Artificial Neural Network based Bidirectional Converter Control for Electric Vehicle Charging

Latha Ramasamy[1], Navaneethan Soundirarajan[2], Varsha R J[3]

{1-rla.ee@psgtech.ac.in, 2-snn.ice@psgtech.ac.in, 3-varshajothikrishnan@gmail.com}

PSG College of Technology, Coimbatore, Tamilnadu, India-641004

Abstract. Extensive research has been ongoing in the field of Electric Vehicle (EV) chargers. This article addresses transfer of electric power from the grid to EV and from an EV to grid, a configuration of a single-phase charger system consists of bidirectional AC-DC converter integrated with bidirectional DC-DC converter. An artificial neural network (ANN) controller is employed for controlling the charging current and voltage. ANN model produces the required duty cycle to feed the maximum power under both Grid to Vehicle(G2V) mode and Vehicle to Grid (V2G) mode. The ANN is trained for the measured battery voltages and battery current to estimate the bidirectional converter's duty cycle. The implementation of the neural network is presented in this study, and simulation results are accomplished using Matlab/Simulink. The simulation findings support the effectiveness of the suggested control technique as well as its practicality. A comparative study is made to show the enhanced performance of the proposed controller than the conventional Proportional-Integral (PI) controller.

Keywords: Artificial Neural Network (ANN), Electric Vehicle (EV), Grid to Vehicle (G2V), Vehicle to Grid(V2G), PI controller, DC-DC Converter

1 Introduction

In today's world, internal combustion engines are being phased out in favor of Electric vehicles, which help to reduce carbon-di-oxide and other harmful gas emissions. As the growth of Electric vehicles is increasing, utility grid networks are concerned about increasing the demand for energy to charge Electric vehicles. Conventionally batteries are charging by receiving energy from the power grid and referred to as Grid to Vehicle mode. With the advent of smart grid technology, a new concept arises for utility grid network and EV market referred to as Vehicle to Grid mode. Energy stored in the battery is return to the power grid. Battery chargers play a significant role in the V2G concept. The system requires a bidirectional AC-DC rectifier for grid-connected operation and a bidirectional DC-DC converter for vehicle operation to balance the power flow and adjust the voltage [1,2]. This paper aims to propose a bidirectional battery charger system with an artificial neural network-based control strategy. The objective of the control strategy is to feed the maximum power under both Grid to Vehicle (G2V) mode and the Vehicle to Grid (V2G) mode of operation.

ICSETPSD 2023, November 17-18, Coimbatore, India

DOI 10.4108/eai.17-11-2023.2342838

A battery charger, which is utilized for bidirectional power flow with a sinusoidal input current and adjustable power factor, is a key aspect of the two-way power flow between the electric vehicle and the grid. Because of power electronic devices, voltage deviation and harmonic injection increase the frequency of battery charging and discharging capabilities, putting strain on the battery and electric car charge controller.. In [3] new control strategy is presented to control the charging and discharging capability of EV battery by injecting the active power from the bidirectional vehicle to grid (V2G)charger to grid. The topology of an interleaved buck-boost bidirectional converter for a non-isolated onboard battery charger for EV for G2V and V2G mode is emphasized [4]. Different configurations of bidirectional onboard chargers for four quadrant operation analyzed by incorporating regenerating braking control in the chargers to determine the driving range of the vehicle[5]. DQ current control technique is explained in [6] for a high power density Silicon Carbide (SiC) based bidirectional converter. The harmonics in the AC input current due to the clamp circuit are eliminated in that paper.

