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Electric Vehicle to Grid Integration

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Abstract: Electric Vehicle will be a necessity in several years because of the increase in prices of crude oil due to shortage. The energy storage will play a major role in day to day life which can be done using some techniques, smart grids, efficient components such as batteries and ultra capacitors or using renewable energy. This paper focuses on the various aspects of vehicle to grid integration. These include charging a battery to its discharging. The report shares the various topologies used in the power flow.

Keywords: V2G Integration, LCL filter, SOC, control methods, Proportional Integral control (PI),Total harmonic Distortion, Electric vehicle, SOH.

I. INTRODUCTION

Battery vehicles store energy electrochemically in the batteries, with lead-acid currently cheapest but with Nickel Metal-Hydride (NiMH), lithium-ion, and lithium-metal polymer batteries becoming more competitive due to longer cycle life, smaller size and lower weight. Operationally, they plug in to charge their batteries and unplug to drive. Battery vehicles must have grid connections for charging, so the incremental costs and operational adjustments to add V2G are minimal. Because of the increased duty cycle, electric-vehicle batteries can deliver 85% of their charge without damaging the batteries or shortening their useful life. The emergence and implementation of advanced smart grid technologies will enable enhanced utilization of Electric Vehicles (EVs) as mobile energy storage devices which can provide system-wide services. With significant penetration of EVs in the near future, the concept, introduced in literature as Vehicle to Grid (V2G), will be practically possible. The V2G[1] concept eases the integration of renewable energy into power system and gives new force to inevitable move toward power generation by clean energy resources. Therefore utilizing energy storage in EVs is undeniable due to economic and environment benefits

A. 1.1 V2G INTEGRATION

Conventional thinking is based on the idea that EVs would be connected to the grid for charging during the evening until next day morning hours. This point of view lacks a significant proposition that is made possible by the fact that vehicles are parked over 90 percent of the time. If these distributed energy resources are connected to the grid, it could be used to provide possible grid services as V2G system.

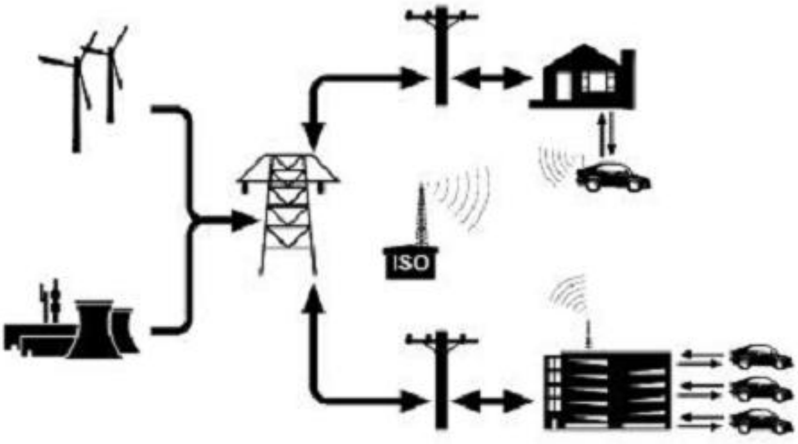

Figure 1.1

Electricity is grouped in several different markets with correspondingly different control regimes. Here we discuss four of them —base load power, peak power, spinning reserves, and regulation — which differ in control method, response time, duration of the power dispatch, contract terms, and price. It is not realistic for electric vehicles to afford base load power because the cost per kWh of electric energy is high and the operation time is limited. While the economic value of other three services is high and can compensate some of the high initial invest. The combination of spinning reserves and regulation reserves is called “ancillary service”. [2].

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A. Peak power

Peak power is typically generated by power plants that can be switched on for short periods. Since peak power is typically needed only a few hundred hours per year, it is economically sensible to draw on generators that are low in capital cost, even if each kWh generated is more expensive. V2G peak power may be appropriate for this purpose. The required duration of peaking units can be 3–5 h, which for V2G is possible but difficult due to on-board storage limitations. Vehicles could overcome this energy -storage limit if the vehicles are aggregated, or if there were refuelling. Electric vehicles can afford power in peak period while consume power in off-peak period. This action can reduce the difference between the maximum and minimum of the power load.

1) B.Spinning reserves

Spinning reserves refers to additional generating capacity that can provide power quickly, generally within 10 min, upon request from the grid operator. Generators providing spinning reserves run at low or partial speed and thus are already synchronized to the grid. Spinning reserves are paid for by the amount of time they are available and ready. For example, a 1MW generator kept "spinning" and ready during a 24-h period would be sold as 1MW-day, even though no energy is actually produced. If the spinning reserve is called, the generator is paid an additional amount for the energy that is actually delivered. These arrangements are favourable for electric vehicles, since they are paid as "spinning" for many hours, just for being plugged in, while they 1014incur relatively short periods of generating power. Contracts for spinning reserves limit the number and duration of calls, with 20 calls per year and 1 hour per call typical maxima. This is feasible because they generally have more energy storage capacity and can be refuelled quickly for driving.

