

## VEHICLE-TO-GRID TECHNOLOGY IN A MICRO-GRID USING DC FAST CHARGING ARCHITECTURE

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### ABSTRACT

Electric vehicle (EV) batteries are now being used as potential energy storage devices in microgrids. EV batteries can help with micro-grid energy management by storing the energy when there is a surplus (Grid-To-Vehicle, G2V) and supplying energy back to the grid when there is a demand (Vehicle-To-Grid, V2G). To realise this concept, proper atmosphere and control systems must be developed. This principle defines an architecture for instituting a V2G-G2V system in a microgrid using level-3 EV charging. A micro-grid test system with a DC fast charging station for EV interfacing is modelled. To illustrate V2G-G2V power transfer, simulation studies are carried out. The test results show that EV batteries can purposefully regulate power in a microgrid using G2V-V2G modes of operation. The charging station design ensures that the grid injected current has minimal harmonic distortion, and the controller provides better dynamic performance in terms of DC bus voltage stability.

### INTRODUCTION

Energy storage systems are major elements of a microgrid because they enable for the integration of intermittent renewable energy sources. When electric vehicle (EV) batteries are plugged in for charging, they can be used as effective storage devices in micro-grids. Most personal transportation vehicles are parked for approximately 22 hours per day, showing an idle asset. EVs could potentially aid in microgrid power management by storing surplus power (Grid-To-Vehicle, G2V) and returning it to the grid when there is a demand for it (Vehicle-To-Grid). V2G applied to the general power grid faces some challenges, such as being difficult to control, needs a large number of EVs, and being difficult to realise in the short term [1]. It is simple to implement a V2G system in a micro-grid in this scenario. The Society of Automotive Engineers defines three charging levels for EVs. Level 1 charging connects the vehicle's on-board charger to a standard household (120 V) outlet through a plug.

This is the slowest charging technique and is suitable for people who travel less than 60 kilometres per day and have all night to charge. Level 2 charging allows use of a dedicated Electric Vehicle Supply Equipment (EVSE) at home or at a public station to provide power at 220 or 240 volts and up to 30 amps. DC fast charging is another name for level 3 charging. DC fast charging stations deliver up to 90 kW of charging power at 200/450 V, reducing charging time to 20-30 minutes. Due to the quick power transfer required when EVs are used for energy storage, DC fast charging is preferred for trying to implement a V2G architecture in micro-grid. The dc bus can also be used to integrate renewable energy sources into the system. The majority of previous studies have used the V2G concept in the general power grid for services like as peak shaving, valley filling, regulation, and spinning reserves. V2G development in a microgrid facility to support power generation from intermittent renewable energy sources is still in its early stages. In addition, most of the works reported use level 1 and level 2 ac charging for V2G technology. The power

rating of the on-board charger limits the capacity of these ac charging systems. Another issue is that the distribution grid was not designed to handle bidirectional energy flow. There is a research need in this scenario for developing technically viable charging station architectures to facilitate V2G technology in micro-grids. This paper proposes an infrastructure for dc quick charging stations with V2G capability in a micro-grid facility. The dc bus used to connect EVs is also used to integrate a solar PV array into the micro-grid. The proposed architecture allows high power bi-directional charging for EVs through off-board chargers. The proposed model's effectiveness is assessed using MATLAB/Simulink simulations for both V2G and G2V modes of operation.

**DC FAST CHARGING STATION CONFIGURATION FOR V2G**

The DC fast charging station configuration for implementing V2G-G2V infrastructure in a microgrid. Off-board chargers connect the batteries of electric vehicles to the dc bus. An LCL filter and a step-up transformer connect the dc bus to the utility grid via a grid connected inverter. The charging station's key components are described below. The chargers for dc fast charging are located off-board and are housed in an EVSE. A bidirectional dc-dc converter is the fundamental component of an off-board charger with V2G capability. It serves as the link between the EV battery system and the dc distribution grid. Figure 2 depicts the converter configuration. It is made up of two IGBT/MOSFET switches that are always controlled by complementary signals. Buck operation mode (charging mode): When the upper switch is turned on, the converter functions as a buck converter, stepping down the input voltage to the charging voltage of the battery. Current flows through the switch and inductor to the battery when it is turned on.

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

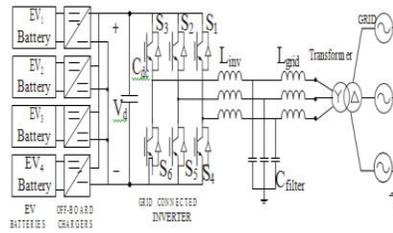


Fig.1 EV Charging station for fast dc charging

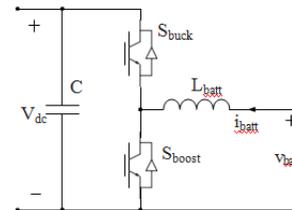


Fig.2. Battery charger configuration

2) Boost mode of operation (discharging mode):

When the lower switch is turned on, the converter acts as a boost converter, converting the battery voltage to the dc bus voltage.

mode of operation is given by

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

Where D is the duty cycle of the lower switch.

