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COMPARISON OF PI AND AI CONTROLLERS USED FOR DC-DC CONVERTER FOR EV FAST CHARGING

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ABSTRACT

The usage of Electric Vehicles is increasing rapidly, we need to decrease the time required for charging. Therefore there is a demand to built High rated Charging Stations (CS) to reduce drivers Range Anxiety. Neutral Point Clamped (NPC) Converter containing Charging Station have benefits, but this converter has problem of unbalanced power. To overcome this problem, Comprehensive DC Power Balance Management (PBM) in coordination of Fast Chargers based on High Power Converter is used. Active DC PBM (APBM) is used to support balancing power of NPC converter so that an extra circuit for balancing is abolished. Where as Passive DC PBM (PPBM) is used to remove fluctuating currents in the neutral terminals and enable consistent operation of fast chargers. In these paper the DC-DC Converter is controlled using both proportional plus Integral(PI) and Artificial Intelligence(AI) controllers. The performance of PI controller is compared with AI controller to evaluate the system performance. Simulation results are validated using MATLAB/SIMULINK software.

KEYWORDS: AI controller, High power charging stations, Comprehensive DC PBM.

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I. INTRODUCTION

A feasible alternative to traditional internal combustion engine vehicles (ICEVs), Electric vehicles (EVs) are slowly rising their shares in the automobile industry due to low consumption of fuels and carbon emission gases [1], [2]. The price, time for charging and charging facilities are consumer's key importance, they are affecting their choice of EVs [3], [4]. So in order to increase the purchase of electric vehicles, need to implement the quick charging stations. If fast chargers minimize replenishment of EVs at reasonable rates than the normal replenishment of ICEVs and the fast charging stations scattered across the cities, then purchase of EVs would be increased [1], [5].

Not only the charging station circuit, the DC-DC converter used for fast chargers also plays an important role in terms of system efficiency and time required for charging battery. Usually Level I and Level II chargers are used for slow charging with low power rating so, they are mounted on board. The voltage and power rating are very high (DC Level III) for fast charging to reduce charging time. The DC voltage ranges from 200V to 600V and power from 50kW to 240kW, so it is mandatory to be off board charging station.

The bipolar dc bus circuit is studied in [6] and NPC converter used in centralized grid converter to convert AC-DC as shown in Fig 1. The bipolar bus gives more power capacity and flexibility for loads connected to it. The NPC converter's switching frequency is twice the switching frequency of device. Therefore results in low dv/dt, filter circuts and good performance in current. To solve problems arrived due to configuration in [6], comprehensive dc PBM is used. DC-DC converter used in high power fast charging stations does not need electrical isolation. So these convereters are more economical.

The social optimality of the proposed policies is established when each station is equipped with multiple charging slots[7]. The characteristics of EV charging, charging and discharging periods of loads for energy storage systems for whole day are studied in [8]. To support V2G and reactive power compensation the charging station was designed[9]. The performance of converters like classical buck converter, QZS and QZSC are studied in [10]. Measurements of EV fast charging process ABB Terra 52 charging stations installed in Aleksandro Lodzki(Poland) in [11]. The intelligent decision making system based on ANN is presented in [12]. The impact of EV charging stations on grid and distribution network in countries like Bangladesh is analysed in [13]. The step up DC-DC converter topologies in terms of start up currents and passive components are analysed in [14].

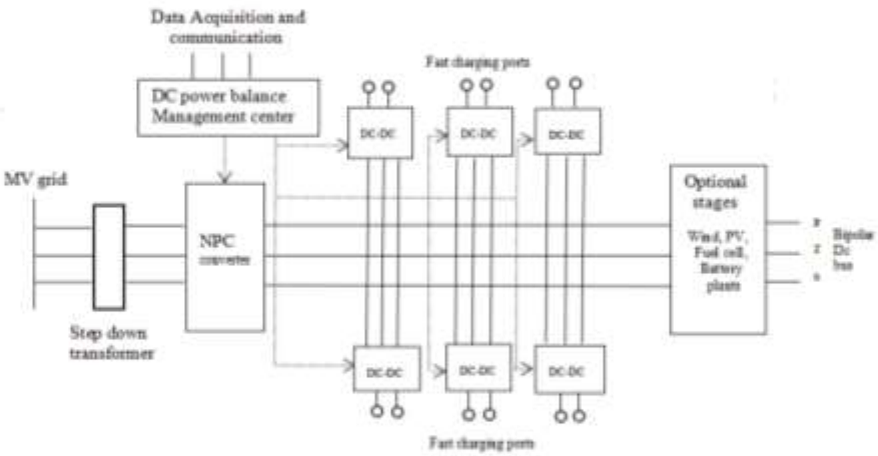


Fig. 1: Block Diagram of Controlling DC-DC Converters through DC Power Balance Management