1) C. Regulation services

regulation is used to regulate the frequency of the grid by matching generation to load demand. Regulation must be under direct real-time control of the grid operator, with the generating unit capable of receiving signals from the grid operator's computer and responding within a minute or less by increasing or decreasing the output of the generator. Some markets split regulation into two elements: one for the ability to increase power generation from a baseline level, and the other to decrease from a baseline. These are commonly referred to as "regulation up" and "regulation down", respectively. Regulation is controlled automatically, by a direct connection from the grid operator. Compared to spinning reserves, it is called far more often (say 400 times per day), requires faster response (less than a minute), and is required to continue running for shorter durations (typically a few minutes at a time). D. Renewable energy storage and backup

The most important role for V2G may ultimately be in emerging power markets to support renewable energy. The two largest renewable sources likely to be widely used in the near future, photovoltaic (PV) and wind turbines are both intermittent. At low levels of penetration, the intermittency of renewable energy can be handled by existing mechanisms for managing load and supply fluctuations. However, as renewable energy exceeds 10–30% of the power supply, additional resources are needed to match the fluctuating supply to the already fluctuating load. Intermittency can be managed either by backup or storage. "Backup" refers to generators that can be turned on to provide power when the renewable source is insufficient. "Storage" has the advantage of additionally being able to absorb excess power, but adds the constraint that giving back power is duration-limited.

In V2G, the hybrid electric vehicles and fuel-cell electric vehicles can offer backup, battery electric vehicles and plug-in hybrid electric vehicles can offer storage

II. BATTERY CHARGING

A. 2.1 Batteries charging process

As previously commented, the load profile of the EVs batteries charging systems has high importance to the power grid management. Depending on the design of the electrical grid and the type of charging and discharging processes, EVs can be a problem or a benefit to the power grid. The batteries charging and discharging processes can be realized in two different ways: controlled and uncontrolled. In the controlled way, the batteries are charged or discharged in accordance to the capability and the needs of the power grid, and in accordance with the conveniences of the vehicle´s owner, which is the main figure in this process. In this scenario of real time control, several parameters should be taken into account, namely, energy price (to sell or to buy) and batteries State-of-Charge (SoC) and State-of-Health (SoH - reflects the batteries degradation along their lifetime). Various autonomous distributed V2G control scheme had been proposed, and also a coordinated charging scheme for multiple PHEVs had been presented for a residential distribution grid. In the uncontrolled way, as the name suggests, there is no control over the charging system. The only control that exists from the moment in which the vehicle is plugged to the end of the process, is the decision if the process of charging or discharging can start immediately or after a fixed time delay (controlled by the vehicle´s owner in accordance with his convenience). Since there is no control over the charging systems, peaks of power consumption can occur in the electrical power grid, during some periods in which exist a large number of EVs simultaneously charging their batteries. These power peaks can bring overload problems to the power grid. Similar problems can occur when the energy stored in the batteries is delivered back to the electrical power grid. Despite these problems, nowadays, the uncontrolled way is the most common charging procedure. As predicted in, the smart charging (in controlled way) will be a necessity in midterm, in order to prevent a large demand of energy peaks over the power grid.

The batteries charging systems can be of two types: public chargers and residential chargers. Public chargers are an optimal solution to charge the batteries of the vehicles using energy from several sources of energy (as wind or sun) and can be deployed at strategic places around a town or city, like for example, at companies, public buildings and shopping centers parking lots. On the other hand, residential chargers are designed to deliver low power, in an efficient way, since in general they are used to make a complete charge of the batteries during long periods of time (slow charging). The main benefits of these two types of chargers are the comfort for the user, and the freedom of the user to charge the batteries whenever he wants, according with the best prices of energy. The main disadvantage is that, since each charging process is independent, the limit of overload of the electrical power grid can be easily reached.

Some vehicles allow the charge of their batteries with off-board batteries charging systems, like public charging stations, but almost every vehicle is equipped with its own on-board batteries charging systems. This charging system is an AC-DC power circuit that must be controlled in order to respect the vehicles batteries nominal characteristics to preserve their lifespan. Additionally, it should monitor the batteries during their operation to prevent damages during the charging or discharging processes. The AC-DC power circuit can be implemented with different topologies according to the characteristics desired for the system. Figure 3 illustrates graphically the main categories in which can be divided the different topologies of the batteries charging systems for EVs.

