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Off-Board Bidirectional EV Charger with Reactive Power Compensation and Lowered Total Harmonic Distortion

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ABSTRACT

This paper discusses a newly designed off-board Electric Vehicle (EV) battery charger system that supports both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operations while also compensating for reactive power. The system architecture features a utility-connected AC-DC cascaded H-bridge (CHB) converter that controls the power exchange between the grid and the battery through a bidirectional DC-DC converter at the back end. To enhance safety, the charger includes galvanic isolation between the grid and the user end. The proposed system uses an ANFIS controller to manage EV power and battery current, adhering to active power commands for both G2V and V2G modes and providing reactive power compensation as required. Additionally, a control algorithm based on an adaptive notch filter has been developed to estimate network phases and achieve accurate current synchronization without the need for phase-locked loops (PLLs), simplifying controller design and enhancing both the steady-state and dynamic performance of the system. Experimental results, obtained in a MATLAB environment, demonstrate the effectiveness of the proposed system in managing reactive power in V2G and G2V settings.

Keywords—Grid to vehicle, EV charger, Power quality, Vehicle to grid.

1.INTRODUCTION

Electric vehicles (EVs) have gained significant traction in developed countries due to their reduced fuel consumption and lower greenhouse gas emissions. A key factor in the wider adoption of EVs is the increase in the installation of off-board charging stations. These off-board systems can operate in both bidirectional and unidirectional modes. Bidirectional operation, encompassing grid-to-vehicle (G2V) and vehicle-to-grid (V2G) processes, allows for the active exchange of electricity in both directions, with V2G operations particularly beneficial for energy storage in the grid.

Despite the advantages, the potential degradation of EV batteries during V2G operations remains a concern. However, off-board chargers can mitigate this issue by offering additional power quality services such as voltage regulation, reactive power compensation, harmonic compensation, and power factor correction without relying on EV batteries' integration with utility systems. Due to their capacity to manage higher power levels, off-board systems are often preferred over on-board systems for these services.

In conventional power systems, the power source typically supplies reactive current, which can lead to additional losses across the extensive transmission and distribution reactances, thereby reducing system efficiency and voltage quality. Consequently, local generation of reactive power demand is preferable. Moreover, household appliances like compressors, refrigerators, and smart devices also draw reactive power, for which users are often inadequately charged. In contrast, an EV bidirectional charger can locally supply reactive power without the need for additional VAR sources.

This paper focuses on the operation of an EV charger in grid service enhancement. The integration of off-board charging stations offering auxiliary services in underutilized public spaces—such as parking lots, restaurants, shopping centers, residential complexes, and office buildings—promotes the use of EVs.

The charging system discussed aims to compensate for reactive power consumption by adjusting the DC link voltage through the EV battery system, impacting battery life and adding extra charge-discharge cycles. Although this process helps in managing reactive power, the charger's capability to operate simultaneously in V2G and G2V modes with reactive power compensation is not addressed extensively. Similarly, while the system design facilitates reactive power support to the grid, using EV batteries to adjust DC link voltage may impair their efficiency and longevity. The proposed charger control strategy focuses on managing the DC system via batteries and controlling reactive power in V2G operations, yet it does not explore the charger's capability to perform in more than one operational mode simultaneously.

2. MATERIALS AND METHODS

It describes the development of an efficient control method for a two directional off board EV charger in order to provide reactive power adjustment when recommended from the utility system. The suggested charger regulator additionally supports reactive power correction while the charger is operating in V2G or G2V mode. In this research the reactive power compensation is achieved at V2G operational mode. Furthermore, the suggested charger architecture includes galvanic separation, which increases the EV charger's reliability in real applications. During charging, the charger controller after compensation provides best power factor with unity. By removing PLL from the controller, the planned charger regulator method employs an adaptive notch filter (ANF) for synchronization with the grid. As a result, the regulator has enhanced variations and lowered complexity of implementation. In addition, direct control of power is used in the controller to achieve a quick transient reaction to a variation in command power. The usage of ANF in its place of PLL increases the charger's performance in long run steady operation. The DC connection output voltage regulator is introduced to the internal current controller loop to keep the DC connection voltage at its orientation value.

