MODELING OF HYBRID ELECTRIC VEHICLE CHARGER

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Abstract— Bidirectional DC-DC converters (BDCs) are used in recent years. And also their efficiency results are improved to apply different control methods. ANN algorithms is one of the new control topic in literature. This paper attempts to improve the dynamic performance of bidirectional dc-dc converter. And it deals with a novel control scheme related with an adaptive input voltage control by using ANN algorithms based on bi-directional on-board charger (OBC). There are numerous power electronics components in a HEV. The proposed circuit has a battery charging ability by adding power relays into the generator drive system. Therefore, the conventional OBC can be removed from the vehicle and thus the power density of the vehicle is increased. Because the proposed charging circuit allows bi-directional power delivery from grid to vehicle, a model predictive current controller is proposed to achieve the fast-dynamic response and improve the harmonic characteristic of grid current. The simulation results verify the validity and feasibility of the proposed integrated charging system design and its control method**.**

Keywords— *Bidirectional DC-DC converters (BDCs), ANN algorithms, on-board charger (OBC), Electric Vehicles (EVs).*

1. INTRODUCTION

Generally, Electric vehicles (EVs) and hybrid EVs (HEVs) have received attention for a decade with requirement of emission restriction in urban transportations. Among them, HEV is compromise alternative for conventional combustion engine vehicle and EV considering the limitation such as combustion of petroleum, air contaminant emissions and the limited driving range [1], [2]. HEVs are consist of various mechanical and electrical components such as engine, transmission, battery, charger, traction motor and its driving inverter [3]. In addition, there are an additional generator and its drive inverter called starter generator system. The function of starter-generator system is to start the engine from an idle stop and converter the kinetic energy of the vehicle to the electrical energy and send it into the secondary battery [4]. In this study, the starter-generator system is modified to have a function of the battery charger instead of the on-board charger (OBC), which is equipped in conventional HEVs. Thus, the modified starter-generator system operates as two different modes. One is the operation of motor drive as the conventional starter-generator. Second is the battery charger. These integrated charging system is used as substitute for conventional OBC and thus, the conventional OBC can be eliminated from the HEV. Therefore, the modified circuit results in the reduction of the required volume and weight of the HEVs along with the incensement of the power density. During the past decades, feedback-based current control method such as proportional-integral (PI) controller has been in the limelight for the outstanding performance of the power converter [5]-[6]. The PI current controller produces fine control results by transforming the time-variant variables into the time-invariable variables on the synchronous reference frame. In this control method, however, some of the disadvantages exist due to the design of the controller using the system parameter. In addition, it is difficult to design the gain of the controller when the system is complicate. In this paper, thus, the model predictive current control (MPCC) method is proposed for the control of the single-phase full-bridge inverter when the proposed integrated circuit is in the battery charging mode. Because the single-phase two-level inverter produces only three different output voltage, the conventional MPCC produces high total harmonic distortion (THD) in output current while the three-phase two-level inverter generates eight different voltage vectors. In order to reduce the THD in output current, the sampling time should be increased and it results in insufficient calculation time. This paper applies the advanced MPCC method to limit the di/dt of the output current and improve the harmonic characteristic. Compared with the conventional feedback-based control method, the proposed MPCC method provides fast dynamic response. In addition the harmonic characteristic of output current is improved compared to the conventional MPCC method. The validity of the proposed integrated charging system's design and its control method is verified with simulation results.

