drop across the inductor will be the difference between the inverter output voltage and the dc grid voltage. The dc grid voltage provides more stable voltage to counteract the rate of change of inductor current and the current ripple is controlled in a better fashion in a dc grid connected mode.

The proposed converter system can also be used for transferring power between a single-phase ac grid and the vehicle in either direction without any extra component. The rated conditions of the motor and utility interface are quite similar. The inverter is able to regulate the motor phase current in the entire speed range. When changing from the motor control mode to ac grid connected mode of operation, the back EMF voltage is replaced with the grid voltage. Considering the operating conditions with the grid, motor inductance would be enough to handle the grid connected modes of operation.

Also, in the blocked rotor condition, motor magnetizing inductance dominates and contributes to the phase inductance significantly. For high enough inductance required in case of ac grid, the rotor can be locked which will give high inductance in the blocked rotor condition. In the charging mode, the machine is thermally stable with no electromechanical power flow through the air gap of the machine. The machine ratings are within limits in all the operating modes as there is only electric loading,and no magnetic loading except during traction operation. The current limit is higher in converter modes compared to the traction mode current limit.

II.PV ARRAY MODELLING AND CHARACTERISTICS:

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current The PV array is made up of number of PV modules connected in series called string and number of such strings connected in parallel to achieve desired voltage and current. The PV module used for simulation study consists of 36 series connected polycrystalline cells.

A.PV Model:

The electrical equivalent circuit model of PV cell consists of a current source in parallel with a diode as shown in Fig. 2.

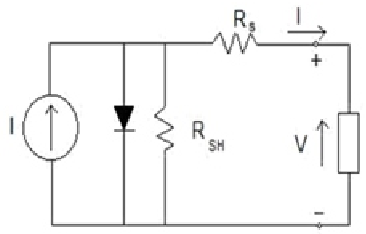

Fig.2 Electrical Equivalent Circuit Model of PV Cell

A Maximum Power Point Tracking (MPPT) circuit, which allows the maximum output power of the PV array. A Power Factor (PF) control unit, which tracks the phase of the utility voltage and provides to the inverter

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a current reference synchronized with the utility voltage. A converter, which can consist of a DC/DC converter to increase the voltage, a DC/AC inverter stage, an isolation transformer to ensure that the DC is not injected into the network, an output filter to restrict the harmonic currents into the network. The MPPT algorithm, the synchronization of the inverter and the connection to the grid are discussed. Tracking the DC voltage and current allows MPP calculation which gives the inverter to function efficiently.

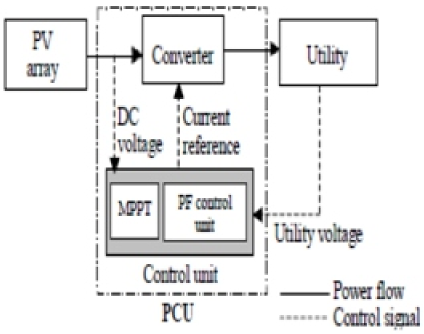

Fig 3 Schematic Diagram of Grid-Connected PV System

From the electrical equivalent circuit of the PV cell, PV output current (IPV) is given by

$$I_{PV} = I_{Ph} - I_D - I_{sh} \quad (1)$$

Where

$$I_D = I_0\left(e^{\frac{q(V_{PV}+I_{PV}R_S)}{\eta kT}} - 1\right) \quad (2)$$

And

$$I_{sh} = \frac{V_{PV} + I_{PV}R_S}{R_{sh}} \quad (3)$$

The parameters q, η, k and T denote the electronic charge, ideality factor of the diode, Boltzmann constant and temperature in Kelvin respectively. Iph is photocurrent, I0 is diode reverse saturation current, IPV and VPV are the PV output current and voltage respectively. As the value of Rsh is very large, it has a negligible effect on the I-V characteristics of PV cell or array. Thus (1) can be simplified to

$$I_{PV} = I_{ph} - I_0\left(e^{\frac{q(V_{PV}+I_{PV}R_S)}{\eta kT}} - 1\right) \quad (4)$$

