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AN INTELLIGENT BIDIRECTIONAL INTERLEAVED ELECTRIC VEHICLE CHARGER WITH ADAPTIVE CURRENT CONTROL AND DISTURBANCE REJECTION

[1]MR.K.RAJESH BABU, [2]THATI SHIVA KUMAR, [3]SINGAM VIJWAL SAI, [4]KASANI SAI RAM

[1](Assistant professor), EEE. Guru Nanak Institutions Technical Campus, Hyderabad.

[234]B.Tech Scholars, EEE. Guru Nanak Institutions Technical Campus, Hyderabad

ABSTRACT

In order to enable rapid charging from a single-phase distribution grid, our proposal suggests using a multi-leg variable frequency converter-based electric vehicle (EV) charger with an enhanced adaptive current modulation method. The multi-leg bridgeless converter reduces electromagnetic interference (EMI) while increasing input energy usage. Because fewer big passive components are needed thanks to the high-frequency converter leg, the suggested architecture is more resilient to frequent parameter fluctuation. For quicker dynamical control in grid-to-vehicle (G2V) and vehicle-to-grid (V2G) scenarios with diverging distribution grid conditions, an adaptive sliding mode control (ASMC) has been devised. Because the tracking error is contained inside the pre-defined sliding surface during a rapid shift in adaptive gain variation, the ASMC offers a superior dynamic responsiveness. In order to handle additional nonlinearities during the EV charging operation, the suggested control action essentially removes the proportional-integral (PI) controller. To examine the different dynamic responses of the converter and the suggested control action, a MATLAB & SIMULINK model is created. In order to confirm the intended character with the improvement of the source-end power factor during active power exchange in the G2V mode of operation of 3.3 kW EV charger.

1.INTRODUCTION

1.1 General

The increasing number of electric vehicles (EVs) in the transportation industry is expected to contribute significantly to the greater drive towards sustainable mobility. The system is now more user-friendly overall because to the widespread use of digital control, whether in the motor controller or car charger, and the efficient stimulation provided by a central management system (CMS).
In the utility grid, EVs are becoming more often seen as a broad spectrum of distributed energy. Therefore, in order to address different grid power quality difficulties, the EV battery storage units are now exposed to bi-directional charging rather than being limited to uni-directional charging operation alone. Bidirectional charging is becoming more and more appealing due to ongoing advancements in battery technologies that have better depth of duty (DOD), charging or discharging rate (C-rate), and overall longevity. In order to meet different grid-connected power needs, the EV charge controller is more accurately monitored and controlled by many reliable control algorithms in the current environment. The efficiency of smooth control action for rapid charging and grid power quality management is primarily contingent on the bi-directional energy usage and converter architecture. While the single-stage isolated arrangement [1] is appropriate in certain situations, the two-stage power conversion architecture is most often used for EV charging operations. The use of multistage AC-DC converters to enhance grid power quality has been covered in a number of literary works [2]. In order to provide an EV battery unit with a changeable charging option at varying states of charge (SOC), isolated multi-stage AC-DC topologies, such as those shown in [3], are often recommended. The Front-end rectification (FER), intermediate power factor correction (PFC), and an isolated DC-DC stage are the three stages involved in the unidirectional charging procedure. Numerous converter topologies may be appropriately accommodated at every step of the operation, depending on the application and degree of complexity. The bidirectional EV operation was driven by the desire to use EVs in different grid power quality-related concerns. In the majority of commonly used bi-directional charging topologies, a regulated voltage source converter takes the role of the FER and PFC stage to provide a two-stage power conversion. In several EV charger designs, the efficiency of the second stage power conversion has adequately boosted by multiple switching adjustments. Several literatures have described common topologies, including dead-band modification, resonant power conversion, double phase shift modulation, and single-phase shift (SPS) approach [4-5]. In [6], a multifunctional EV charger with optimal switching under various load circumstances was able to reach an efficiency of up to 95% at the DC-DC conversion stage. Even while most DC-DC converters can achieve b1 high efficiency via a variety of modulation techniques, more attention has to be paid to the overall system efficiency and stability of the whole cascaded converter setup. A grid-connected charger's FER must be appropriately constructed to regulate the bi-directional charging current while putting the least amount of switching stress on it.
Even while the input passive filters diminish the switching transients, they may be further reduced by using a bridgeless interleaved architecture. In [7], a multi-loop interleaved boost rectifier architecture with a series combination of phase-shifted switches and a parallel combination is presented. The neighboring legs of a multi-leg boost interleaved rectifier design work in phase-shift mode to reduce current ripple. The interleaved bi-directional bridgeless rectifier (IBBR) is known for its benefits, which include decreased common-mode noise interference, low conduction losses, and inherited potential for bi-directional current carrying capabilities [8]. While the IBBR can be easily controlled by the cascaded control approach, it might be challenging to preserve audio susceptibility in multiple stage converter topologies and range-bound rigid load regulation during rapid charging operation. A multi-loop control with feed-forward voltage control is experimentally verified in [9] to maintain voltage imbalances in common mode capacitors. However, greater duty ratios used to keep the DC connection constant at low battery SOC levels often result in continuous ON/OFF sequences across semiconductor switches. Similar outcomes are also seen under light load circumstances, when it is preferable to use a pulse skipping method to lower switching loss [10].