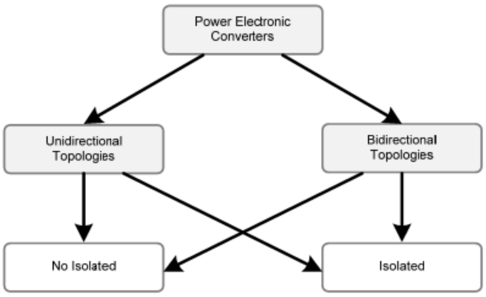


Figure 2.1

B. 2.2 Power electronics circuits topologies:

Typically, the power electronics circuit topology of batteries charging systems is formed by two power electronics converters: an AC-DC converter followed by a DC-DC converter. Both power converters can have different topologies and can be arranged together in different ways, with and without isolation between them. The AC-DC converter is used to rectify the AC voltage from de power grid to a DC voltage. The DC-DC converter is used to adapt the rectified voltage to a level of voltage compatible with the batteries' voltage and Batteries Charging Systems for Electric and Plug-In Hybrid Electric Vehicles. In Figure 4 is shown the main AC-DC power converters topologies used to rectify the power grid AC voltage, and in Figure 5 is shown the main DC-DC power converters topologies used to control the batteries charging and discharging processes.

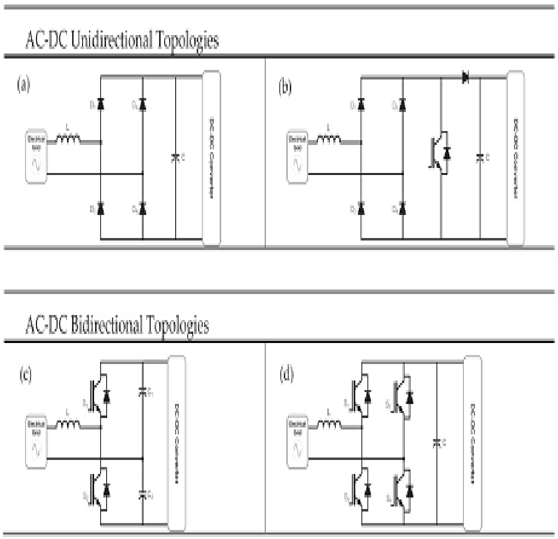


Figure 2.2.1

(a) Unidirectional full bridge uncontrolled converter.(b) Unidirectional full bridge uncontrolled converter with boost converter. (c) Bidirectional half-bridge full-controlled converter.(d) Bidirectional full-bridge full-controlled converter.

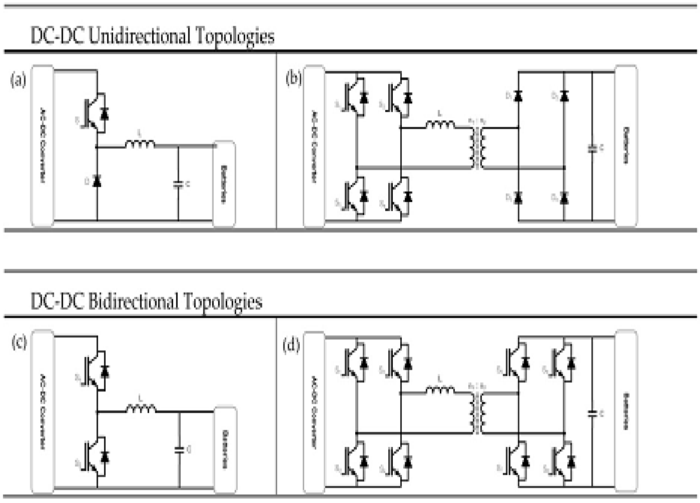


Figure 2.2

(a) dc-dc buck converter (b) unidirectional isolated converter (c) bidirectional buck boost converter (d) bidirectional isolated converter

2.3 CHARGING METHODS

Charging method	**Nominal supply voltage**	**Maximum current**	**Branch circuit breaker rating**	**Continuous input power**
AC Level 1	120 V, 1-phase	12 A	15 A	1.44 kW
AC Level 2	208 to 240 V, 1-phase	32 A	40 A	6.66 to 7.68 kW
AC Level 3	208 to 600 V, 3-phase	400 A	As required	> 7.68 kW
DC charging	600 V maximum	400 A	As required	<240 kW

Table 2.1

1) AC Level 1 Charging

AC Level 1 provides charging through a 120 volt (V) AC plug and requires electrical installation. Most, if not all, PEVs will come with an AC Level 1 cord set so that no additional charging equipment is required. On one end of the cord is a standard, three-prong household plug (NEMA 5-15 connector). On the other end is a J1772 standard connector (a connector basically used for charging the Electric vehicles), which plugs into the vehicle.AC Level 1 is typically used for charging when there is only a 120 V outlet available. Based on the battery type and vehicle, AC Level 1 charging adds about 2 to 5 miles of range to a PEV per hour of charging time.