The presence of AC-DC and DC-DC converter aids in power flow control during charging and discharging modes. Bidirectional chargers increase the usability of electric vehicles by allowing energy transfer from vehicle to grid (V2G) or vehicle to home (V2H) as well as charging from grid to vehicle (G2V)[7,8]. In [9], topology and operation of an interleaved buck-boost converter, which consists of a line frequency commutated unfolding bridge with low semiconductor losses and lower battery current ripple, are presented. The energy and power required for charging EV batteries may have an adverse impact on the distribution grid that can be minimized utilizing onboard EV battery chargers. Therefore, a bidirectional modular single-phase on-board charger integrated with a smart grid is developed under optimized current sharing environments [10,11]. The performance of the converter to interface the vehicle's energy storage device with an external charger and switched reluctance motor drive is analysed, and it is demonstrated that it can be used in a wide range of applications [12]. Conventional (PI) controllers that are used to control the bidirectional converters are not so optimal because they produce high peak overshoot and voltage ripple [13]. A closed-loop control mechanism in a D-Q rotating frame is suggested for bidirectional single-phase AC/DC converters. Using the D-Q frame in single-phase power conditioning systems is difficult due to the degrees of freedom necessary for orthogonal systems. In [14], all-pass filters are used to generate the orthogonal signals without degrading the dynamics of the closed-loop control system and with less noise. A novel multi-input multi output bidirectional DC-DC converter is proposed with high voltage gain for electric and hybrid vehicle applications [15]. [16] proposed a prediction-based control technique for a dc-dc converter. In conjunction with a conventional PID, neural network-based control is used to improve transient response and suppress output voltage undershoot and reactor current overshoot.

The effect of charging of electric motorcycle on the distribution network using load flow techniques to identify the slow and fast charging of motorcycle is investigated [17]. A framework for the deployment of smart charging infrastructure for EVs is being developed. In the current scenario, the advantages and disadvantages of various proposed techniques for EV charging infrastructure are weighed against the various available technologies. Also proposed is a smart bidirectional interface with a multilevel cascaded power converter and embedded strategies. [18]. The article discussed the power factor correction of single-phase converters for electric vehicle applications. An improved configuration of the power quality converter, its design feature, and the specific value of a converter selection are presented[19]. From the literature, it has been observed that conventional PI controller has its own limitations such as the controller provides significant dynamic performance at one operating point but not at all the operating points. But the approach of ANN guarantees satisfactory performance even if there is a change in the system parameters. Indeed, ANN-based controllers consider the entire system as a black-box model and improve the system performance as the network is properly tuned without any mathematical model of the system.

In this article, an EV charger with bidirectional DC-DC converter control is designed using an artificial neural network (ANN). The use of an ANN-based bidirectional DC-DC converter aids in the reduction of peak overshoot. The following is how the paper is structured. Section 2 presents the control methods used in this paper, following the introduction of the proposed system in Section 1. Section 3 describes how ANN concepts are put into practise. Section 4 describes the system design and its Matlab modelling. Section 5 contains the simulation results. Section 6 contains the conclusions. It also describes the impact of the proposed converter.

2 Proposed Bi-Directional Charger

The block diagram of a bidirectional AC-DC topology that must be combined with a bidirectional DC-DC topology to implement the bidirectional charger is shown in Fig.1. The modified buck-boost design was chosen for the bidirectional DC-DC converter due to the reduced number of high-current inductors and the integrated high voltage bus. [8,9].

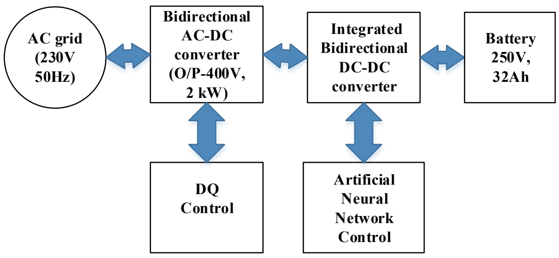

Fig.1 Block Diagram of the proposed charger

The DC-DC topology is well suited for EV applications, due to the built-in high voltage bus. Combining the two topologies result in a fully functional bidirectional charger system capable of charging the battery pack of an electric vehicle as well as providing an interface for V2G interactions. The schematic of the proposed bidirectional charger system is shown in Fig.2.