**BATTERY STORAGE SYSTEM**

A battery is a device made up of one or more electrochemical cells with external connections that is used to power electrical devices like flashlights, cell phones, and electric cars. When a battery is supplying electricity, the positive terminal is known as the cathode and the negative terminal is known as the anode. [2] The negative terminal is the source of electrons that will flow to the positive terminal via an external electric circuit. When a battery is connected to an external electric load, a redox reaction occurs, converting high-energy reactants to lower-energy products and delivering the free-energy difference to the external circuit as electrical energy. Historically, a "battery" was a device composed of multiple cells; however, the term has come to refer to devices composed of a single cell.

Because the electrode materials are irreversibly changed during discharge, primary (single-use or "disposable") batteries are used once and then discarded; an alkaline battery used in flashlights is an example. variety of portable electronic devices. Secondary (rechargeable) batteries can be discharged and charged up multiple times with an applied electric current; reverse current can restore the original composition of the electrodes. Lead-acid batteries used in automobiles and lithium-ion batteries used in portable electronics including laptops and mobile phones are two examples.

The term "battery" was coined by Benjamin Franklin in 1748 to describe a group of electrical devices by analogy to a battery of cannons (Benjamin Franklin borrowed the term "battery" from the military, referring to weapons that work together).

Alessandro Volta, an Italian physicist, invented and described the first electrochemical battery, the voltaic pile, in 1800.

This was a stack of copper and zinc plates separated by brine-soaked paper discs capable of producing a steady current for an extended period of time. Volta was unaware that the voltage was caused by chemical reactions. He believed that his cells were an infinite source of energy, and that the corrosion effects at the electrodes were merely a nuisance, rather than an unavoidable byproduct of their operation, as Michael Faraday demonstrated in 1834.

A battery is made up of a number of voltaic cells. A conductive electrolyte containing metal cations connects two half-cells in series to form each cell. The electrolyte and the negative electrode, to which anions (negatively charged ions) migrate, are in one half of the cell; the electrolyte and the positive

The terminal voltage (difference) is the electrical driving force or across the terminals of a cell and is measured in volts. The open-circuit voltage is the terminal voltage of a cell that is neither charging nor discharging and equals the cell's emf. Because of internal resistance,[18] the terminal voltage of a discharging cell is less than the open-circuit voltage, while the terminal voltage of a charging cell exceeds the open-circuit voltage. [19] Because an ideal cell has negligible internal resistance, it will maintain a

constant terminal voltage of until it is exhausted, at which point it will drop to zero. If such a cell maintained 1.5 volts and produced a charge of one coulomb, it would have performed 1.5 joules of work when fully discharged. [17] Internal resistance increases in actual cells during discharge[18], and open-circuit voltage decreases as well. When voltage and resistance are plotted against time, the resulting graphs are typically curves; the shape of the curve varies depending on the chemistry and internal arrangement used.

Batteries are classified into primary and secondary forms:

Primary batteries are intended to be used until their energy is depleted and then discarded. Because their chemical reactions are usually irreversible, they cannot be recharged. When the battery's supply of reactants runs out, it stops producing current and becomes useless. [22]

#### **Main article:** Rechargeable battery

Secondary batteries, also known as secondary cells or rechargeable batteries, must be charged before use; they are typically assembled with discharged active materials. Electric current is used to (re)charge rechargeable batteries, which reverses the chemical reactions that occur during discharge/use. Chargers are devices that supply the required current.

The sealed valve regulated lead-acid battery (VRLA battery) is a popular replacement for lead-acid wet cells in the automotive industry. The VRLA battery employs an immobilised sulfuric acid electrolyte, which reduces leakage and increases shelf life. [27] The electrolyte is immobilised by VRLA batteries. The two types are:

Gel batteries (or "gel cell") use a semi-solid electrolyte.

The electrolyte is absorbed in a special fibreglass matting in Absorbed Glass Mat (AGM) batteries.

#### **Cell types**

Many different types of electrochemical cells, with varying chemical processes and designs, have been

developed, including galvanic cells, electrolytic cells, fuel cells, flow cells, and voltaic piles.<sup>[29]</sup>

### **Wet cell**

A liquid electrolyte is used in a wet cell battery. Other names for this type of cell include flooded cell (because liquid covers all internal parts) and vented cell (because gases produced during operation can escape to the outside air). Wet cells were a precursor to dry cells and are commonly used as an electrochemistry learning tool. They can be constructed using common laboratory supplies such as beakers to demonstrate how electrochemical cells work. A concentration cell is a type of wet cell that is important in understanding corrosion. Wet cells can be either primary (non-rechargeable) or secondary (rechargeable). All practical primary batteries, including the Daniell cell, were originally built as open-top glass jar wet cells. Leclanche cells, Grove cells, Bunsen cells, Chromic acid cells, Clark cells, and Weston cells are examples of primary wet cells. The first dry cells used the Leclanche cell chemistry. Wet cells are still used in automobile batteries and in industry for standby power for switchgear, telecommunications, and large uninterruptible power supplies, but gel cells have been used in many places instead. Lead-acid or nickel-cadmium cells are commonly used in these applications.