These paper proposes the controlling of DC-DC converters with AI controllers. The high power dc-dc converter are used in fast chargers for high rated fast charging stations. The existing system has fast chargers with DC PBM capability which helps to remove additional balancing circuit and transformers. The NPC converter used as centralized grid converter will control the grid side currents leads to high power quality. The comprehensive DC PBM is used to solve the unbalanced power problems among positive and negative DC bus.

The PI controllers used in fast chargers have high steady state error. To reduce this AI controllers in the fast chargers are proposed which can reduce the error and leads to stable operation. The performance of proposed fast chargers with AI controllers are verified through simulation results.

II. PI CONTROLLER

A PI controller is a feedback controller which produces error by taking difference between two variables. The rise time decreases and overshoot and settling time decreases by using PI controller.

When proportional gain increases, it effects on control signal proportionally to error. Closed loop system will act fast because controller pushing harder for a given level of error. The erroer will not removed completely but reduced by incresing $K_{p.}$

When integral gain (K_i) added to the controller, it will reduce the error. If the error is constant, the integrator increases their gain, so control signal increases there by reduces the error. The only effect of integral term is it can make the system slow, because it will takes time to unwind when the sign of the error signal changes.

The output of PI controller y(t) can be written as,

$$y(t) = K_p e(t) + K_i \int e(t)dt \quad (1)$$

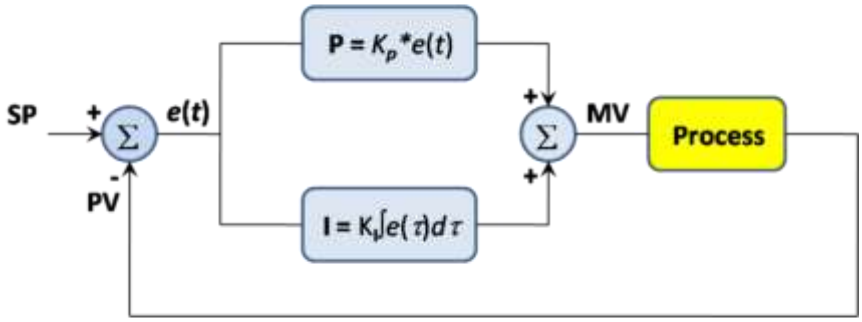


Fig. 2: Basic Block Diagram of PI Controller

III. AI CONTROLLER

An Artificial intelligence is an information processing model inspired by the way how biological neural system like brain process information. The central aspect of this paradigm is the new framework of the Model Application development system. It consists of a large number of fully integrated processing components, which work together to solve particular problems.

An ANN is set for a particular applications, such as pattern Recognition or evaluation of data, by way of learning. Genetic learning involves the modifications of Synaptic linkages between the neurons. That's it Also true Ann. It offers very extensive capabilities for Modelling of complex systems, predictions, controls and Achievement.