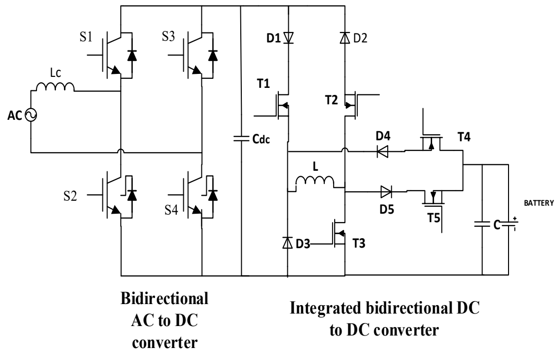

Fig.2 Schematic of the Proposed Charger

In the system, a DC-DC converter is a non-isolated converter with 5 switches and 5 diodes. The converter operates in both boost and buck mode respectively corresponding to charging and discharging modes of the battery.

3 Control Strategies

Power can flow in both directions through a bidirectional converter. A two-quadrant converter or a four-quadrant converter is another name for it. An AC/DC bidirectional converter in the bidirectional charger operates as a controlled rectifier or as an inverter for charging and discharging modes, respectively. The power switch drive can be controlled by any operation mode, AC or DC voltage. The dual-loop control strategy is used to regulate DC voltage and AC current[20]. The inner PI controller regulates AC current while the outer PI controller regulates voltage. The rectifier side detects grid voltage, grid current, and output DC voltage. A Phase-Locked Loop (PLL) is used to track the magnitude of the grid voltage and for phase synchronisation.

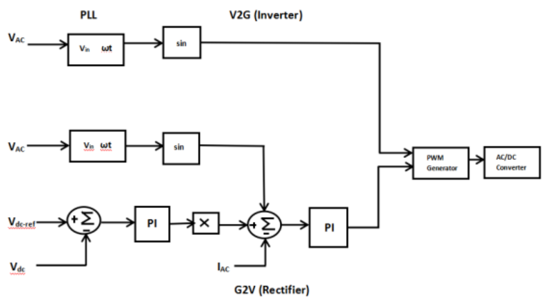

Fig. 3 Control Structure of Bidirectional AC-DC Converter

The Bidirectional DC-DC converter in the charger circuit interfaced with the DC link and the battery. It acts as a buck or boost converter during G2V and V2G mode respectively. In the G2V mode, the battery of an electric vehicle will be charged and the energy is supplied by the utility grid. In DC/DC converter, the bidirectional power flow is controlled by voltage control technique. In the V2G mode, the battery will be discharged and the energy is injected into the utility grid. The control structure for the AC-DC converter and DC-DC converter is shown in Fig.3 and Fig.5 respectively.

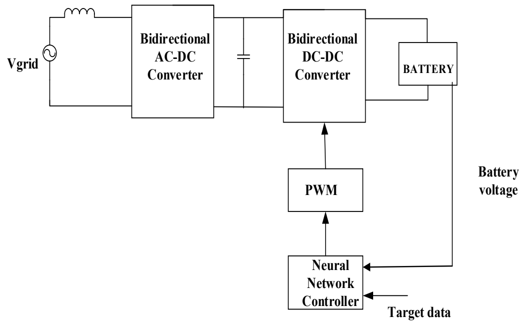

Fig.4 Control structure of Bidirectional DC-DC Converter with ANN Control

4 Converter Design

The bidirectional AC-DC converter consists of a filter inductor(L_c) and DC link capacitor (C_{dc}) between a bidirectional AC-DC converter and a DC-DC converter. The DC-DC converter also consists of an inductor and capacitor. The ripple voltage and ripple current of 5% is considered.. In this section, the relationship of input voltage, V_{dc}, and duty cycle in producing output voltage related to boost converter are observed. The value of output voltage, V_b depends on the duty cycle. Equations (1) and (2) are used to calculate the values of AC side inductor and DC side capacitor values. Equations (3) and (5) are used to calculate the value of DC side inductor and load side capacitor values.