For PV array consisting of Ns series and Np parallel connected PV modules, (4) becomes,

$$I_{PV} = N_p\left\{Iph - I_0\left(e^{\frac{q(V_{PV}+I_{PV}R_S)}{\eta kTN_S}} - 1\right)\right\} \quad (5)$$

B.PV Characteristics:

The PV model is simulated using Solarex MSX60, 60W PV module. The simulated I-V and P-V characteristics of the Solarex PV module at constant temperature and varying insolation are shown Fig.3 respectively. It can be seen from Fig. 3 that the decrease in insolation reduces the current largely but voltage fall is small. Shows that the reduction in insolation reduces the power largely as both voltage and current are decreasing. The effect of temperature on I-V and P-V characteristics of Solarex PV module is shown in Fig4 respectively. It can be seen from Fig.4 that the increase in temperature reduces the open circuit voltage largely but rise in current is very small. Fig.4 shows that the increase in temperature reduces the PV output power as the reduction in the voltage is larger than the increase in current due to temperature rise.

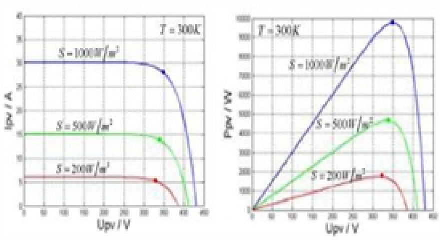

Fig.4 I-V and P-V curves

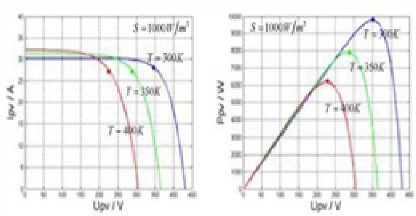

Fig.5 I-V and P-V curve at different temperatures

Different types of topologies have been developed for electric vehicles for battery charging and bidirectional power flow between the battery and the power supply. However, the traction inverter uses the standard six-switch configuration that has elements of the various power converter topologies. The proposed converter topology utilizing the traction inverter along with the switches used for reconfiguration is shown in Fig. 6 shows the detailed switch or relay arrangements required for different modes of operations. Several different configurations can be obtained by appropriate positioning of the switches, which results in

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a novel methodology for bidirectional power transfer between a vehicle battery and dc or ac grid. Including the use of the topology as the traction inverter during vehicle operation this power converter can be operated in five different modes: 1) power flow from the battery to the dc grid, 2) power flow from the dc grid to the battery, 3) traction mode, 4) power flow from the battery to single-phase ac grid and 5) power flow from a single-phase ac grid to the battery. The reconfiguration switches can be realized with relays or contactors depending on the ratings of the currents. Those relays and contactors are controlled in a coordinated way to accommodate the different modes of use. The contactors with optimum current capacity should be used to minimize the size of the contactor. The size of the contactor has to be accommodated based on the current rating chosen. To minimize the space and size of the contactors, all the switches can be integrated into a single package. The switches will be controlled for the different modes of operation using State 1 and State 2 conditions given in Table I.

TABLE I SWITCH POSITIONS AND CONVERTER STATES

Switch	State 1	State 2
Switch1	Pole positions:1 and 3	Pole positions: 2 and 4
Switch2	1 and 2 disconnected	1 and 2 connected
Switch3	Pole positions: 1 and 3	Pole positions: 2 and 4
Switch4	1 and 2, and 3 and 4 disconnected	1 and 2, and 3 and 4 connected
Switch5	1 and 2 disconnected	1 and 2 connected

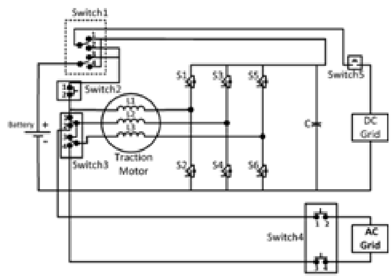

Fig.6 Converter with switches capable of interfacing with both ac and dc grid.

