Vehicle-To-Grid Technology in a Micro-grid Using DC Fast Charging Architecture

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***Abstract*—** Due to the issues of climate change and global warming, the transportation industry is gradually shifting from the usage of hydrocarbon fuels to electricity. The electric vehicles (EVs) are uses battery to store the energy with is subsequently used to convert into mechanical energy while driving the vehicle. Similarly, Microgrids are used in distribution system that adds renewable energy sources along with the loads. The batteries placed in the EVs could be used significantly applied as energy storage units within the MG system. A good control system have to research and developed in order to satisfy the goal of fast charging of the EV batteries to avoid large queues at the charging stations. In this paper, the implementation of a MG model based vehicle to grid (V2G)-grid to vehicle (G2V) system using the level-3 fast charging of EV's is presented. A level3 fast charging model consist of a fast DC charging technology for operating the electric vehicle. Various simulation conditions were realized and results have been observed to carry out to operate the power flow of V2G-G2V. Test results shows that regulation of the active power is achieved in the MGs by using the batteries of the EVs as dispatchable sources via the G2V-V2G operational modes. The charging infrastructure that is built should be attaining minimum harmonic distortions for injecting current into the of grid as well as while charging the EV and the controller should always give the very good dynamic results in the point of the DC-bus-link-voltage-stability.

.Keywords— DC fast charging, Electric vehicle, Grid connected inverter, Micro-grid, Off-board charger, Vehicle-to-grid

I. INTRODUCTION

The major cause of vehicle pollution is the rapid increase in the number of vehicles. Over the last few decades, most vehicles have been produced. The population of vehicles was about 1.4 billion in 2020 itself. The rapid growth in vehicles means more fuel is required which results in the emission of harmful gases in the environment that causes air pollution. Other major factors that contribute to the increase in vehicular pollution in urban areas are poor fuel quality, use of old vehicles, congested traffic which results in smog, no proper traffic management two-stroke engines, no proper maintenance of vehicles. To deal with this problems, it is necessary to reduce the air pollution from the environment by avoiding carbon emissions. Normally, gasoline or diesel vehicles are more responsible for air pollution due to the usage of fossil fuels . To replace fossil fuels in the transportation sector and to reduce the air pollution, here Electric Vehicles gives an opportunity. This is the main reason most countries are currently focus on the development of electric vehicles (EVs). These are widely spreading technology in our modern world. EVs are mechanically quite simplified, easy to maintain, and also more durable than fossil fuel typed vehicles. It makes less pollution than gasoline or diesel type of vehicles .

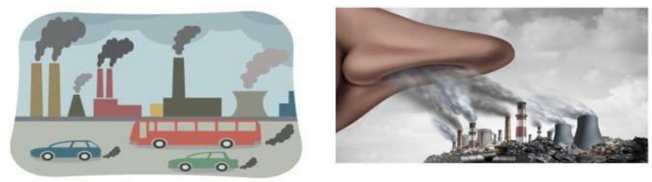

Fig 1 ; Pollution

A) Vehicle-to-Grid Technology: The growth of electric vehicles and the smart grid has lead to the creation of vehicleto-grid (V2G) technology. Imagine using your electric vehicle to power your home during a storm-induced power outage. While your vehicle may not be able to power your entire house, there likely would be enough energy to charge your phone, power the lights, and keep your refrigerator on. How is this possible? Through the useofV2Gtechnology.

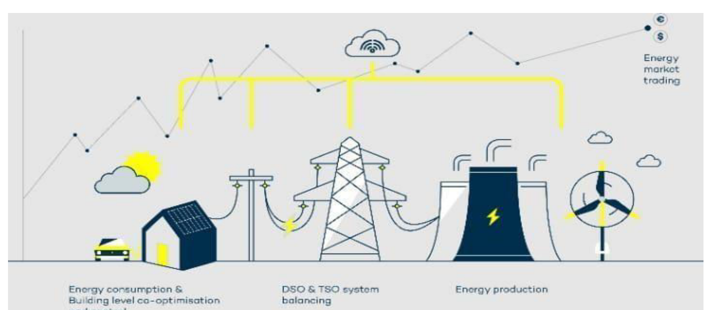

Fig 2 : vehicle to grid Technology

B) What is V2G? :Vehicle-to-grid technology involves drawing unused power from the car into the smart grid. V2G, which is also known as vehicle-grid integration (VGI), can help the energy grid supply electricity during peak hours. It can also create an extra power source when weather-dependent renewable energy sources are not available. For example, a home that uses solar power cannot generate electricity at night, but an EVs could provide a secondary source of power if needed.

