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Araştırma Makalesi / Research Article

DC Fast Charging Station Modeling and Control for Electric Vehicles

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Abstract

Due to environmental problems in the world, the need for electric vehicles is increasing. While the transition to Electric Vehicles continues, the acceleration of this process plays an important role in reducing environmental problems. In order to accelerate this transition, charging units should become widespread and charging time should be reduced. Higher power charging units are needed to reduce charging time. This is where DC (Direct Current) fast charging units come into play. In this study, the charging process of electric vehicles, the behavior of the DC fast charging unit on the battery and the control systems are modeled in MATLAB/Simulink environment. The designed model represents the electric power system that will charge electric vehicles and is suitable for more than one electric vehicle to be included in the DC fast charging system. The simulation is integrated according to the DC level-2 charging conditions. The system model consists of 1 AC(AC Current)/DC converter, 1 DC busbar, 2 DC/DC converters to charge electric vehicles and multiple EV batteries. The system model includes the design methods (AC/DC-DC/DC) design and different control strategies) and descriptions of these components. The simulation result shows that the filter and control system integrations in the electrical power system exhibit more stable behavior by correcting the negative effects on the power system. Thus, it offers positive outputs about the integration of DC fast charging units, which will increase rapidly in the future, into the power system and how this process should be established.

Keywords: Control System, DC Fast Charging, Electric Vehicle, MATLAB/Simulink.

Elektrikli Araçlar İçin DC Hızlı Şarj İstasyonu Modellemesi ve Kontrolü

Öz

Dünyadaki çevresel sorunlardan dolayı elektrikli araçlara olan ihtiyaç artmaktadır. Elektrikli Araçlara geçiş devam ederken bu sürecin hızlanması çevresel sorunların azalmasında önemli rol oynamaktadır. Bu geçişin hızlanması için şarj ünitelerinin yaygınlaşması ve şarj süresinin azalması gerekmektedir. Şarj süresini azaltmak için daha yüksek güçlü şarj ünitelerine ihtiyaç vardır. Burada DA (Doğru Akım) hızlı şarj üniteleri devreye girmektedir. Bu çalışmada, elektrikli araçların şarj edilme süreci DA hızlı şarj ünitesinin batarya üzerindeki davranışı ve kontrol sistemlerinin MATLAB/Simulink ortamında modellemesi yapılmıştır. Tasarlanan model, elektrikli araçları şarj edecek elektrik güç sistemini temsil etmekte olup DA hızlı şarj sistemine dahil edilecek aynı anda birden fazla elektrikli araç için uygundur. Simülasyon DA seviye-2 şarj koşullarına göre entegre edilmiştir. Sistem modeli, 1 adet AA(Alternatif Akım)/DA dönüştürücü, 1 adet DA bara, Elektrikli araçları şarj edecek 2 adet DA/DA dönüştürücü ve birden fazla elektrikli araç bataryasından oluşmaktadır. Sistem modeli, bu bileşenlerin tasarım yöntemlerini (AA/DA-DA/DA tasarımı ve farklı kontrol stratejilerini) ve açıklamalarını içermektedir. Simülasyon sonucu, elektrik güç sistemindeki filtre, kontrol sistemi entegrasyonlarının güç sistemindeki olumsuz etkileri düzeltilerek daha kararlı davranışlar sergilediğini göstermektedir. Böylelikle ilerleyen süreçte hızla artacak olan DA hızlı şarj ünitelerinin güç sistemine entegrasyonu ve bu sürecin nasıl oluşturulması gerektiği hakkında olumlu çıktılar sunmaktadır.

Anahtar Kelimeler: Kontrol Sistemi, DA Hızlı Şarj, Elektrikli Araç, MATLAB/Simulink.

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1. Introduction

Carbon emissions of conventional vehicles are among the biggest reasons for the continued rise of global warming in the world. EVs (Electrical Vehicles) work thanks to electric motor and battery cell packages. Since EVs are user and eco-friendly vehicles, the transition from internal combustion engine vehicles needs to be fast and practical. Shortening charging time is an important issue that will speed up the transition. However, this will cause more load in the power system, so both shortening charging time and improving power quality on the grid are seen as the most basic goals for EVs. DC fast chargers play an important role in this process to reduce charging time to optimal conditions. Due to the size and capacity of these systems, the charging system of EV is located outside the vehicle because of the high voltage and current. This allows the time to be reduced to 10 to 20 minutes levels. SAE J1772 standard, three-level DC fast charging;

1. DC Level 1; 200/450 V, 80 A, up to 36 kW,
2. DC Level 2; 200/450 V, 200 A, up to 90 kW,
3. DC Level 3; 200/600 V, 400 A, up to 240 kW,

allows (Sortomme et al., 2011).

While the entry of EVs into the market is increasing rapidly, the rapid charging of these vehicles without control systems and coordination has negative effects on the electricity distribution network (Clement et al., 2010). Basic problems that cause deterioration in grid power quality; current and voltage harmonics on the line, phase imbalance, voltage deviations, DC shift, leakage are rational. EV chargers are based on power electronics and are not linear, creating high-level harmonics in line current drawn from the grid (Thiringer et al., 2015). Control of the grid with intelligent control systems while charging the vehicle reveals G2V(Grid to Vehicle) and V2G(vehicle to grid) technologies, thus enabling control methodologies for EVs to operate in harmony with each other and with the grid (Deilami et al., 2011). The control and component connection system of the networked EV is shown in Figure1.

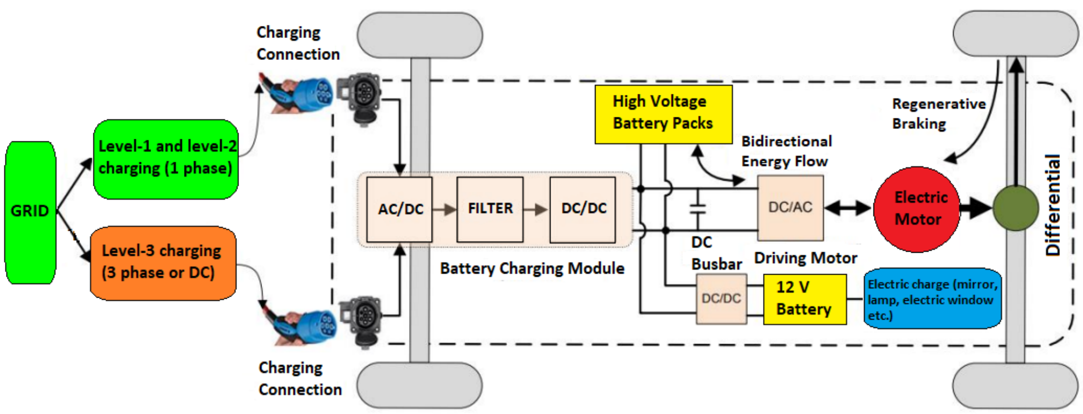


Figure 1. Control and component connection system of EV connected to the network.

EVs are tools with two-way power flow, rechargeable on single- and three-phase networks, and include DC/DC and AC/DC converters. The DC part represents the battery, while the AC part represents the power from the grid (Shyamala et al., 2015). When designing the control system and charging units throughout, the following considerations are given:

1. Suitable areas for EVs to park in (important for the number of EVs to charge)
2. Demand forecast for DC fast charging slots for designated suitable area
3. Parameter constraints on the grid (permissible power and rated voltage level)
4. Per unit, the permissible charging power ratio.

One of the most important components for charging these electric-based vehicles is the charging ports, and the other is the charging sockets. In addition to complying with the standards to be charged, EV's electrical infrastructure must also be suitable for charging the charging unit and fasteners. There are standard and prepared charging levels suitable for each EV. For example, the current parameter for EV or hybrid EV can be charged from low-level-1 chargers or from level-2, level-3 chargers that can offer high-value current. The connection equipment to be used may also vary depending on the type of charging unit, the current presented to the vehicle, the voltage level and the country in which the system is located.

In addition to the fact that EVs can be provided with the conditions required for optimal charging and control systems that keep these conditions within a certain framework, there are international standards for ensuring control. These standards both ensure safety and provide optimal solutions. Below isa list of charging port and socket standards in Figure-2 and Figure-3.

