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A BI-DIRECTIONAL INCORPORATED EV CHARGER WITH DISTURBANCE REJECTION USING ADJUSTABLE CURRENT CONTROL MECHANISM

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ABSTRACT

This Research presents the design and implementation of a bi-directional electric vehicle (EV) charger incorporating a disturbance rejection system using an adjustable current control mechanism. As electric vehicles gain widespread adoption, efficient and reliable charging systems are crucial for both vehicle performance and grid stability. The proposed charger supports bi-directional power flow, enabling energy transfer between the vehicle and the grid (Vehicle-to-Grid, V2G) or other power storage systems, improving energy utilization and grid support. By employing an adjustable current control mechanism, the system can dynamically adapt the charging and discharging currents in response to external conditions, ensuring optimized power transfer and improved efficiency. This adaptive control strategy enhances the charger's robustness, minimizes the impact of disturbances, and extends battery life by preventing overcharging or excessive discharging. Simulation results and experimental validation demonstrate the effectiveness of the system in real-world conditions, highlighting its potential for improving EV charging infrastructure and grid integration. The proposed design not only offers a reliable and efficient solution for EV charging but also supports future developments in smart grid technologies.

Keywords: *Bi-directional EV charger, Disturbance rejection, Adjustable current control, Vehicle-to-Grid (V2G), Grid integration.*

INTRODUCTION:

The larger motivation towards sustainable mobility is substantially projected with the introduction of more EVs in the transport sector. The extensive use of digital control either in the vehicle charger or motor controller with the effective stimulation from a central management system (CMS) has made the overall system to be more accessible. The EVs are now more frequently considered as a wide range of distributed energy in the utility grid. Hence rather confining the EVs only to uni- directional charging operation, the EV battery storage units are now exposed to bi-directional charging to address various grid power quality issues. Continuous improvement in battery technologies with a higher depth of duty (DOD), charging or discharging rate (C-rate) and overall lifecycle has made the bi- directional charging to be more attractive at present. In the present-day scenario, the EV charge controller is more precisely monitored and managed by several robust control algorithms to address various grid-connected power demands.

The effectiveness of seamless control action for grid power quality management and fast charging operation is largely dependent upon the converter topology and bi-directional energy utilization. The two-stage power conversion topology is most widely adopted for EV charging operation, though the single-stage isolated configuration [1] is suitable in certain applications. In several works of literature, the multistage AC- DC converters have been discussed for grid power quality improvement [2]. To ensure a variable charging option for an EV battery unit at different levels of state of charge (SOC), usually isolated multi-stage AC-DC configurations as in [3], are preferred. The unidirectional charging operation is carried out by front-end rectification (FER), intermediate power factor correction (PFC) and finally by an isolated DC-DC stage. At each stage of the operation, a wide range of converter topologies can be accommodated suitably based upon the application and the complexity level. The inclination to utilize EVs in various grid power quality-related issues motivated the bi-directional EV operation. In most of the widely adapted bi-directional charging topology, the FER and PFC stage is replaced by a controlled voltage source converter that forms a two-stage power conversion. In various EV charger configurations, the efficiency of the second stage power conversion has satisfactorily increased by several switching modifications. Single-phase shift (SPS) technique, double phase shift modulation, dead-band modification and resonant power conversion are some of the common topologies as discussed in several literatures [4]. In an efficiency of up to 95% at the DC-DC conversion stage was achieved through optimized switching at different load conditions in a multifunctional EV charger. Though high efficiency is quite achievable in most of the DC-DC converters through various modulation strategies, the overall system efficiency and stability in the complete cascaded converter configuration require more attention. The FER in a grid-connected charger is required to be designed suitably to control the bi-directional charging current with minimum switching stress on it. Though the switching transients are minimized the input passive filters, adopting bridgeless interleaved topology it may be further reduced. Inherited potential for bi-directional current carrying capabilities, low conduction losses and reduced common-mode noise interference are some of the commonly prompted advantages of the interleaved bi-directional bridgeless rectifier (IBBR).