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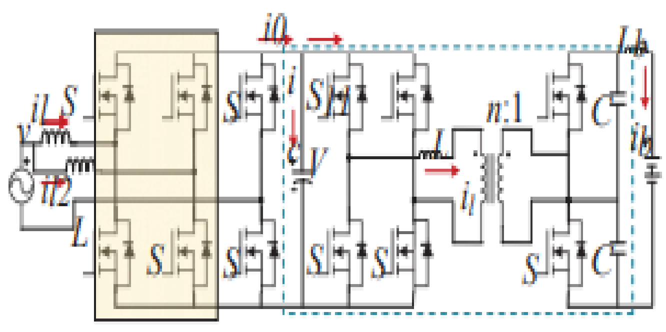

Fig-1.1: Circuit topology for multi-leg inverter based EV charger

A higher concentration of EV charging stations may result in even worse system performances with poor grid power quality. In a system-level bi-directional EV charging topology, the intermediate DC link is fed from the FER during G2V mode of operation, and the charging current solely depends upon the EV mode operation. When the controller is in G2V mode, it should preserve grid power quality while simultaneously providing enough current for charging EV battery units. In the same way, in the V2G mode of operation, the battery voltage maintains the DC connection, and the controller runs in current control mode to feed back to the grid based on the required amount of active or reactive power. To satisfy the required charging current in the event of a low battery state of charge and available fast charging operation, the FER dynamics should be relatively quicker. In order to properly analyze the intended dynamics of an EV charging unit, it is necessary to consider a variety of plant non-linearities while charging or discharging in diverse environments. Fig. 1 depicts the schematic structure of an EV charger. For both the G2V and V2G types of EV charging operation, a system level mathematical model has been constructed in this research. A bi-directional current tracking technique is suggested for FER regulation. To get a quicker convergence in the presence of source-end disturbances, the controller performance is examined with parameter mismatch. This paper's major contribution uses adaptive sliding mode topology to quickly achieve the present trajectory. The most common method of filtering out harmonic disturbances in the electrical grid is to employ bigger input passive inductors.

1.2 Existing System

Interleaved Converter Configuration is the current problem that has to be addressed for this project since it uses several converter modules that operate in parallel to share the load and lower ripple current. Adaptive control, model predictive control, and proportional-integral-derivative (PID) algorithms are examples of current control algorithms that adjust charging and discharging current in response to system and environmental factors.

Adaptive control strategies use adaptive approaches to dynamically modify control parameters in response to changing variables, such as changes in temperature, grid characteristics, and battery state of charge (SoC). The general goal of bi-directional EV charging applications is still to maximize charging efficiency, maintain grid stability, and improve user safety, even if exact implementations may differ throughout systems and manufacturers. It would be essential to study recent literature or speak with pertinent industry experts to learn about the most recent developments and precise information on currently in use systems.

1.3 Proposed System

Because fewer big passive components are needed thanks to the high frequency converter leg, the suggested architecture is more resilient to frequent parameter fluctuation. For quicker dynamical control in grid-to-vehicle (G2V) and vehicle-to-grid (V2G) scenarios with diverging distribution grid conditions, an adaptive sliding mode control (ASMC) has been devised. Because the tracking error is contained within the predetermined sliding surface during a rapid change in adaptive gain variation, the ASMC offers a greater dynamic responsiveness. Additionally, in order to handle additional nonlinearities during the EV charging operation, the suggested control action essentially removes the proportional-integral (PI) controller. To investigate the different dynamic reactions of the converter and the suggested control action, a MATLAB & SIMULINK model is created.