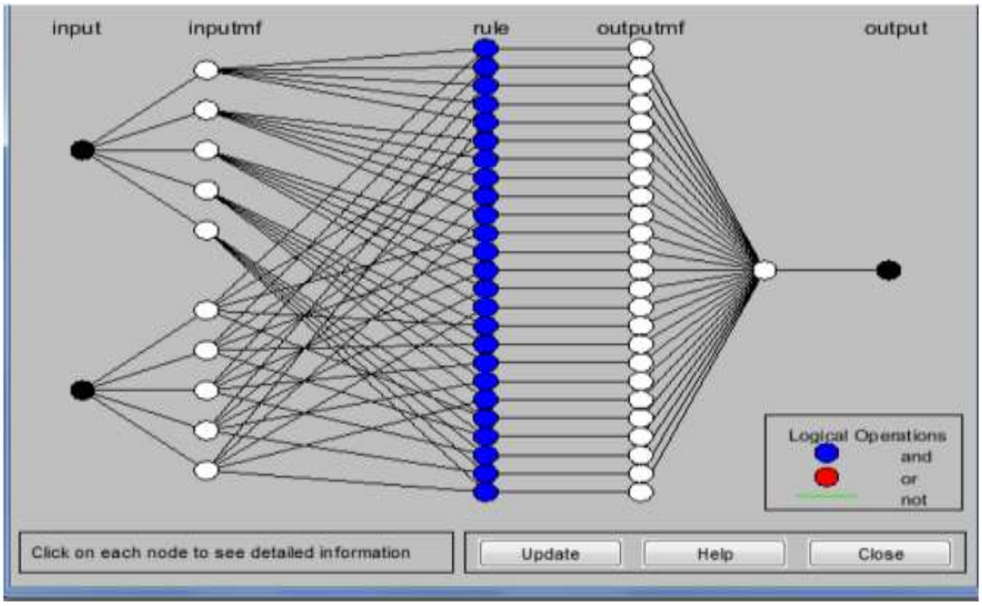
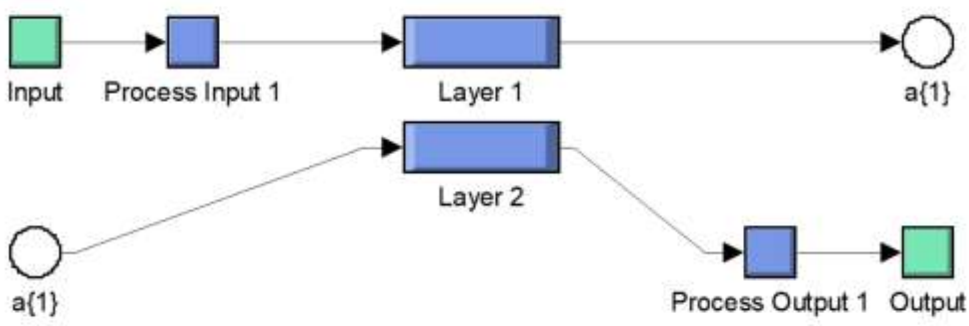
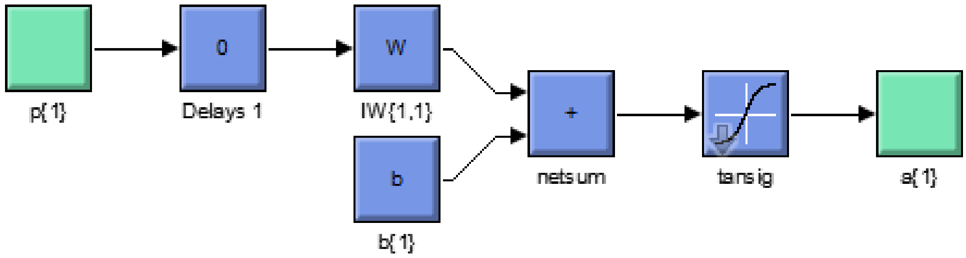


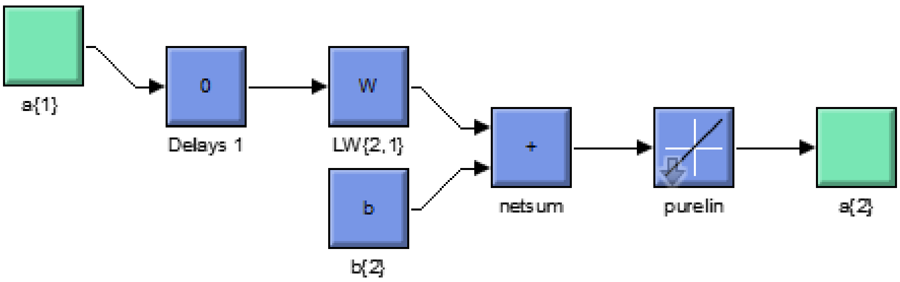
Fig. 3: Design of Neural Network



(a) Function fitting neural network



(b) ANN based Layer 1



(c) ANN based Layer 2

IV. DC-DC CONVERTER

A. Toplogy

The circuit of high power converter for fast chargers can be shown on Fig.4, it is composed of two 3 level DC-DC converters connected in parallel for handling high currents. Each converter unit consists of four switches with Free-wheeling diodes and two output inductors.