Figure 2. EV Charging ports.

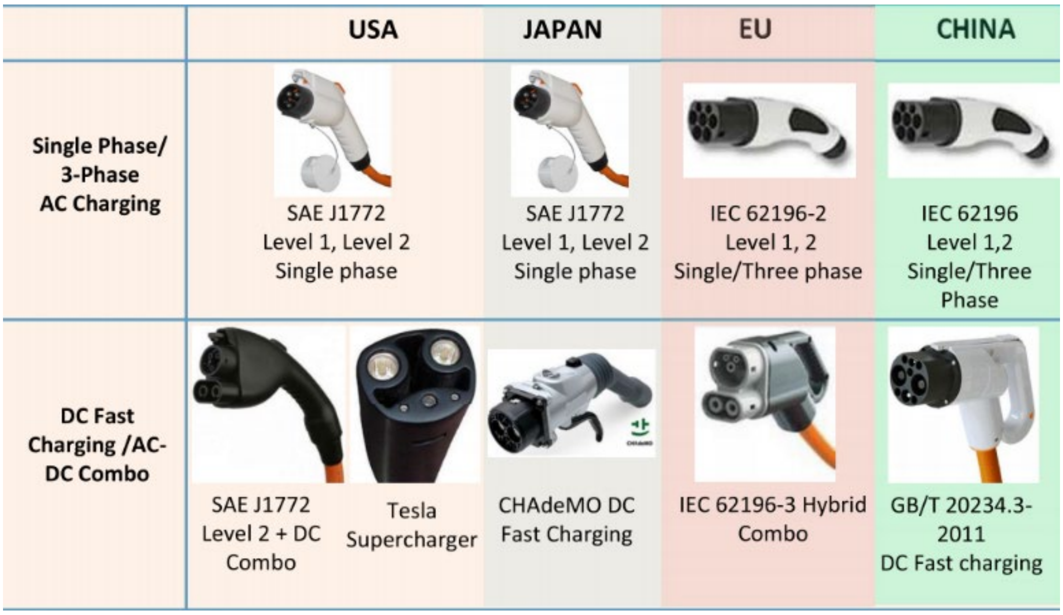


Figure 3. EV Charging Sockets.

Given all these factors and the conditions required, improvements to EVs will further the charging infrastructure and EVs. Thus, the transition from internal combustion engine vehicles to electric motor vehicles will gain speed while at the same time becoming a practical process. It should be noted that ensuring safety, increasing charging speed, ease of access to chargers are important issues in the transition to EVs.

In the study, the concept known as "charging station" was referred to as a "charging unit" in order to be a more accurate use. This study includes the calculation of the parameters of the charging unit and other electrical power system equipment, the presentation of mathematical formulas, the design of the Simulink model, the interpretation of battery measurements by sharing, the general evaluation of the model. These contents are presented in stages in the following sections. The simulated transducers used in this study are simple/ideal type transducers. It's not like that in the real world.

2. Materials and Methods

2.1 Calculation of Parameters of DC Fast Charging Unit

The fast-charging unit requires DC connection. Controlling the DC connection is also important. There are several different DC bars voltage control schemes. Two of these control schemes are widely used: Master slave and droop control. For DC bar control strategy and models, it is recommended to examine the article in reference (Karlsson et al.,2003) in detail.

The voltage of the DC connection is adjusted according to the mains voltage. In this study, DC connection voltage can be regulated independently of the mains voltage. This arrangement can be made according to the ratio of the cutting voltage of the battery and the modulation index of the battery charger. The stabilization of the DC bar with the inverter output connection depends on the size of the capacitor, which continues its fluctuations in the DC current value. This fluctuation can be very high as a large number of EV chargers can be connected to the bar. For this reason, the capacitor value should be high. It is appropriate to use the equality presented as (4) from calculations on to find the appropriate DC capacitor value.

Here are the highlights: the maximum values at the current and voltage value of the specified DC charging level are the reference values of the current and voltage values in the battery. The reason for the assignment of these values is because the specified EV cannot exceed the maximum power value. Below is the formula for calculating the power of EV in equality (1).

$$P_{EA} = V_{maks} \times I_{maks} \tag{1}$$

The importance of making the visible power calculation is due to the fact that the load coefficient to be formed in the power system, the power to be withdrawn from the number of charging slots to which the EV to be charged can be connected, and the power factor value of the system can be easily met by the active and reactive forces required by the system. Below is the formula for calculating the visible power value in equality (2).

$$A = \frac{k_{y\ddot{u}k} \times N_{yuva} \times P_{EA}}{cos\, \phi} \tag{2}$$

The task of the capacitor on the DC bus is to ensure that the fluctuation is kept at a certain level because the variability of the fluctuation current on which the EV charger on the DC bar can be connected to multiple values. When the switching status is low (BUCK) the switching block at the bottom of the output terminal is short that the DC connection is shorted to the negative end of the DC connection is ideally zero. On the other hand, the switching block is effective when the switching status is high (Boost). For this reason, the output voltage is ideal to the output voltage as the positive end of the DC connection is ideally equal to the V_{dc} parameter . In the equities in the following (3) and (4), the DC bar capacitor value and DC bar voltage can be made.

$$\mathrm{V_{dc}} \leq \frac{\mathrm{V_{a,min}}}{\mathrm{m_{min}}} \tag{3}$$

$$C_{dc} = \frac{A \times 2 \times n \times T \times \Delta G \times \cos\phi}{(V_{dc})^2 \times \Delta V} \quad (4)$$

2.2 Battery Charger

Double-sided DC / DC converter selection plays a very important role in the chargers of EVs. Most existing bidirectional DC / DC converters are characterized by current or voltage supplied from one side . The current in double-sided transducers must be transported to both sides. Since there is no power key that works in this way, the one-way power key such as MOSFET or IGBT should be preferred in parallel with the diode (Tytelmaier et al., 2016).

Battery chargers are power converters. These systems are an indispensable part of many power systems that require energy transfer from one voltage value to another, as the required voltage value may be different from the voltage value provided. These systems can be used in three different structures: Buck, Boost and Buck-Boost Converters. IGBT switching is used in the modeling that represents the charger. The reason for two IGBT switching use in the design is charged with two different values expressed as Buck (low value) and Boost (high value) when charging the battery. The Buck-Boost converter produces larger than the DC bar (Boost) and smaller (BUCK) output voltage. The battery charger is always composed of two-way DC / DC converter through two IGBT switching operating with complementary control signals.

The DC / DC Buck-Boost Converter should be monitored when designing several steps. Stages required for designs to be made from the basic level;

• Determine the status variables for the power circuit and type the switching status space model.

• Assign values according to open and closed conditions for switching blocks.

• Set the conditions that manage the status of the switching blocks

• Connect the switching status space model with the expected system model by applying all operating modes of the transducer by applying the current-voltage laws.

• Convert the resulting model into integral form.

• Model the extracted equations through simulink blocks.

• Use the resulting switched status space model to design linear and non-linear controllers.

• Analyze the model by simulating the closed cycle.

• Set up the algorithm to work in the appropriate intervals of the whole model and determine the step size (Khajezadeh et al., 2014).

After these steps, the duty cycle of the Buck-Boost converters (Duty Cycle) will range from 0 to 1. When the transistor is on, the input voltage to the inductor is applied and thus increases the current in a linear manner. The capacitor provides the load current and partially discharges. The transistor is closed in the other loop. In this case, the voltage in the inductor returns in the polarity and switches to the diode transmission. In this cycle process, the warehouse energy is loaded in the inductor and charges the capacitor again. The following Figure 4 has Buck-Boost Converter.