2. PROPOSED SYSTEM CONFIGUARATION

To eliminate converter switching harmonics, the FER stage is coupled to a VSC bridge with an input filter for the majority of bi-directional power flow operations. For the main stage power conversion discussed in this study, a cascaded BIBR is used. To lessen the input current's ripple contents, the three-leg BIBR uses an interleaved inductor and phase-shifting operation. The extra tertiary leg functions at a comparatively low line frequency level and is meant for half cycle switching.

A. Mathematical Model of FER

The operation of the FER can be analyzed from Fig.1 based upon the different operational modes. In Mode-I, the leg-1 of the front-end converter is operated by switching S_{a2} with line inductor. The stored energy is latter dissipated to the intermediate electrolytic DC bus capacitor through the diode with switch S_{a1}. Similar operation may be observed in the second leg with the switch S_{b2} and the anti-parallel diode with switch S_{b1} in phase shifted mode. Considering i_{l1}, i_{l2} and v_{DC} as the states of the FER plant model, the averaged state space model for the complete operation can be presented in the following state matrix form.

Mode-I

$$\begin{bmatrix} \dot{i}_{l1} \\ \dot{i}_{l2} \\ \dot{v}_{DC} \end{bmatrix} = \begin{bmatrix} -\frac{r_1}{l_1} & 0 & 0 \\ 0 & -\frac{r_2 + r_c}{l_2} & -\frac{k_1 + r_c}{k_1 . l_2} \\ 0 & \frac{1}{C} & \frac{1}{k_1 . C} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ v_{DC} \end{bmatrix} + \begin{bmatrix} \frac{1}{l_1} \\ \frac{1}{l_2} \\ 0 \end{bmatrix} . V_s$$

Where $r1$, $r2$, r_c are the equivalent series resistance (ESR) of input filter inductors l_1, l_2 and DC link capacitor. The term k_1 is obtained from the charging current of DAB in G2V operation.

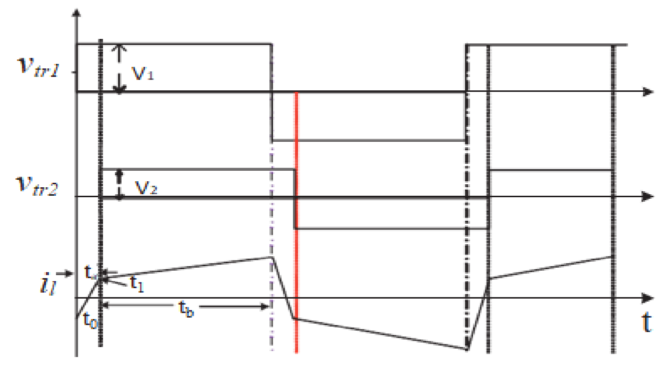

Fig. 2.1 Current dynamics across DAB with SPS control

Considering a single phase-shift operation in the isolated Dual Active Bridge (DAB) converter as shown in Fig. 2.1 , the average transmitting current [11] between the primary to secondary bridge can be derived as,

$$i_l(t_0) = -\frac{nV_b}{4f_s l_r}[k_1 - (1-2D)]$$

$$i_l(t_1) = -\frac{nV_b}{4f_s l_r}[1 - k_1(1-2D)]$$

Where D, V_b, f_s represents the phase-shift ratio, battery terminal voltage and switching frequency of DAB converter respectively.

The variable k_1 is assumed to be unity, which represents a ratio between primary to secondary voltage and expressed as

$$k_1 = {V_{DC}}/{n.V_b}$$

The output voltage expression can be represented as,\

$$[V_0] = \begin{bmatrix} 0 & r_c & 1+\frac{r_c}{k_1} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ v_{DC} \end{bmatrix}$$

Mode-II

In this mode of operation the second leg of the FER short circuits itself with the source to gain energy across the second interleaved inductor, while the primary inductor dissipates energy to capacitor. The state matrix in this mode of operation can be presented as,

$$\begin{bmatrix} \dot{i}_{l1} \\ \dot{i}_{l2} \\ \dot{v}_{DC} \end{bmatrix} = \begin{bmatrix} -\frac{r_1+r_c}{l_1} & 0 & -\frac{k_1+r_c}{k_1.l_1} \\ 0 & -\frac{r_2}{l_2} & 0 \\ \frac{1}{C} & 0 & \frac{1}{k_1.C} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ v_{DC} \end{bmatrix} + \begin{bmatrix} \frac{1}{l_1} \\ \frac{1}{l_2} \\ 0 \end{bmatrix} .V_s$$

