Vehicle to Grid Technology (V2G) For the Application of Electric Traction

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Abstract: **A grid connected PV system with batteries as the energy storage element for application to electric train has been proposed in this paper. Battery packs and PV arrays are cascaded together to the utility through a bidirectional dc converter and boost converter. The PV module terminal voltage is regulated by a switched dc-dc step up boost converter, which uses the Incremental Conductance algorithm to track the maximum power point (MPP).A bidirectional DC/DC converter efficiently regulates flow of power between battery and grid. Bidirectional Inverter provides supporting grid functions which enhances grid stability. Simulation of the proposed system is performed in MATLAB/SIMULINK and the results are found to be satisfactory.**

Index terms: **Solar PV, Grid integration, Electric traction, Maximum power point tracking (MPPT)**

I. INTRODUCTION

Vehicle-to-Grid (V2G) technology was developed to tackle the problem of ever increasing carbon emission levels from transport and power generation sector. The general term of sending active power from a vehicle to a grid is called V2G. Grid Enabled or Plug in Hybrid Electric Vehicles (PHEV) save around 700 $ on annual fuel consumption when compared with vehicles with internal combustion engines [1].

A massive energy reserve and the possible potential of integrating EV batteries to the grid have unleashed its economic benefits and therefore research in this field has accelerated in the last decade [2].Optimal power flow management strategies in PHEVs to increase efficiency has been formulated by many researchers in [3-13].Energy Storage Systems are playing a huge role in maintaining the grid stability and reliability through integration of solar powered electric vehicles into the grid i.e. the V2G technology.

Batteries and Ultra capacitors (UCs) are some popular storage systems. Batteries have low output power density and can store large quantity of power (100 Wh/kg) but cannot provide large amounts of power within a short time. On the other hand, ultra capacitors have low storage potential (1 Wh/kg) but can provide large bursts of power within a short span of time. Different configurations of UCs and batteries are presented in [14-18].

Partial shading of a solar photovoltaic power plant leads to a deficit in the power availability which can be compensated by fast reacting energy storage systems such as Batteries, Ultra capacitors etc. Auxiliary Diesel Generators have response time of the magnitude of 10 seconds or more which is not fast enough to counter the variation of renewable energy systems. In [19], electric vehicles and PV module interact with the grid to cause a three way power flow between the grid, PV array and the electric vehicle. Such hybrid systems are able to cope up with the fluctuating power demand rapidly and enhance grid flexibility.

Vehicle to grid technology describes a system in which plug-in electrical vehicles or hydrogen fuel cell electric vehicles communicate with the power grid to sell demand response services by either returning electricity to the grid. This enable the usage og electric vehicles as distributed storage devices. The stored power can be utilized to feed the electrical system during periods of peak demand or for use in homes and offices. On average, the vehicles are parked for 95 percent of the time, allowing the usage of batteries as a V2G supply.

II. SYSTEM OVERVIEW

Figure 1 depicts the proposed topology consists of energy storage system in the form of batteries onboard the electric train combined with the DC/DC bidirectional chargers which integrates it to the PV system. DC/DC converter serves the purpose of controlling the terminal voltage of PV array for carrying out Maximum Power Point Tracking (MPPT) operation. Incremental Conductance algorithm is utilized as the MPPT method.

The DC/AC inverter and the DC/DC converter of boost type manage the power flow between PV array, battery, load and utility. In the case of enough solar insolation, the DC/DC converter charges the battery and PV arrays supply power to the load through DC/AC inverter.

In the case of non-insolation or less insolation, the stored energy in battery should be delivered to load through Boost DC/DC converter and bidirectional DC/AC inverter. Therefore, the switch mode DC/DC Step Up converter must be able to conduct bidirectionally in order to charge and discharge the battery [20].

A high voltage DC bus acts as a point for integration of bidirectional dc–dc train chargers, hence efficiently utilizing the already existing inverter setup for integration with the grid. The proposed architecture augments dc charging capability which becomes fast and highly efficient as it consumes power directly from the PV module or the power grid.