$$L_c = \frac{m*v_{dc}}{6*F_s*h*\Delta i_c} \quad (1)$$

$$C_{dc} = \frac{I_{dc}}{2*\omega*\Delta v_{dc}} \quad (2)$$

$$L = \frac{1}{2} * \frac{V_b*V_{dc}}{\Delta I} * \frac{V_{dc}}{V_b} * \frac{1}{F_s} \quad (3)$$

A boost converter has an output voltage that is greater than the input voltage depending on the duty cycle of the switching pulse. Its voltage gain expression is given by equation (4).

$$\frac{V_b}{V_{dc}} = \frac{D}{1-D} \quad (4)$$

$$C = I_o * \frac{D}{F_s} * \Delta V \quad (5)$$

5 Artificial Neural Network Based Control

Artificial Neural Network (ANN) is a type of neural network that uses brain processing to create algorithms that can be used to model complex patterns and predict problems. It is a model-free technique that can be trained to control the process of the duty cycle regulation. ANN controller structure is created in Matlab/nftool. The structure consists of two input layers, one hidden layer, and one output layer. ANN controller used to stabilize the output voltage of the DC-DC converter. Since the converter output voltage, V_b is a function of the duty cycle D. A control system should be constructed that varies the duty cycle to cause the output voltage to follow a given reference V_{dc}. The input voltage of the converter is based on grid voltage. In this paper, the input voltage should be kept constant. Input voltage V_{dc} and battery voltage V_b, are chosen as inputs to the neural network. The output layer consists of a single output to provide a duty cycle to the DC-DC converter which is a positive number between 0 and 1.

Initially, a set of samples required input and target output is generated for the network behaviour. The inputs and target of the neural network are stacked as lookup tables into array memory and the corresponding duty cycle is calculated effectively. The output of the controller is connected to the DC-DC PWM generator. The generated pulses are given to the switches. Since the Scaled Conjugate Gradient (SCG) algorithm consumes less memory and provides faster response, in this paper ANN is trained with the SCG algorithm.

6 Results and Discussion

6.1. Simulation of grid to vehicle mode (G2V)

The feasibility of the proposed bidirectional converter and its control concept has been verified through MatLab/Simulink. The simulation diagram is shown in Fig.6. In grid to vehicle mode, the bidirectional AC-DC converter receives a 230 V input voltage from the grid. The DC-link capacitor voltage should be kept at 400 V, which is supplied as input to the bidirectional DC-DC converter.

This paper's DC-DC converter functions as a buck-boost converter. When the DC bus voltage exceeds the battery voltage, the circuit operates as a buck converter. The simulation diagram of the non-isolated bi-directional DC-DC converter is shown in Fig.5. The AC-DC converter controls the DC bus voltage in G2V operation mode. In this case, the voltage PI controller is used to obtain the current reference id*. The utility grid provides energy to charge the battery in this mode.

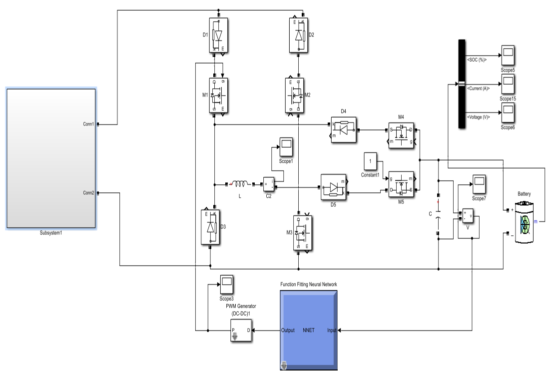

Fig.5]

6.2. Simulation of vehicle to grid mode (V2G)

In V2G mode, the DC-DC converter works as a boost converter while discharging the battery. In this mode, the battery power is injected into the utility grid. In this mode of operation, the DC bus voltage is controlled by a DC-DC converter and the PI controller generates a current reference as $i_{bat} = i_d^*$. Fig.6 shows the simulation diagram of the DC-DC converter when it is operated in V2G mode.