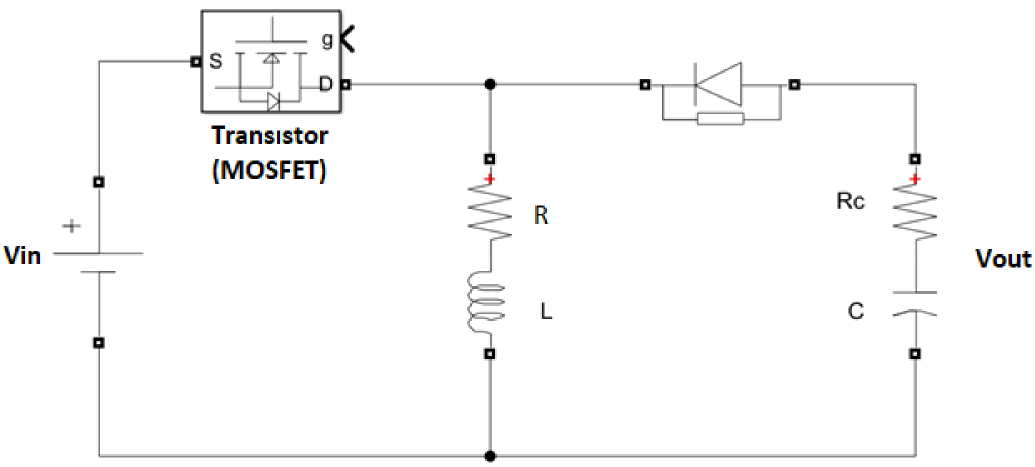


Figure 4. DC/DC buck-boost converter circuit diagram.

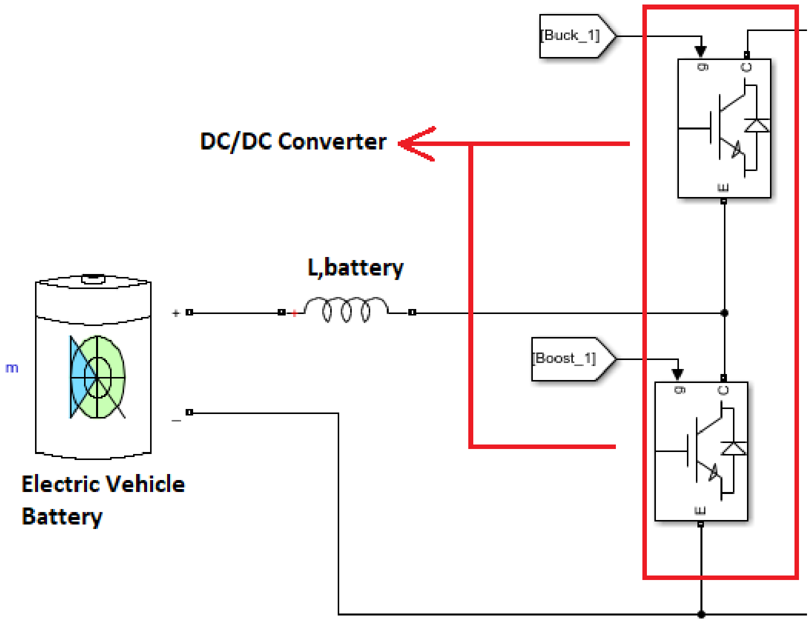


Figure 5. Battery charger modeling (DC/DC converter).

2.3 Electric Vehicle Battery

Recently, rapidly advancing technological developments also increase the need for portable power supplies. The batteries for portable power are indispensable. The batteries can be used as a power source by storing electrochemical energy. Batteries can be examined as primary and secondary in two separate categories in two separate categories, Zn (zinc), NiMH (nickel-metal hydride), NiMH (nickel cadmium), and li-ion (lithium ion), and li-ion (lithium ion) batteries. In this study, preferred lithium-ion batteries are entering the lithium battery family. This battery family often includes the advantages of energy intensity, without memory impact, flexibility, as well as in addition to the system protection needs, disadvantages such as challenges and costs in transport. The said power density is the measure of how much energy may be due to the clayogram (kg) or the discharge at a certain time period on a liter (L). The energy density is the amount of energy on the basis of kilogram (kg) or liters (l).

For long distances, Battery EVs are one of the largest disadvantages to be limited range. Especially with low temperature, low battery capacity and strength of the auxiliary devices, the requirements of the additional energy requirements decrease in the reasons. On the other hand, the battery is required for the power, security and economy of an EV. The best design of the battery management system will significantly contribute to the life of the battery.

The battery model is used to define working dynamics. This model is indispensable for estimating SOC status and simulation of battery management system. It is also difficult to model and simulate this process . In general, a battery model is divided into two electrochemical, artificial neural network and equivalent circuit model (Pramanik et al., 2016). The equivalent circuit model comprises resistance, capacitors, fixed voltage source and other circuit elements to simulate the battery dynamics (Qin et al., 2019). When the widely used equivalent circuit models are examined, Rint, RC, PNGV, Thevenen models (Johnson, 2002).

Thevenin links a parallel RC element in series, based on the Rint model describing the dynamic features of the battery. This circuit diagram is mainly composed of three different parts: open circuit voltage (VOC), internal resistance and equivalent capacitor (Singh et al., 2008). The model of the-equivalent circuit models were used when simulating in this study was used and are shared below in Figure 6.

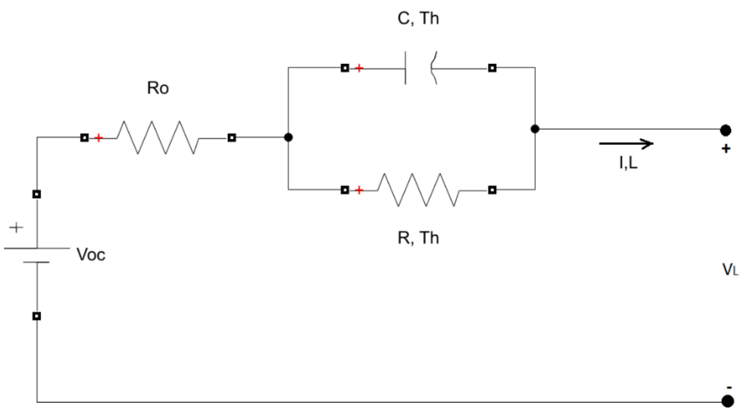


Figure 6. Battery Thevenen equivalent model.

The battery characteristics to be selected in the power system model to be calculated are important. These parameters should be revised according to the desired result as there will be a battery in the system that will draw power as a load. Electric vehicle battery parameters are given in Table 1.

Table 1. Electric Vehicle Battery Parameters.

Description	Value reference
Battery Technology	Lithium-ion
SOC	%50
Battery Capacity	35 kWh
m_{min}	0,125
Series Resistance (R_{series})	0,0175 Ω
Transient Resistance ($R_{transient}$)	0,245 Ω
Transient Capacitor ($C_{transient}$)	8,1 F
Battery Inductance (L_b)	0,002 H
Open-Circuit Voltage (V_{oc})	400 V
Minimum Battery Voltage ($V_{min, bat}$)	200 V
Control Loop	CC/CV(Constant Current/Constant Voltage)

2.4 Three Phase Inverter

AC/DC converters, inverters or rectifiers;

- ASDs(Adjusted Speed Drives),
- In HVDC(High Voltage Direct Current) transmission,
- In electrochemical processes,
- Telecommunication power supplies,
- Battery charging,
- Ups
- High-capacity magnet power supplies,
- High-power induction heating tools,
- Aircraft transducer systems,
- Plasma power supplies,
- Renewable energy conversion systems

it is widely used in many applications such as.

Since multi-phase AC/DC converters have all the potential applications for unilateral and double-sided power flow from six pulses to more than six pulses, important work is being done to develop new topologies of multi-impact AC/DC converters. The main advantage of using the greater number of pulses is the reduction of the current fluctuation. Categorization of multi-phase AC/DC converters occurs within the framework of power flow, number of pulses used, isolated and non-ins isolated topologies. Based on various techniques used to improve ac current profile and DC output voltage waveform. The classification of multi-phase AC/DC converters is shared below in Figure-7 (Iqbal et al., 2018).