C) Why V2G Is Important a) It Makes Power Distribution More Efficient b) It Expands Capacity for Renewable Energy Storage c) It Reduces Energy Costs and Price Volatility.

II .DC Fast Charging Infrastructure Configuration for V2G Application

The configuration for dc fast-charging station to implement V2G-G2V infrastructure in a micro-grid is shown in Fig. 3.EV batteries are connected to the dc bus through off-board chargers. A grid connected inverter connects the dc bus to the utility grid through an LCL filter and a step-up transformer. The important components of the charging station are described below

EVs is shown in the figure :3. To realize the V2G-G2V applications based device within the MG system with the layout for the fast charging based on dc power to execute V2G-G2V stations and the supply to EV batteries that comes through the off-board charger. Here, the inverter connects to a bus bar of the LV distribution network of the MG system via the inductorcapacitor-inductor (LCL) filter along with a transformer of the step-up type. There are several prototypes developed for the fast charging setup.

A). Battery Charger Configuration

For dc fast charging, the chargers are located off-board and are enclosed in an EVSE. A bidirectional dc-dc converter forms the basic building block of an off-board charger with V2G capability. It forms the interface between EV battery system and the dc distribution grid. The converter configuration is shown in Fig. 4. It consists of two IGBT/MOSFET switches that are always operated by complimentary control signals.

1) Buck mode of operation *(charging mode):* When the upper switch (S_{buck}) is operating, the converter acts as a buck converter stepping down the input voltage (V_{dc}) to battery charging voltage (V_{batt}) . During the on state, current flows through the switch and inductor to the battery. This is the charging operation, where the power flow is from the grid to