2) AC Level 2 Charging

AC Level 2 equipment (often referred to simply as Level 2) offers charging through 240 V (typical in residential applications) or 208 V (typical in commercial applications) electrical service. AC Level 2 EVSE requires installation of home charging or public charging equipment and a dedicated circuit of 20 to 100 amps, depending upon the requirements. This charging option can operate at up to 80 amperes and 19.2 kW. However, most residential AC Level 2 will operate at lower power. Many such units operate at up to 32 amperes, delivering 7.2 kW of power. These units require a dedicated 40 amp circuit.

Most homes have 240 V service available, and because AC Level 2 can charge a typical EV battery overnight, this will be a common installation for homes. AC Level 2 equipment uses the same connector on the vehicle that Level 1 equipment uses. Based on the vehicle and circuit capacity, AC Level 2 adds about 10 to 20 miles of range per hour of charging time.

3) DC Fast Charging

Direct-current (DC) fast charging equipment, sometimes called DC Level 2 (typically 480 V AC input), enables rapid charging along heavy traffic corridors and at public stations. A DC fast charge can add 60 to 80 miles of range to a light-duty PHEV or EV in 20 minutes.

4) Inductive Charging

First, a power supply will produce high frequency alternating currents in the transmitter pad or coil that inductively transfer power to the receiver coil. After receiving the high frequency power via induction, the receiver electronics then converts it to DC,which is suitable for charging a battery. Such systems are usually loosely coupled, hence resonance and high frequency operation is required.

III. MODES OF OPERATION

3.1 CHARGER OPERATION MODES:

There are two control methods to influence the magnitude and the direction of P and Q. The first option is to control the charger voltage vc(t),and its phase angle, δ. The second option is to control the charger current, ic(t)and its phase angle, θ.

CONTROL VARIABLES	P	Q
Vc(t) and δ	$\frac{Vs \times Vc}{Xc} Sin\delta$	$\frac{Vs^2}{Xc}\left[1-\frac{Vc}{Vs}\sin\delta\right]$
Ic(t) and θ	$Vs \times Ic \times Cos\theta$	$Vs \times Ic \times \sin\theta$

Table 3.1

Table 3.2

SL. NO.	P	Q	Operation mode of charger
1	POSITIVE	ZERO	Charging
2	NEGATIVE	ZERO	Discharging
3	POSITIVE	POSITIVE	Charging and inductive
4	POSITIVE	NEGATIVE	Charging and capacitive
5	NEGATIVE	POSITIVE	Discharging and inductive
6	NEGATIVE	NEGATIVE	Discharging and capacitive

Vector diagram of the different modes of charging

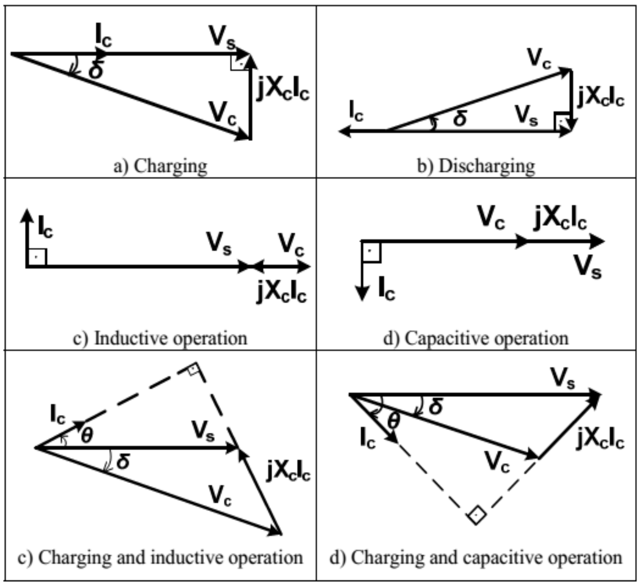


Figure 3.1

How much V2G power can a vehicle provide?
Three independent factors limit V2G power: (1) the current-carrying capacity of the wires and other circuitry connecting the vehicle through the building to the grid, (2) the stored energy in the vehicle, divided by the time it is used, and (3) the rated maximum power of the vehicle's power electronics. The lowest of these three limits is the maximum power capability of the V2G configuration.