The expression of output voltage V_0 at DC link is represented as,

$$[V_0] = \begin{bmatrix} r_c & 0 & 1+\frac{r_c}{k_1} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ v_{dc} \end{bmatrix}$$

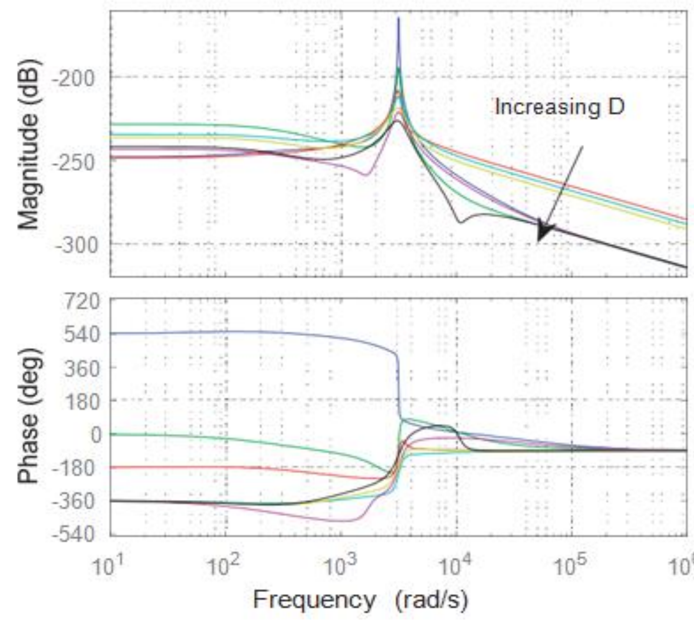

Fig. 2.2 Frequency response of FER with phase-shift variation in DAB converter

Figure 2.2 displays the frequency response of the output voltage to the control input transfer function (Gvd), together with a change in the DC-DC converter's phase-shift at various charging current levels. Figure 4 shows that the system transfer function Gvd becomes unstable when the phase shifting ratio at the secondary stage of power conversion across DAB begins to grow. When the phase shifting ratio between the two DAB bridges increases further to allow for fast charging, the presence of right half plane zero becomes dominant.

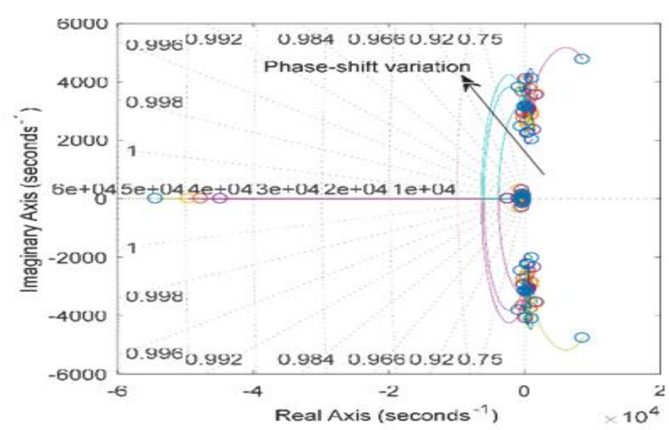

Fig. 2.3 Root-locus plot to verify the presence of RHP zero and its variation with phase-shifting ratio

3. PROPOSED CONTROL DEVELOPMENT OF FER

Regarding plant stability, the system transfer function for the FER illustrates range bound-ness for a certain range of phase, which is well explained in [12]. In [13], the control method using a single-leg high-frequency switch and a unidirectional LED driver is shown. As seen in Fig. 3.1, the control loop with PI compensator and cascaded voltage may simplify the control approach.