B. Modulation and principle

In the case where the circuit in balanced condition and the two convereter units are working in in-phase mode (as no phase difference between their gating signals.

To analyze the converter 2 operating modes are presented when Dx1=Dx4=D≤0.5, the waveforms of converter is shown in simulation results and also displays the waveforms when Dx1=Dx4=D≥0.5. where dx1 and dx4 are duty cycles obtained from controller and x indicates 1or 2 equivalent to unit 1 or 2. As modulation signals Dx1 and Dx4 are compared to two interleaved signals at 180^0 carrier signals c1, c4 to produce outer switches sx1 and sx4 gate signals. While sx2, sx3 will operate complimentarily to switches sx1 and sx4 respectively.

V. COMPREHENSIVE DC PBM

If the unbalanced power here between buses is not in the limits of central NPC converter's predefined control zone, the APBM is triggered for balancing the power so that there is no need of extra circuits for balancing. Where the unbalanced power is inside the balanced region, then the passive PBM is triggered to enhance the operation of the fast chargers in balanced region and to reduce fluctuation of the neutral currents. The comprehensive DC PBM will benefit the combination of APBM and PPBM in achieving the far more better cooperation for the charging station's total power balance. Therefore, it is proposed to cause the switching between APBM and PPBM by the power difference between Pp and Pn. The APBM is selected if ΔP is outside the pre-determined zone; If ΔPis within the zone, the PPBM is selected. For this the transition rule is as follows:

$$PBM = \begin{cases} APBM, & if \Delta P \notin \left[-P_{be}, P_{be}\right] \\ PPBM, & if \Delta P \in \left[-P_{be}, P_{be}\right], \end{cases} \quad (2)$$

Where P_{be} is selected on the basis of the NPC converter balance limits[6] and the sharing of balance tasks between the converter and the converter fast chargers.

The PBMC commands the reference power P_b^* for balance, which is calculated by collecting voltage and current values from loads which are connected to bipolar dc bus and getting the information of number of fast chargers 'n' which are in operation.

$$P_b^* = \Delta P / n = (P_n - P_b) / n \qquad (3)$$

We can calculate the power to be balanced P_{bx} obtained from the each converter by,

$$P_{bx} = (D_{x1} - D_{x4}) v_i i_{ox} \qquad (4)$$

By generating the control signals $\Delta\overline{D}_x$, the power can be controlled. And the control signals $\Delta\overline{D}_x$ have limits in the boundary[- $\Delta\hat{D}_x$, $\Delta\hat{D}_x$], and $\Delta\hat{D}_x$ is defined as:

$$\Delta\hat{D}_x = \begin{cases} \min\{\overline{D}_{x1}, \overline{D}_{x4}\}, & \overline{D}_{x1,x4} \le 0.5 \\ 1 - \max\{\overline{D}_{x1}, \overline{D}_{x4}\}, & \overline{D}_{x1,x4} \le 0.5 \end{cases} \qquad (5)$$

The control signals ΔD_x is obtained by multiplying $\Delta\overline{D}_x$ by sign of Output current i_o:

$$\Delta D_x = \Delta\overline{D}_x \operatorname{sgn}(i_0) \qquad (6)$$

The final modulation signals D_{x1}, D_{x4} are obtained by above calculated ΔD_x and original modulation signals $\overline{D}_{x1}$ $\overline{D}_{x4}$

$$D_{x1} = \overline{D}_{x1} + \Delta D_x \qquad (7)$$

$$D_{x4} = \overline{D}_{x4} - \Delta D_x \qquad (8)$$

VI. SIMULATION AND RESULTS

Fast charger is simulated by MATLAB / Simulink with comprehensive DC PBM with both PI controller and AI controller. A 240 kW rating converter is intended for verification, and the parameter values of the system model are given in below table I.