1) . Power limited by line

Vehicle-internal circuits for full-function electric vehicles are typically upwards of 100 kW. To calculate the building-wiring maximum, one needs only the voltage and rated ampere capacity of the line:

Pline=VA

Where P_{line} is power limit imposed by the line in watts (here usually expressed in kW), V the line voltage, and A is the maximum rated current in amperes.

2) . Power limited by vehicle's stored energy

The previous section discussed V2G power as limited by the line capacity. The other limit on V2G power is the energy stored on-board divided by the time it is drawn. More specifically, this limit is the onboard energy storage less energy used and needed for planned travel, times the efficiency of converting stored energy to grid power, all divided by the duration of time the energy is dispatched. This is calculated as

$$P_{\mathrm{vehicle}} = \frac{\left(E_{\mathrm{s}} - \frac{d_{\mathrm{d}}+d_{\mathrm{rb}}}{\eta_{\mathrm{veh}}}\right)\eta_{\mathrm{inv}}}{t_{\mathrm{disp}}}$$

where $P_{vehicle}$ is maximum power from V2G in kW, E_s the stored energy available as DC kWh to the inverter, d_d the distance driven in miles since the energy storage was full, d_{rb} the distance in miles of the range buffer required by the driver (explained below), η_{veh} the vehicle driving efficiency in miles/kWh,η_{inv} the electrical conversion efficiency of the DC to AC inverter (dimensionless), and t_{disp} is time the vehicle's stored energy is dispatched in hours.

In a specific application of Eq. (3), d_d would depend on the driving pattern, the vehicle type (e.g., battery EDVs may be recharged at work), and the driver's strategies for being prepared to sell power. The d_{rb} refers to the “range buffer,” the minimum remaining range required by the driver. It is not an engineering measure of the vehicle but is specified by the driver or fleet operator who will determine d_{rb} based on, for example, the return commute or the distance reserved for an unanticipated trip to a convenience store.

IV. SIMULATION AND RESULTS

In the simulation the impact of charging a battery on grid discussed. In the normal case when a system from which an uncontrolled converter is used the current waveform gets distorted due to the reason of power electronic converter. Similarly the grid current will gets distortion and give rise to harmonics in the system. Also if the charging system is a fast charging system it will take more than 200 ampere which affects the system adversely. Hence a simulation model is shown in which the battery is charged through a distribution grid.

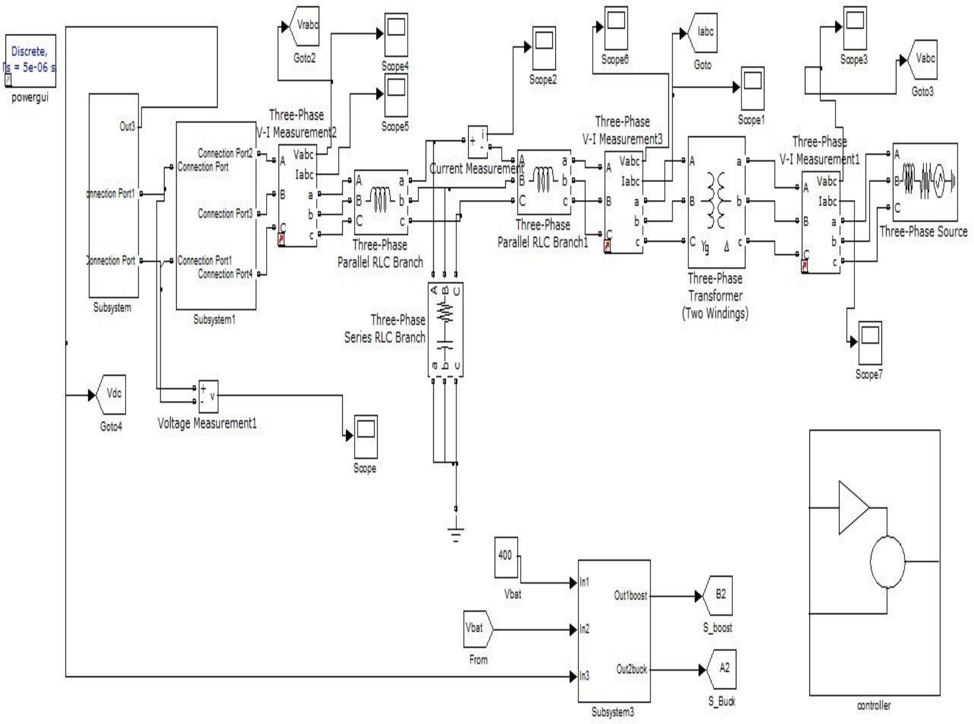
PARAMETER	VALUE
N_{slot}	10
EV charging current	200
P_{EV}	90 KW
COSØ	0.95
K_{load}	1.1
V_{bat}^{min}	200
m_{min}	0.125
L_{bat}	2 mH
R_{series}	0.0175Ω
$R_{transient}$	0.245Ω
$C_{transient}$	8100mF
V_{oc}	400
Battery capacity	35kWh
Battery time constant	2s
SOC	50%