Fig. 7 shows the OFF condition where all the switches are in State 1; in this situation, there will be no power transfer. If there is any fault in one or multiple phases in the motor the converter configuration will be switched to State 1 as shown in Fig. 8, and there will be no power transfer between the grid and the battery. The usual protection schemes for a traction inverter will take in Fig. 8 is the typical traction machine operation which is used in the motor drives of electric and hybrid vehicles.

The voltage that appears across the motor inductances is dependent on the inverter dc bus voltage, amount of motor inductance, motor back EMF voltage, and the switching frequency of the controller. The maximum current limit is within the thermal limit of the machine, and the ripple in current is dictated by the fixed inductance of the machine as the machine windings cannot be changed. The bus capacitor is selected to handle the voltage ripple and the appropriate switching frequency is selected beyond the acoustic range of frequencies.

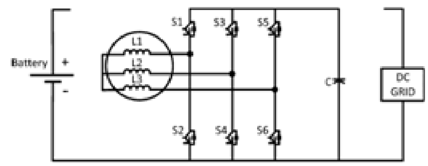

Fig. 7 Circuit with all switches in State 1

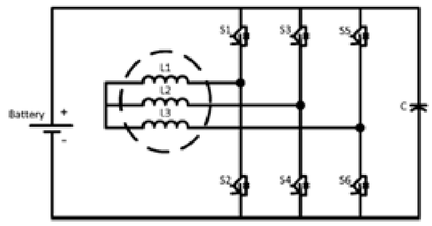

Fig.8 Circuit with Switch 1 is in State 2 for traction mode operation

Traction machines can be of induction, permanent magnet, or switched reluctance machine types. Inductance variations for permanent magnet synchronous and induction machines with respect to the position change are minimal. However, there are variations of the inductance value at different rotor positions for interior permanent magnet and switched reluctance machines.

With a dc grid, the rotor is not required to be locked as it will be aligned with the maximum inductance path. Consequently, the ripple will be lower. The current controller would act to compensate for the variations in the inductance and balance the phase currents. The difference in the current ripple between the phases could still be an issue, but is not expected to be a significant one.

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IV. SIMULATION RESULTS AND DISSCUSION:

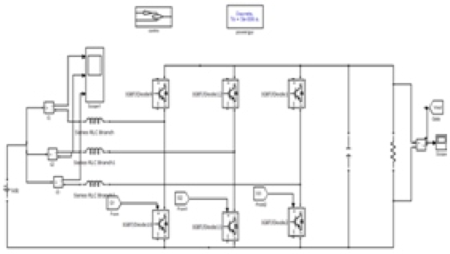

Fig.9 Matlab/Simulink model of proposed converter.

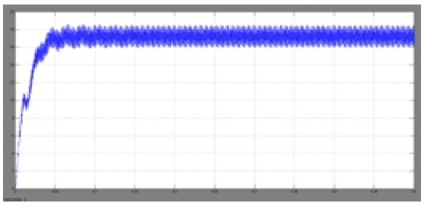

Fig.10 Simulated wave form of DC output voltage.

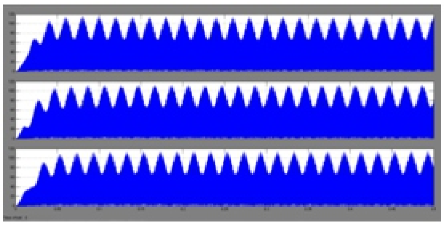

Fig.11 Phase currents in the three windings of the machine from coupled simulation.