A dry cell employs a paste electrolyte with just enough moisture to allow current to flow. Because there is no free liquid in a dry cell, it can operate in any orientation without spilling, making it suitable for portable equipment. In comparison, the first wet cells were typically fragile glass containers with lead rods hanging from the open top that required careful handling to avoid spillage. Lead-acid batteries did not achieve the safety and portability of dry cells until the development of the gel battery.

The zinc-carbon battery, also known as the dry Leclanché cell, has a nominal voltage of 1.5 volts, which is the same as the alkaline battery (because both use the same zinc-manganese dioxide combination). A typical dry cell consists of a zinc anode, typically in the form of a cylindrical pot, and a carbon cathode, typically in the form of a central rod. The electrolyte is ammonium chloride paste, which is

applied next to the zinc anode. A second paste composed of ammonium chloride and manganese dioxide, the latter of which acts as a depolariser, fills the remaining space between the electrolyte and the carbon cathode. Zinc chloride is used in place of ammonium chloride in some designs.

### **Molten salt**

Molten salt batteries are either primary or secondary batteries that use molten salt as their electrolyte. They work at high temperatures and must be well insulated to keep the heat in.

### **Reserve**

A reserve battery can be stored unassembled for an extended period of time (unactivated and providing no power) (perhaps years). When the battery is needed, it is assembled (by adding electrolyte, for example); once assembled, the battery is charged and ready to use. The impact of firing a gun, for example, could activate a battery for an electronic artillery fuze. The acceleration causes an electrolyte capsule to rupture, thereby activating the battery and powering the fuze's circuits. After being stored for an extended period of time, reserve batteries are typically designed to have a short service life (seconds or minutes) (years). A water-activated battery for oceanographic instruments or military applications is activated by immersion in water.

### **Cell performance**

A battery's characteristics can change over time due to factors such as internal chemistry, current drain, and temperature. At low temperatures, a battery cannot provide as much power. As a result, in cold climates, some car owners install battery warmers, which are small electric heating pads that keep the car battery warm.

In 2017, Tesla built the world's largest battery in South Australia. In 2013, a \$500 million battery capable of storing 36 MWh of electricity was built in Hebei Province, China. In Fairbanks, Alaska, a large battery made of Ni-Cd cells was discovered. It measured 2,000 square metres (22,000 square feet) and weighed 1,300 tonnes. It was created by ABB to provide backup power in the event of a power outage.

Battery life (and its synonym battery lifetime) have two meanings for rechargeable batteries, but only one for non-rechargeables. It can refer to the amount of time a device can run on a fully charged battery or the number of charge/discharge cycles possible before the cells fail to function properly in the case of rechargeables. Because cells last only one cycle, these two lives are equivalent for a non-rechargeable. (The term shelf life refers to how long the performance of a battery will last between manufacture and use.) As the temperature rises, the available capacity of all batteries decreases. In contrast to most modern batteries, the Zamboni pile, invented in 1812, has a very long service life with no need for refurbishment or recharge, despite only supplying nanoampere current. Since 1840, the Oxford Electric Bell has rung almost continuously on its original pair of Zamboni pile batteries.. [citation needed]

### Self-discharge

Old rechargeable batteries, particularly nickel-based batteries, self-discharge faster than disposable alkaline batteries; a freshly charged nickel cadmium (NiCd) battery loses 10% of its charge in the first 24 hours and then discharges at a monthly rate of about 10%. In contrast, newer low self-discharge nickel metal hydride (NiMH) batteries and modern lithium designs have a lower self-discharge rate (but still higher than for primary batteries)

### Corrosion

Internal parts may corrode and fail, or active materials may gradually degrade into inactive forms.

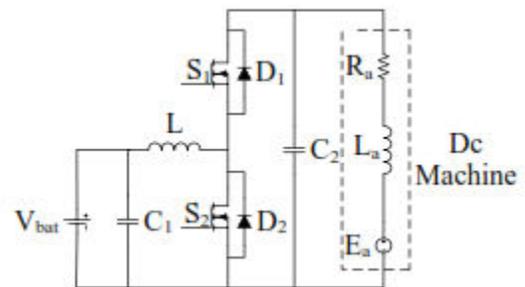
#### Changes in physical components

The chemical composition of the active material on the battery plates changes with each charge and discharge cycle; active material may be lost due to physical changes in volume. When most nickel-based batteries are purchased, they are partially discharged and must be charged before use. [41] Newer NiMH batteries are ready to use when purchased and have only a 15% discharge rate over a year. [42]

### PROPOSED DC DC CONVERTER

A buck-boost converter is a type of DC-to-DC converter in which the magnitude of the output

voltage is greater or less than the magnitude of the input voltage. It is similar to a flyback converter that uses a single inductor instead of a transformer. The term "buck-boost converter" refers to two different topologies. Both are capable of producing a wide range of output voltages, ranging from much higher (in absolute magnitude) than the input voltage to nearly zero.



**Proposed converter**

A buck (step-down) converter is used in conjunction with a boost (step-up) converter.

The output voltage is usually the same polarity as the input voltage, but it can be lower or higher. A non-inverting buck-boost converter may use a single inductor for both the buck and boost inductor modes, employing switches instead of diodes,[2][3], or it may employ multiple inductors but only a single switch, as in the SEPIC and uk topologies.