T	1/50
n	0.5
f_{sw}	5000Hz
V_{grid}	20 kV ph − ph
f_{grid}	50Hz
short circuit leval	1200
X/R Ratio	8

Table 4-1: Charging station input parameters

PARAMETER	VALUES
S_{rated}	1050 kVA
V_{dc}	1.5 kV
Δr	20%
Δx	10%
C_{dc}	18mF
L_{inv}	0.48mH
Transformer	200/0.8 kV
L_{grid}	0.69mH
C_f	165μF
R_d	1.31Ω

Table 4-2: Charging station resulting parameters



4.1Electric Vehicle Battery Charger Unit

For processing the both charging and discharging functions by the proposed EVs charging infrastructure, the DC-DC buck boost converter is employed in this work as shown below. IGBTs are employed in the DC-DC buck-boost converter. The unit consists of two IGBT switches which performs buck and boost mode of operation under the required control strategy. The main application of the buck-boost converter is in regulated dc power supplies, where both positive and negative-polarity outputs are desired with respect to the charging or discharging functions of EVs in the charging station. The converter output voltage can also be either higher or lower than the battery voltage depending on the specific situation.

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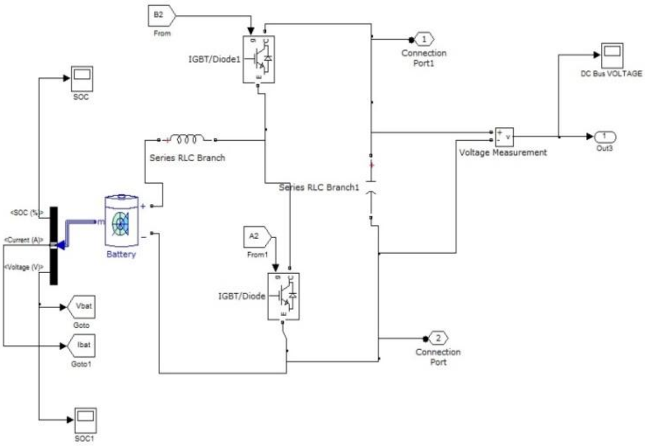


Various AC/DC converters have been used for charging purpose with respect to different kinds of batteries in distinct application. For the EVs charging station in this work, three phase Voltage Source Converters (VSCs) controlled by Pulse Width Modulation (PWM) generating signal is used to achieve the expected performance. The PWM has been commonly used for the power control strategy. Power exchange between AC grid and the DC converter is controlled by the AC-DC converter. It is a bi-directional converter. The switches are IGBTs with gate pulses fed to them to control its operation. Subsystem 1 shows the 6 IGBTs.

4.2LCL Filter

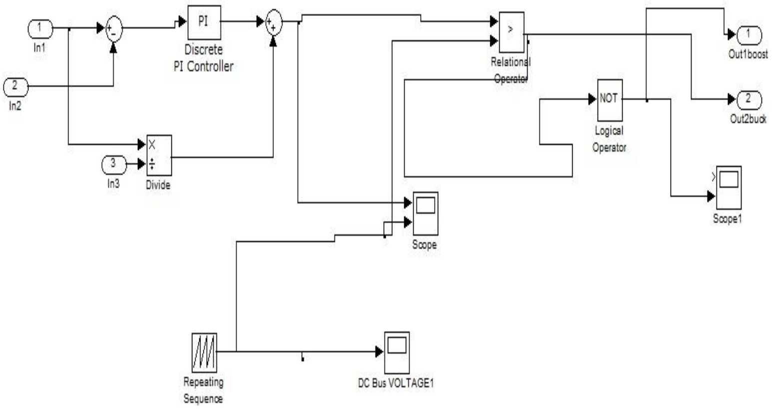
In designed grid side AC/DC converter, it is extremely important to consider the influence of high frequency harmonics caused by conventional power devices that work under high switching frequency. Hence, a filter is equipped for the purpose of reducing the high frequency harmonics and preventing the other sensitive electric devices from disturbance and power losses.