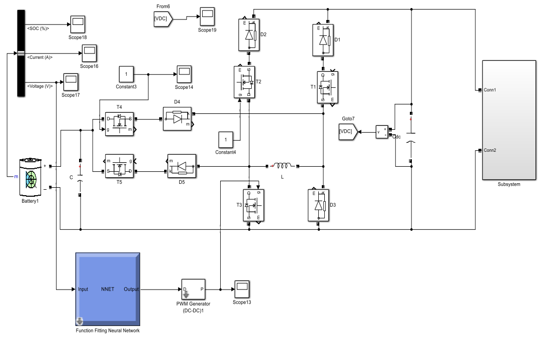

Fig.6 Integrated Bidirectional DC-DC Converter

The DC-DC converter operates in boost mode in vehicle to grid mode, increasing the 250V input voltage to 400V DC. The bidirectional AC-DC converter converts the 400V DC voltage to 230V AC voltage and returns it to the grid.

6.3. Simulation Results

To validate the proposed system, simulations were performed with the Matlab, considering both V2G and G2V mode of operations. The parameters used for the bidirectional charger are shown in the Table.1, Table.2 and Table.3.

Table 1. Bidirectional AC-DC Converter Specifications

S.No.	Name	Rating
1	Input Voltage	230 V
2	Input current	10 A
3	Power	2 kW
4	Switching frequency	20 kHz
4	Output voltage	400 V
6	Modulation index	0.9

Table 2. Bidirectional DC-DC Converter Specifications

S.No.	Name	Rating
1	Input Voltage	400 V
2	Switching Frequency	20 kHz
3	Output Voltage	250 V

4	Output Current	10 A

Table 3. Battery Specifications

S.No.	Name	Rating
1	Battery Voltage	250 V
2	Battery current	32Ah
3	Type	Lithium ion

Figures 7-16 show the simulation results for input voltage, input current, DC link voltage, battery voltage, and battery current in G2V mode. The duty cycle of the converter in buck mode has been set at 62.5% in order to step down the voltage from 400V to 250V with a current of 10A.

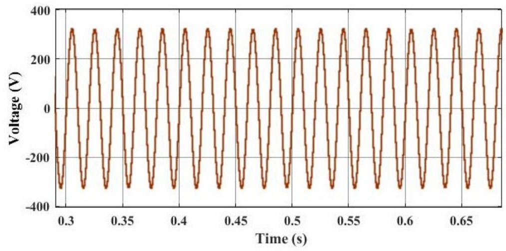

Fig.7 Input Voltage

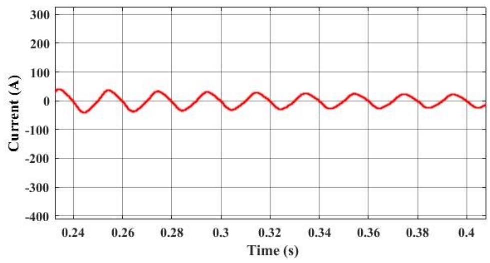

Fig.8 Input Current

In the simulations, the entire charging system of 2 kW has been designed. The bidirectional AC-DC converter converts 230V input AC voltage into 400V DC voltage. The DC-Link voltage serves as the input to the bidirectional DC-DC converter and PWM pulses generated by the ANN controller are shown in Figure.9 and Fig.10 respectively. For the switching frequency of 20kHz and the duty cycle is 62.5%.