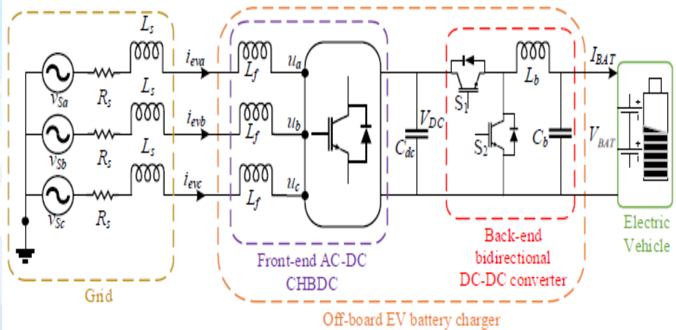

FIGURE.1: Suggested system configuration

Bidirectional Electric Vehicle Charger

Figure 1 characterizes the off-board EV indicting prototypical layout. The created EV designer is utilized to evaluate the charger's compensation capabilities of reactive power as healthy as the charger's V2G and G2Vworking operation. The grid connected front ended AC-DC- CHBDC is a model with a one motivated voltage source. Figure. 2 represents the complete structure design of the utility looking converter. The present converter configuration has three H-bridge components per phase.

The main side of a single-phase toroidal core transformer (TCT) is connected to every H-bridge output. The 3 transformers secondary winding elements are connected in series, and the secondary voltages of all transformers are summed together to generate the yield voltage. As seen in Fig. 2, every H-bridge donates similarly to the output phase voltage, i.e. 33.33%. TCT are used as a high frequency link in front-end converters, but their use at the yield end recovers presentation above outdated transformer-based designs. The TCT allows the system to run on a sole DC excitation voltage. Additionally, it removes the need for extra voltage equivalent sensors to ensure identical power delivery throughout the segments. The described H-bridge architecture also has very little charging current Harmon's, voltage and current control experiences and galvanic isolation. To enhance the converter output voltage quality, the network interconnected CHBDC is linked to utility system via L-filter, as illustrated in Fig. 1. Because of its multilayer construction, the L-filter is capable of eliminating switching harmonics of higher-order nature. The EV batteries are discharged and charged using the back-end DC-DC operation. Figure.1 depicts the BBDC's detailed circuit configuration. By varying the both switches (S1, S2), the described setup may function in two modes such as boost and buck operation. Manipulating switch S1 works the BBDC as a buck operation, while manipulating S2 activates boost mode. As a result, discharging and charging EV batteries may be talented by working the BBDC in boost and buck operation.

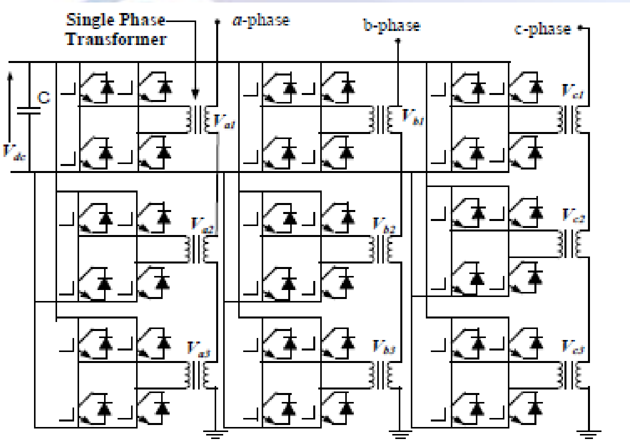

FIGURE.2: CHBDC internal structure

Control design of the suggested model

The control considered has two major goals: the first operation includes the EV battery charging in G2V operation and the second function includes the assignment of active power in V2G operation when grid requires it and also to supply sufficient reactive power when grid required for proper operations. Figure.3 presents the detailed structure of the controller. The suggested regulator method makes use of ANF to retain the grid and the pony in synchronization. The ANF functions successfully nevertheless of organization disorders and substitutes the ordinary PLL in the system controller.