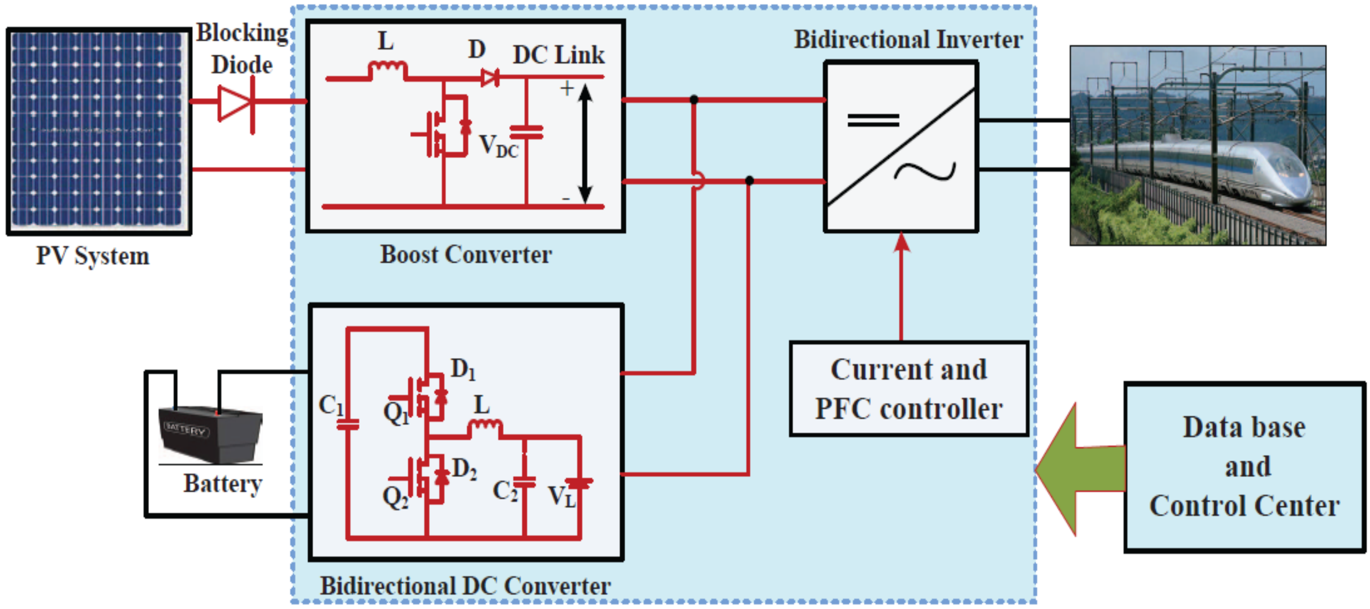


Figure 1 Block Diagram of Proposed System

Employing the same DC/AC bidirectional inverter for both charger and PV functions reduces hardware cost. Efficient delivery of real power to the grid at unity power factor is the primary function of the grid-tied PV inverters. The prime function of grid-tied PV DC-AC inverters is to deliver real power to the grid as efficiently as possible at unity power factor [21]. As mentioned in [22] and [23], however, the extra remaining capacity of the bidirectional inverter can be utilized to provide additional grid supporting functions such as generation of reactive power and fast compensation of flicker.

A. BIDIRECTIONAL DC/DC CONVERTER

Bidirectional DC/DC Converter is capable of transferring energy bi-directionally between two dc buses. These were traditionally used in dc motor drives. Recent applications include energy storage systems in fuel cell energy systems, uninterruptible power supplies (UPS) and PHEVs. It shows excellent control characteristics in all the operating modes. In order to provide a continuous and smooth power flow to the utility in a fluctuating natured renewable energy based system, energy storage coupled with dc converter with bidirectional power flow capability compensates this power fluctuation.