Bidirectional DC-DC converters (BDCs) are used a lot of industrial areas such as electric vehicles, uninterruptable power supplies, fuel cells, solar panel cells as energy sources are searched in order to improve the quality of power at the transmission, distribution lines and other areas. All of these industrial applications give importance on system loss, efficiency drop, shortening the life of circuit elements. Thus, it should be improved control systems in order to prevent power losses as far as possible and the efficiency of bidirectional power flow is so important for high quality electrical energy. At this point, lots of control methods are applied for improving converter efficiency. One of these control methods is Artificial Neural Network (ANN) based on different types of algorithms. ANN involves feed-forward (FF), support vector machine (SVM) and self organizing map (SOM) algorithms. They are classified according to have supervised or unsupervised learning. These algorithms are operated for finding the best efficient input voltage of the converter and which one is an appropriate algorithm among all of these algorithms at this study. There are some studies in literature about the ANN [1-7] however generally they do not use to control power electronic devices. Fig. 1 shows the BDC topology and essential dataset is extracted from the simulation of Single-Phase Full-Bridge Isolated BDC that is operated between 100V and 400V input voltages and constant 160V output voltage by using MATLAB/Simulink. This converter model also contains snubber capacitors that is parallel connected to IGBTs for improving system efficiency. The dataset of the converter is detected by ANN that is trained using supervised or unsupervised learning to produce low error values. In this direction, the best input voltage can be chosen according to the converter efficiency maps in ANN algorithms and classification of the input voltages are shown in fifth chapter. This paper presents a new control method for predicting adaptive dc link voltage by using ANN algorithm. With this algorithm, the predictive and adaptive properties of artificial neural networks (ANNs) are used for fast estimation of the reference dc link voltage. In addition, the other supervised and unsupervised control algorithms also are applied to the proposed system. And then, the performance analysis of both proposed controller and other ANN algorithms control methods are compared. Finally, the effectiveness of the novel control method are satisfied by using MATLAB/Simulink program.

2. CONFIGURAION OF INTEGRATED CHARGING SYSTME USING STATER-GENERATOR

Usually, a conventional HEV includes a starter-generator, its drive inverter, battery, and OBC, separately. Therefore, the increasing power density is one of the most important challenge for the HEVs design. This paper introduces the integrated circuit has the ability of the battery charging and motor drive.

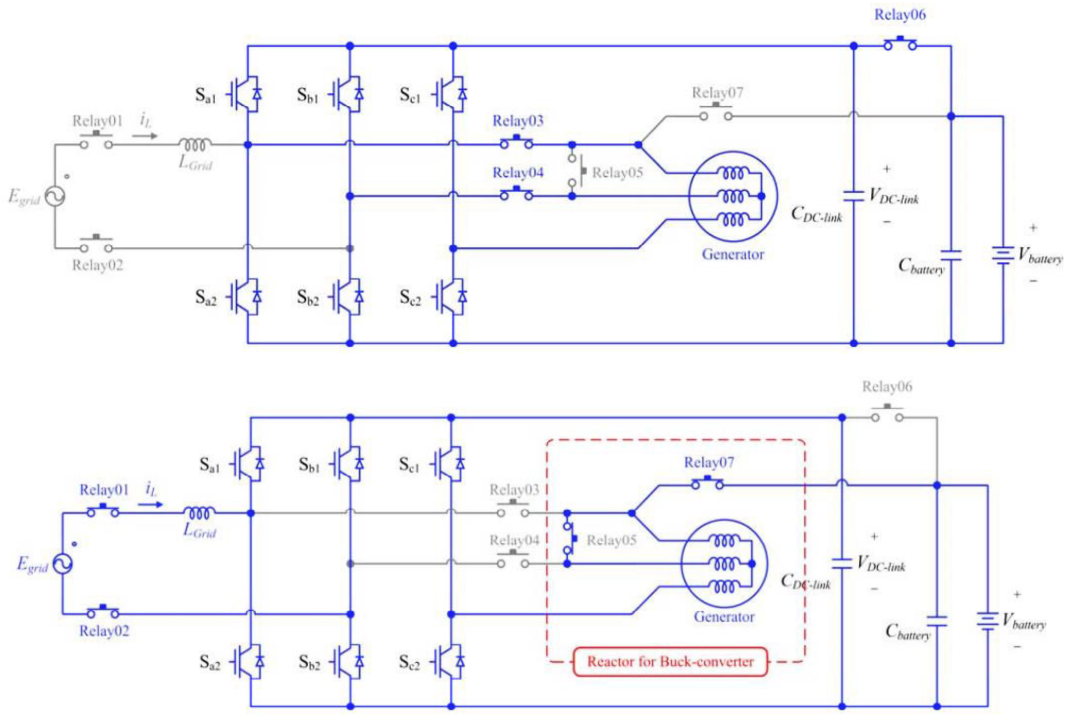


Fig. 1. Construction of the integrated charging system: (a) starter generator drive mode.

