Smart Grid Environment, On Board Charging Interface for Vehicle to Grid (V2G)

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Abstract **—**The developments in the power grid and advancements in vehicle technology made Vehicle to Grid (V2G) a reality. The concept of connecting a group of electric vehicles (EV) to the grid for power transaction is called V2G. *Vehicle to Grid is* used for peak shaving, valley filling, meet the time varying load demand and helps in maintaining grid stability for a shorter duration of time. electric vehicles need a bidirectional charger to either draw or inject power to the grid. In this abstract On board charging for V2G in Smart Grid environment is proposed. In this abstract an architectural framework of On-board V2G Integrator is proposed. A single-phase on-board charger with low complexity control scheme is presented for EV power transaction. The system designed for voltage rating of 230V and the simulations is carried out in MATLAB/SIMULINK and obtained results comply with IEEE 1547 standard.

Key words- On board charger, EV, V2G, Smart Grid

I. INTRODUCTION

The concept of connecting a group of electric vehicles (EV) to the grid for power transaction is called Vehicle to Grid (V2G). V2G plays a prominent role in fulfilling the grid requirements and meet the load demand. EVs also support the ancillary services like load leveling, voltage regulation, frequency regulation and balancing. EVs need a bidirectional charger to sell or buy power from the grid. Farther the bidirectional charger has the direct current (DC) link capacitor which is inherently able to provide the reactive power to support the power grid. The state of charge (SOC) of the EV battery plays a key role in V2G operation and promotes the concept of Vehicle-to-Home (V2H), Vehicle-to-Vehicle (V2V) and V2G (Liu et al., 2013; Pinto et al, 2014). The architectural and conceptual framework of V2G is shown in Fig. 1. The EV can be connected to the home grid or other interface using the On-Board or Off-Board bidirectional charger or V2G integrators. In this abstract an architectural framework of On-board V2G integrator is proposed. A single-phase on-board charger with low complexity control scheme is presented for EV power transaction. The system designed is also suitable for V2H as the charger considered is designed for voltage rating of 230 V. The DC-AC bidirectional converter is made to operate at unity power factor injecting or drawing the grid current with low harmonic distortion. The control scheme employed consists of a PR controller for grid current control as an alternative to the widely used PI controller for both V2G and G2V operation (Teodorescuet al, 2006). The low gain of PI controller at grid frequency leads to steady state error and also the limited bandwidth hinders the response time. The DC-DC converter employed has both the capability of stepping up (boost) the

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DC link voltage during V2G operation and stepping down (buck) the DC link voltage during G2V operation in comparison to battery voltage.

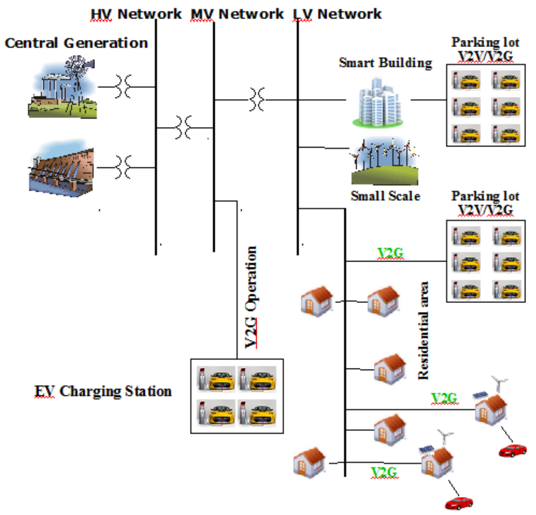

Fig.1. Conceptual framework of V2G

PROPOSED ON BOARD V2G INTEGRATOR

Fig.2 shows the topology diagram of the proposed system consisting of cascaded power converters. It consists of two power stages. The first stage is bidirectional DC-DC converter and the second stage is a bidirectional DC-AC converter. The direction of power flow is dictated by the operating mode. The active power flows from the batteries to the dc link and then to the grid during V2G mode of operation.

The power flow from and to the grid is processed using two stage cascaded converters consisting of a bidirectional DC-DC and DC-AC converters. The LCL filter is used as an interface between DC-AC converter and the grid to attenuate the grid current harmonics. A proportional-resonant (PR) controller is employed for the control of grid current and to enable the unity power factor operation of the DC-AC converter.

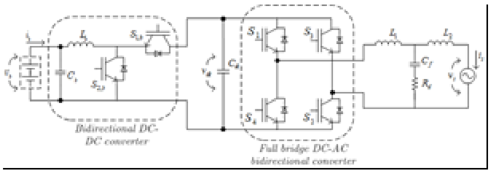

Fig.2.Topology of the proposed-on board charger

The setbacks associated with conventional proportional integral (PI) controller for single phase system is elevated by employing PR controller. The power electronic interface for the power transaction from V2G and G2V may involve one or more stages. Most of the EV chargers are of conductive type, where there is an electrical contact between the vehicle and the utility. Bidirectional converter topologies are to be used chargers for V2G operation. In addition to traction batteries the auxiliary battery used for lighting, wipers needs to be charged. A reconfigurable battery charger in which the auxiliary battery is charged by the main traction battery is proposed in (Yilmaz & Krein, 2013 ;Teodorescuet al, 2006).