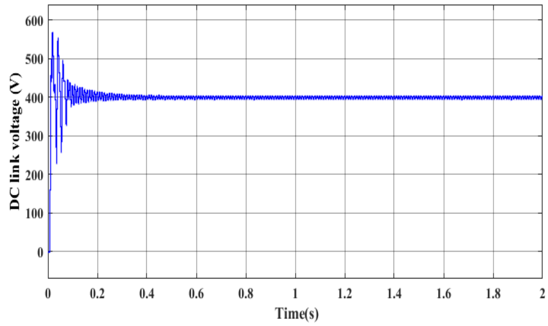

Fig.9 DC-link Voltage in G2V Mode

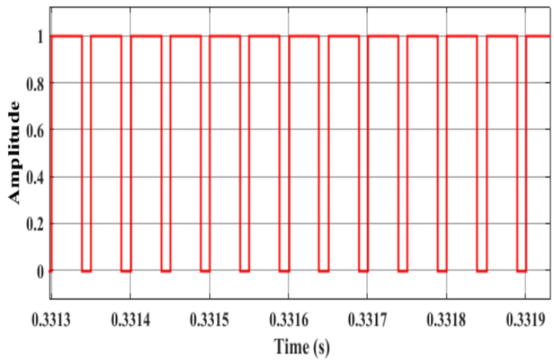

Fig.10 PWM Pulses to Bidirectional DC-DC Converter in G2V Mode

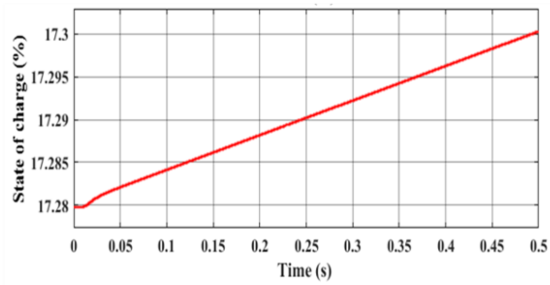

Fig.11 Battery State of Charge

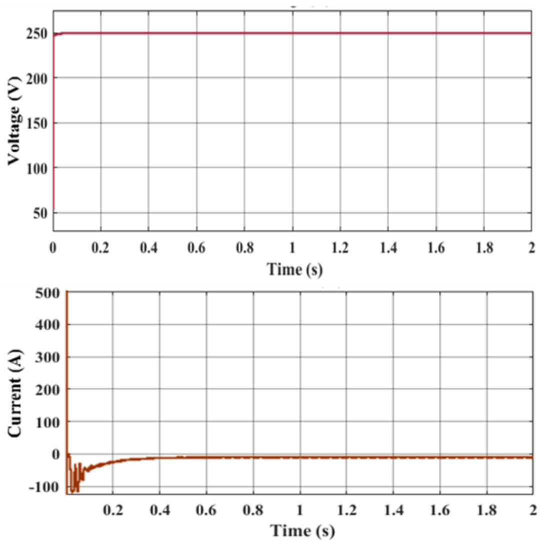

Fig.12 Battery Voltage and Battery Current

The battery serves as a load in G2V mode. As a result, the battery is being charged. In this mode, the input 230 V and current 10 A are fed into the bidirectional AC-DC converter shown in Figs. 7 and 8 to maintain the DC link voltage as a constant active current reference to the grid. During G2V operation, the EV battery monitors grid power. As a result, the battery's state of charge (SOC) rises, as illustrated in Fig.11. The battery current is negative while charging; once fully charged, the current is zero. Figure 12 depicts the corresponding battery voltage and current. When compared to the PI controller, the overshoot in the battery voltage and current is reduced when using the ANN controller. The bidirectional DC-DC converter acts as a boost converter in V2G mode. In boost mode, the DC-DC converter steps up a battery voltage of 250 V to a DC-link voltage of 400 V via constant control of output voltage, as shown in Fig.13. Figure 14 depicts PWM pulses to the DC-DC converter generated by the ANN controller with a duty cycle of 37%.