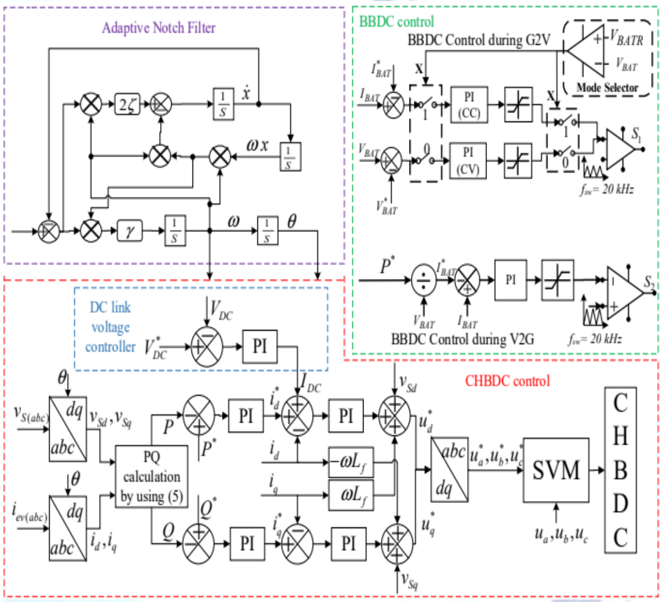

FIGURE 3: Detailed structure of the controller

Grid to Vehicle(G2V) Mode operation:

In G2V operation, the sufficient active power taken commencing the utility by the charger to control the batteries. For charging of the batteries, this study employs the constant voltage (CV) and constant current (CC) techniques. In the preliminary charging state, the charging current reference is fixed to the accurate power level below continuous current till the voltage of the battery reaches the manufacturer's rated permissible voltage level. Following that, the system is charged at highest voltage level by decreasing current checkout the current extents its esteemed threshold value and the voltage of battery extents its highest level. In this approach of operation, the CHBDC mechanism system follows the charging power instruction P and keeps UPF at its input. The reactive power value kept Q = 0 in this operating state. The BBDC acts as a buck operation during charging by managing the interchanging of S1 to manage the battery charging current (DEF) and voltage (GDEF). Figure.3 describes the BBDC control topology during G2V operation. The variables are identical to those in Fig 1.

Vehicle to grid(V2G) Mode of operation:

In this style of process, the EV charger maintains a 180 degrees phase shift among EV voltage and current by fixing the reactive power reference to zero value. The control method of the EV charger gets the command to create the reference current (reference power P and time interval). Without accounting for the loss of power in the EV charger, the current reference of the battery may be calculated. Energy storage to the electric grid. When an EV is associated to the utility, the charger's chief purpose is G2V working. Though, with the addition of a BBDC, power transmission in two ways is allowed for a limited time.

TABLE.1: Test system modelling parameters

Parameters	Specifications
Charger apparent power	12.6KVA
CHBDC Filter	L_f=2.5mH(25A)
BBDC elements	L_b=3.7mH,C_b=660μF
Grid Impedance (Z_s)	R_s=0.1Ω of a,L_s=1.6mH
DC link capacitor(C_{DC})	2200μF/500V
Transformer(CHBDC)	1kVA,1-φ,Toroidal core
Supply System	230Vrms,50Hz
EV Battery	Nominal voltage= 192V

4. SIMULATION RESULTS AND VALIDATION

The Simulink design is created to assess the suggested EV charger operation efficiency throughout the charger's described modes of operation. Table-I lists the test system parameters utilized in this work. The charger first operates in G2V mode, accusing the battery through the consideration which would give sufficient reactive power when it is required from the effectiveness system. Based on the recommendations of the reactive power, the charger changes its modes of operation.