The proposed circuit is composed of three-phase two-level inverter, starter-generator, and seven power relays as shown in Fig. 1. The advantage of this circuit is that the battery can be charged with the power rating of the starter-generator drive circuit. When this circuit design is applied to the traction motor drive circuit, the battery can be charged with the high-power rating of the traction motor drive circuit.

3. STARTER-GENERATOR DRIVE MODE

Fig. 1(a) shows the circuit configuration for the startergenerator drive mode. In this mode, relay 06 is turned on to connect the battery with the three-phase inverter. The DC-link and battery share the same electrical node and the three-phase inverter is fed by the battery to drive the starter-generator. Relay 03 and 04 are turned on and the three-phase currents from the inverter are delivered to the starter-generator. This mode is same with the original starter-generator operation, which is driving the generator or breaking the vehicle by using the regenerative energy.

4. BI-DIRECTIONAL OBC MODE

To construct the single-phase bi-directional OBC circuit, the integrated circuit is reconfigured as shown in Fig. 1(b). The circuit of OBC mode is composed of grid filter reactor, fullbridge AC-DC converter, bi-directional DC-DC converter, and battery. Relay 05 and 07 are turned on to use the winding of starter-generator as a filter reactor of the DC-DC converter, and relay 01 and 02 are turned on to connect the grid with the fullbridge converter. The equivalent inductance of the filter inductor is 1.5 times of a single winding in starter-generator. This OBC circuit provides two different power transmission states. When the power is delivered from grid to vehicle, the battery is charged and the state is called G2V mode. On the contrary, V2G mode delivers the stored energy in battery to grid as conventional energy storage system (ESS).

5. ANN BASED CONTROL OF CHARGER

There are two outputs of ANN controller, the first signal controls the voltage level through rectifier between grid and DC-link capacitor, second, the current controlling signal that is being fed to Buck/Boost converter for maintaining the charging current. The voltage-controlled scheme is implemented through grid voltage and DC-link voltage regulation. Therefore, certain parameters are calculated as the controller's critical inputs. Firstly, the error between the calculated DC-link voltage and the preset DC-link voltage reference are obtained. The calculated error is then sent to ANN controller which responds by creating a corresponding phase shift angle. Secondly, the direct and quadrature voltages from the instantaneous grid voltage, are obtained. The actual voltage is compared against the desired direct voltage. The error between the two given as input of ANN Controller, that sets the magnitude of the required modulation signal.

For controlling of DC/DC converter. The key operating equations may be derived for the buck and boost operation modes by (1) to (4) for buck mode and (5) to (9) for boosting operation respectively.

$$V_{EVBattery} = V_{DCLink} - L_o . \frac{dI_{Charging}}{dt}$$

$$I_{Charging} = \frac{1}{L_o} . \int_0^{T_{on}} (V_{DCLink} - V_{EVBattery}).dt$$

$$V_{EVBattery} = -L_o . \frac{dI_{Charging}}{dt}$$

$$I_{Charging} = \int_{T_{on}}^{T_{off}} \left(-\frac{V_{EVBattery}}{L_o}\right).dt$$

$$V_{EVBattery} = L_o . \frac{dI_{Charging}}{dt}$$

$$I_{Charging} = \frac{1}{L_o} . \int_0^{T_{on}} (V_{EVBattery}).dt$$

$$V_{EVBattery} + V_{L_o} = V_{DCLink}$$

$$I_{Charging} = \frac{1}{L_o} . \int_{T_{on}}^{T_{off}} (V_{EVBattery} + V_{DCLink}).dt$$

The current-controlled loop will first define the bidirectional buck-boost converters mode of operation by the battery reference current (negative for charging and positive for discharging). The calculated error between the actual battery current and reference battery current will determine the duty ratio output of the ANN controller. The duty ratio is fed to the PWM (Pulse Width Modulation) modulator, which sends the switching signals of IGBT's. Training of ANN requires a minimal error between the target result and the network one-handed out. In this work, a classic LM based technique is employed to accomplish this training. To this issue, the device built here has two input and two outputs. The training parameters are listed in table 1. Considering the kth neuron of the pth layer connected to the nth neuron of the preceding layer, the error equation for a particular node is expressed in equation (9). Equation (10) shows summative error E.