It should be highly efficient, reliable, and lightweight and compact in size in order to meet the demands of the proposed application effectively. This converter possesses either a current fed or voltage fed structure. In the current type operation, it behaves as a current source, similar to a conventional dc-dc boost converter whereas in the voltage type operation it acts similar to a voltage source, imitating the characteristics similar to a buck converter installed at it input terminals.

B. DC/DC BOOST CONVERTER

A switched mode dc-dc boost converter is connected at the output terminal of the PV panel and operates in the MPPT mode to step up the voltage magnitude as desired. The DC link capacitor attached at the output of the boost converter regulates the output voltage and maintains it at a constant magnitude irrespective of the variation in the environmental temperature or solar irradiation levels.

C. DC/AC BIDIRECTIONAL INVERTER

A hysteresis current controlled Pulse Width Modulated Bidirectional H-bridge inverter has been utilized for this work. Hysteresis current control technique is implemented due to its simplistic implementation and robustness to parametric variations and uncertainties. The PWM Inverter provides the reactive power and the harmonics generated due to the non linear nature of the load/utility. The inverter injects current into the grid at unity power factor.

III. PROPOSED CONTROL ALGORITHM

In order to ensure power flow and balance in the grid, PV array and energy storage systems, three simple algorithms have been formulated based on conditions arising from different power levels of the grid, PV array and ESS.

Case I::If (PEV < PPV):

In this case, when the rooftop PV module is operated in this mode at MPPT, the power generated by the panel is greater than the power capacity of the battery installed in the electric train. Under such a scenario, the excess remnant power is supplied back to the grid via the bidirectional inverter using the hysteresis current control. The reference current for tracking by the hysteresis control is calculated as:

PEX=PPV-PEV (1)
IREF=PEX/VGRID (2)

The controller operates as a hysteresis current controller. The grid current tracks the reference current within a fixed band. This current control technique is simple to implement and provides fast dynamic response in order to keep up with the fast changing reference current imposed due to external disturbance or consumer demand. Another major advantage of hysteresis current control is the degree of robustness it exhibits against uncertain parametric variations. Fixed band hysteresis current control is carried out in this mode of operation.

In the grid connected mode, the bidirectional inverter functions as a buck converter. The state space average model has been presented in [24]. It has the following form:

$$\frac{di}{dt} = -\left(\frac{R_O R_L + R_O R_C + R_C R_L}{L_f(R_O + R_C)}\right)i - \frac{1}{L_f}\left(\frac{R_O}{R_O + R_C}\right)v + \frac{v_s d}{L_f}$$

$$\frac{dv}{dt} = \frac{1}{C_f}\left(\frac{R_O}{R_O + R_C}\right)i - \frac{1}{C_f}\left(\frac{1}{R_O + R_C}\right)v$$

$$v_o = \left(\frac{R_O R_C}{R_O + R_C}\right)i + \left(\frac{R_O}{R_O + R_C}\right)v$$

where,

*R*O is the load resistance, *R*C is the parasitic resistance of the buck capacitor, *L*f is the buck inductor, *C*f is the buck capacitor, *R*L is the parasitic resistance of the buck inductor, *v*s is the source voltage and *i*s is the source current and *v*o is the output voltage, *d* is the duty cycle.

Case II::If (*PPV* < *PEV*):

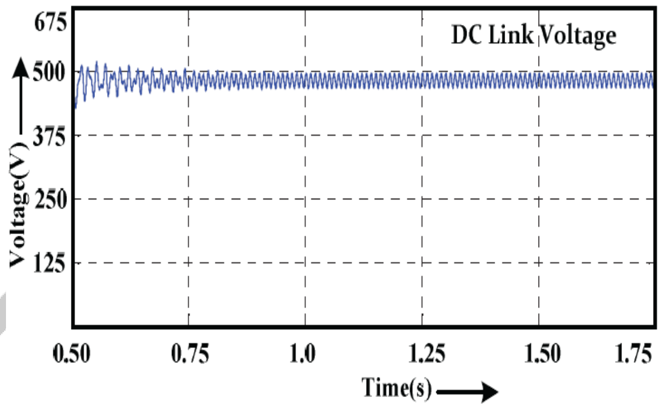
In this case, the excess demand of the dc loads installed in the electric train is supplied from the grid. The MOSFET switches of the inverter gets turned off and the current is rectified by the diodes connected in antiparallel to the MOSFET switches. DC current which is obtained is fed to the battery in the train, thereby charging it through the bidirectional dc/dc converter to suffice the power requirements as demanded. A power factor correction controller ensures that the source power factor is maintained. The raw data for is acquired from the Data and Control Center which specifies the particular requirements of the system, which is expected of the Hysteresis and PFC controller. It was mentioned in [24], that a bidirectional inverter acts as a boost converter when operating in the PFC mode. The state space model derived from the equivalent circuit is mentioned below:

$$\frac{di}{dt} = -\left(\frac{R_L + (1-d)\dfrac{R_O R_C}{R_O + R_C}}{L_f}\right) i - \left(\frac{(1-d)R_O}{L_f (R_O + R_C)}\right) v + \frac{v_s}{L_f}$$

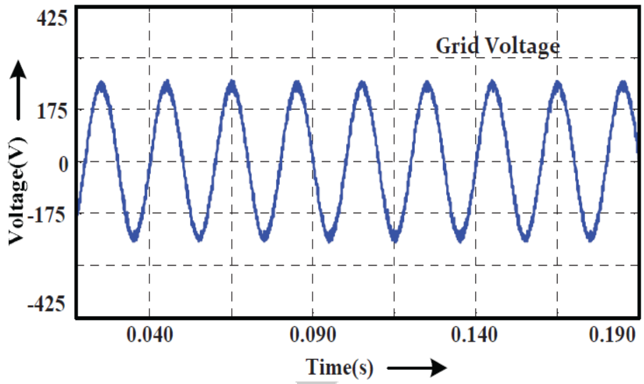
$$\frac{dv}{dt} = \left(\frac{(1-d)R_O}{C_f (R_O + R_C)}\right) i - \left(\frac{1}{C_f (R_O + R_C)}\right) v$$

$$V_o = (1-d)\left(\frac{R_O R_C}{R_O + R_C}\right) i + \left(\frac{R_O}{R_O + R_C}\right) v$$

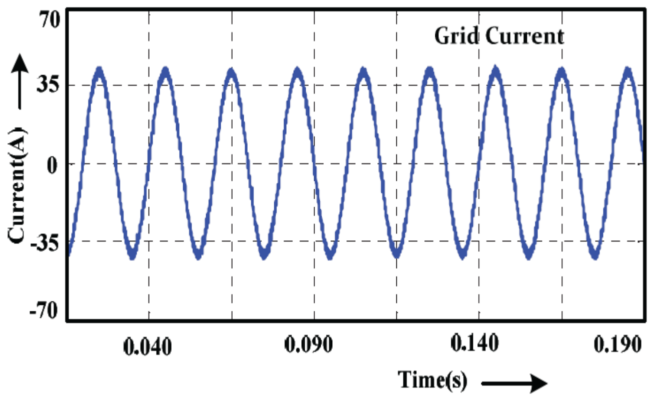
IV.SIMULATION RESULTS



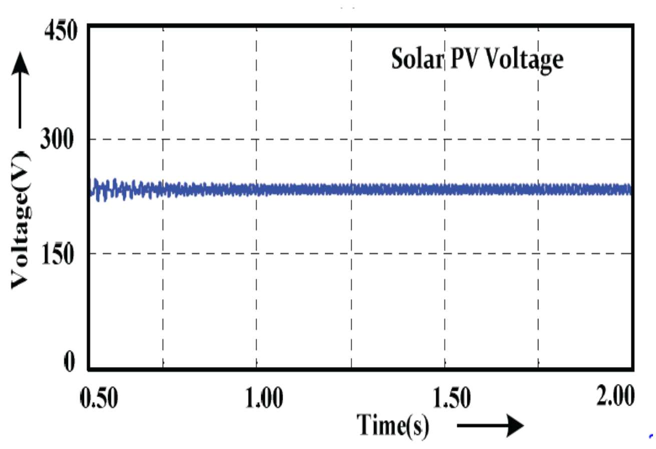
(a)



