An Active Front-End Controlled On-Board Charger for Power Quality Improvement in Electric Vehicles

Dr. K. Vijayakumar[1], Arulselvan M[2], Harini R K[3], Tharunraj R[4]
[1]Me.,Phd Associate Dean (Academics) Dr. Mahalingam College Of Engineering And Technology, Coimbatore,India Affiliated To Anna University, Chennai
[2,3,4] Department Of Electrical And Electronics Dr. Mahalingam College Of Engineering And Technology, Coimbatore,India Affiliated To Anna University, Chennai

Abstract—**With the increased use of electric vehicles (EVs) in recent years, there has been an increasing demand for an effective and reliable charging system that will ensure minimum impact on the electricity grid. The on-board charger (OBC) acts as a converter between the alternating current from the grid to the direct current required to charge the battery of the electric vehicle. Most existing chargers make use of diode bridge rectifiers coupled with DC-DC converters. Such chargers are inexpensive and easy to construct but have several disadvantages including low power factor, high total harmonic distortion and poor efficiency of power utilization which causes degradation of power quality.**

This paper proposes an Active Front-End (AFE) controlled on-board charger for electric vehicle applications to get around these problems. The suggested system uses a three-phase Voltage Source Converter (VSC) with Insulated Gate Bipolar Transistors (IGBTs) and an RL input filter to cut down on harmonics. To control the DC-link voltage and shape the input current, a closed-loop control strategy that uses dq-axis transformation, Phase-Locked Loop (PLL), and Proportional-Integral (PI) controllers is used.

Simulation and analysis of the proposed system have been carried out using MATLAB/Simulink. It is observed that the proposed system performs satisfactorily by providing a power factor of nearly unity and reducing THD considerably, along with ensuring a constant DC output voltage. Thus, the proposed system serves as a useful approach toward enhancing power quality in EV charging systems.

Index Terms—**Active Front-End (AFE), Electric Vehicle (EV), Power Quality, Total Harmonic Distortion (THD), Power Factor, PI Controller, MATLAB/Simulink.**

I. INTRODUCTION

Due to the rise in environmental pollution and exhaustion of fossil fuels, more people have turned to electric vehicles for their daily transportation needs. Electric cars are seen as a better option than internal combustion engine cars since they are energy-efficient and environmentally friendly. With the growing popularity of EVs, there is a rising need for better and efficient charging stations for EVs.

One of the vital parts of the electric car is the on-board charger that changes the input AC power to DC power. The traditional approach involves the use of diode bridges followed by DC-DC converters in the design of the system. Even though this approach is easy and affordable, it has many problems related to power quality.

Harmonics in the current will result in waveform distortion and loss. It will make the electrical devices heat up. Low power factor makes the use of electrical energy inefficient and causes excess flow of current into the electrical system from the source. All these factors not only impact the performance of the charger but also cause poor power quality in the entire electrical network.

One way that can be used to overcome these problems is by adopting Active Front-End (AFE) rectifiers. These devices do not use traditional methods; rather, they utilize controlled power electronic switching mechanisms. The input currents and voltages can be regulated through a control algorithm, and hence, unity power factor is achieved with minimal harmonic distortion.

This research focuses on the development of an Active Front-End based onboard charger to enhance the power quality in EV charging applications. The design uses a three-phase voltage source converter with an RL filter and employs closed-loop control, which comprises dq axis transformation, PLL, and PI control. The design's effectiveness is simulated by using MATLAB/Simulink software.

II. SYSTEM CONFIGURATION

This system for AC to DC conversion using Active Front-End has been divided into two subsystems; the first one is called the power circuit, and the other one is known as the control system.

The Power Circuit comprises three phase AC source, RL input filter, Active Front-End Rectifier and a DC-Link Capacitor which is further connected to the Load.

The Control System comprises Measuring blocks, Phase Locked Loop (PLL), Coordinate Transformation, P.I. Controllers, and Pulse Width Modulator.