4.3Constant Voltage (CV) Strategy

Constant-voltage chargers maintain nearly the same voltage input to the battery through the charging process, regardless of the battery's state of charge. Constant voltage chargers usually cause a high initial current to the battery because of the greater potential difference between the battery and charger [3].CV strategy, the battery charges under a constant voltage source. The converter will operate in buck mode (charging process).

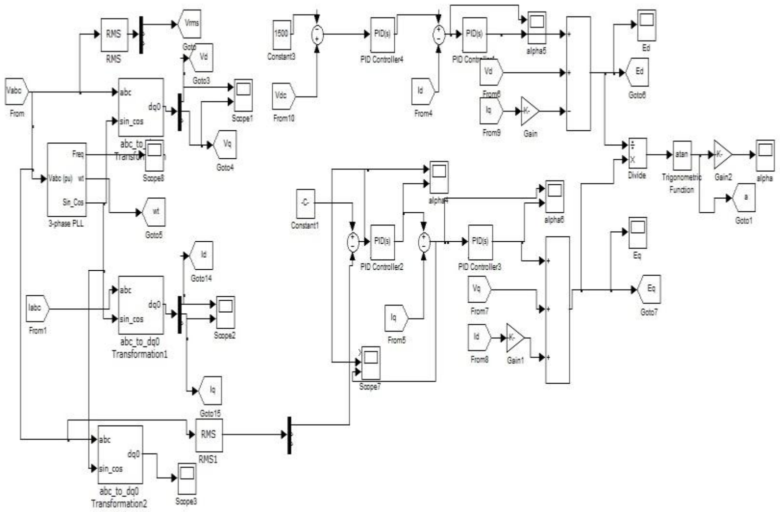
4.4 Constant Current (CC) Strategy

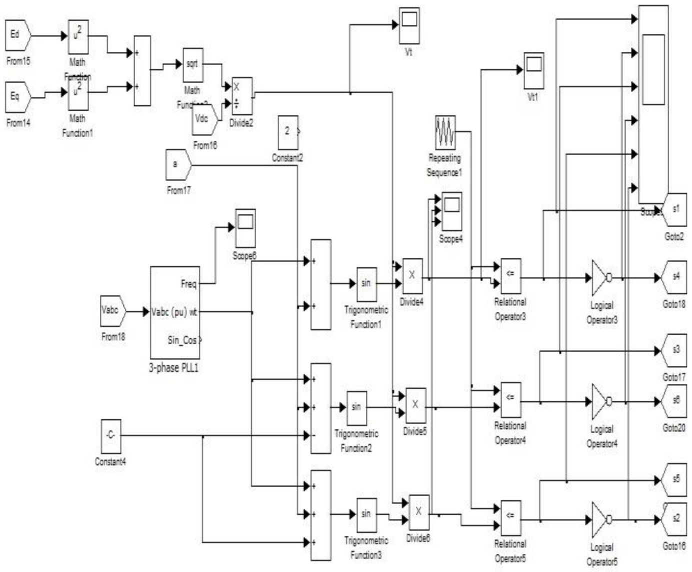
Constant-current charging simply means that the charger supplies a relatively uniform current, regardless of the battery state of charging or temperature. This charging scheme helps eliminate imbalances of cells and batteries connected in series. However, determining the charging current level could be a challenging task. In CC strategy, the battery operates as a constant current source. The output duty ratio m_{cc}defines the boost-mode operation of the converter. The converter will operate in boost mode (discharging process



4.4Converter Control

Control of PWM-VSI has been implemented in the rotating (synchronous) dq reference frame because the synchronous frame controller can eliminate steady state error and has fast transient response by de-coupling control. Control in dq reference frame shown in Fig 5 is used to control the converter operation [10]. It consists of voltage and current loops connected in cascade structure. The controller controls the DC bus voltage, alternating current, and the real & reactive power. Grid synchronization is made possible using a PLL block shown in the block.[4]





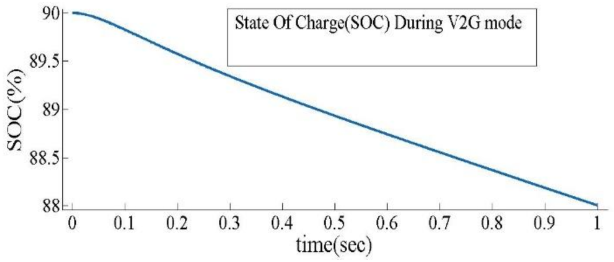


Figure 4.1: SOC of battery during discharge of battery

The SOC graph during V2G mode is shown in Figure 6.15.As SOC is decreasing indicates the discharging of battery .Here the initial SOC is taken as 90%To extend the service life of battery the rate of charge/dis charge should not be high.