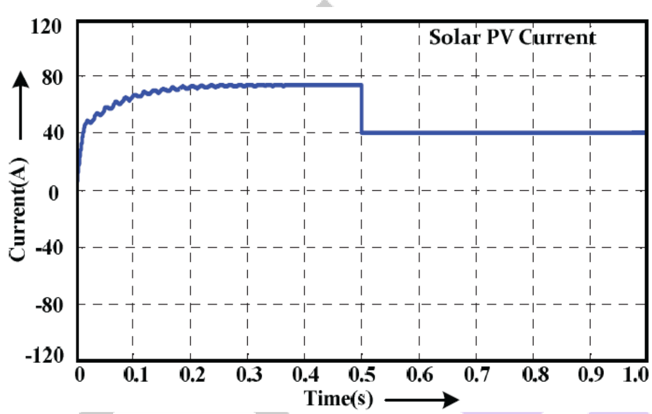
(b)



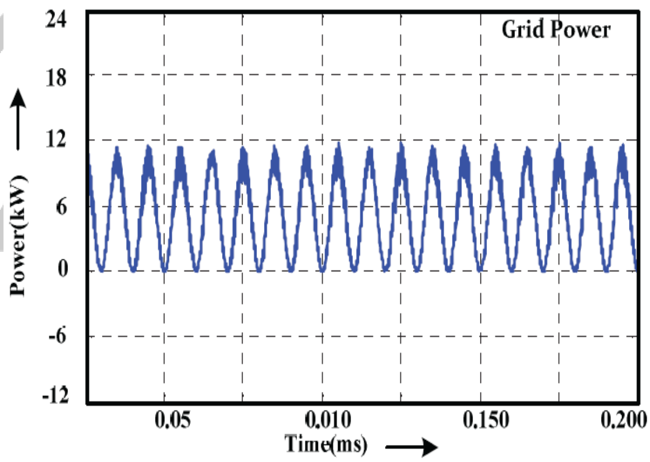
(c)


Solar PV Voltage
Voltage(V)
450
300
150
0
0.50
1.00
1.50
2.00
Time(s)

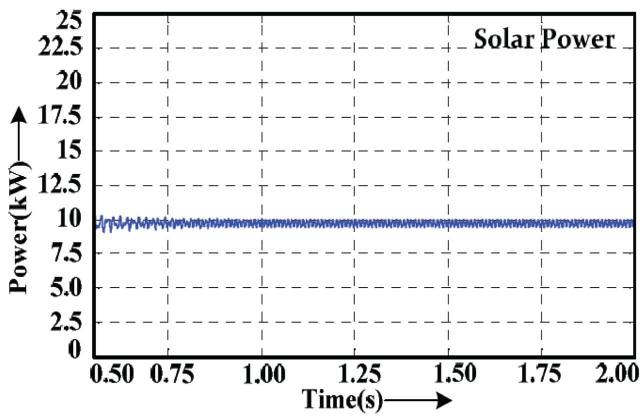
(d)


Solar PV Current
Current(A)
120
80
40
0
-40
-80
-120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Time(s)

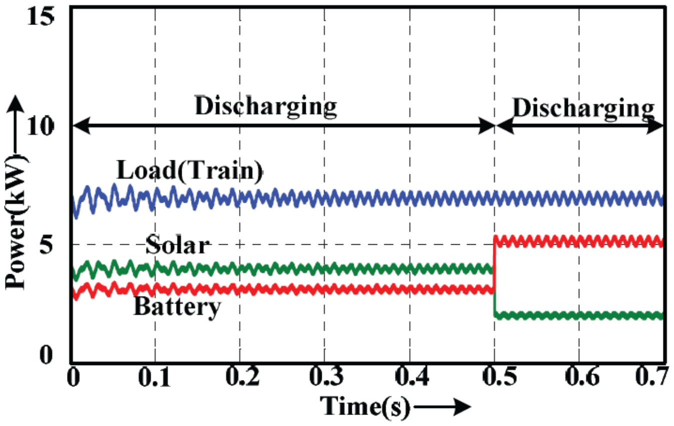
(e)