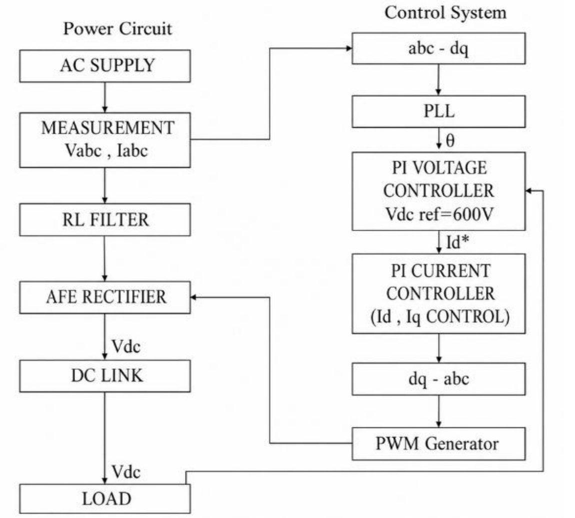

Figure 1. Block Diagram of Proposed System

Three-phase AC Source has been used for this model with a supply voltage of 380 Volts at a frequency of 50Hz. The Input Voltage and Current have been fed to the control system from the measuring blocks.

The Active Front-End rectifier, made with IGBT switch technology, converts AC into DC power in a regulated manner. The DC-Link Capacitor regulates the output voltage to produce a DC power source for the load or the battery of the electric vehicle.

The Control System makes sure that the input current is a sine wave and is in phase with the input voltage, hence achieving unity power factor.

III. CONTROL STRATEGY

The control strategy employed in this system follows the closed-loop structure where the dq-axis transformation technique is adopted. In such a control scheme, the AC variables are transformed into DC variables using the dq-axis transformation technique, thus simplifying the control design.

Firstly, the voltages and currents of the three-phase inputs are sampled and converted to dq variables through the abc–dq transformation. The PLL is adopted to obtain the phase angle of the grid voltage.

There are two feedback control loops in this control strategy.

In the outer control loop, the difference between the DC link voltage and the reference voltage of 600 volts is calculated. This difference is then fed into a PI controller that produces the reference current for the d-axis.

On the other hand, the inner control loop calculates the error between the actual current and the reference current and feeds it into a PI controller. While the d-axis controller manages the active power, the q-axis controller maintains the reactive power at zero levels.

The output from the current controller is changed into the abc frame again by doing dq to abc transformations. The

signals obtained are used to produce the PWM pulses used to control the switching in the IGBT converter.

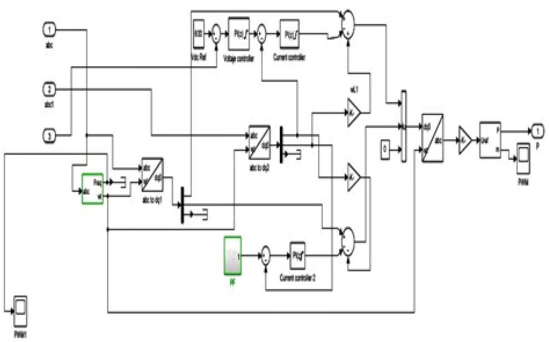

Figure 2. Simulation Of PLL Sub-System

This type of control system makes sure that the input currents are sinusoidal, while the output voltage is maintained at a constant level.

IV. MATHEMATICAL MODEL

DC Voltage Error

$$e(t) = V_{dc,ref} - V_{dc}$$

PI Controller

$$I_d = K_p e(t) + K_i \int e(t)dt$$

Unity Power Factor

$$I_q = 0$$

V. SIMULATION MODEL

A simulation and modeling of the designed active front-end-controlled On-Board charger are done through MATLAB/Simulink platform to study the behavior of the design under different operating conditions. The simulation is executed in a discrete domain with a sampling time of 1e-6 seconds.