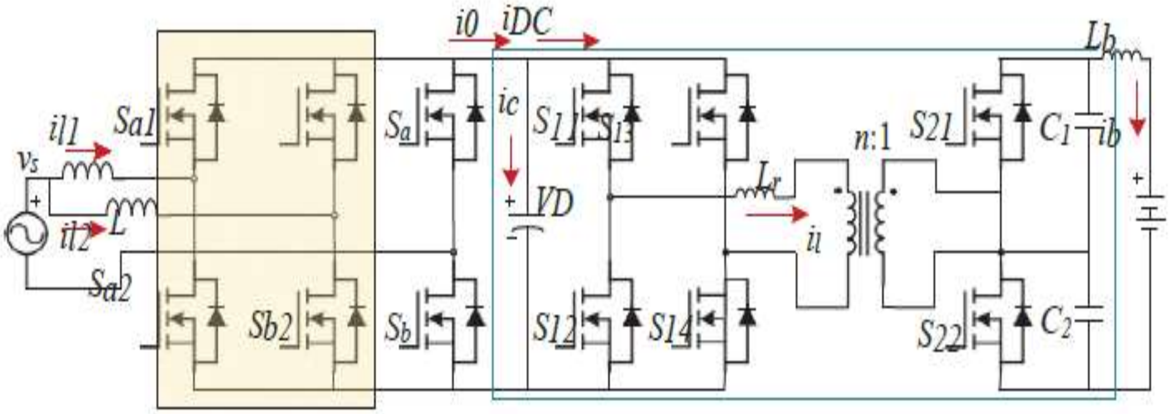

Figure1: Design of inverter based EV charger

LITERATURE SERVEY

Bi-directional electric vehicle chargers play a crucial role in the integration of electric vehicles (EVs) into the energy grid. These systems support both charging and discharging operations, enabling Vehicle-to-Grid (V2G) and Vehicle-to-Home (V2H) applications. Studies such as those by Mwasilu et al. (2014) and Gough et al. (2017) have demonstrated the potential for bi-directional charging in enhancing grid stability by allowing EVs to function as distributed energy storage systems [5]. These chargers can help balance peak demand, enable renewable energy integration, and offer ancillary services such as frequency regulation and voltage support. Disturbance rejection in power electronic systems, such as EV chargers, has been a focal point of research due to the need for stable and reliable operation under fluctuating grid conditions. Traditional proportional-integral-derivative (PID) control methods have been widely used for disturbance rejection in EV charging applications. However, more recent advancements in adaptive and model predictive control have provided improved performance. For example, Liserre et al. introduced a disturbance observer-based control method for rejecting external disturbances, achieving better dynamic response and reducing system vulnerabilities to grid-side disruptions like voltage sags and harmonic distortions. Adjustable current control mechanisms are essential for optimizing charging efficiency, protecting the battery, and mitigating grid disturbances [6]. Vasquez explored various current control schemes, including droop control and virtual impedance techniques, which allow for better control over power flow in both directions. These techniques are essential for managing the dynamic behavior of batteries and grid interactions. In bi-directional chargers, adjustable current control can adapt to changing grid conditions, ensuring smooth power transfer and improved overall system efficiency. Research by Wang et al. (2020) and Meng et al. (2021) has investigated advanced control strategies, such as model predictive control (MPC) and fuzzy logic control, to enhance the performance of EV charging systems [7]. These control techniques allow for real-time adjustment of the charging current in response to grid disturbances, optimizing both battery life and energy efficiency. The ability to adjust the charging profile dynamically based on grid and battery conditions is critical for maintaining system stability in a bi-directional charger setup. The integration of V2G technology into EV chargers has been extensively studied for its potential to improve grid resilience and flexibility. Kempton and Tomic (2005) were among the first to propose V2G as a means of utilizing the energy stored in EVs for grid support. Their work laid the foundation for understanding how bi-directional chargers can be used to support demand response, load balancing, and renewable energy integration. Further advancements in V2G technology, such as those proposed by Sundstrom and Binding (2012), have shown that bidirectional chargers can enhance power quality and reliability, especially when combined with real-time adaptive control mechanisms. Bi-directional chargers, when connected to the grid, must handle various power quality issues such as voltage dips, frequency deviations, and harmonics. Zhang et al. (2019)

discussed how adaptive control mechanisms, in conjunction with disturbance rejection techniques, can mitigate these issues, ensuring stable and efficient operation [8]. Their research highlighted the importance of integrating intelligent control strategies into EV chargers to enhance their grid responsiveness and adaptability.