Table I: Simulation Parameter

PARAMETER	Sym.	SIMULATED VALUES
TOTAL DC VOLTAGE	2Vi	3.3 PU
INPUT CAPACITANCE	Ci	0.56 PU
OUTPUT INDUCTANCE	Lf	1.25 PU
OUTPUT CAPACITANCE	Cf	0.6 PU
SWITCHING FREQUENCY	Fs	72 PU
BASE FREQUENCY	Fb	60 HZ
BASE VOLTAGE	Vb	600 V
BASE POWER	Pb	240 KW

(a) Simulated circuits

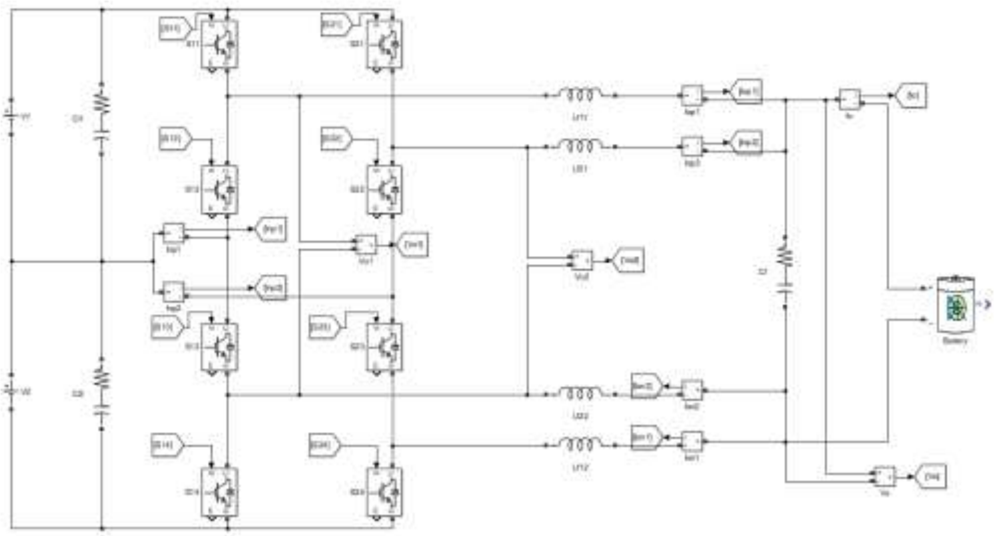
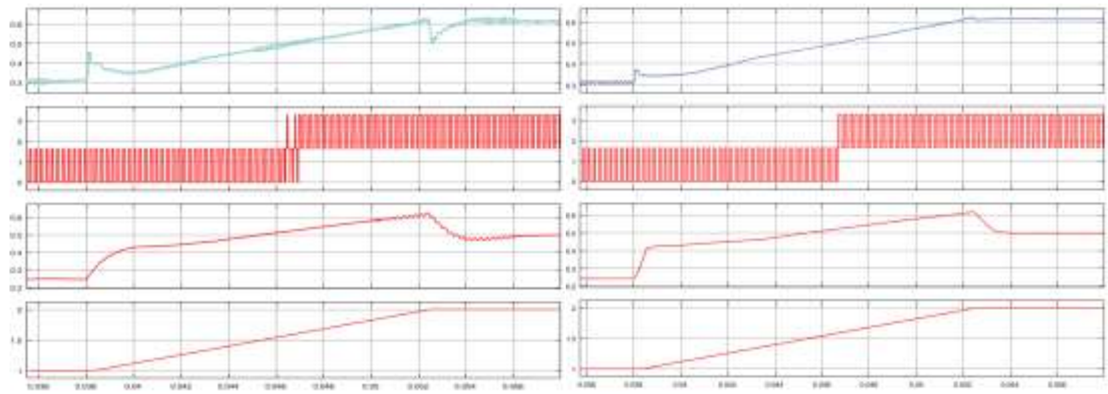


Fig. 4: Simulated Circuit for dc-dc Converter

(b) Simulated Results and discussion

The simulation results for changing from constant current to constant voltage condition for both PI and AI contollers are given in Fig 5. Modulation signals, output voltage across converters first unit, total output current and output voltage are compared using both PI and AI controllers.

Fig 5. shows that the modulation signals D11 and D14 using PI and AI controllers. The signals obtained AI controller have smooth signal compared to PI controller. The steady state error is less in case of AI controller and balanced operation can be achieved. In the same way the voltage and current signals have less error and steady state operation can be seen.