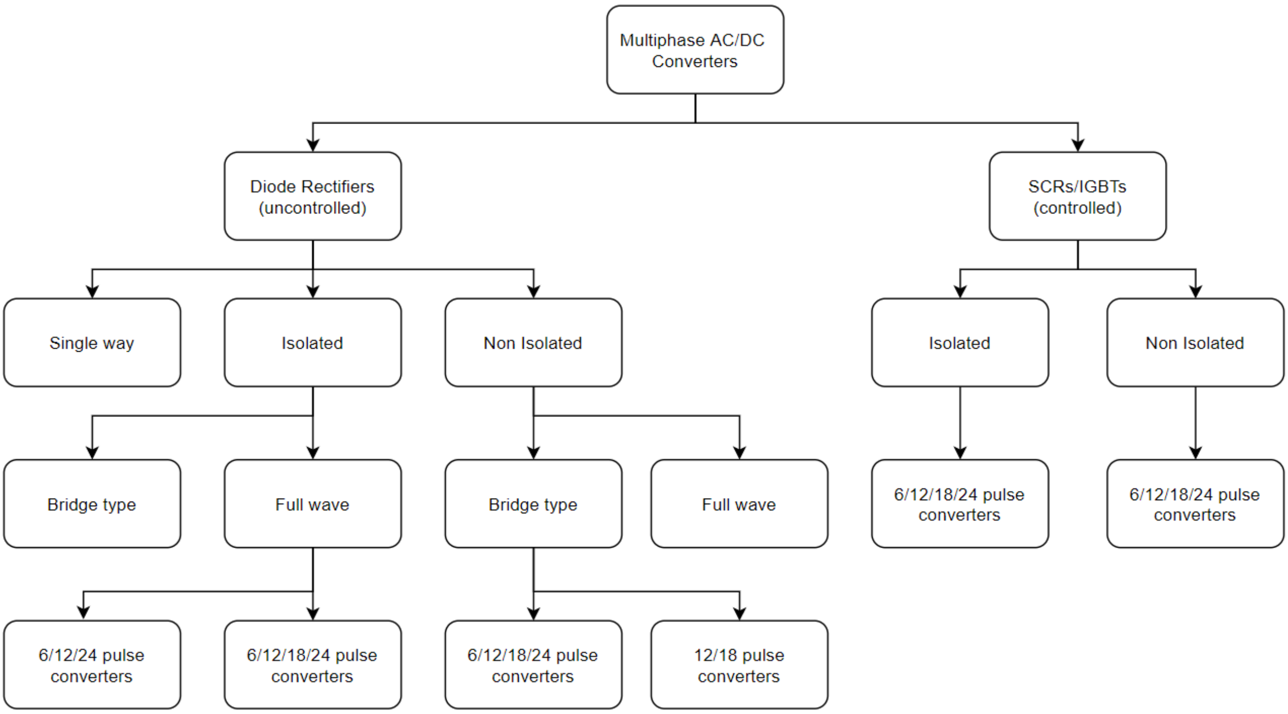


Figure 7. Multi-phase AC/DC converter categorization.

The three-phase inverter in the modeled power system is used to turn AC power DC power. The Universal Bridge block used as the inverter in the design is used by the IGBT preferential choice. The universal bridge block allows the use of six power switches connected in a bridge configuration and the use of power transformation. Is a block in the basic structure used to form two-level voltage welded converters .

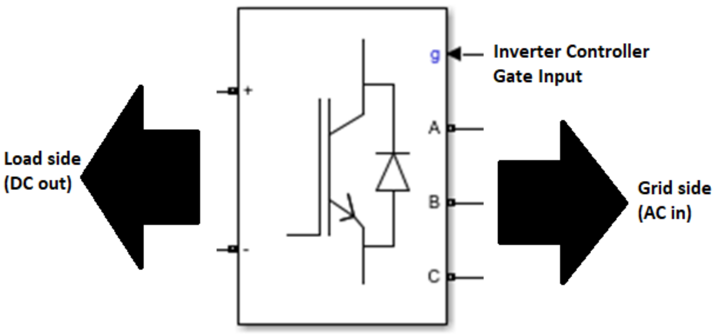


Figure 8. MATLAB/Simulink block three-phase inverter.

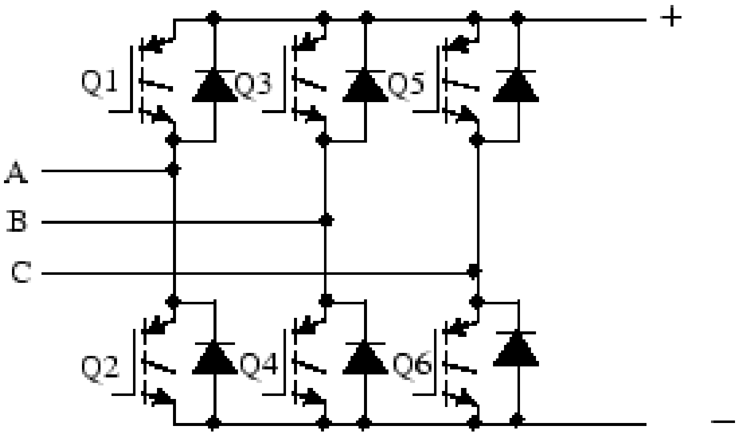


Figure 9. Three-phase inverter configuration (AC/DC converter).

The transformative topologies that can be used for electric vehicles are given in Table 2.

Table 2. Converter Topologies for Electric Vehicle.

Parameters/Topology	2-L Bridge	3-L D-NPC	3-L A-NPC	3-L D-NPC	Bi-directional Inverter	2-L Inverter/ Rectifier
Phase Number	3	3	3	3	6/3	1/3
Transistor/ Diode Number	6/6	12/18	18/18	12/12	12/12	6/7
Capacitor Number	1	2	2	2	1	2
DC Voltage Range (V)	300-600	400-1000	400-300	300-600	400 - 1000	300 -400
Power Density	High	High	Midlevel	Midlevel	Midlevel	High

2.5 Filter

Filters are divided into two separate groups in terms of construction elements, active and passive filters. The filter model used in this study belongs to the passive filter group. Passive filters are used as mains converter interface to reduce the harmonic effect in the system and to meet electromagnetic compatibility standards. Many passive filter topologies have been reported in the literature. Inductive filters were first recommended in the literature. These filters are first order filters. For this reason, a high value inductor is required to reduce the harmonic effect, but a high value inductor will lead to a high voltage drop. Therefore, the response of the control time is affected by this situation. Therefore, in order to reduce the size of reactive circuit elements, higher value switching frequencies should be preferred. It should be noted that increased switching frequency increases the losses in the power converter. The characteristic of second order LC filters is that they increase the higher frequencies and the reduction in filter volume. The downside of the LC filter topology is the presence of a resonant frequency that can amplify high order current harmonic components, and in addition, problems from inrush currents in the output capacitor arise. High-order current harmonic components cause general instability in the installed system. LCL filters, as an alternative solution to LC filters, with developments, It is a third-order passive filter used in many voltage source applications. The LCL filter topology results in a reduction in volume and voltage drop through inductors compared to the simplest L topology. In addition, the two inductors used serve to limit the inrush current in the capacitor and increase converter durability due to the degree of inductance variation in the network. The most important advantage of the LCL filter over the LLCL filter, which uses two inductors, is that the system can remain in a steady state. In grid interactive inverters, current control is generally used as a control method because the waveform and phase value of the current carried to the grid are important .It causes a reduction in volume and voltage drop by means of inductors. In addition, the two inductors used serve to limit the inrush current in the capacitor and increase converter durability due to the degree of inductance variation in the network. The most important advantage of the LCL filter over the LLCL filter, which uses two inductors, is that the system can remain in a steady state. In grid interactive inverters, current control is generally used as a control method because the waveform and phase value of the current carried to the grid are important. It causes a reduction in volume and voltage drop by means of inductors. In addition, the two inductors used serve to limit the inrush current in the capacitor and increase converter durability due to the degree of inductance variation in the network. The most important advantage of the LCL filter over the LLCL filter, which uses two inductors, is that the system can remain in a steady state. In grid interactive inverters, current control is generally used as a control method because the waveform and phase value of the current carried to the grid are important system to remain in a steady state. In grid interactive inverters, current control is generally used as a control method because the waveform and phase value of the current carried to the grid are important system can remain in a steady state. In grid interactive inverters, current control is generally used as a control method because the waveform and phase value of the current carried to the grid are important. Applying Kirchhoff's laws and transforming it into a rotating reference frame reveals the continuous pattern of the LCL filter in the dq transform frame (Dannehl et al., 2009). LCL mains filters are more preferred for reducing PWM (Pulse Width Modulation) sourced harmonics due to their good filtering properties at higher levels of resonant frequencies . An example of this is high power applications, especially where the switching frequency is very limited by the losses (Teichmann et al., 2005). In LCL filters, as in LC filters, the increase in capacitor size leads to a reduction in filter cost and weight . The LCL filter provides better decoupling between the filter and mains impedance and lower levels of fluctuation of current stress on the mains inductor. LCL filter design was made in the modeled power system, since the LCL filter was deemed appropriate thanks to the mentioned features. The mains voltage at the common junction is subject to background disturbances at low frequency harmonic levels.