METHODOLOGY:

Development of the System and Controller Design

A single phase EV charger with dual loop control is simulated and the performance is shown in Fig. 6.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. DC link voltage is maintained with a PI controller to provide the reference current for current control loop. During the fast charging requirement the current control is required to provide the desired PWM output without degrading the DC voltage To verify the convergence of the estimated error with the time- varying reference current, a Lyapunov candidate function (LCF) is considered with a positive definite function, radially unbounded and decrescent with as The dual bridge isolated DC-DC converter is operated in a phase shifting operation to transfer the desired power in either of the V2G or G2V modes. In G2V mode operation the primary side of the dual active bridge (DAB) converter operated with leading phase shift mode. Though the EV battery current is limited from grid side current control technique but still the power variation is possible with the variation of the phase-shift. In V2G mode DAB secondary side operates in leading phase shift mode and the current control is obtained from the EV side phase-shift regulation. The electrolytic rectifier was an early device from the 1900s that is no longer used. When two different metals are suspended in an electrolyte solution, it can be found that direct current flowing one way through the metals has less resistance than the other direction. These most commonly used an aluminum anode, and a lead or steel cathode, suspended in a solution of tri-ammonium ortho-phosphate. To convert AC currents into DC current in electric locomotives, a synchronous rectifier may be used. It consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load just when the sinusoidal current goes through a zero-crossing. The contacts do not have to switch a large current, but they need to be able to carry a large current to supply the locomotive's DC traction motors.

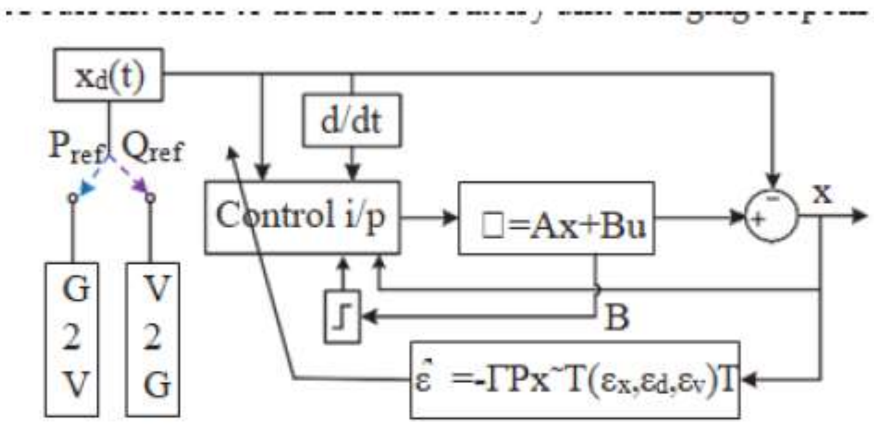

Figure2: Control diagram for G2V and V2G operation

Rectification Technology

Early power conversion systems were purely electro-mechanical in design, since electronic devices were not available to handle significant power. Mechanical rectification systems usually rely on some form of rotation or resonant vibration in order to move quickly enough to match the frequency of the input power source, and cannot operate beyond several thousand cycles per second. Due to the complexity of mechanical systems, they have traditionally needed a high level of maintenance to keep operating correctly. Moving parts will have friction, which requires lubrication and replacement due to wear. Opening mechanical contacts under load results in electrical arcs and sparks that heat and erode the contacts. The device is enclosed in a bulbous glass vessel or large metal tub. One electrode, the cathode, is submerged in a pool of liquid mercury at the bottom of the vessel and one or more high purity graphite electrodes, called anodes, are suspended above the pool. There may be several auxiliary electrodes to aid in starting and maintaining the arc. When an electric arc is established between the cathode pool and suspended anodes, a stream of electrons flows from the cathode to the anodes through the ionized mercury, but not the other way. [In principle, this is a higher-power counterpart to flame rectification, which uses the same one-way current transmission properties of the plasma naturally present in a flame. The voltage source provides the input DC voltage to the switch control, and to the magnetic field storage element. The switch control directs the action of the switching element, while the output rectifier and filter deliver an acceptable DC voltage to the output. Traditional source inverters are Voltage Source Inverter and Current Source Inverter. The input of Voltage Source Inverter is a stiff dc voltage supply, which can be a battery or a controlled rectifier both single phase and three phase voltage source inverter are used in industry