Buck Boost converter-principle of operation-applications

#### Buck Boost Converter Overview

A Buck converter is a switch mode DC to DC converter that can transform the output voltage to be less or greater than the input voltage. The magnitude of the output voltage is determined by the switch's duty cycle. It's also known as a step up/step down converter. The name step up/step down converter refers to the fact that the input voltage, like a step up/step down transformer, can be stepped up/down to a level greater/less than the input voltage. The law of conservation of energy states that input power must equal output power (assuming no losses in the circuit).

Power input (Pin) = Power output (Pout)

When in step-up mode  $V_{in} < V_{out}$  in a Buck Boost converter means that the output current is less than the input current. As a result, when using a Buck Boost converter in step up mode

$I_{in} > I_{out}$  and  $V_{in} < V_{out}$

When a Buck Boost converter is in step down mode  $V_{in} > V_{out}$ , the output current is greater than the input current. As a result, if a

$$V_{in} > V_{out} \text{ and}$$

$$I_{in} < I_{out}$$

**Buck converter operation principle**

The main working principle of a Buck Boost converter is that the inductor in the input circuit resists sudden changes in input current. When the switch is turned on, the inductor stores magnetic energy from the input and discharges it when the switch is turned off. The capacitor in the output circuit is assumed to be large enough to allow the RC circuit in the output stage to have a high time constant. In steady state, a constant output voltage  $V_o(t) = V_o(\text{constant})$  exists across the load terminals because the time constant is large in comparison to the switching period. Buck Boost converter circuit diagram

The circuit diagram for the Buck Boost converter is shown below.

**Modes of operation for Buck Boost converters**

The Buck Boost converter has two operating modes.

- a) Continuous conduction mode, in which the current through the inductor is never zero, implying that the inductor partially discharges before the switching cycle begins.
- b) Discontinuous conduction mode, in which the inductor is discharged completely at the end of the switching cycle.

**Buck converter circuit analysis**

Assume that the current swing (from maximum to minimum value) through the inductor and the voltage swing through the capacitor are very small and vary linearly throughout the analysis. This is done to make the analysis and results more understandable.

Case 1: Continuous conduction mode When switch S is turned on

When the switch is turned on for a period of time, the diode will be open circuited because it does not allow currents to flow from input to output in the opposite direction. As a result, the Buck Boost converter, as shown below, can be redrawn.

$$I_L = (1/L) * \int V * dt$$

Assume that prior to the opening of switch the inductor current is  $I'_{L, off}$ . Since the input voltage is constant

$$I_{L, on} = (1/L) * \int V_{in} * dt + I'_{L, on}$$

Assume the switch is open for  $D * T_s$  seconds, where D is the duty cycle and  $T_s$  is the switching time period. At the end of the switch-on state, the current flowing through the inductor is denoted as

$$I_{L, on} = (1/L) * V_{in} * D * T_s + I'_{L, on} \text{ (equation 1)}$$

Hence  $\Delta I_{L, on} = (1/L) * V_{in} * D * T_s$ .

case 2: When switch is off

When the switch is turned off, the diode is forward biased because current can flow from the output to the input (p to n terminal), and the Buck is forward biased. As shown below, the boost converter circuit can be redrawn.

The inductor is now discharged by the diode and RC combination. Assume that the inductor current is  $I''_{L, off}$  prior to closing the switch. The current that flows through the inductor is denoted by

$$I'''_{L, off} = -(1/L) * \int V_{out} * dt + I''_{L, off}$$

The inductor is discharging, as indicated by the negative sign at the beginning of the equation. Assume the switch is open for the number of seconds given by  $(1-D) * T_s$ , where D represents the duty cycle and  $T_s$  represents the switching time period. At the end of the switch off state, the current flowing through the inductor is denoted as

$$I'''_{L, off} = -(1/L) * V_{out} * (1-D) * T_s + I''_{L, off} \text{ (equation 2)}$$

Because the current flowing through the inductor does not change abruptly in steady state, the current at the end of the switch on and off states should be equal. Furthermore, the currents at the beginning of the switch off state must equal the currents at the end of the switch on state. Hence

$$I'''_{L, off} = I_{L, on} \text{ also } I'_{L, off} = I''_{L, off}$$

Using the equations 1 and 2 we get

$$(1/L) * V_{in} * D * T_s = (1/L) * V_{out} * (1-D) * T_s$$

$$V_{in} * D = V_{out} * (1-D)$$

$$V_{out}/V_{in} = D/(1-D)$$

Vout can be greater than or less than Vin because  $D < 1$ . When D is greater than 0.5, the Buck boost converter acts as a boost converter with Vout greater than Vin. For  $D < 0.5$ , the Buck boost converter functions as a buck converter because  $V_{out} < V_{in}$ .

Assuming no losses in the circuit and applying the law of conservation of energy

$$V_{out} * I_{out} = V_{in} * I_{in}$$

This implies that  $I_{out}/I_{in} = (1-D)/D$ , implying that for  $D < 0.5$ ,  $I_{out} > I_{in}$  and for  $D > 0.5$ ,  $I_{out} < I_{in}$ . The output voltage rises while the output current falls as the duty cycle increases.