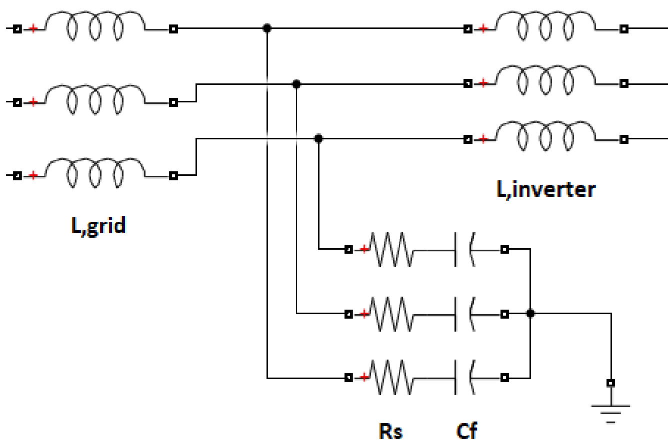


Figure 10. LCL Filter.

The inductance value of the inverter side inductor can be calculated by adjusting the THD_i between 10% and 30% based on the fundamental and switching frequency passed at the 1691 2010 International Power Electronics Conference. Taking THD_i below 10% at first increases the inductance of the inverter side inductor. Accordingly, the resonant frequency decreases and approaches the bandwidth of the controller. On the contrary, if the inverter side inductor inductance is taken more than 30%, this time the resonant frequency will increase and resonance may occur in the switching frequency bandwidth. For these reasons, a suitable value between 10% and 30% should be taken in order for the resonant frequency to be between the bandwidth of the controller and the switching frequency. In addition, Equation (6) below can be used to obtain the network inductance. After setting the appropriate DAF value for this, this calculation can be made (Park et al.,2010). Equation (5), which calculates the inductance value of the inverter coil, is shared below. The appropriate DAF value for this designed model was taken according to the parameter in Table-3.

$$\mathrm{L_{inv}} = \frac{\mathrm{V_s}^2}{\mathrm{A} \times THD_i \times 2\pi \mathrm{f_{sw}}} \times \sqrt{\frac{\pi^2}{18} \times \left(\frac{3}{2} - \frac{4\sqrt{3}}{\pi} \times \mathrm{m_i} + \frac{9}{8} \times \mathrm{m_i}^2\right)} \tag{5}$$

$$L_{şebeke} = \frac{DAF+1}{DAF \times C_f \times 2\pi (f_{sw})^2} \tag{6}$$

While designing the LCL filter, the impedance of the circuit, the capacitor and the inductance of the coil are shared in the equation (7), (8), (9) below.

$$\mathrm{Z_t} = \frac{(\mathrm{V_{a,t}})^2}{\mathrm{A}} \tag{7}$$

$$C_t = \frac{1}{\omega_{rez} \times Z_t} \tag{8}$$

$$L_t = \frac{Z_t}{\omega_{rez}} \tag{9}$$

For the design of the filter capacitor, the maximum power factor change seen by the network is assumed to be 5% since it is multiplied by the basic capacitor value of the system in the equation 10 below.

$$C_f \leq \frac{0{,}05 \times A}{2\pi f_s \times (V_s)^2} = \frac{0{,}05}{\omega_{rez} \times \mathrm{Z_t}} = 0{,}05 \times C_t \tag{10}$$

The most important parameter in filter design is the cutoff frequency. This value should be at least half the switching frequency of the converter because the converter must have sufficient damping in the switching frequency range. The cutoff frequency of the LCL filter can be calculated by the following equations (11) and (12).

$$\omega_{rez} = \sqrt{\frac{L_{inv} + L_s}{L_{inv} \times L_s \times C_f}} \tag{11}$$

$$f_{rez} = \frac{\omega_{rez}}{2\pi} \tag{12}$$

The LCL filter will amplify the frequencies within the cutoff frequency range, as it cannot act against oscillations. Therefore, filter damping needs to be added in the design. The simplest way is to add a damping resistor (Kahlane et al., 2014). Equation (13) is shared below to calculate the LCL filter damping resistance.

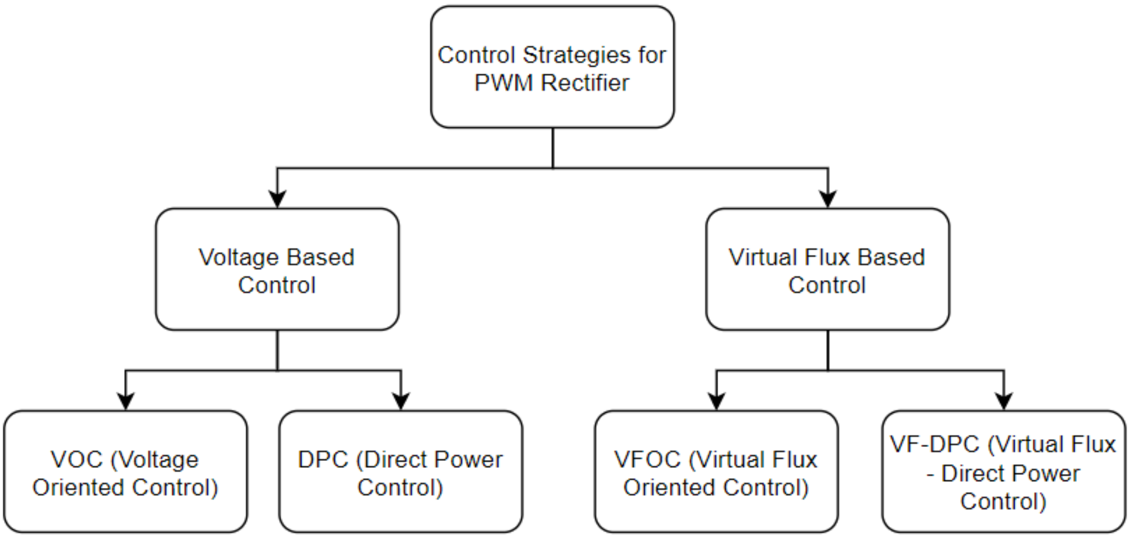
$$R_s = \frac{1}{3 \times C_f \times \omega_{rez}} \tag{13}$$

After calculating the resonance frequency, and determining the switching frequency and network frequency, it should be taken into account that the resonant frequency value should be between 10 times the network frequency and half of the switching frequency. Equation (14) for this calculation is shared below.

$$10 \times f_s < f_{rez} < \frac{f_{sw}}{2} \tag{14}$$

2.6 Inverter Controller

Power electronics applications in grid systems are growing rapidly due to the potential to change the future of power systems in terms of production, operation and control .There are several control strategies in PWM rectifiers. These control strategies are shared in the diagram in Figure-11 below.



Multi-phase AC/DC converter categorization.

All mentioned control strategies can achieve the same goals such as high-power factor and near sinusoidal current input waveforms.

• Voltage Directional Control: A strategy that guarantees high dynamic and static performance through an internal current control, but the quality depends on the current control strategy.

• Direct Power Control: Based on instantaneous active and reactive power control loop. Does not include internal current control loop and PWM modulator.

• Virtual Flux Based Control: Represents a direct analogy of induction motors control.

It would be appropriate to choose these control strategies according to the model of PWM rectifiers to be used.