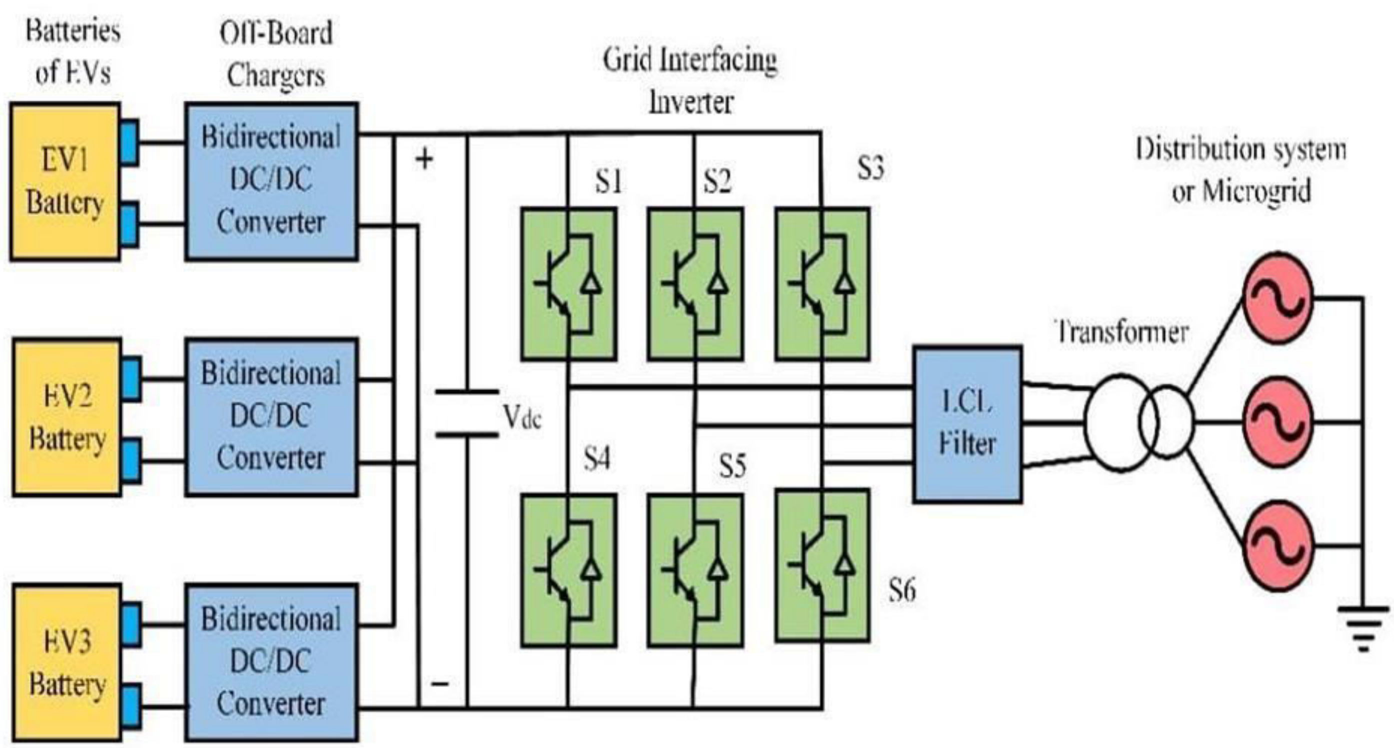

Fig 3 : Schematic diagram of off-board charger and grid interfacing inverter

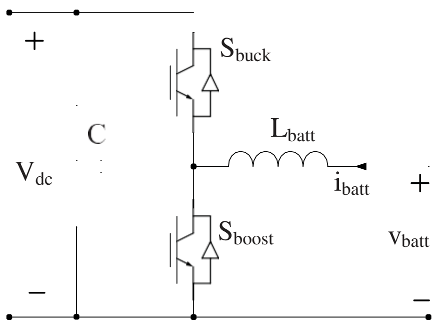

Fig. 4. Battery charger configuration

vehicle (G2V). When the switch is off, the current takes its return path through the inductor and diode of lower switch and completes the circuit. If D is the duty ratio of the upper switch, the battery voltage is given by:

$$V_{batt} = V_{dc} * D$$

2) Boost mode of operation *(discharging mode):* When thelower switch (S_{booct}) is operating, the converter acts as a boostconverter stepping up the battery voltage (V_{batt}) to the dc bus voltage(V_{dc}). When the switch is in on state, current

to flow through the inductor and completes its circuit through the anti-parallel diode of the upper switch, and the capacitor. The net power flow in this case is from the vehicle to the grid (V2G) and the battery operates in the discharge mode. If the capacitor is large enough to provide a constant dc voltage, the output voltage during boost mode of operation is given by:

$$V_{dc} = \frac{V_{batt}}{1 - D'}$$

where D' is the duty cycle of the lower switch .

B) Grid Connected Inverter and LCL Filter

The grid connected inverter (GCI) converts the dc bus voltage into a three phase ac voltage and also allows the reverse flow of current through the anti-parallel diodes of the switches in each leg (Fig. 1). An LCL filter is connected at the output terminals of the inverter for harmonic reduction and obtaining a pure sinusoidal voltage and current. The design procedure for determining the LCL filter parameters for this work is adapted.

II. CONTROL SYSTEM

A. Off-Board Charger Control

A constant current control strategy using PI controllers is implemented for charge/discharge control of the battery charger circuit and is shown in Fig.5. The controller first compares the reference battery current with zero, in-order to determine the polarity of the current signal, to decide between charging and discharging modes of operations. Once the mode is selected, the reference current is compared with the measured current and the error is passed through a PI controller to generate the switching pulses for S_{buck}/S_{booct}. S_{booct} will be turned off throughout the charging process and S_{buck} will be turned off throughout the discharging process.

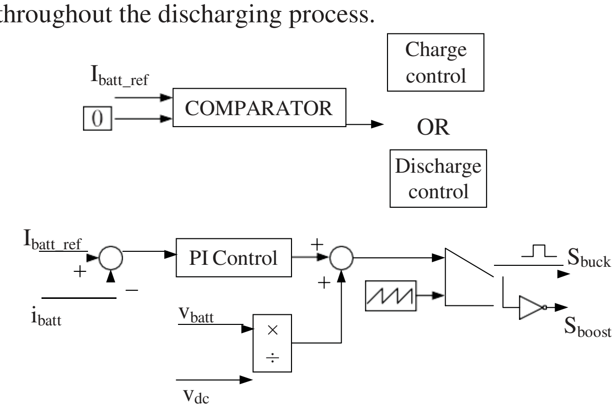

Fig. 5. Constant current control strategy for battery charger

B. Inverter Control

A cascade control in synchronous reference frame is proposed for the inverter controller. The conventional standard vector control using 4 PI controllers in a nested loop is shown in Fig. 6. The control structure consists of two outer voltage control loops and two inner current control loops. The d-axis