### Mode of discontinuous conduction

When the converter is operated in discontinuous mode, as previously stated, the inductor completely drains its stored energy before the switching cycle is completed. The current and voltage wave forms of a Buck Boost converter in discontinuous mode are depicted in the figure below.

The inductor drains all of the current accumulated during the charging interval of the same switching cycle in discontinuous mode..

$$I_L = (1/L) \int V_L * dt = (1/L) * \text{area}$$

under the curve of voltage v/s time. Hence from the wave forms shown in the figure

$$V_{out} * \delta * T_s = V_{in} * D * T_s$$

$$V_{out}/V_{in} = D/\delta$$

The output to input current ratio is  $I_{out}/I_{in} = 1/D$  according to the law of conservation of energy.

Applications for buck boost converters

- It is used in power supplies that self-regulate.
- It consists of consumer electronics.
- It is used in battery-powered systems.
- Adaptive control applications
- Power amplifier applications

## SIMULATION RESULTS AND ANALYSIS

### INTRODUCTION

Simulink is a software package that allows you to model, simulate, and analyse dynamical systems. It can model linear and nonlinear systems in continuous time, sampled time, or a combination of the two. Because models are hierarchical, we can build them

from the top down or from the bottom up. We can see the system from a high level, then double-click on blocks to descend the levels and see increasing levels of model detail. This method reveals the structure of a model and how its components interact. After we've established a model, we can simulate it by selecting one of several integration methods from the Simulink menus or by typing commands into MATLAB's command window. We can see the simulation results while it is running by using scopes and other display blocks. Furthermore, for "what if" exploration, we can change parameters and immediately see what happens.

### BLOCK DIAGRAM

A Simulink block diagram is a graphical representation of a dynamic system. It is made up of a series of symbols called blocks that are linked together by lines. Each block represents an elementary dynamic system that generates an output either continuously (a continuous block) or at specific time intervals (a discrete block). The lines represent the connections between block inputs and outputs. Every block in a block diagram is an example of a particular type of block. The relationship between a block's outputs and its inputs, states, and time is determined by the type of the block. A block diagram can contain as many instances of any type of block as is required to model a system. Simulink can simulate elementary dynamic systems represented by blocks. A block consists of:

- 1) A set of inputs,
- 2) A set of states, and
- 3) A set of outputs.

A block's output is a function of time and the inputs and states of the block (if any). The function that connects a block's output to its inputs, states, and time is determined by the type of block of which the block is an instance. Blocks that are continuous versus discrete The standard Simulink block set includes both continuous and discrete blocks. Continuous blocks respond in real time to changing input. In contrast, discrete blocks respond to changes in input only at integral multiples of a fixed interval known as the block's sample time. Discrete blocks maintain a constant output between sample time hits. Each discrete block has a sample time parameter that lets you set the sample rate.

Depending on whether they are driven by continuous or discrete blocks, Simulink blocks can be either continuous or discrete. An implicit sample rate is a block that can be either discrete or continuous. If any of the block's inputs are continuous, the implicit sample time is continuous. If all of the input sample times are integral multiples of the shortest time, the implicit sample time is equal to the shortest time. Otherwise, the input sample time is equal to the inputs' fundamental sample time, where the fundamental sample time of a set of sample times is defined as the set's greatest integer divisor.

### **SIMULINK BLOCK LIBRARIES**

Simulink categorises its blocks into block libraries based on their behaviour.

- 1) The Sources library contains signal generation blocks.
- 2) The Sinks library includes blocks for displaying or writing block output.
- 3) Blocks in the Discrete library describe discrete-time components.
- 4) The Continuous library includes blocks for describing linear functions.
- 5) The Math library includes blocks that describe common mathematical functions.
- 6) The Functions & Tables library includes blocks describing general functions and table look-up operations.
- 7) The Nonlinear library contains blocks that describe nonlinear functions.
- 8) The Signal & Systems library contains blocks that allow for multiplexing and demultiplexing, external input/output, data passing to other parts of the model, and other functions.
- 9) The Subsystems library contains building blocks for various types.

### **SUB SYSTEMS**

Simulink models a complex system as a collection of interconnected subsystems, each represented by a

block diagram. Simulink's Subsystem block and the Simulink model editor are used to create a subsystem. To create hierarchical models, we can embed subsystems with subsystems to any depth. We can write conditionally executed subsystems that run only when a transition on a triggering or enabling input occurs.

### **SOLVERS**

Simulink simulates a dynamic system by computing its states at successive time step solvers over a specified time span using model information. Solving the model refers to the process of computing the successive states of a system from its model. There is no single method for solving a model that is applicable to all systems. As a result, Simulink provides a set of programmes known as solvers, each of which represents a unique approach to solving a model. The Simulation Parameters dialogue box allows us to select the best solver for our model.

#### **Fixed-Step and Variable-Step Solvers**

From the start to the end of the simulation, fixed-step solvers solve the model at regular time intervals. The step-size is the size of the interval. We can either specify the step size or let the solver decide. In general, decreasing the step size improves accuracy while increasing the time required to simulate the system.