III. VEHICLE TO GRID MODE OF OPERATION

In this mode of operation the DC-AC bidirectional converter injects the sinusoidal current into the grid in phase with the grid voltage. The reference current generated by the PI controller 1 is compared with the actual grid current and the error is processed through the PR controller. The DC-DC converter acts as a boost converter by stepping up the battery

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voltage and draws a constant current from the battery. The specification of the various parameters of the system and the controller parameters are shown in Table I and II respectively.

A. Three level bidirectional DC-AC converter control

In grid connected operation, the converter operates in a current controlled mode as the voltage across it is maintained by the infinite grid. Thus, for proper operation, synchronization with the grid voltage is mandatory. This is achieved using a phase locked loop (PLL) which generates an in phase component of the grid voltage and eliminates any harmonics present.

Table I. Specification of the Proposed On Board Charger

Parameter	*Value*	*Unit*
Grid voltage (RMS)	230	V
Grid frequency	50	Hz
Maximum input current (RMS)	35	A
Maximum input power	8	KVA
Output voltage range (DC)	190-270	V
Maximum output current (DC)	30	A
Inductor L_1	0.3	mH
Inductor L_2	0.5	mH
Capacitor C_f	2	μF
Capacitor C_b	800	μF
Capacitor C_{dc}	1000	μF
Switching frequency of DC-AC converter	10	kHz
Switching frequency of DC-DC converter	25	kHz

Table II. Parameters of various controllers

	K_P	K_I
PI controller 1	0.3	2
PI controller 2	0.75	5
PR controller	3	10000

An LCL filter acting as an interface between the DC-AC converter and the grid reduces the harmonic distortion in the grid current being injected. As the filter is of order three, the amount of attenuation provided over high frequency range is more even with a smaller value of passive components. However the filter poses a significant problem due to its low or zero impedance at the resonant frequencies makes the design of current controller complicated. A general approach to damp the resonance oscillations is to add a damping resistor in series with the filter capacitor. Even though the method seems to be effective in stabilizing the overall filter characteristics, it suffers from the increased power loss.

As an alternative to passive damping, approach to introduce the same effect using feedback of the parameters which can serve as a damping term known as active damping. For an application with a stiff grid, a passive damping method is often preferred for its simplicity and low cost. The control of DC-AC converter is achieved through two loops with outer loop as voltage control loop and with inner loop as a current control loop. Various controllers like stationary frame control, dq frame control and abc frame controllers are employed to maintain the grid current to be sinusoidal with lower harmonic distortion. In this abstract a proportional resonant (PR) compensator is used to track a sinusoidal current reference signal with zero steady state error as the controller introduces an infinite gain theoretically at the grid frequency.

$$I_g(s) = G_p(s)\left(\frac{s^2 L_1 C_d + sC_d R_d + 1}{sC_d R_d + 1} V_g - V_{inv}\right) \tag{1}$$

AS, the magnitude and phase response of $\frac{s^2 L_1 C_d + sC_d R_d + 1}{sC_d R_d + 1}$ are 0 dB and 0o at the fundamental frequency of the grid. Therefore, equation (1) can be simplified to the equation

$$I_g(s) = G_c(s)\left(V_{inv} - V_g\right) \tag{2}$$

The relationship between the input and the output of the current loop can be derived as

$$I_g(s) = H_1(s) \cdot I_g^*(s) + H_2(s) \cdot V_g(s) \tag{3}$$

To successfully track the $i_g^*(t)$ signal without steady state errors, the magnitude of $H_1(j\omega)$ has to be equal to 1 at the fundamental frequency of $i_g^*(t)$. Thus, it is clear that if $G_c(j\omega)$ has infinite gain at fundamental frequency, $H_1(j\omega)$ would have a unity gain. The control structure of a PR controller is given in equation (4).

$$G_c(s) = K_p + \frac{K_i \cdot 2 \cdot \xi \cdot \omega_o \cdot s}{s^2 + 2 \cdot \xi \cdot \omega_o \cdot s + \omega_0^2} \tag{4}$$

where $\omega_o = 2\pi f_o$, K_i is the fundamental harmonic gain, and ξ is the damping factor.

The control block diagram of the bidirectional DC-AC & DC-DC converter is shown in Fig.3.The gain of around 82 dB at the grid frequency (50 Hz) leads to zero steady state error in tracking of the reference current generated. The converter DC link voltage should be greater than the peak value of the grid voltage, so that the power can be transferred from EVs to the grid. Assuming that the sinusoid current is being pumped into the grid, the DC link voltage will have a second harmonic component. This leads to control system instability if it is not filtered out before using for control purpose. Thus, band stop filter (BSF) is used to remove 100 Hz component in Vdc. The unipolar pulse width modulation scheme is employed for gating the power switches.