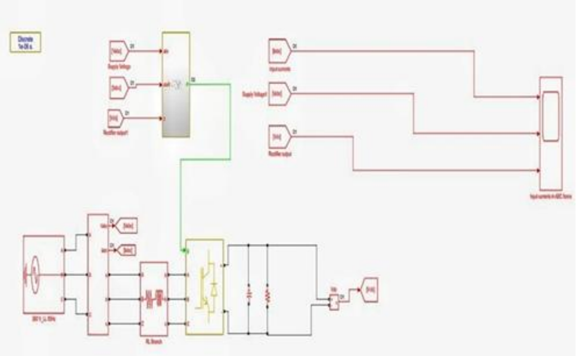

Figure 3. Simulation Of Proposed System

Some important parts included in the simulation model are the three-phase AC power source, an RL-input filter, a voltage source converter, a DC-Link capacitor, and finally, the resistive load which simulates the EV Battery

The three-phase AC source generates sinusoidal voltages at 380 Volts amplitude and frequency of 50 HZ. An RL filter is used as a filtering technique where it is placed between the source and the VSC. The design parameters of the inductance and resistance are considered to reduce the harmonic distortion.

The heart of the entire system lies in the Active Front-End converter that uses IGBT switches configured in a bridge form. The switching of these switches is done using PWM pulses produced in the control subsystem.

After the Active Front-End, a DC-Link Capacitor is present that produces a constant voltage by suppressing the voltage ripples. The load present across the DC link is the battery of the electric vehicle considered here, and this can be simulated as a resistive load.

This control subsystem has a Phase Locked Loop (PLL), abc-dq and dq-abc conversions, voltage and current controllers (both of these being PI type) and a PWM generator.

Moreover, measurement blocks are employed to measure the input voltage, input current, and DC-link voltage. An analysis block known as THD analysis block is used to analyze the harmonics present in the input current.

This simulation is developed to validate whether the circuit can generate a stable output DC voltage, keeping the input current sinusoidal in nature.

VI. RESULTS AND DISCUSSION

1. Input Voltage Waveform

The input voltage wave form obtained from the three-phase AC supply is seen to be symmetrical and sinusoidal in shape. The magnitude of the voltage wave form is held constant at 380 volts and frequency at 50 Hz. There is no distortion in the wave form, thus implying that it is an ideal wave form.

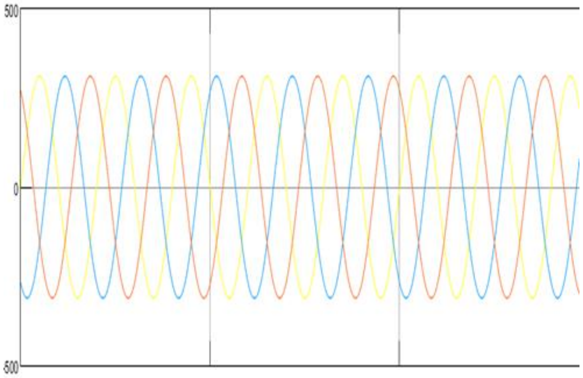

Figure 4. Input Voltage Waveform

2. Input Current Waveform

One of the important parameters that measure power quality is the input current waveform. In the new design, it is seen that the input current waveform is almost sinusoidal and is perfectly synchronized with the input voltage waveform. This shows that the power factor of the proposed model is almost unity.

The utilization of Active Front End (AFE) Converter and d-q axis control system helps minimize the harmonic content of the current and ensure the continuity of the current drawn from the source.

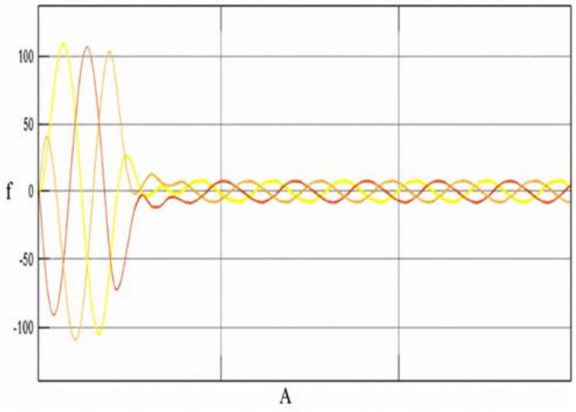

Figure 5. Input Current Waveform

3. DC-Link Voltage

The DC-link voltage is held constant at a reference level of 600 V. The graph illustrates the smooth increase of the voltage during the first transitory period, after which the voltage stabilizes.