#### **Continuous and Discrete Solvers**

Continuous solvers use numerical integration to compute the continuous states of a model at the current time step based on the states at previous time steps and the state derivatives. Continuous solvers rely on the model's blocks to compute the discrete state values at each time step. Mathematicians have created a plethora of numerical integration techniques for solving ordinary differential equations (ODEs), which represent the continuous states of dynamic systems. Simulink includes a large number of fixed-step and variable-step continuous solvers, each of which implements a different ODE solution method. Some continuous solvers divide the simulation time span into major and minor steps, where a minor time step is a subset of the major time step. At each major time interval, the solver generates a result.

## MODEL EXECUTION PHASE

Simulink computes the system's states and outputs at intervals from the simulation start time to the simulation finish time during the simulation model execution phase, using information provided by the model. Time steps are the successive time points at which the states and outputs are computed. The step size is the amount of time between steps. The step size is determined by the solver used to compute the system's continuous states, the fundamental sample time of the system, and whether the system's continuous states have discontinuities (Zero Crossing Detection). The model specifies the initial states and outputs of the system to be simulated at the start of the simulation.

- 1) Simulink Updates the outputs of the models' blocks in sorted order. Simulink computes a block's outputs by invoking the block's output function. Simulink passes the current time and the block's inputs and states to the output function as it may require these arguments to compute the block's output. Simulink updates the output of a discrete block only if the current step is an integral multiple of the block's sample time.
- 2) Updates the model's block states in sorted order. Simulink computes the discrete states of a block by invoking its discrete state update function. Simulink computes a block's continuous states by numerically integrating the continuous states' time derivatives. It uses the block's continuous derivatives function to compute the time derivatives of the states.
- 3) Optionally checks for discontinuities in blocks' continuous states. Simulink detects discontinuities in continuous states using a technique known as zero crossing detection.
- 4) Calculates the time for the following time step. Simulink will repeat steps 1 through 4 until the simulation timer expires.

## BLOCK SORTING RULES

Simulink sorts the blocks using the following basic update rules:

- 1) Before any of the direct-feed through blocks that it drives, each block must be updated. This rule ensures that when direct-feed through blocks are updated, their inputs remain valid.
- 2) Non-direct-feed through blocks can be updated in any order, as long as they come before any direct-

feed through blocks they drive. This rule can be met by placing all non-direct-feed through blocks in any order at the top of the update list. Simulink can thus ignore non-direct-feed through blocks during the sorting process.

## DETERMINING BLOCK UPDATE ORDER

Simulink categorises blocks based on the relationship of outputs to inputs in order to create a valid update ordering. Direct feed through blocks are those whose current outputs are determined by their current inputs. The remaining blocks are known as non-direct-feed through blocks. Non-direct-feed through blocks include the Integrator (whose output is solely determined by its state), the Constant (which has no input), and the Memory (its output is dependent on its input in the previous time step). You can assign update priorities to blocks in Simulink. Simulink prioritises updating higher priority blocks over lower priority blocks. Simulink respects priorities only if they are set.

Some SIMULINK blocks used in this thesis are listed below.

MATLAB is a powerful programming language used in scientific computing. It combines computation, visualisation, and programming in a user-friendly environment in which problems and solutions are expressed in familiar mathematical notation.

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualisation  
Scientific and engineering graphics

MATLAB is an interactive system with an array as its basic data element that does not require dimensioning. This enables the solution of many technical computing problems, particularly those involving matrix and vector formulations, in a fraction of the time required to write a programme in a scalar non-interactive language like C or FORTRAN.

The MATLAB system consists of six main parts:

**(a) Development Environment**

This is a collection of tools and facilities that aid in the use of MATLAB functions and files. A large number of these tools have graphical user interfaces. The MATLAB desktop and Command Window are included, as well as a command history, an editor and debugger, and browsers for viewing help, the workspace, files, and the search path.

**(b) The MATLAB Mathematical Function Library**

This is a large collection of computational algorithms that range from simple functions like sum, sine, cosine, and complex arithmetic to more complex functions like matrix inverse and matrix multiplication.

**(c) The MATLAB Language**

This is a high-level matrix/array language with features such as control flow statements, functions, data structures, input/output, and object-oriented programming. It enables both "programming in the small" for quick and dirty throw-away programmes and "programming in the large" for large and complex application programmes.

**(d) Graphics**

MATLAB provides extensive support for graphing vectors and matrices, as well as annotating and printing these graphs. It includes high-level data visualisation, image processing, animation, and presentation graphics functions in two and three dimensions. It also includes low-level functions for fully customising the appearance of graphics and building full graphical user interfaces on MATLAB applications.

**(e) The MATLAB Application Program Interface (API)**

This is a library that enables the development of C and FORTRAN programmes that interact with MATLAB. It includes support for calling MATLAB routines (dynamic linking), using MATLAB as a computational engine, and reading and writing MAT-files.

**(f) MATLAB Documentation**

To assist in learning about and using all of MATLAB's features, it provides extensive documentation in both printed and online formats. It covers all of the primary MATLAB features in depth, with numerous examples. The online help for MATLAB contains task-oriented and reference information about MATLAB features. The documentation for MATLAB is also available in printed and PDF formats.