RESULT ANALYSIS:

The discussed ASMC control algorithm is developed in the mat lab and Simulink platform to obtain satisfactory results, simulated result of FER and DAB converter dynamics are presented. The experimental setup is developed to validate the simulated waveform through digital microcontroller with a 3.6 kVA 50 kHz high frequency transformer. The parameter design and selection is well described in various research literatures, it presents the unity power operation of FER rectifier in G2V mode. A resistive load is connected at the DC-DC converter to verify the change in load while maintaining the source-end power factor at unity. An instantaneous load change is applied to verify the current following with minimum time delay. The VDC dynamics presents a constant voltage to validate the outer PI compensation in the voltage control loop

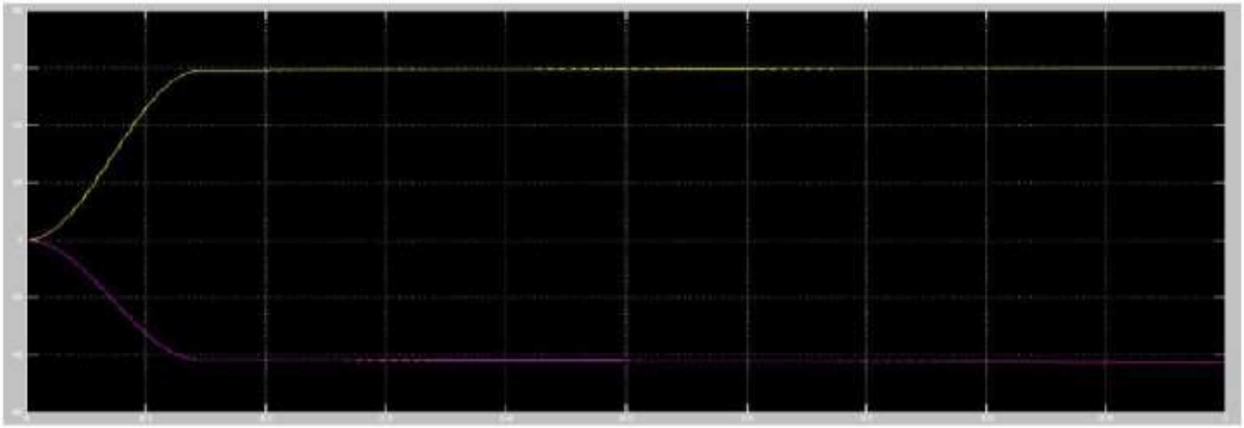

Figure3: Transition Between the G2V and V2G Mode of operation

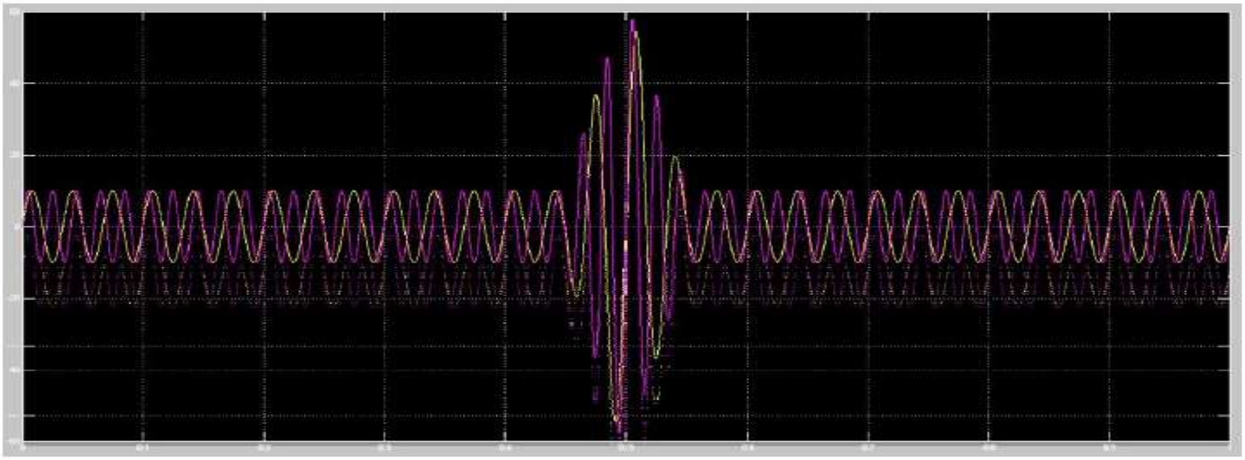

Figure4: Charging in V2G Mode