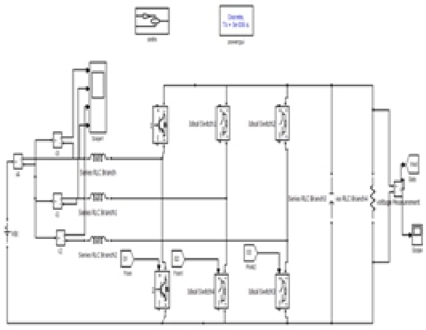

Fig.12 Integrated converter and induction machine operation with dc grid; V2G boost mode of operation.

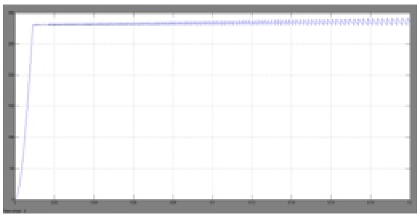

Fig.13 Simulated Output voltage of the integrated motor/converter: for boost operation.

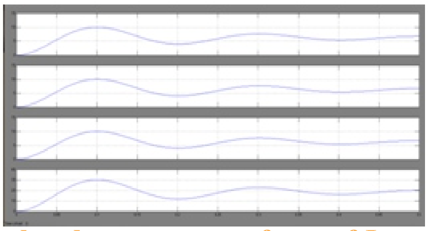

Fig.14 Simulated output wave form of Input current in boost mode of operation and shared input currents in the three-phase windings on the machine.

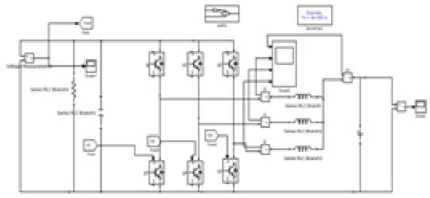

Fig.15 Integrated converter and induction machine operation with dc grid; V2G buck mode of operation.

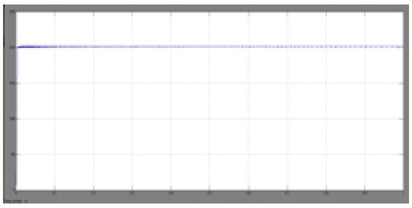

Fig.16 Simulated Output voltage of the integrated motor/converter: for buck operation.

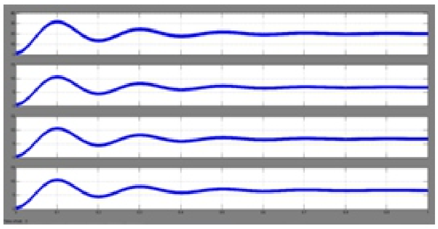

Fig.17 Simulated Output current wave forms in buck mode of operation and shared output currents in the three-phase windings on the machine.

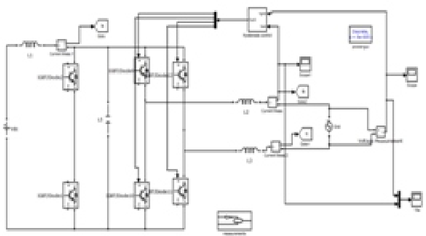

Fig.18 Power flow between the battery and an ac grid: from battery to ac grid (Mode 4).

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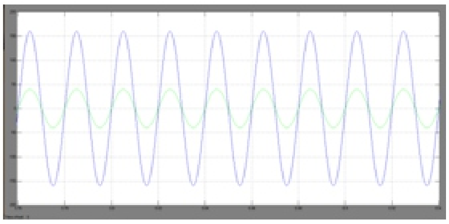

Fig.19 Simulated output wave form of grid voltage and grid current in mode 4.

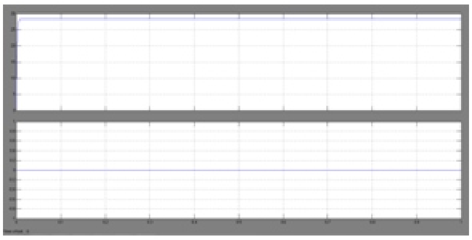

Fig.20 Simulated command id and iq currents of Mode 4.