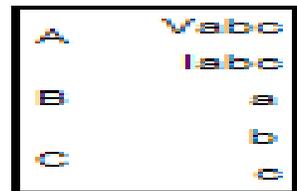
**(1) Three phase source block**



Three Phase Source Block

**(2) VI measurement block**

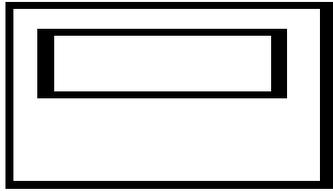
The V-I Three-Phase A measurement block is used in a circuit to measure three-phase voltages and currents. It returns the three phase-to-ground or phase-to-phase voltages and three line currents when connected in series with three-phase elements.



Three Phase V-I Measurement

**(3) Scope**

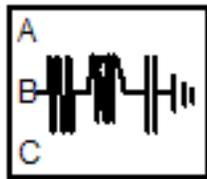
During a simulation, display signals are generated. The Scope block shows its input in relation to simulation time. The Scope block can have multiple axes (one for each port); all axes share a time range but have independent y-axes. You can change the amount of time and the range of input values displayed using the Scope. The Scope window can be moved and resized, and the Scope's parameter values can be changed while the simulation is running.



Scope

**(4) Three-Phase Series RLC Load**

The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.



Three-Phase Series RLC Load

**(5) Three-Phase Breaker block**

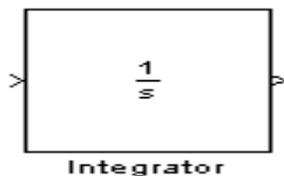
The Three-Phase Breaker block implements a three-phase circuit breaker, the opening and closing times of which can be controlled by an external Simulink signal or an internal control signal.



Three-Phase Breaker Block

**(6) Integrator**

**Library:** Continuous



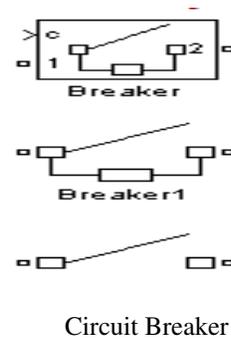
At the current time step, the integrator block outputs the integral of its input. The output of the block y is

represented by the following equation as a function of its input u and an initial condition y0, where y and u are vector functions of the current simulation time t.

**(7) Breaker**

Implement circuit breaker opening at current zero crossing.

**Library:** Elements



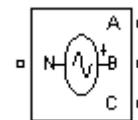
The model includes a series Rs-Cs snubber circuit. It is possible to connect it to the circuit breaker. If the Breaker block is in series with an inductive circuit, an open circuit, or a current source, a snubber must be used.

When the breaker is closed, Ron represents resistance. The Ron value can be set as low as necessary to be insignificant in comparison to external components (a typical value is 10 m ohms). When the breaker is open, the resistance is infinite.

**(8) Three-Phase Programmable Voltage Source**

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics

**Library:** Electrical Sources



Three Phase Voltage Sources

**(9) Trigonometric Function**

Specified trigonometric function on input

**Library:** Math Operations



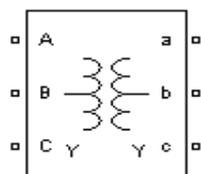
Trigonometric Function

**Purpose:** The Trigonometric Function block performs common trigonometric functions

**(10) Three-Phase Transformer (Two Windings)**

Implement three-phase transformer with configurable winding connections

**Library:** Elements

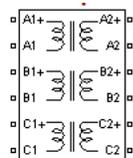


Three Phase Transformer

**(11) Three-Phase Transformer 12 Terminals**

Implement three single-phase, two-winding transformers where all terminals are accessible

**Library:** Elements



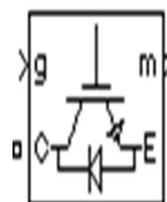
**Two winding Transformer**

**Purpose:** Three single-phase, two-winding linear transformers with twelve winding connectors are implemented by the Three-Phase Transformer 12 Terminals block. When the primary and secondary are not necessarily connected in Star or Delta, this block can be used in place of the Three-Phase Transformer (Two Windings) block to implement a three-phase transformer.

**(12) IGBT/Diode**

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

**Library:** Power Electronics



IGBT

**Purpose:** The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.

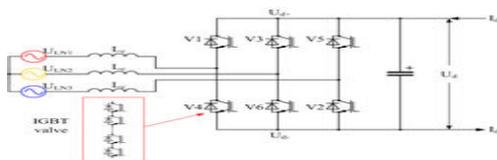
**PROPOSED SYSTEM SIMULATION**

In contrast to line-commutated HVDC converters, voltage-source converters maintain a constant polarity of DC voltage and power reversal is achieved instead by reversing the direction of current. This makes voltage-source converters much easier to connect into a Multi-terminal HVDC system or “DC Grid”. HVDC systems based on voltage-source converters normally use the six-pulse connection

**Two-level converter**

From the installation of the first VSC-HVDC scheme (the Hellsjön experimental link in Sweden in 1997[7]) until 2012, the majority of VSC HVDC systems built were based on the two level converter. The name comes from the fact that the voltage at the AC output of each phase is switched

between two discrete voltage levels, which correspond to the electrical potentials of the positive and negative DC terminals. When the upper of two valves in a phase is turned on, the AC output terminal is connected to the positive DC terminal, resulting in an output voltage of +12 Ud relative to the converter's midpoint potential. When the lower valve in a phase is turned on, the AC output terminal is connected to the negative DC terminal, resulting in a voltage of -12 Ud at the output. The two valves for one phase must never be turned on at the same time, as this would result in an uncontrolled discharge of the DC capacitor, potentially causing severe damage to the converter equipment.