If the utility requires reactive power, the designed controller can operate with various charging power. Figure.4represents the charger's presentation in G2V operation when charging with P=12 kW. Fig.5 depicts, the EV charger output voltage THD in G2V condition which is 1.26% with proposed controller. Fig.6 presents the yield current of EV charger in G2V condition whereas Fig. 7 represents the yield current THD of EV feeder in G2V condition is 6.95%. Fig. 8 represents the active power output of 12 kW in G2V operation. Fig.9 represents reactive power requirement of EV charger in G2V condition which is fixed at zero to operate the system at unity power factor and the Fig. 10 illustrates the DC link voltage variation. The utility recommends inductive reactive power from the charger during charging at 1.5 s by changing its operational mode from G2V to G2V with V4G.Q= 9.8 KVAR and P= 6.8 kW are the power commands sought from the grid.

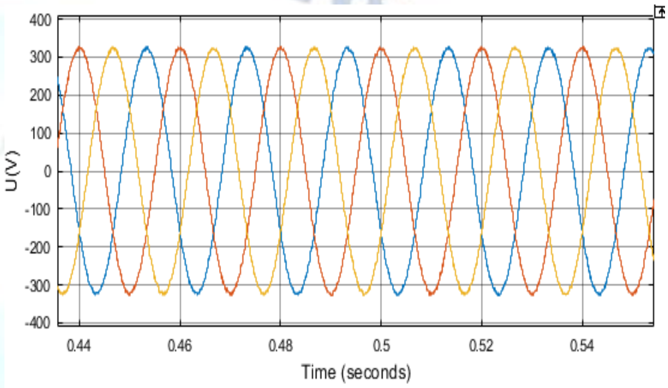

FIGURE.4: EV charger output voltage in G2V condition

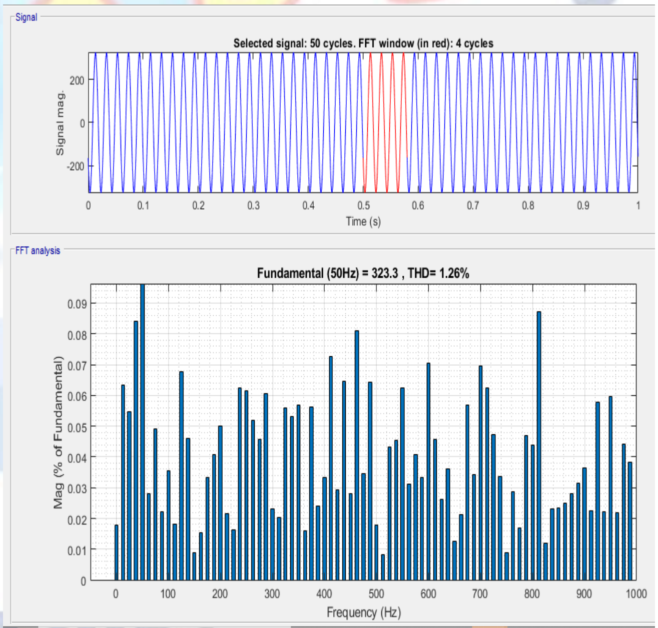

FIGURE.5: EV charger output voltage THD in G2V condition

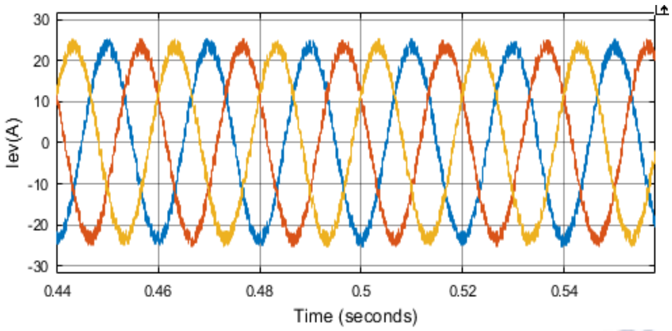

FIGURE.6: Output current of EV charger in G2V condition

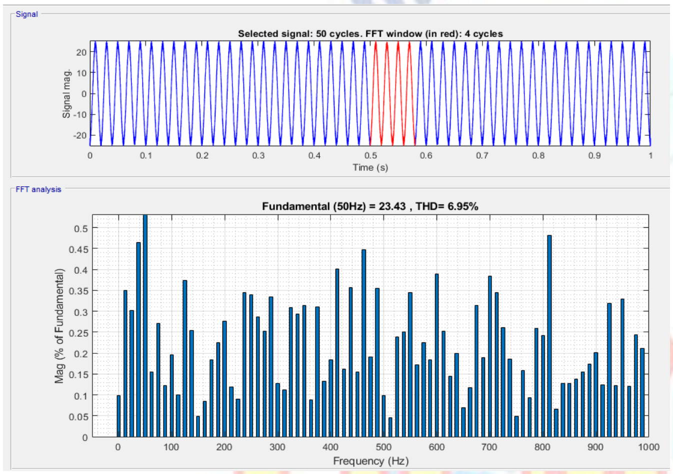

FIGURE.7: Output current THD of EV charger in G2V condition

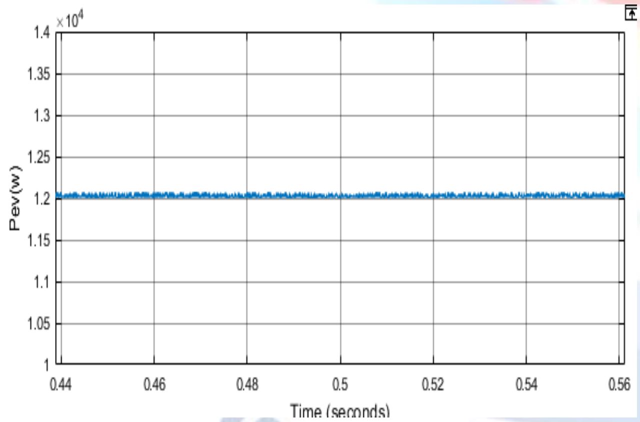