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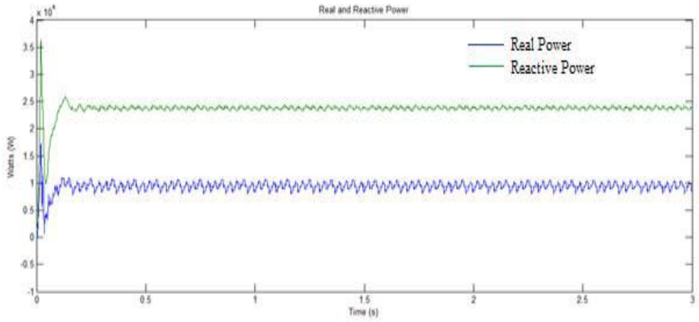

Figure 4.2: Real and Reactive power

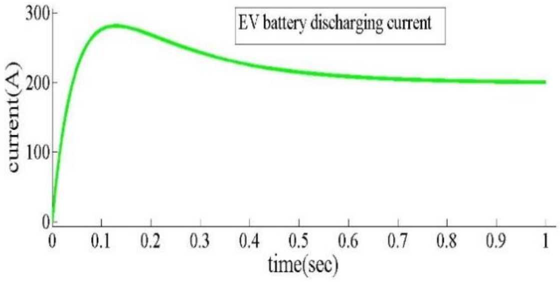

Figure 4.3: Discharging current

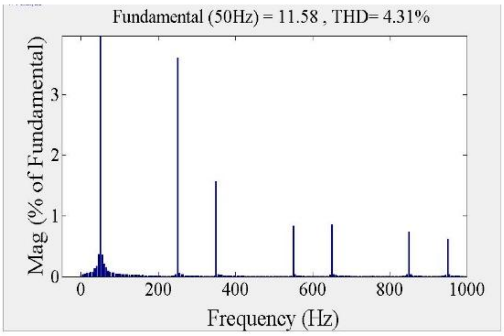

Figure 4.4: FFT analysis for current waveform

V. LIMITATIONS OF VEHICLE TO GRID

INTEGRATION

Battery Life - Concerns exist that the increased cycling of the batteries in this application will adversely affect the life of the battery. Current Li-ion batteries have a cycle life of 1,000 cycles irrespective of whether they are used for transport or static needs. The breakeven sell back rate will reduce over time as battery costs reduce. The requirement for electricity from vehicles into the grid is only likely to happen at times of peak demand, because of the costs associated with it. In addition to the above costs the consumer bears the cost of installing the replacement power pack. On the other hand, the extra cycling for V2G is supposed to be shallow cycles that create less wear on the battery. It is the deep cycles that really hurt battery life. Equipment Life - Transformers are designed to have a load and then cool off. There may be an impact on life expectancy if they are run constantly. Capital Cost - Vehicle based bi-directional power interfaces can be expensive and require adding an onboard inverter so that the vehicle can send power upstream since most vehicles were designed only to take power from the grid. Battery Exchange - Batteries can be readily changed in vehicles with a simple architecture, but vehicles with integrated power packs to improve vehicle dynamics will not be so amenable to a swap and this operation may prove to be very costly. The extent of this cost is not known and not easily estimated without a known architecture

VI. CONCLUSION

The possible gains to be made from a smart V2G approach should not be understated. The V2G concept advocates because it offers mutual benefits to the transportation and the electric power systems. It could assist the former by reducing petroleum use, strengthening the economy, reducing strain on petroleum infrastructure, and improving the natural environment. It could help the latter by providing a new demand for electricity, ideally during the parts of the day when demand remains low. Moreover, it could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants.” The above quote does an excellent job of explaining the many benefits of V2G. This paper has focused largely on the V2G effect on the electric power system, while largely assuming the benefits to the transportation system. However, the transportation ramifications may be more telling and more central to the pursuit of V2G in the first place. When considering V2G, one is best served realizing the summation of the many benefits to the many sectors. Its benefits to the electrical grid are interesting and necessary, but to this point, the roles that the EV could fill have been accomplished via more traditional means. However, the effect of V2G, really the electric vehicle as a whole, is most important in its role to reduce dependence on the modern fossil fuelled automobile. Such a replacement would benefit the environment in ways that go beyond the extent of this paper. While the focus has been on a specific niche that the EV could fill, one must be careful not to confine the EV into this niche role. Its benefits to society by replacing the fossil fuel automobile paradigm may be greater than its participation in V2G. To this point, it does not seem appropriate to say that V2G alone will make the difference in individual decisions to buy an EV, but that V2G will be a benefit of increased EV penetration or as a part of some larger circumstances.

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