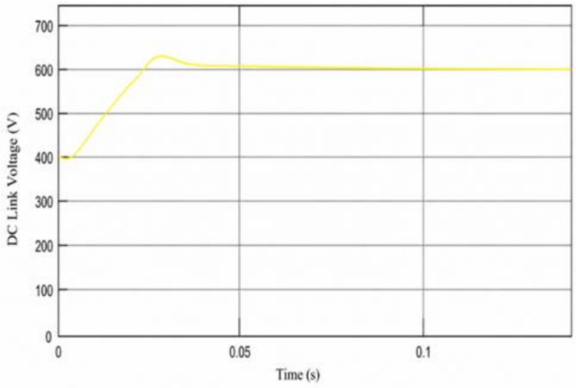

Figure 6. Dc-Link Voltage

It is important to note that without the use of the DC-link capacitor, the voltage ripple could not have been reduced; the output voltage would not be able to stay constant. In addition, the PI controller controls the voltage very effectively.

4. THD Analysis

THD was analyzed with the help of the FFT-based THD measurement block. The result obtained indicates that the magnitude of the component of the fundamental frequency, which is 50 Hz, is 7.527, while THD is 4.80%.

From the FFT analysis spectrum:

- The fundamental frequency component prevails, suggesting appropriate energy conversion
- Higher order harmonics exist; however, their amplitudes are much smaller than that of the fundamental component
- The entire current waveform is almost sinusoidal, as can be seen from the time-domain waveform plot

The THD ratio of 4.80% is within acceptable levels (<5%, according to IEEE standards), thus validating the efficacy of the suggested AFE rectifier circuit for reducing harmonics.

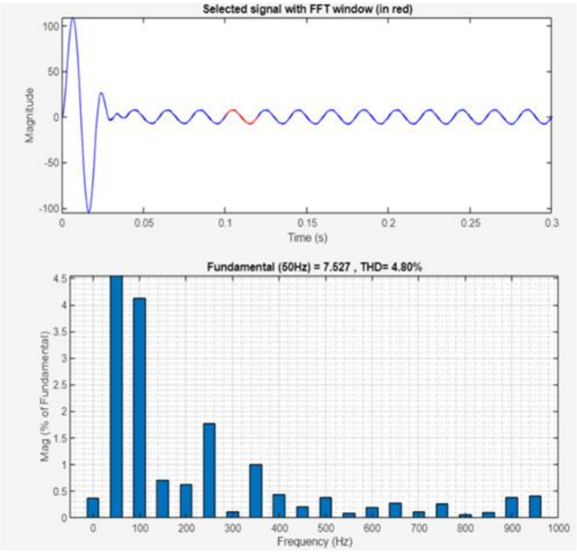

Figure 7. FFT Plot of THD

5. Performance

People look at how well the system works under different conditions, like power factor, harmonic distortion, and voltage regulation. Compared to traditional rectifier-based chargers, the system works much better.

The input current is sinusoidal and in phase with the input voltage. This is a clear sign that the power factor is almost one. Also, the THD is much better. Also, the DC output voltage stays the same with very little ripple.

These results show that the Active Front-End controlled charger that was made is a good design. It will make the power better and make sure it runs well.

VII. CONCLUSION

An Active Front-End controlled on-board charger has been presented and examined in this study. It consists of an RL input filter, a three-phase voltage source converter, and closed loop control that uses the dq axis transformation approach.