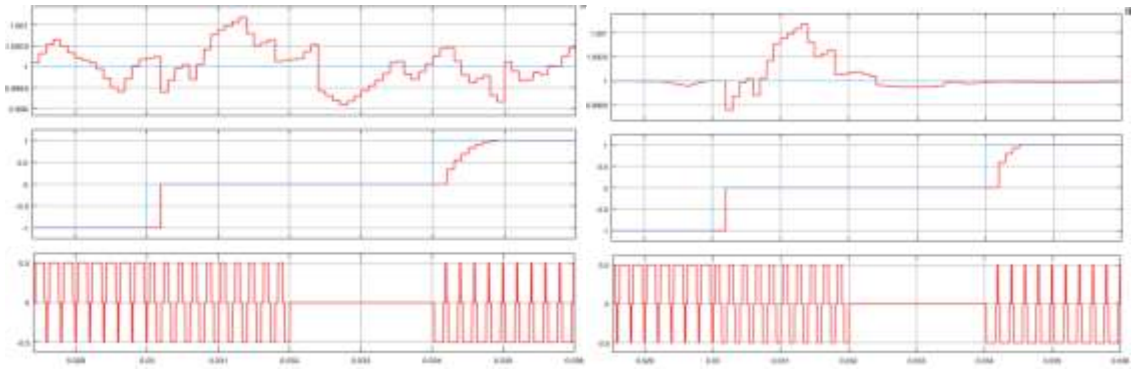
With PI Controller With AI Controller

Fig. 5: Simulation Performance for Changing from Constant Current to Constant Voltage Condition. (a) Modulation Signals D11 and D14. (b) Output Voltage of First Unit V_{01}. (c) Output Current I_0. (d) Voltage Across Output V_0

Fig 6. shows the conduction of PBM in constant current condition for D≤0.5. Here current, balance power & neutral point currents are compared. The output current signal had more dampings using PI controller which can be drastically reduced by using AI controller.

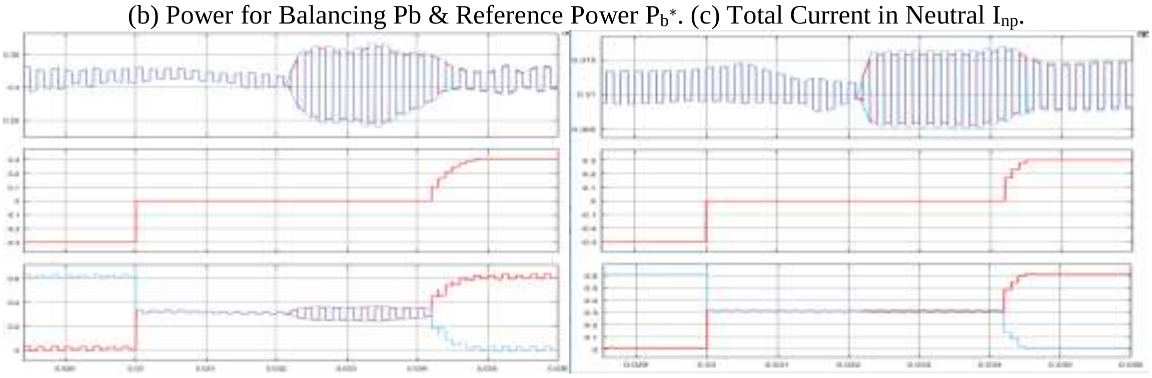
The Fig 7. and Fig 8. shows the simulated outputs of Modulation signals and output currents at constant current condition when D≤0.5. Modulation signals and current signals are compared using both PI and AI controllers.

The modulation signals D11 and D14 shown in Fig 7 can observe the changes clearly obatined using both controllers. As well as the current signals as shown in fig.8, are continuous and uniform by using AI controller.