$$e_j = y_j - f\left(x_i, w_{k,n}^p\right)$$

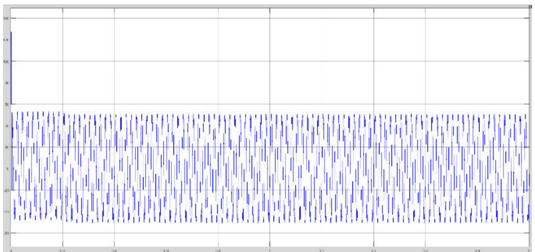
$$E = \frac{1}{N} \sum_{l=1}^{N} e_j^2$$

The weight updating algorithm for any weight is given by:

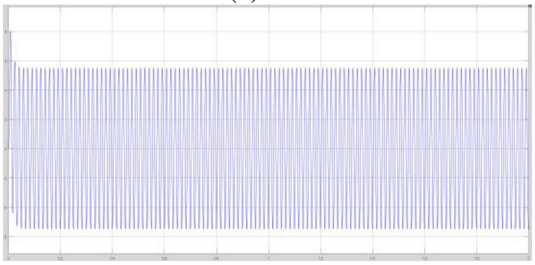
$$\gamma_{k+1} = \gamma_k - \beta_k^{-1} . \delta_k$$

Where $\gamma_k = w_{k,n}^p \beta_k \delta_k$ are LM parameters. The training characteristics of the ANN model is represented in Figs. 2–5. Results of Training shows the ANN network has an ideal fitting characteristic with negligible error.

6. SIMULATION RESULTS

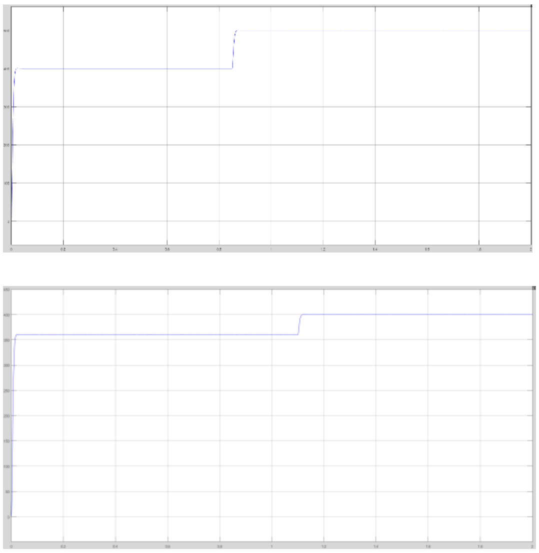


(a)

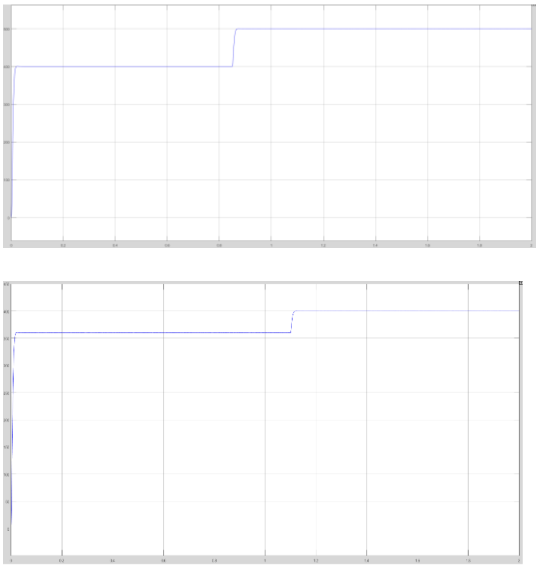


(b)

Fig. 2. Simulation results of the MPCC method: (a) Current control by conventional MPCC method and (b) Current control by proposed MPCC method