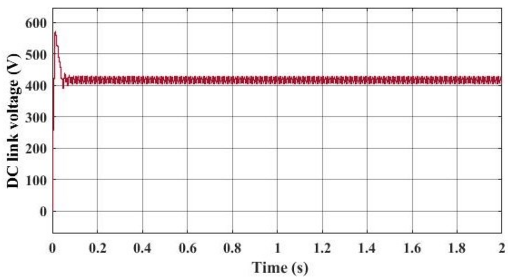

Fig.13 DC-Link Voltage in G2V Mode

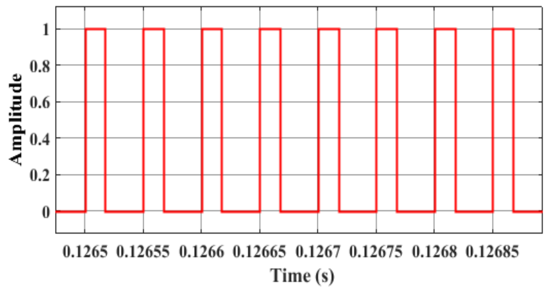

Fig.14 PWM Pulses to Bidirectional DC-DC Converter

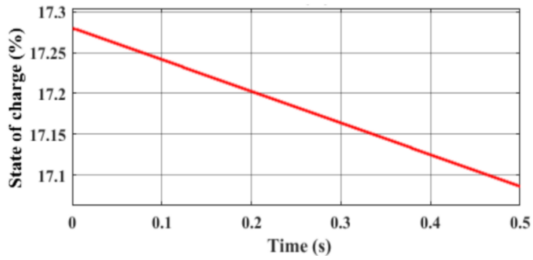

Fig.15 Battery State of Charge

In V2G mode the battery acts as an input. It supplies power to the grid so the battery is getting discharged so the battery SOC decreases as illustrated in Fig..15. During discharging the battery current is positive. The corresponding battery current is shown in Fig.16.

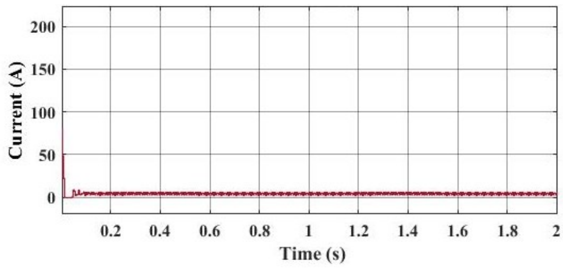

Fig.16 Battery Current

7 Conclusion

A bidirectional charger for electric vehicle battery charging applications is designed and simulated in this work. The charger was built to work in both grid-to-vehicle and vehicle-to-grid modes. The DQ control method is used to control the front-end bidirectional AC-DC converter. The AC-DC converter's bidirectional capability is achieved by maintaining a constant 400 V at the DC link. Voltage and current control are both implemented. The measured battery voltage is fed as input to the neural network controller in both G2V and V2G modes, and the duty cycle is obtained as output. The ANN's input and target data are generated and used to train the network. A comparative study is made between the results of PI and ANN controller for the bidirectional DC-DC converter. When ANN control is used in G2V mode, the peak overshoot of DC link voltage and battery current response are reduced by about 5% and 83%, respectively, when compared to PI control. Similarly in V2G mode, reduction of peak overshoot is achieved about 11% and 98% respectively. In the proposed integrated bidirectional DC-DC converter, out of 5 switches and 5 diodes, only one switch is PWM operated which reduces the control complexity of the system.

References

[1] Omer C, Kobayashi J, &Dylan Erab C. (2012), "Bidirectional High power quality grid interface with a novel bidirectional non inverted buck boost converter" IEEE Transactions on Vehicular Technology, 61(5), 2018-2032.

[2] Prashanthi Y &Suman K. (2018), "Bidirectional AC–DC Converter for A DC Distribution System", Proceedings of National Conference on Engineering, Science, Technology in Industrial Application and Significance of Free Open Source Softwares.