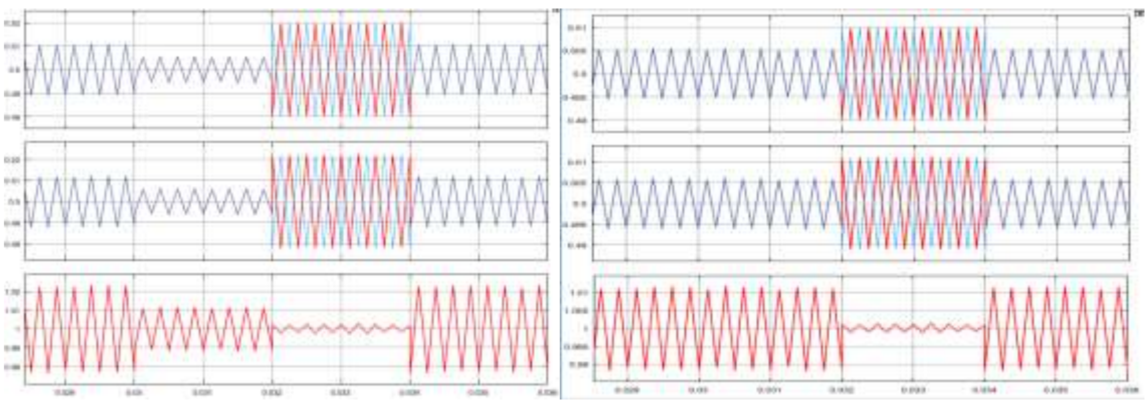
With PI controller With AI controllers

Fig. 6: Simulation Signals of PBM in Constant Current Condition, for D≤0.5:(a)Output Current I_0& Reference Current I_0*.
(b) Power for Balancing Pb & Reference Power P_b*. (c) Total Current in Neutral I_{np}.



With PI Controller With AI Controller

Fig. 7: Modulation Signals in Constant Current Condition, for D≤ 0.5: (a)Initial Modulation Signals D_{11}&D_{14}, (b) Control Signal for Power Balance ΔD1, (c) Resulted Modulation Signals D_{11}&D_{14}.

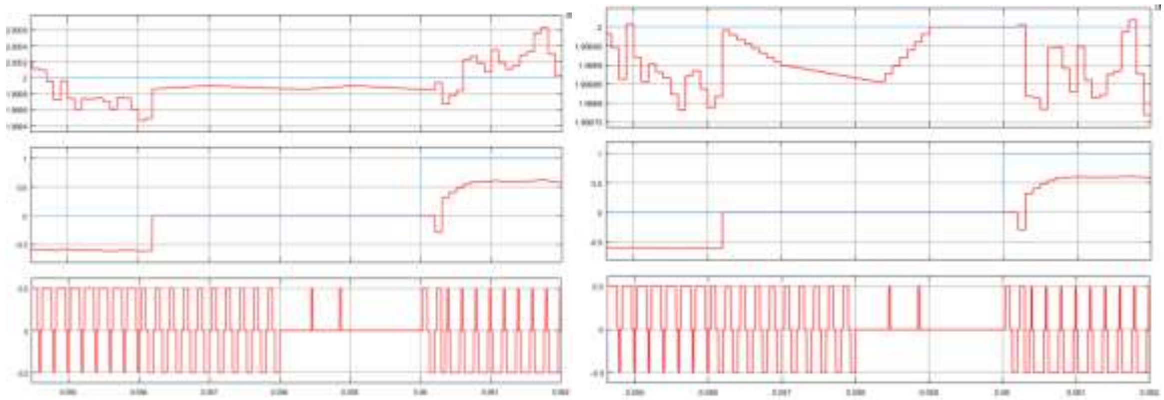


With PI Controller With AI Controller

Fig. 8: Signals of Output Currents in Constant Current Condition, for D≤ 0.5: (a) Output Current from First Unit $I_{op1}$and I_{on1}.
(b) Output Currents from Second unit$I_{op2}$and I_{on2}. (c) Output Current I_o.