The abc/dq, abc/αβ transformation is applied in the control model. These are called transfer transformations. This is because the current must be in phase with the mains voltage. For this, while making the transfer conversion, the wt or in other words θ (phase angle) on the model should be connected to the abc/dq transfer conversion (Svensson, 2001). As a solution to this situation, it may be possible to use arctan (arc tangent trigonometric function) to filter the voltage signal received from the network and obtain θ from it (Arruda et al., 2001). In addition, the PLL model has become the newest method for obtaining the phase angle of the grid voltages in the case of distributed generation systems.As in the general modeling for the synchronous rotating frame control structure, coupling operations and forward voltage are often used to improve the performance of the PI(Proportional+Integral) controller. For a better understanding of the transfer transformations, the abc/dq Park transformation and the abc/αβ Clarke transformation are shown in Figure-12 and Figure-13 as a graphical representation below.

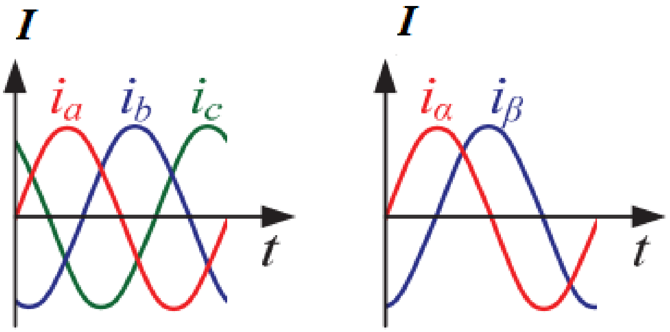


Figure 12. abc/αβ Clarke Transformation.

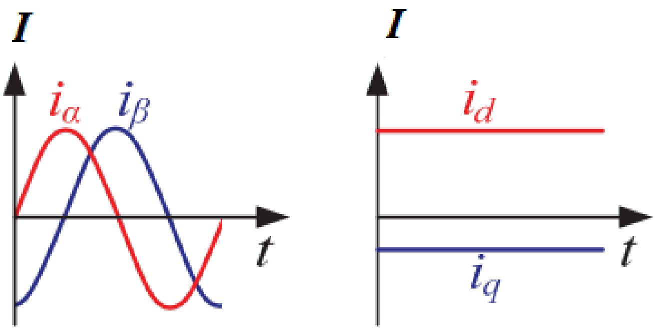


Figure 13. abc/dq Park Conversion.

The inverter voltage is converted from three phase abc to dq0 using the Park transform. Here, a 50 Hz synchronization signal is also used via the PLL block. Then, Vd reference signal and Vq reference signal will be compared to generate the error signal, and the voltage value given in equation (15) shared below will be fed to the control algorithm PI controller (Bhattacharjee et al., 2018).

$$v(t) = K_p e(t) + K_i \int_0^t e(t)\,dt \tag{15}$$

One of the control strategies that can be applied when a fault occurs on the system is to monitor the positive series of mains voltages. In contrast to the unit power factor control, a PLL(Phase Lock Loop) system is required that can detect the imbalance in the control structure in case of failure.

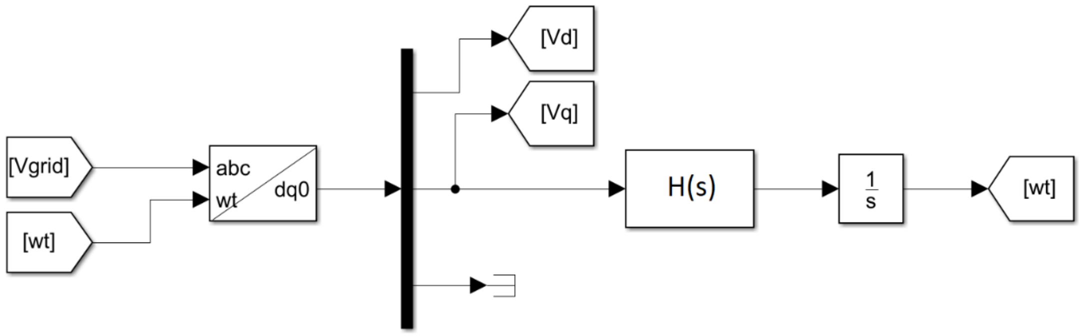


Figure 14. Inverter control Simulink model (PLL block diagram).

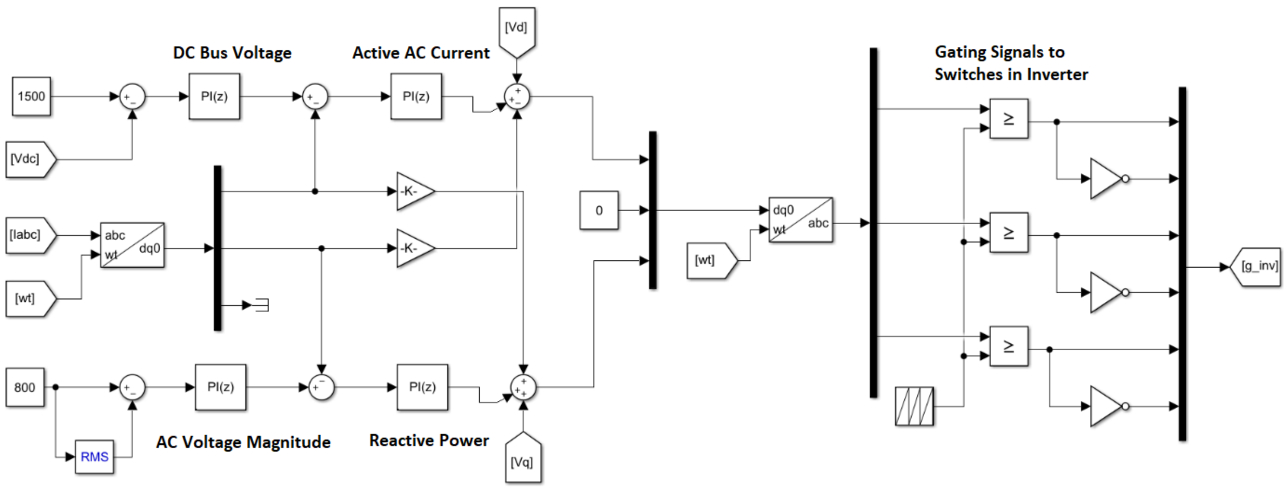


Figure 15. Inverter control Simulink model.

2.7 Battery Charger Controller

There is a need to charge the battery in the most appropriate way according to the power requirement of the EV, and to control the battery due to the coordination between the battery cells and the positive and negative effects it will create on the entire storage system. The battery control system measures important values such as temperature, voltage, current, SOC and gives information about the problems.

For fast charging, the charging process should be checked as high-speed charging can damage the battery. The SA/SG charge control strategy is the most suitable fast charging method for charging the lithium-ion battery because lithium-ion batteries are vulnerable to damage when exceeding the maximum voltage limit (Moon et al., 2011). When the battery voltage reaches the upper voltage limit, SA mode switches to SG mode. As a battery charge control strategy, battery charge control can be performed by using only SA, only SG, or SA/SG at the same time. Commercial battery chargers usually start with SA mode and continue in many steps of constant current at a rate of 0.5°C to 1°C or cut-off voltage. The battery will continue to be charged by maintaining the charging current SG up to 0.1°C. Two different charging modes, SA/SG, have a direct impact on the charging time, the amount of energy supplied to the battery and then the energy to be recovered. Basically, two additional charging steps, known as balancing and buffer charging, are also included, designed for periodic battery maintenance. This type of charging mode of the battery is shown in the Figure-16 below. New technology battery chargers basically, As seen in Figure-16, they are DC/DC converters operating in closed-loop control that operate in SA/SG charging mode. The life cycle of a battery varies considerably depending on the healthy charging of the battery. A healthy charging strategy not only shortens the charging time, but also significantly extends the life and capacity of the battery. The converter in SA mode operates in this control logic by providing constant current transmission. Here the converter acts as a current source. While charging the battery, up to 80-90% is done with SA mode. As this strategy continues, tensions continue to rise slowly and gradually. This phase will continue to increase the voltage until it reaches the assigned reference voltage value. After reaching this level, the charge will switch to SG mode, stabilizing the voltage and reducing the current. In this way, the converter will start operating in constant voltage mode. When this mode is activated, the current will continue until the current drops to 0.1 C, which represents the end of the SG charge cycle. In this way, the battery charge reaches 100% and the battery is charged to full capacity (Ferdous et al., 2020).