outer loop controls the dc bus voltage and inner loop controls the active ac current. Similarly, the q-axis outer loop regulates the ac voltage magnitude by adjusting the reactive current, which is controlled by the q-axis inner current loop. Also, dq decoupling terms ωL and feed-forward voltage signals are added to improve the performance during transients.

III. MICRO-GRID TEST SYSTEM CONFIGURATION

The micro-grid test system configuration with the dc fast charging station is shown in Fig. 7. A 100 kW wind turbine (WT) and a 50 kW solar PV array serve as the generation sources

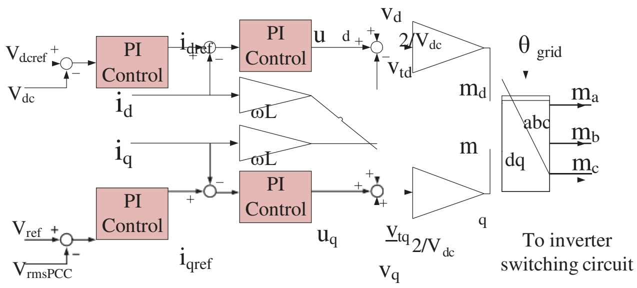

Fig. 6. Inverter control system

in the system. The EV battery storage system consists of 4 EV batteries connected to a 1.5 kV dc bus of the charging station through off-board chargers. The solar PV is also connected to this dc bus through a boost converter which has a maximum power point tracking (MPPT) controller. The utility grid consists of a 25 kV distribution feeder and a 120 kV equivalent transmission system. The wind turbine driven doubly-fed induction generator is connected to the micro-grid at the point of common coupling (PCC). Transformers are used to step up the voltages and connect the respective ac systems to the utility grid.

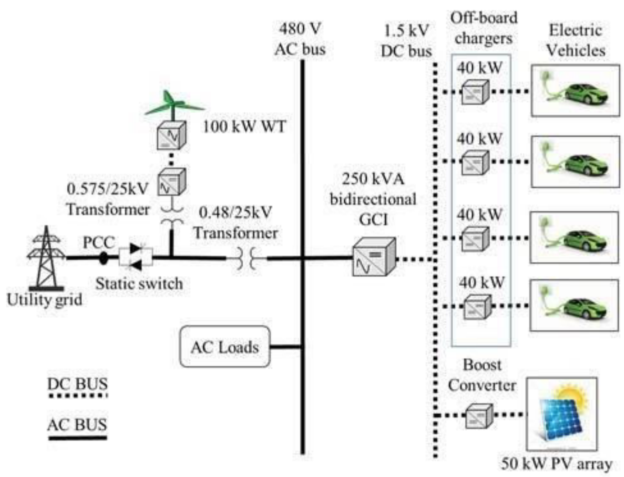

Fig. 7. Proposed microgrid test system configuration

IV. SIMULATION RESULTS

The charging station design procedure is adapted from and the obtained parameter values are given in Appendix. The wind turbine is operated at rated speed giving an output maximum power of 100 kW. The solar PV is operated at standard test conditions (1000W/m^2 irradiance and 25^{o}C temperature) giving the maximum power output of 50 kW. A 150 kW resistive load is connected to the 480 V ac bus. The reactive current reference to GCI is set to zero for unity pf operation. The initial state of charge (SOC) of the EV batteries is set at 50%. Once the steady state conditions are reached, batteries of EV_1 and EV_2 (Fig. 1) are operated to perform the V2G-G2V power transfer. The current set-points given to the battery charging circuits of EV_1 and EV_2 batteries are shown in Table I and the results are shown in the subsequent figures.

The battery parameters when EV_1 is operating in V2G mode and EV_2 operating in G2V mode are shown in Figs. 8 and 9, respectively.