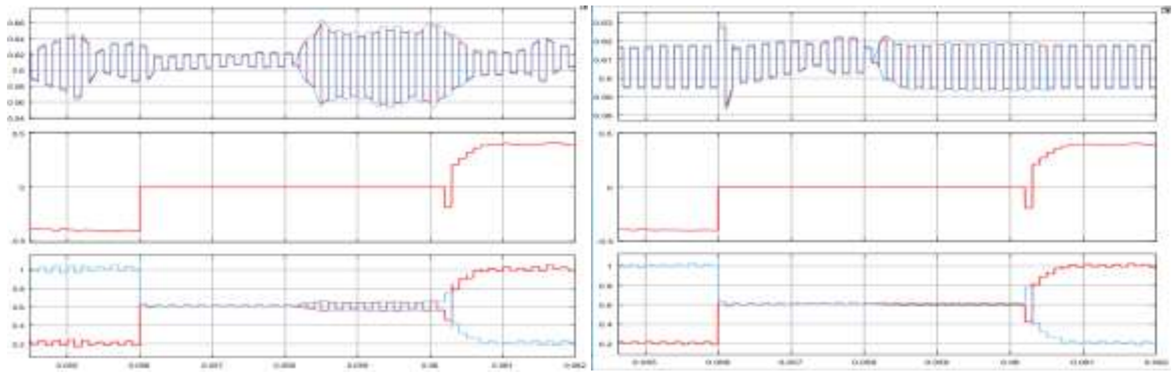
We have discussed about signals in case of D≤ 0.5 from the above results. In the same way, when the condition where D>0.5 also shows the improvement of voltage, modulation current signals as shown in Fig 9, 10 and 11 respectively. In Fig.9 the voltage signals have high impact using PI controller rather than AI.

Fig.10 shows the modulation signals D11 and D14 which shows the difference between both controllers. And also the current signals in Fig.11 shows how effective using AI controller.



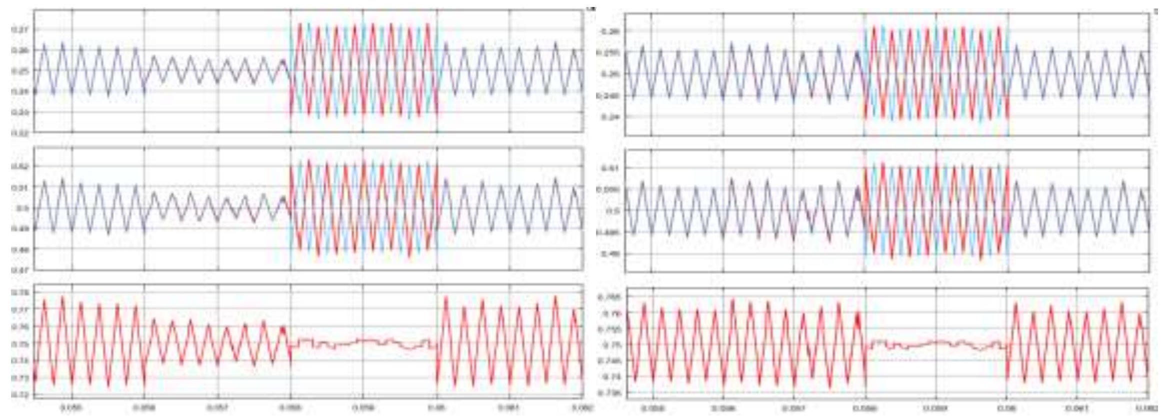
With PI Controller With AI Controller

Fig. 9: Results of PBM in Constant Current Condition, for D>0.5:(a)Output Voltage V_o& Reference Voltage V_o* (b)Power Balance P_b& Reference Power P_b*. (c) Current at Neutral Point I_{np}.



With PI Controller With AI Controller

Fig. 10: Modulation Signals in Constant Voltage Condition, for D>0.5: (a)Initial Modulation Signals D_{11}& D_{14}, (b) Control Signal for Balancing Power ΔD_1, (c) Resulted Modulation Signals D_{11}&D_{14}.



With PI Controller With AI Controller

Fig. 11: Signals of Output Currents in Constant Voltage Condition, for D>0.5: (a) Output Current from First Unit $I_{op1}$and I_{on1}. (b) Output Currents from Second Unit $I_{op2}$and I_{on2}. (c) Output Current I_o.

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VII. CONCLUSION

The DC-DC converter used in Fast chargers is controlled using PI and AI controllers. The fast chargers used in this project has a capacity of DC power balancing and results in removing extra circuit for power control and high rating transformers. And there by increasing overall system performance. The performance of PI and AI controllers used in DC-DC converters are analyzed. The simulated results shows the AI controller gives high speed response and study state error compared to PI controller. The study state error in using AI controller is low and stabilization is best compared to PI controller. The computation time for AI controller is less than PI controller.

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