Grid Power
Power(kW)
24
18
12
6
0
-6
-12
0.05
0.010
0.150
0.200
Time(ms)

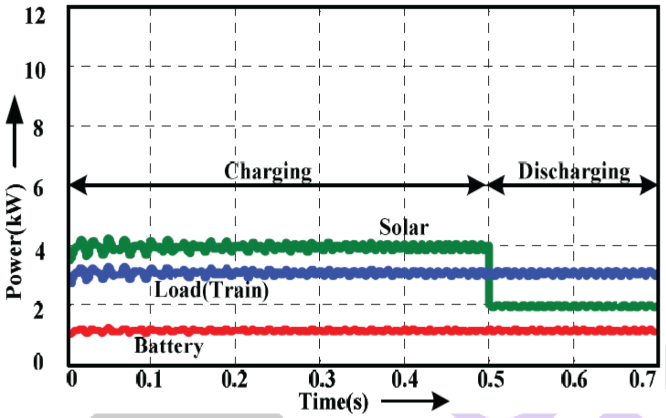
(f)


Solar Power
Power(kW)
25
22.5
20
17.5
15
12.5
10
7.5
5.0
2.5
0
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Time(s)

(g)



(h)



(i)

TABLE I

SIMULATION SET UP PARAMETERS

Parameter	Values
Bidirectional Switching	10 kHz
Boost Switching Frequency	10 kHz
Battery Voltage	12Vx110Ah (20
Solar PV Power	10 kW
DC Link Capacitor	1500 µF
Boost Inductor	100 mH
Inverter Output Voltage	25 kV
Bidirectional inductor	5 mH
Bidirectional capacitor	200 µF

The proposed system was modeled using Matlab/Simulink. In order to model the inductor and capacitor efficiently, the power, voltage and current levels of the simulated system are scaled down to 100 times the actual system. The AC supply to the railway network is in the range of 20-25 kV In Fig.(a), the DC Link voltage successfully tracks the reference voltage of 490 Volt at t=0.75 sec after the solar irradiance level is changed from 1600 W/m2 to 800 W/m2 at t=0.50 sec. Fast recovery of the nominal set point with acceptable steady state ripple is observed. Fig.(b) shows the perfect sinusoidal waveform of grid current with peak value of 36A. Hysteresis current controller is able to minimize the deviation of the grid current with the reference current which further signifies the superiority of this technique.

Similarly the grid voltage is in phase with the grid current having a maximum peak of 250V in Fig.(c). Fig.(d) shows the MPPT voltage of the PV module which is equal to 255 V. The steady state after the change in insolation level is shownin the same. The solar PV current reaches 40A after the variation in the solar irradiance as evident from fig.(e). Fig.(f) and (g) shows the waveforms of grid power and Solar PV power.

The dynamic performance of the proposed system is tested in fig.(h) and (i) where solar PV power is changed at t=0.5 sec due to transition in irradiation level In the situation when $PPV<PLOAD$, battery discharges thereby supplying the remaining load power. The load demand is 7 kW out of which solar PV provides 4 kW and battery gives power output equal to 3 kW. In another operating

mode, when PPV > PLOAD, the electric train load is 3 kW whereas the solar PV provides 4 kW. The battery charges during this duration until solar PV power drops to 2 kW. At this instant, battery starts to discharge and provides the extra 1 kW.

V. CONCLUSION

A grid connected PV system coupled with energy storing batteries with application to Electric train is presented in this paper. Hysteresis control is used as the current control technique which allows interfacing with the grid through the DC link. Easy implementation and reduction on the hardware costs are some of its benefits. Application to transportation network, especially the railways will lessen the power demands from the grid and is more economical in the long run.

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