FIGURE.8: Active power output of EV charger in G2V condition

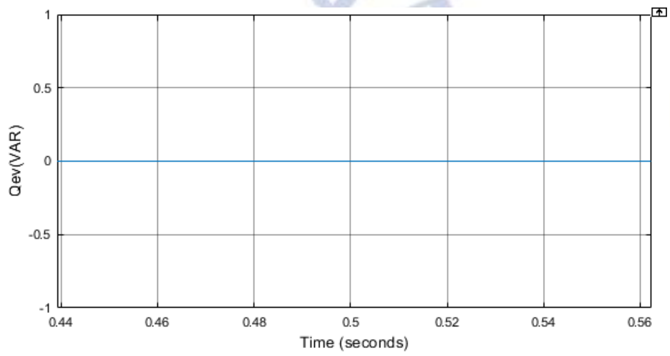

FIGURE.9: Reactive power output of EV charger in G2V condition

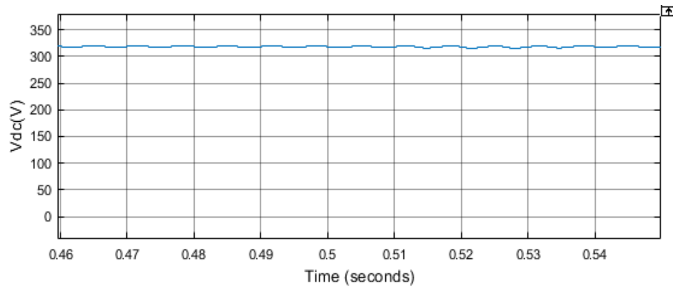

FIGURE.10: DC link output voltage of EV charger in G2V condition

5. CONCLUSION

This paper presents an effective controller method that considers into description G2V and V2G modes, as healthy as compensation of reactive power, and includes EVs as an active system that may supply and feed the energy with storage advancement. For safety reasons, the charger setup includes galvanic separation at the operator area. The devised control procedure performs adequately in various operational conditions, and the approaches of process are healthy implemented when the power instruction is sent. The design offers excellent steady and transient presentation. In lesser than two grid cycles, the off-board charger works to the power signal variation. The battery system is unaffected by reactive power value, which extends life of the battery. The results satisfactorily recommends the suggested controller operation throughout various power signal operations. The results demonstrate that the proposed charger is a good contender for reactive power support amenities to be used by the grid system.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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