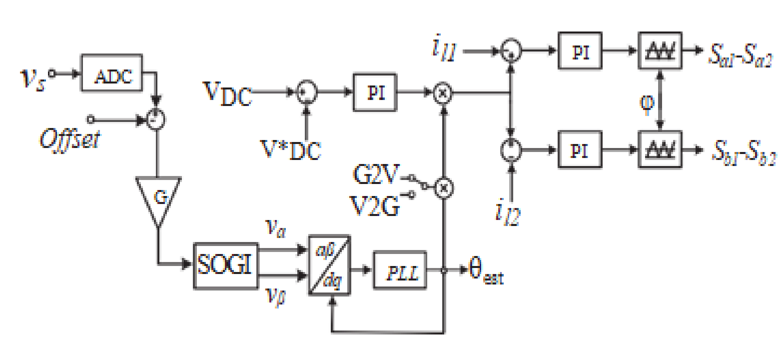

Fig. 3.1 control topology with PI compensator

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A single phase EV charger with dual loop control is simulated and the performance is shown in Fig. 3.1.The controller is designed to provide controlled charging in either of G2V and V2G modes of operation with smaller variation of current reference. But during continuous demand of charging current and robustness of the overall system can't be guaranteed due to the presence of RHP zero. To overcome the limitation of PI verify the effectiveness of command tracking with input disturbance.

4.MATLAB DESIGNS AND RESULTS

RESULTS AND DISCUSSION

To get satisfying results, the suggested ASMC control method is created in the Simulink platform and Mat lab. The simulated results of the DAB converter dynamics and FER are shown in Fig. 4.5. The experimental configuration, which combines a 3.6 kVA 50 kHz high frequency transformer with a digital microcontroller, is designed to verify the simulated waveform. Numerous research publications provide a thorough description of the parameter design and selection [17]. The G2V mode of the FER rectifier operating at unity power is shown in Fig. 4.6. At the DC-DC converter, a resistive load is attached to confirm the load shift while keeping the source-end power factor at unity.

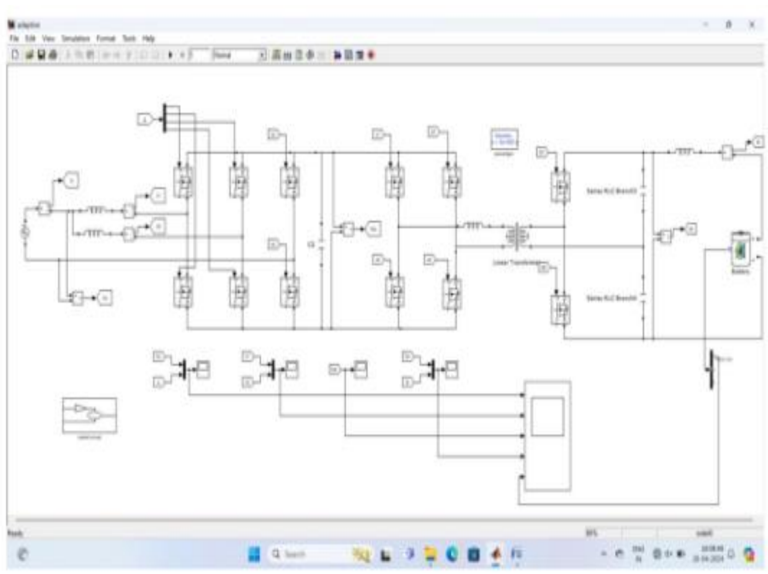

Fig-4.1: Simulink model circuit topology for Adaptive current control for a Bi-directional Interleaved EV Charger