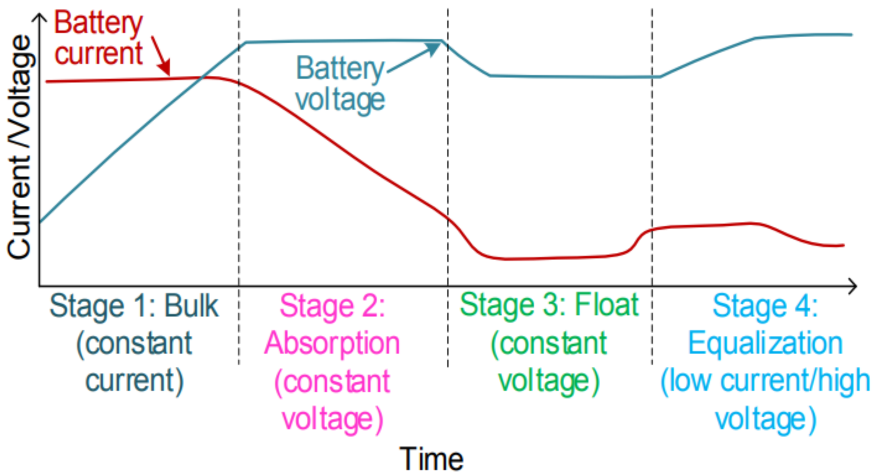


Figure 16. Different steps of battery charging preferred in practice.

When the literature is reviewed, it has been seen that various charging methods are recommended to solve the problems of long charging time, low charging efficiency and temperature rise due to charging in SA/SG method. In terms of modified SA/SG based charge management, open circuit voltage and charge current are input into fuzzy controller to improve SG mode of SA/SG charge method (Chyun et al.,2001) and allow higher charge capacity at the same time. A double loop control method is adopted in (Tsang et al., 2001). It allows the creation of a charge curve similar to that applied from the SA/SG method. This does not necessitate measuring the charging current, which can drive down the realization cost. By commanding the phase error and sending it to the current source to generate the appropriate charging current, A PLL control strategy is recommended, which allows to achieve charging performance similar to the SA/SG charging method. Aiming at improving the negative effects of in terms of constant voltage charging, proposes a current pump battery charging method; Pulse current is used to charge in SG mode, while current pump is used to charge in SA mode (Chen et al., 2021). Battery charge control modeling is shown below. As mentioned, the battery is charged with two different control strategies. In Figure-17, (a) represents the part where the charge is made with constant current, and (b) the part where the charge is made with constant voltage. Each model has outputs representing low (buck) and high (boost) values. These outputs reach the different IGBT switching of the DC/DC converter and form the charging characteristic.

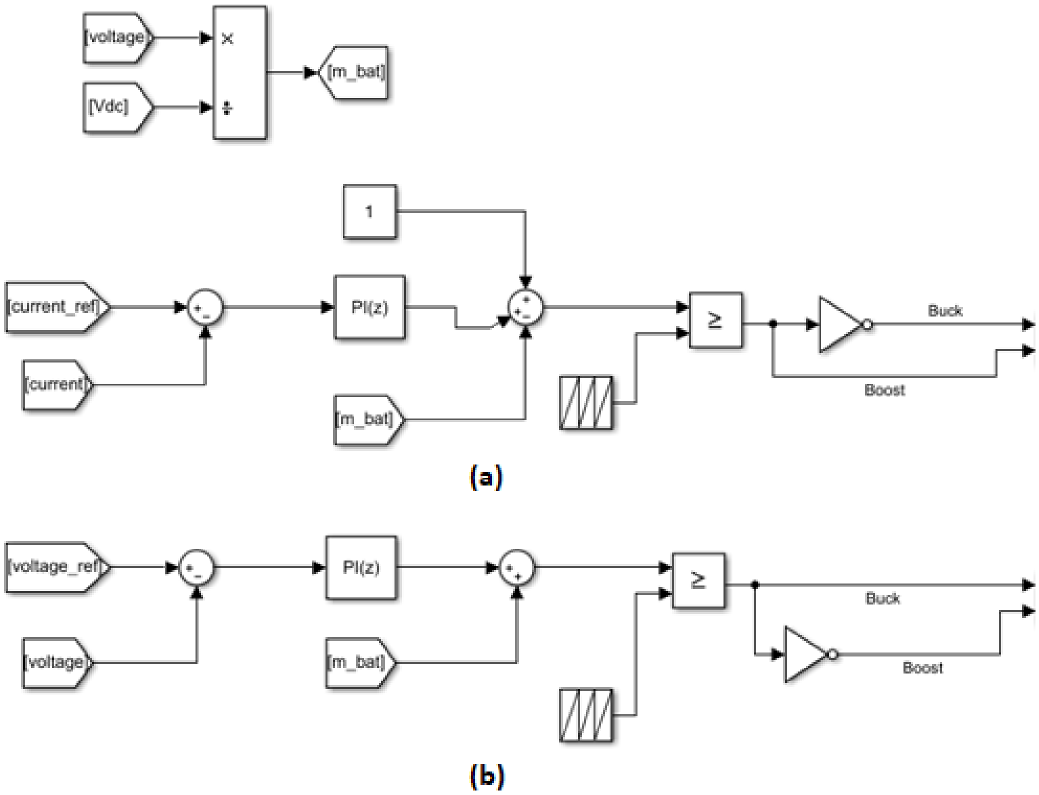


Figure 17. Battery charging control Simulink model.

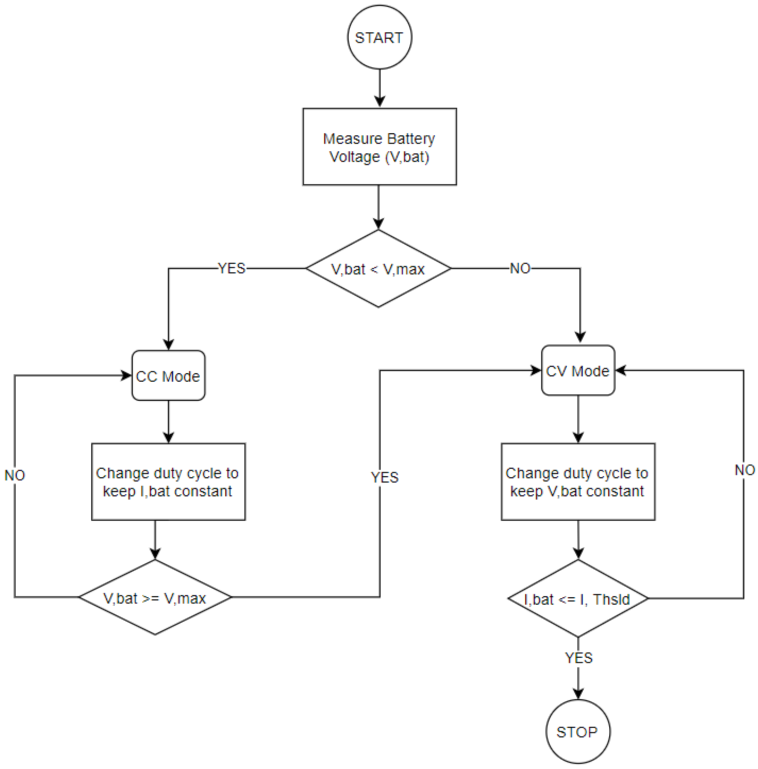


Figure 18. Battery charge SA/SG control flow diagram.

Figure 19 shows the general model of the system. In the previous sections, the modules that make up the system are given in sections.