TABLE I. CURRENT SET-POINTS TO EV BATTERIES

Time range (s)	0 to 1	1 to 4	4 to 6
Current set-point to EV_1 battery (A)	0	+80	0
Current set-point to EV_2 batter y(A)	0	0	-40

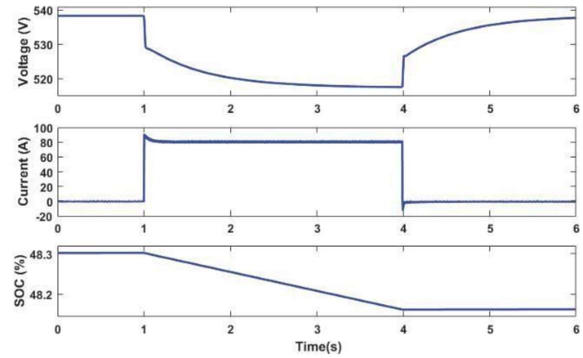

Fig. 8. Voltage, current, and SOC of EV_1 battery during V2G operation

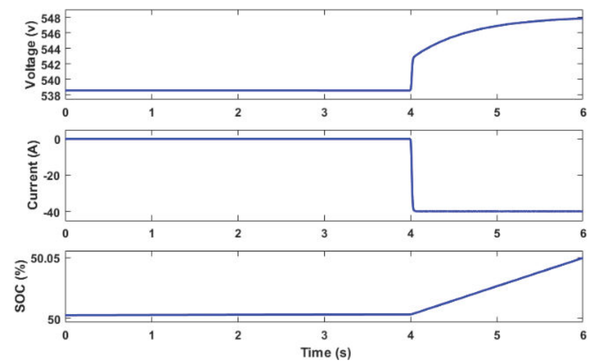

Fig. 9. Voltage, current, and SOC of EV_2 battery during G2V operation

The active power contribution from various components of the system is shown in Fig. 8. The grid power changes to accommodate the power transferred by the EVs. The negative polarity of the grid power from 1s to 4s shows that the power is being fed to the grid from the vehicle. The change in polarity of grid power at 4s shows that the power is supplied by the grid for charging the vehicle battery. This demonstrates the V2G-G2V operation. Also, the net power at PCC is zero showing an optimal power balance in the system.

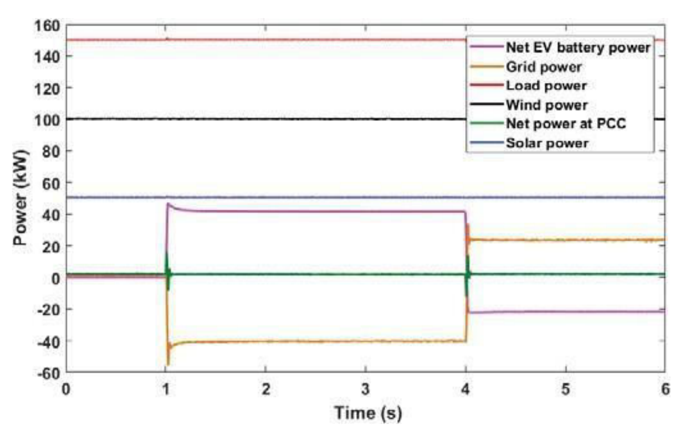

Fig. 10. Active power profile of various components in the system

The dc bus voltage is regulated at 1500 V by the outer voltage control loop of the inverter controller and is shown in Fig. 10. This in turn is achieved by the inner current control loop tracking the changed d-axis reference current as shown in Fig. 11.