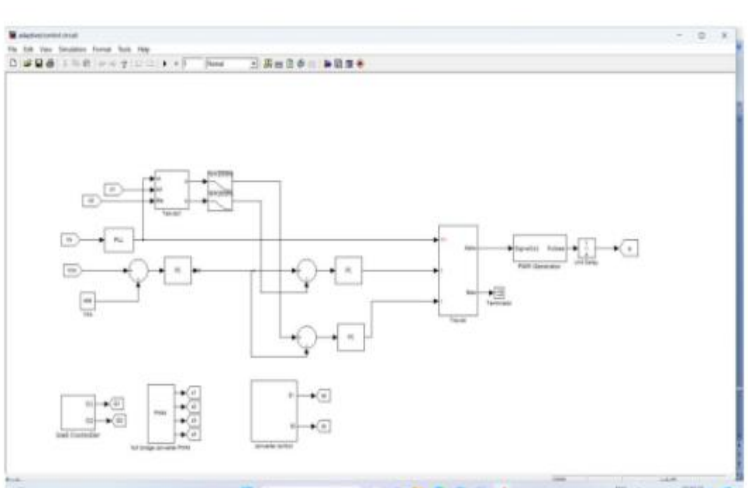

Fig-4.2: Simulink model design for controlling Interleaved EV Charger

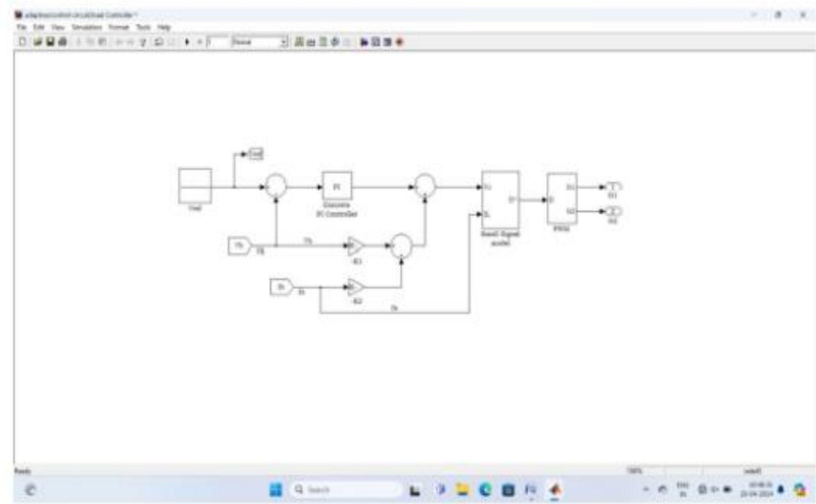

Fig-4.3: Simulink model controller to control the load

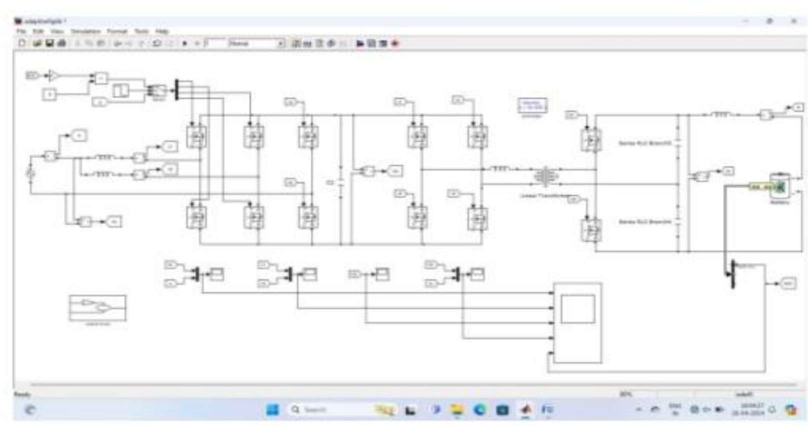

Fig-4.4: Simulink diagram for ASMC during V2G Mode of operation

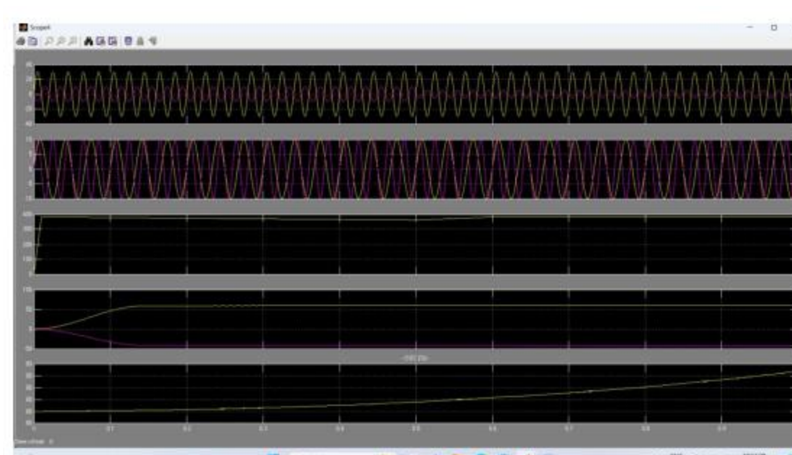

Fig-4.5: Waveform representation to show Dynamic Response of EV charger with PI Controller