Three-phase, two-level voltage-source converter

As a result, terms like "on-state" and "off-state" are meaningless in the MMC. The direct current is divided equally among the three phases, while the alternating current is divided equally among the upper and lower valves of each phase. As a result, the current in each valve is related to the direct current Id and alternating current Iac as follows:

Upper valve: 
$$I_v = \frac{I_d}{3} + \frac{I_{ac}}{2}$$

Lower valve: 
$$I_v = \frac{I_d}{3} - \frac{I_{ac}}{2}$$

The 400 MW Trans Bay Cable scheme is still the largest-capacity MMC HVDC system in operation as of 2012, but many larger schemes are under construction, including an underground cable interconnection from France to Spain consisting of two 1000 MW links in parallel at a voltage of 320 kV.

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 <sub>1</sub> battery (A)	0	+80	0
Current set-point to EV <sub>2</sub> battery (A)	0	0	-40

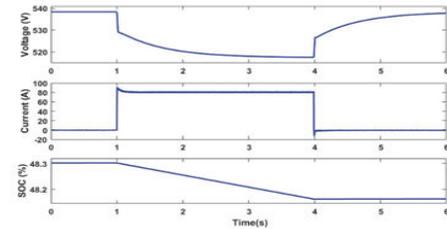


Fig. Voltage, current and SOC of EV1 battery during V2G operation

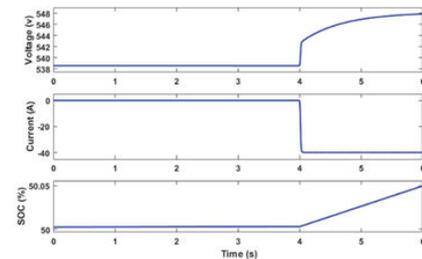


Fig.. Voltage, current and SOC of EV2 battery during G2V operation

. The power on the grid is adjusted to accommodate the power transferred by the EVs. The grid power's negative polarity from 1s to 4s indicates that the vehicle is supplying power to the grid. The polarity change of grid power at 4s indicates that power is supplied by the grid for charging the vehicle battery. This demonstrates the operation of V2G-G2V. Furthermore, the net power at PCC is zero, indicating that the system's power balance is optimal.

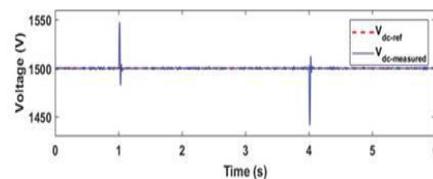


Fig. Variation in dc bus voltage

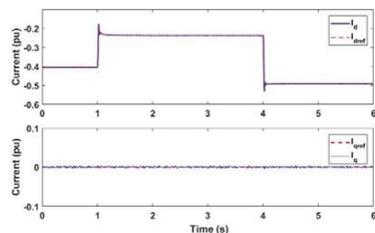


Fig. Reference current tracking by inverter controller

Voltage and current are in phase when G2V is used and out of phase when V2G is used, indicating reverse power flow.

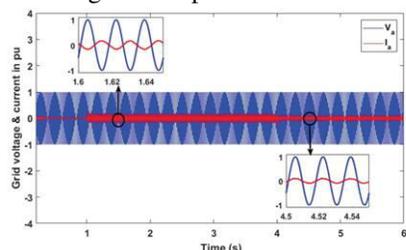


Fig. Grid voltage and grid injected current during V2G-G2V operation

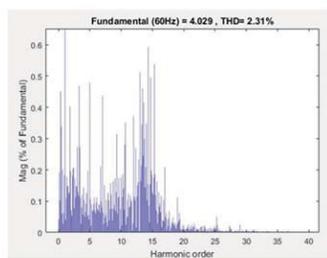


Fig. Harmonic spectrum and THD of grid-injected current

## CONCLUSION

This paper presents the modelling and design of a V2G system in a micro-grid using dc fast charging architecture. To connect EVs to the micro-grid, a dc fast charging station with off-board chargers and a grid-connected inverter is designed. This power electronic interface's control system enables bidirectional power transfer between EVs and the grid. The simulation results show that the power transfer between the EVs and the grid is smooth, and the quality of the grid injected current from the EVs meets the relevant standards. In terms of dc bus voltage stability and tracking the changed active power reference, the designed controller provides good dynamic performance. Active power

regulation aspects of the micro-grid are considered in this work, and the proposed V2G system can be utilized for several other services like reactive power control and frequency.

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