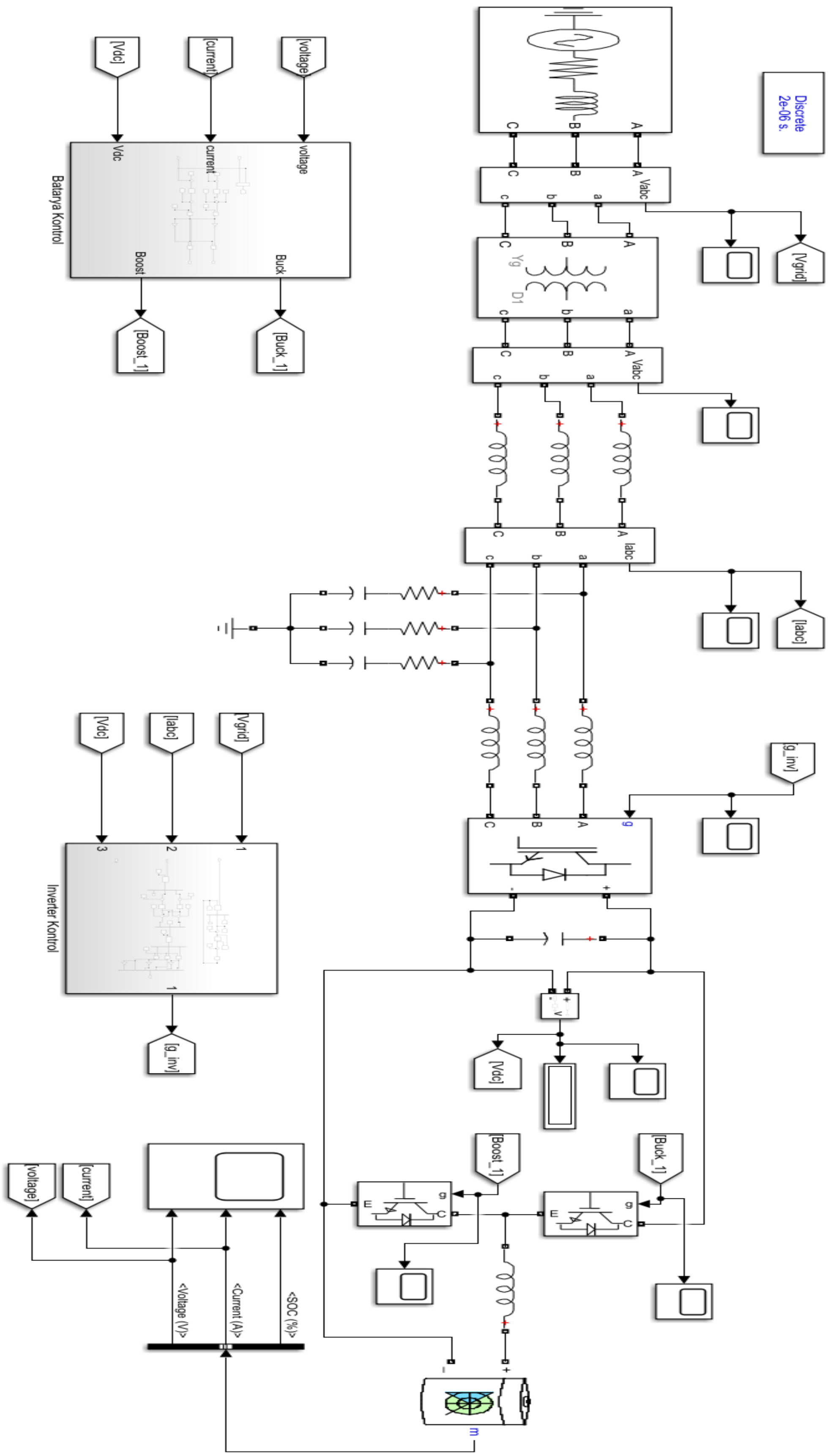


Figure 19. Matlab Simulink Model of the General System

2.8 Simulation

Input and output parameters of the designed Simulink model are given in Table-3 and Table-4. Provided that these parameters are within the scope of the standards, different values can be selected for the model to be designed and simulation can be performed. After designing the model, it is important to determine the simulation sampling and time values to simulate the model. Making the right decisions about these are the issues that are necessary for the simulation to be carried out correctly. The integration method applied for this study is based on “ode23t”. At least 100 samples should be taken in the period with the fastest frequency of the integration method. The simulation time step is based on “2 μs” calculated from the equation shared in (16) below.

$$\tau_s = \frac{t_s}{f_{sw} \times n_s} \tag{16}$$

Table 3. Simulation Input Parameters for Designed Model

Description	Value
THD_i(Total Harmonic Distortion Current)	%5-30
RAF(Reduction Factor	%20
N_{slot}	10
PEA(Power of Electric Vehicle)	90 kW
k_{load}(Overload Factor)	1,1
cos φ(Power Factor)	0,95
T(Period for AC Voltage)	0,02sn
n	0,5
f_{sw}(Switch Frequency)	5 kHz
Three Phase Short-Circuit Level	1200 MVA
Phase-Phase Voltage (Vrms)	20 kV
X/R ratio	8
Frequency	50 Hz
Primer Voltage	20 kV
Seconder Voltage	800 V
Frequency	50 Hz
Winding Connection	Δ – Yg

Table 4. Simulation Output Parameters for Designed Model

Description	Value

A (Apparent Power)	1050 kVAR
ΔG (Power Changing Range)	%10
ΔV (Voltage Range)	%20
C_{dc}(DC Bar Capacity)	0,018 F
V_{dc}(Dc bar Voltage)	1500 V
C_f (Filter Capacitor)	0,000165 F
L, inv (Inverter Inductance)	0,00048 H
L, grid (Grid Inductance)	0,00069 H
Rs (Damping Resistor)	1,31 Ω

3. Conclusions and Recommendations

Increasing environmental problems in recent years, transformation in energy systems, digitalization are the issues that affect the transition to EVs the most. From this point of view, one of the most important issues in the transition to EVs, the integration of charging units into the grid, has been discussed. DC fast charging units come to the fore due to the need for high power energy as the charging time needs to be shortened in order for EVs to be more preferred. In this study, DC fast charging unit for EVs was modeled in MATLAB/Simulink environment.

In the modeling, the power coming from the network creates a DC bus line through the AC/DC converter. The DC bus line represents the stage required for charging the EVs. All EVs to be connected to the charger will draw power from the DC bus. As the number of EVs to be connected to the grid increases, the fluctuations on the DC bus will also increase. In order to keep these fluctuations at a certain level, adding a capacitor is necessary to keep the fluctuations at the desired level. Keeping the fluctuations at a certain level has shown that more effective results are obtained in EV charging. The reason of this; While the battery inside the EV is charging, the indefinite charging process will damage the EV battery. It is important to identify these uncertainties. According to the nominal values of the battery's charging current and voltage; It is necessary to determine cut-off voltage, full charge voltage, discharge current, maximum current values and to determine the current and voltage values for the DC bus supply. The model designed in this study supports fast charging of 10 EVs at DC level-2 at the same time and supports 200 kV mains voltage, 800 V transformer output voltage, 1.5 kV DC bus voltage.

In order to keep the mentioned values at the specified levels, control design is required. The charger charges the EV battery using the power it receives from the DC bus. The part that will control this process is the battery charge controller. The inverter takes the power from the grid and feeds the DC bus after AC/DC conversion. The part that will control this process is the inverter controller.

Battery charge control and inverter control design means controlling the transition of power from the electrical power system to the EV battery. By including these control designs in the model, battery charge and DC bus voltage are kept at desired levels. In the study, the design was carried out using the constant current (SA) strategy in battery charge control and the dq conversion conventional strategy in inverter control. In addition, different inverter control strategies were mentioned in the design, and battery charge control was designed in accordance with the constant current-constant voltage (SA/SG) strategy. A system model is presented in which different control strategies can be applied.

When the results are examined, the battery voltage value fits into the full charge voltage value determined within the framework of the nominal parameters entered into the battery. The voltage increases continuously up to this level and ensures that the current is kept constant. The current value, on the other hand, provides a constant current value based on the discharge current value determined within the framework of the entered nominal parameters. With the implementation of the SA/SG strategy, the current value will decrease after the voltage settles to the full charge voltage and it will perform the charging process at higher currents. In this way, high current will support faster charging. Thus, it has been determined that with the development of control strategies, high-speed charges will be paved. It is recommended to carry out studies by examining the power quality on the grid while charging at high speeds.

Authors' Contributions

All authors contributed equally to the study

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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