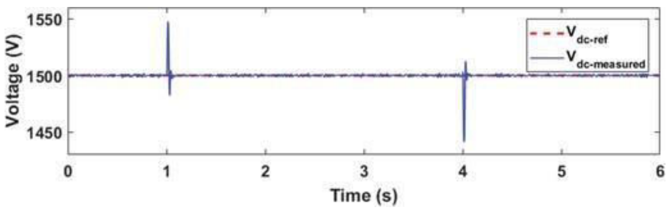

Fig. 11. Variation in dc bus voltage

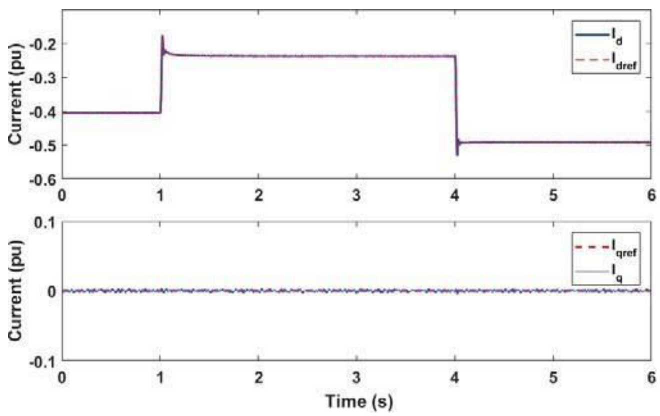

Fig. 12. Reference current tracking by inverter controller

The grid voltage and current at PCC are shown in Fig. 13. Voltage and current are in phase during G2V operation and 180° out of phase during V2G operation showing the reverse power flow.

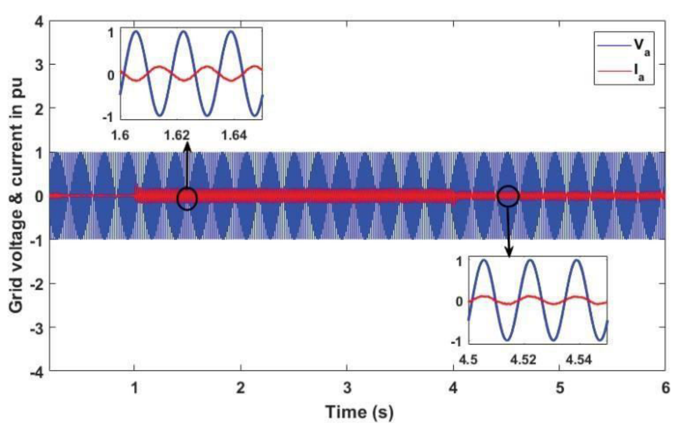

Fig. 13. Grid voltage and grid injected current during V2G-G2V operation

Total harmonic distortion (THD) analysis is done on the grid injected current and the result is shown in Fig. 14. According to IEEE Std. 1547, harmonic current distortion on power systems 69 kV and below are limited to 5% THD. The THD of grid-injected current is obtained as 2.31 % and is achieved by the judicious design of LCL filter.

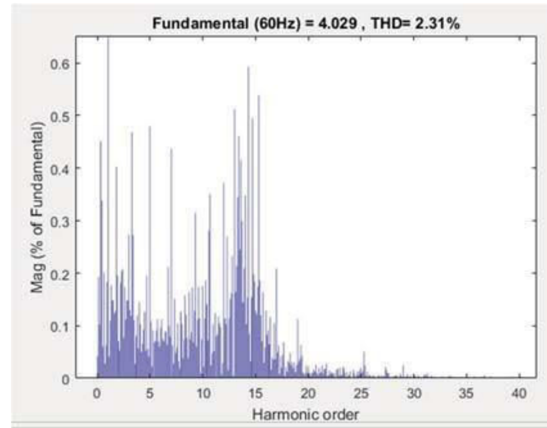

Fig. 14. Harmonic spectrum and THD of grid-injected current

V. CONCLUSIONS

In this report, the design for vehicle to grid (V2G) system is presented that operates within a MG system by considering the DC power fast charging station by implementing an off-board charger that is interfaced with the LV distribution network. Moreover, the detailed control system structure is designed, which allows the bidirectional power transfers taking place between the electric vehicle and to the microgrid, the purity of the current which is injected to the electric vehicle is relevant to accepted standards and obtained by interfacing an LCL filter The developed architecture have good dynamic performance which is regards to DC bus voltage stability. All the details about the regulation features of the active power in the MG environment are elaborated, and the same system will also be used in other control objectives or services like the frequency deviation minimization and properly controlling the reactive power supply Hence, this designed control strategy is very flexible and easy in understanding and implementation,which gives a particular signal to each individul EV and alos helps in future research in EV'

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APPENDIX
CHARGING STATION PARAMETERS

Parameter	Value	Parameter	Value
Rated capacity	250 kVA	EV rated power	40 kW
V_{batt}	500 V	Battery capacity	48 Ah
C_{dc}	850 μF	C_{filter}	133 μF
L_{inv}	0.25 mH	L_{grid}	0.25 mH