[3] Nayak S, Mohanty S&Saikia H.J (2017), "An Improved Control Method for the DC-DC Converter in Vehicle to Grid Charging System," 2017 14th IEEE India Council International Conference (INDICON), 1-6,

[4] Phimphui A &Supatti U (2019), "V2G and G2V Using Interleaved Converter for a Single-Phase Onboard BidirectionalCharger", IEEETransportation Electrification Conference and Expo, Asia-Pacific, 1-5.

[5] Caroline Ann Sam &Jegathesan V (2020),"Bidirectional integrated on-board chargers for electric vehicles-A review",Indian Academy of Sciences, .1-14.

[6] Andhra sridhar A.R. P & Weise N (2015), "Implementation and validation of dq current control of a bidirectional sic single-phase ac-dc converter," IEEE Proc. in Applied Power Electronics Conference and Exposition (APEC),3143 – 3149.

[7] Shridhar Kulkarni, Thorat A.R &IrannaKorachagaon (2017), "Bidirectional converter for Vehicle to grid (V2G) reactive power operation", International Conference on circuits Power and Computing Technologies(ICCPCT), 1-6.

[8] Debasish Mishra,Bhim Singh &B.K.Panigrahi (2018) "Improved Dual Battery Charging System for Grid Connected Bi-directional EV Charger",8th IEEE India International Conference on Power Electronics (IICPE),1-6.

[9] Peng, Tao,Yang, Peng, Hanbing, Dan, Wang, Hui, Han, Hua, Yang, Jian,Wang, Hao, Dong, Hui, &Wheeler, P. (2017) "A Single-Phase Bidirectional AC/DC Converter for V2G Applications", Energies,(10)

[10] Kisacikoglu M.C (2018), "A Modular Single-Phase Bidirectional EV Charger with Current Sharing Optimization," IEEE Transportation Electrification Conference and Expo (ITEC), 366-371.

[11] Omara A.M& Sleptsov M (2016), "Bidirectional interleaved DC/DC converter for electric vehicle application," 11th International Forum on Strategic Technology (IFOST), 100-104.

[12] Ananda Mohan P &Ranga J (2015), "A New Bidirectional DC-DC converter for Electric Vehicles Applications", International Journal of Engineering and Science, 5(3), 14-19.

[13] Kishore Kumar P, Gupta S.P & Mukesh Kumar P (2015), "Comparison of PI and Neural Network based Controllers for Shunt Active Power Filter",International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), 214-218.

[14] Kaviri S.M , Pahlevani M, Mohammadpour B, Jain P & Bakhshai A (2015), "A D-Q rotating frame DC-bus voltage controller for bi-directional single-phase AC/DC converters", IEEE Energy Conversion Congress and Exposition (ECCE), 3468-3473.
[15] Yahyazadeh S, Khaleghi M, Farzamkia S & Khoshkbar-Sadigh A (2020), "A New Structure of Bidirectional DC-DC Converter for Electric Vehicle Applications,"11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)**,** 1-6.
[16] Kurokawa F, Ueno K, Maruta H & Osuga H (2011), "A New Control Method for dc-dc Converter by Neural Network Predictor with Repetitive Training," 10th International Conference on Machine Learning and Applications and Workshops, 292-297.
[17] Wijesekera A & Binduhewa P (2018), "Design of a Small Electric Vehicle Charger with Multi-Ports," 2nd International Conference On Electrical Engineering (EECon), 8-13.
[18] Ul-Haq A, Buccella C, Cecati C & Khalid A H (2013), "Smart Charging Infrastructure for Electric Vehicles" International Conference on Clean Electrical Power (ICCEP), 163-169.
[19] Bharathidasan M & Indragandhi V (2020), "Review of Power Factor Correction (PFC) AC/DCDC Power Electronic Converters for Electric Vehicle Applications", IOP Conference Series: Materials Science and Engineering,.906.
[20] Melo Trovao M, Pedro J, Pereirinha P.G, Humberto J & Carlo A (2017), "A Controllable Bidirectional Battery Charger for Electric Vehicles with Vehicle to Grid Capability,"IEEE Transactions on Vehicular Technology, 67, 114-123.