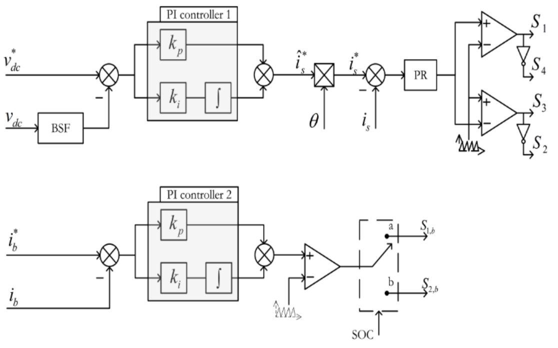

Fig.3. Control block diagram of the bidirectional DC-AC & DC-DC converter.

B. *Bidirectional DC-DC Converter Control*

The DC link voltage is maintained constant by the DC-AC converter and the DC-DC converter acts as a buck converter during this mode (G2V). As per the recommendation by the EV manufacturer generally a constant current charging is done first till the battery voltage reaches the recommended maximum value and then followed by a constant voltage charging. A proportional integral controller (PI) is used for regulating both the DC link voltage and the current (charging/discharging) current from the EV battery.

IV. RESULTS AND DISCUSSION

To demonstrate and validate the feasibility of on-board Integrator, simulation was carried out using MATLAB/SIMULINK. Fig. 4, Fig.5 and Fig.6 show the regulated DC link voltage, battery voltage and the battery current during V2G operation. The bidirectional DC-DC converter acts as a boost converter during this mode. Fig.4 shows the grid voltage and the sinusoidal current being injected to the grid. It can be seen that the current injected is in phase with the grid voltage ensuring the unity power factor operation. The battery is supplied with a constant active power (P = 6 kW) and zero reactive power (Q = 0) as shown in Fig.5. The harmonic level in the grid current being drawn is found to be 2%. The harmonic spectrum of the grid current is shown in Fig.6.

VI. CONCLUSION

A low complexity on-board charger for EVs has been presented. The proposed system allows the integration of EV battery to the grid through power processing stages. The power flows from vehicle battery to grid during V2G mode of operation. The grid current being injected/absorbed is maintained to have a power factor of unity and low harmonic distortion. Design details of the current controller are discussed and simulation results are presented. Simulation is carried out using the MATLAB / SIMULINK platform and the result showing the harmonic analysis of the grid current is found to be within the prescribed power quality limits of IEEE.

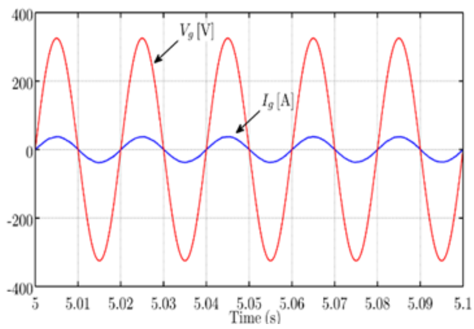

Fig.4. Grid voltage and current

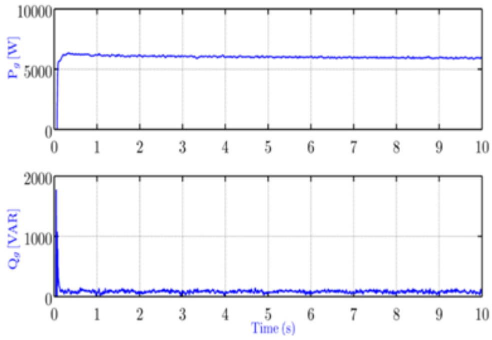

Fig.5. Active and reactive power

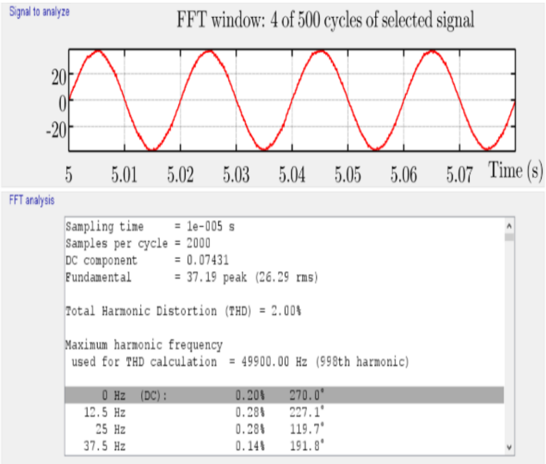

Fig.6. Harmonic spectrum of grid current (2% THD).

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