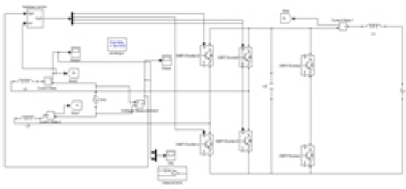

Fig.21 Power flow from ac grid to battery (Mode 5)

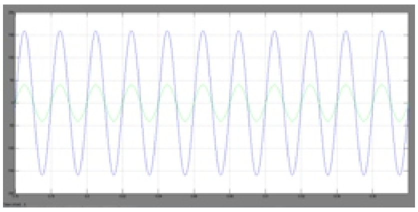

Fig.22 Simulated output wave form of grid voltage and grid current in mode 5

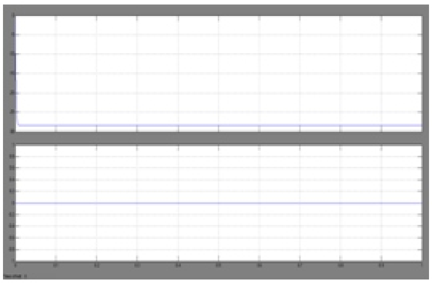

Fig.23 Simulated command id and iq currents of Mode 5.

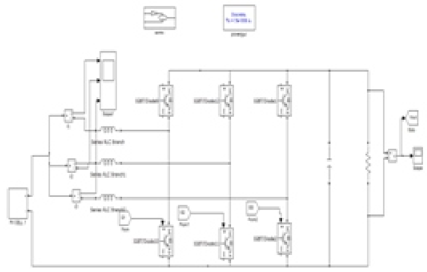

Fig.24 Matlab/Simulink model of proposed converter with PV

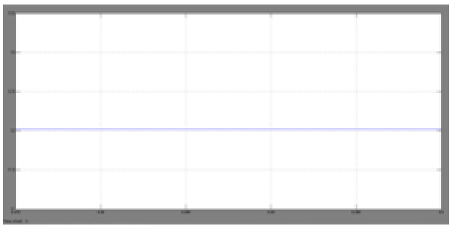

Fig.25 Simulated output voltage wave form of the Pv cell.

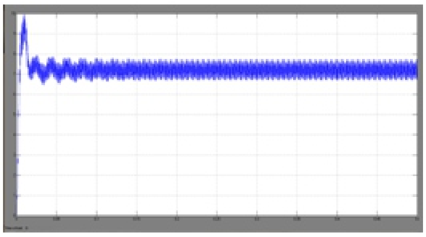

Fig.26 Simulated wave form of DC output voltage.

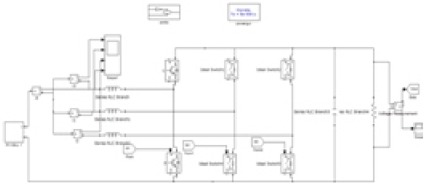

Fig.27 Pv based Integrated converter and induction machine operation with dc grid; V2G boost mode of operatio

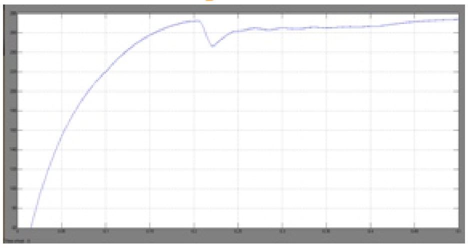

Fig.28 Simulated Output voltage of the pv based integrated motor/converter: for boost operation

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V.CONCLUSION:

The proposed converter is operated in described four modes of operation and PV as input source and load as induction motor drive. The main aim of this concept to check the performance of the induction motor drive by using RES it can work either as a DC-DC converter or as a inverter. The same converter is also given with PV input and the results are analyzed. The converter reconfiguration concept is useful in minimizing the size and parts in the power train of an electric vehicle. The converter performance can be analyzed by using MATLAB/SIMULINK software.

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