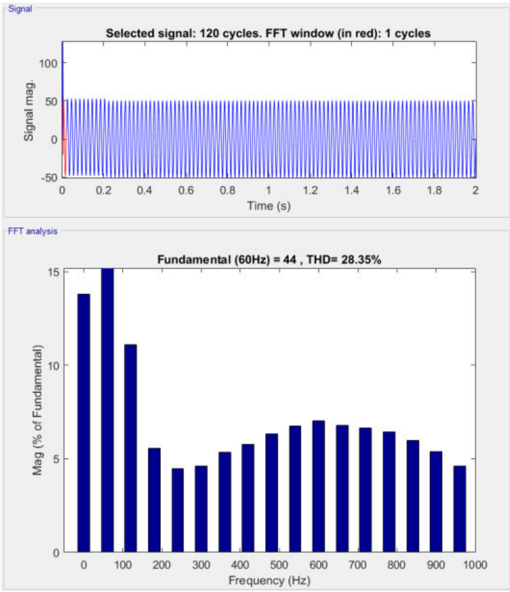


(a)

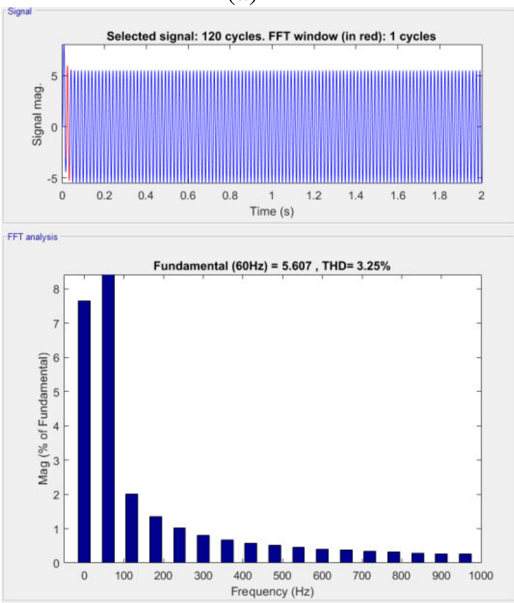


(b)

Fig. 3. Simulation wave forms of the integrated charging system: (a) DC-link voltage control, (b) Battery voltage control.



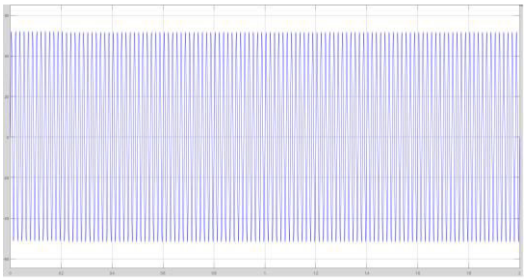
(a)



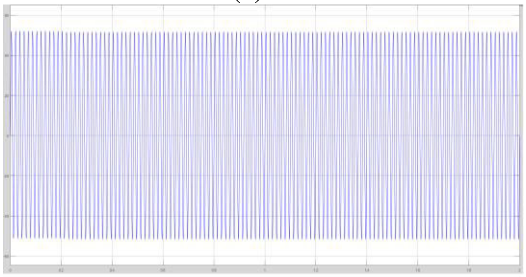
(b)

Fig4. THD of the (a) current is 22.84 %. On the other hand, the current waveform generated by the proposed MPCC method contains reduced current error and ripple. Thus, the harmonic characteristic of grid current is improved and its THD is (b) only 3.93 % by using the proposed control method.

Proposed ANN Controller

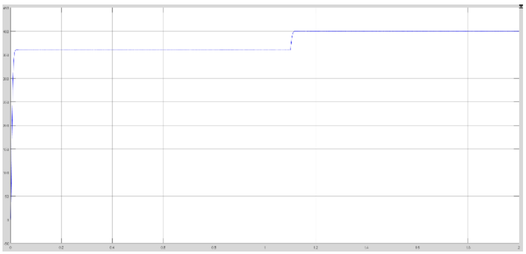


(a)

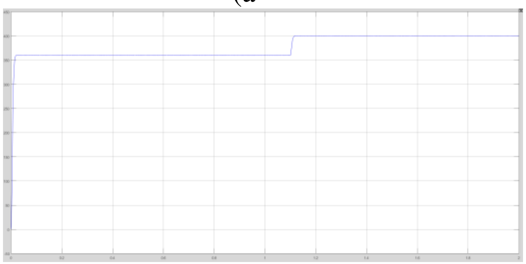


(b)