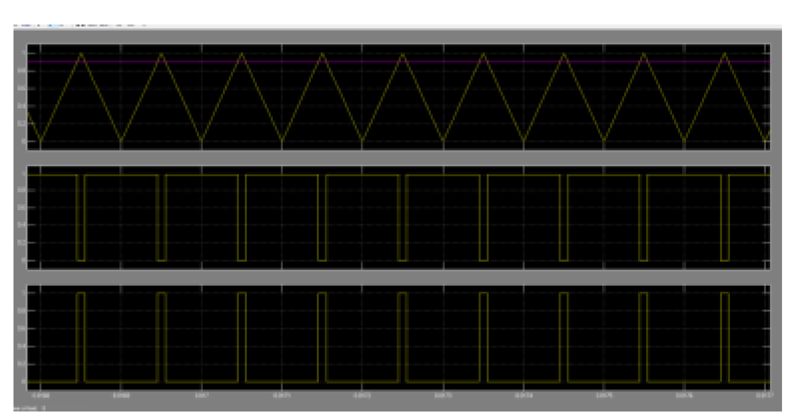

Fig-4.6: Waveforms representation of Load controller through PWM-carrier wave Inverter by using PI Controller

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Fig-4.7: Waveforms representation of ASMC during V2G mode

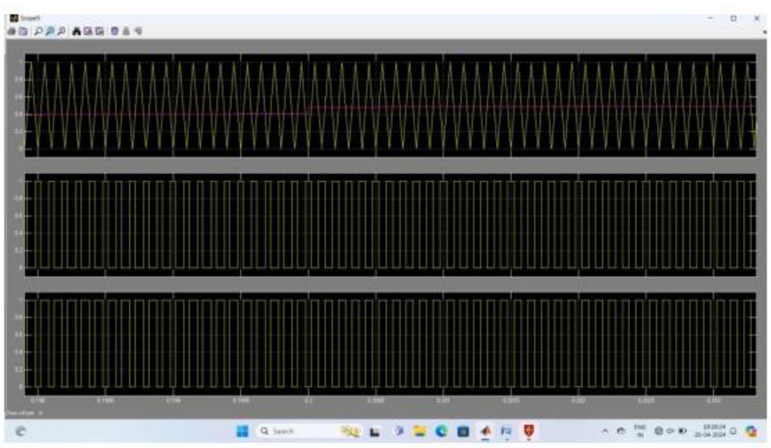

Fig-4.8: Waveforms representation of Load controller through PWM-carrier wave Inverter by using ASMC Strategy.

8.CONCLUSION

This research uses an ASMC to investigate the dynamic response of an EV charger based on an interleaved high frequency input converter for both G2V and V2G operation. Analysis was done on the simulated waveforms for both charging and discharging load circumstances. We also tested the adaptive tracking method with the PI compensator for an instantaneous change in power demand from charging to discharging. Even while an adaptive control mechanism may monitor the reference value with a higher rate of error convergence and resilience, it is not impervious to numerous changes in the inherited disturbances during feedback parameter measurement. Increased error variance might cause the adaptive gain settings to alter unintentionally. In this study, the adaptive tracking law is combined with the inclusion of a sliding error reduction term, which is shown to improve dynamic responsiveness during load changes while preserving unity power factor across the distribution grid.

9.FUTURE SCOPE

The topic of bi-directional interleaved EV charger adaptive current regulation is still developing, and there are a number of promising avenues for future research and development: Superior Control Schemes: Integration of AI and machine learning: Artificial intelligence (AI) or machine learning methods integrated into the control algorithms may allow real-time optimization depending on user preferences, grid circumstances, and battery health, among other variables. Predictive maintenance might increase system uptime and reliability by using data analysis by the control system to anticipate possible repair requirements. Developments in Field Programmable Gate Arrays (FPGAs) and Digital Signal Processors (DSPs) may be able to cut prices and increase processing capacity for intricate control algorithms. To Pay Attention to Grid Integration Identified Communication Protocols: To ensure smooth integration with smart grids and V2G systems, bi-directional chargers will need the development of common communication protocols. Plug-and-play Functionality: Making it easier for EVs to connect to and effectively communicate with the grid by providing "plug-and-play" functionality. Multifunctionality and Sustainability: Recyclable Materials: Using recyclable materials in charger design may help create a more sustainable future. Charging stations with multiple uses: Including extra features like solar panel integration or vehicle-to-home (V2H) power transmission in the design of the station.

• In general, adaptive current regulation for bi-directional interleaved EV chargers seems to have a bright future. This technology combines hardware, grid integration, and sustainability with control algorithm and hardware developments to create an ecosystem for electric mobility that is more dependable, efficient, and ecologically friendly.

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