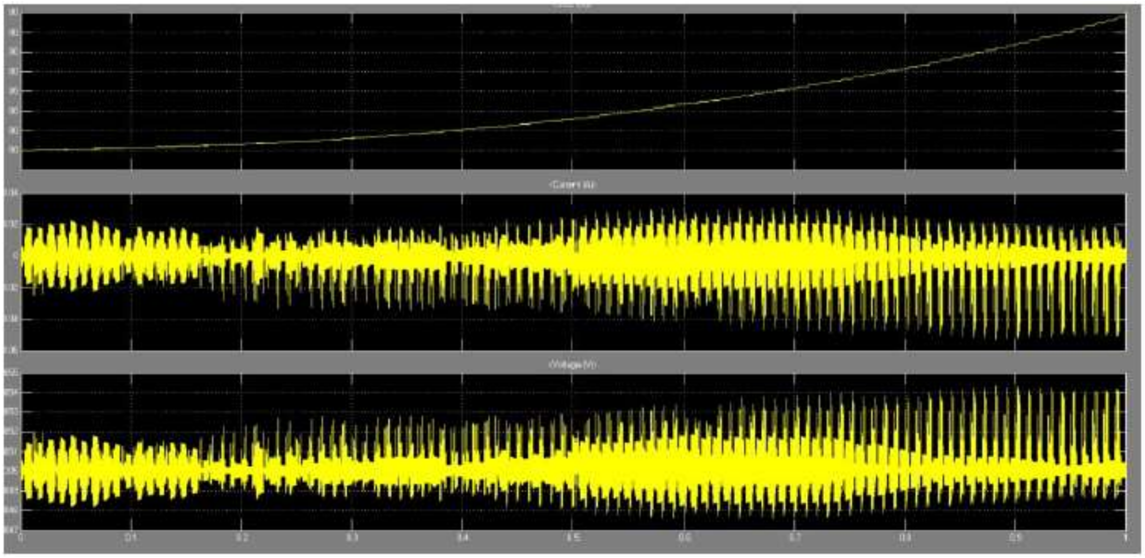

Figure5: G2V Mode

CONCLUSION:

In this paper an ASMC is implemented to study the dynamic response of an interleaved high frequency input converter based EV charger for G2V and V2G operation. The simulated waveforms were analyzed for charging and discharging load conditions. The PI compensator and adaptive tracking algorithm were also compared for an instantaneous shift of charging to discharging power demand. Though an adaptive control mechanism is good enough to track the reference value with faster error convergence rate and robustness, the inherited disturbances during feedback parameter measurement are prone to change multiple times. A larger error variation may lead to unwanted change to adaptive gain parameters. In this work addition of sliding error minimization term is presented in conjunction with the adaptive tracking law and found to provide a better dynamic response during load change while maintaining unity power factor across the distribution grid.

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