Fig5. Simulation results of the ANN technique: (a) Current control by conventional ANN and (b) Current control by proposed ANN



(a



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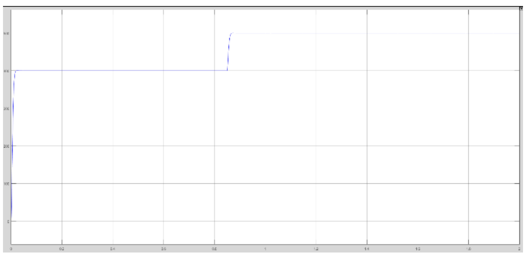
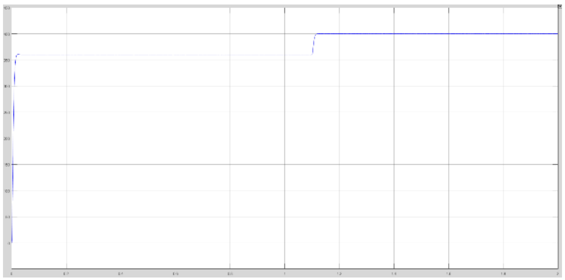
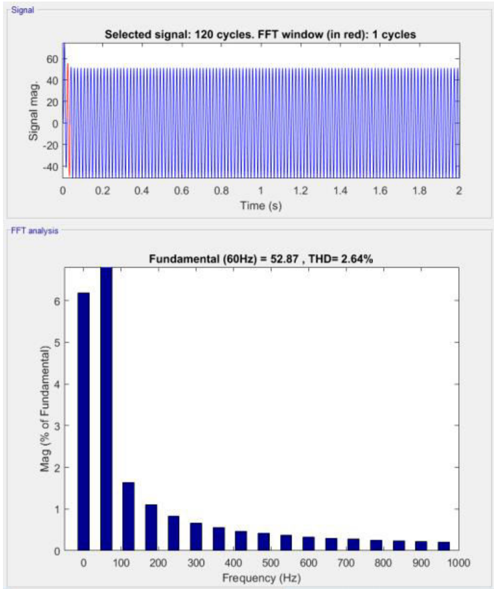




(b)

Fig6. Simulation waveforms of the integrated charging system: (a) DC-link voltage control, (b) Battery voltage control.



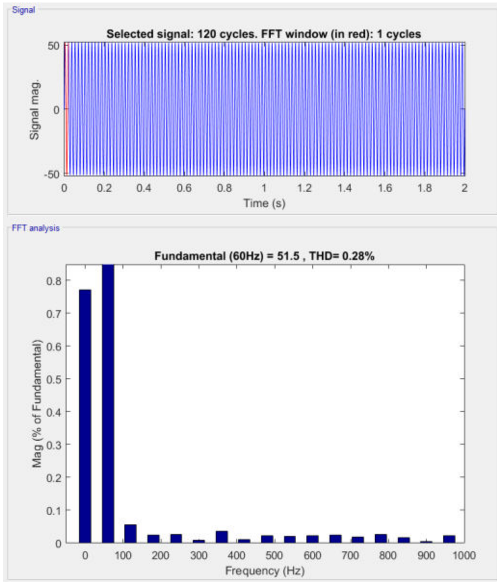


Fig7. THD of the current is 2.64 %. On the other hand, the current waveform generated by the proposed MPCC method contains reduced current error

and ripple. Thus, the harmonic characteristic of grid current is improved and its THD is only 0.28 % by using the proposed ANN control method.

Conclusion

In this paper, authors have presented ANN controller applied to bidirectional V2G charger that allows to boost the capabilities of a joint storage operation and an autonomous EMS in a residential environment, with advantages towards end-users. ANN Based controller could give support to the regulation of grid voltage. Reactive power is extracted from the DC link capacitor to counter the unbalance created by EV loads. The charger is capable of providing different charging modes by varying the charging current through the ANN controller. ANN controller enables bidirectional V2G charger to works at various power rates, which facilitates the integrated power distribution and management for all consumer loads. Simulation results provided validate the performance of ANN-based bidirectional charger. This ANN-based technique is compatible with any battery specific voltage, and current, and gives an economical and feasible solution for three-phase high power applications.

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