It has been shown that the designed system can function with low total harmonic distortion and power factor near unity. Additionally, it keeps the DC output voltage low ripple and consistent. Phase Locked Loop and proportional integral controllers are used to guarantee proper synchronization of system parameters.

The suggested solution exhibits significant improvements in power quality and system efficiency when compared to conventional rectifier-based chargers. It is therefore an excellent option for electric vehicles.

REFERENCES

[1] A. Zhaksylyk, H. Rasool, and E. Abramushkina, Feb 2023, “Review of Active Front-End Rectifiers in EV DC Charging Applications,” Batteries, vol. 9, no. 3, pp. 1–25, doi: 10.3390/batteries9030120

[2] S. Safayatullah, M. A. Hannan, A. Mohamed, and A. Hussain, 2022, “A Comprehensive Review of Power Converter Topologies and Control Methods for Electric Vehicle Fast Charging Applications,” IEEE Access, vol. 10, pp. 40753–40793, doi: 10.1109/ACCESS.2022.3172050

[3] H. Akagi, Dec 2005, “Active Harmonic Filters,” Proceedings of the IEEE, vol. 93, no. 12, pp. 2128–2141, doi: 10.1109/JPROC.2005.859603

[4] M. Liserre, F. Blaabjerg, and S. Hansen, Sept 2005, “Design and Control of an LCL-Filter-Based Three-Phase Active Rectifier,” IEEE Transactions on Industry Applications, vol. 41, no. 5, pp. 1281–1291, doi: 10.1109/TIA.2005.853373

[5] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, Oct 2006, “Overview of Control and Grid Synchronization for Distributed Power Generation Systems,” IEEE Transactions on Industrial Electronics, vol. 53, no. 5, pp. 1398–1409, doi: 10.1109/TIE.2006.881997

[6] Y. Yang, K. Zhou, and F. Blaabjerg, July 2012, “Current Harmonic Reduction Techniques for Grid-Connected Converters,” IEEE Transactions on Industrial Electronics, vol. 59, no. 7, pp. 2849–2860, doi: 10.1109/TIE.2011.2165450

[7] J. Rodriguez, M. P. Kazmierkowski, J. R. Espinoza, et al., May 2013, “State of the Art of Finite Control Set Model Predictive Control in Power Electronics,” IEEE Transactions on Industrial Informatics, vol. 9, no. 2, pp. 1003–1016, doi: 10.1109/TII.2012.2221469

[8] S. Busquets-Monge, J. Bordonau, and D. Boroyevich, July 2008, “Multilevel Diode-Clamped Converter for Photovoltaic Generators with Independent Voltage Control of Each Solar Array,” IEEE Transactions on Industrial Electronics, vol. 55, no. 7, pp. 2713–2723, doi: 10.1109/TIE.2008.924160

[9] B. Singh, B. N. Singh, A. Chandra, et al., Oct 2003, “A Review of Single-Phase Improved Power Quality AC–DC Converters,” IEEE Transactions on Industrial Electronics, vol. 50, no. 5, pp. 962–981, doi: 10.1109/TIE.2003.817609

[10] P. Cortes, J. Rodriguez, S. Vazquez, and L. G. Franquelo, Dec 2008, “Predictive Control in Power Electronics and Drives,” IEEE Transactions on Industrial Electronics, vol. 55, no. 12, pp. 4312–4324, doi: 10.1109/TIE.2008.2007480

[11] M. Malinowski, M. P. Kazmierkowski, S. Hansen, et al., July 2001, “Virtual-Flux-Based Direct Power Control of Three-Phase PWM Rectifiers,” IEEE Transactions on Industry Applications, vol. 37, no. 4, pp. 1019–1027, doi: 10.1109/28.936392

[12] T. Noguchi, H. Tomiki, S. Kondo, and I. Takahashi, May 1998, “Direct Power Control of PWM Converter Without Power-Source Voltage Sensors,” IEEE Transactions on Industry Applications, vol. 34, no. 3, pp. 473–479, doi: 10.1109/28.673726