Implementation of DSM-PI Controller for Electric Vehicle Battery Charging

Dhananjay Sureshrao More[1], Dr. S. M. badave[2], Prof S. M. Mule[3].

Department of Electrical and Electronics Engineering, Marathwada Institute of Technology,
Aurangabad, Maharashtra, India.

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Abstract –
Transportation electrification is happening at a rapid pace around the globe. As the electric vehicle technology recently evolved, the size of on-board storage units has increased, which require charging from an external energy source rapidly. By using renewable charging of electric vehicles is an attractive option to reduce the carbon footprint of an electric vehicle respectively. The intermittent nature of the renewable necessitates a storage unit to provide continuous power. With the system of solar generation, a strong and reliable power converter is deployed to interface these sources and storage units with the electric vehicle for charging. The reliable converter shall now have to operate to quench the charging requirements by sourcing power from solar generation and storage elements for the system. The converter also has capability to capture the generated solar power during the non-charging period and store it in the battery. All these functional requirements demand a unique, reliable and robust energy management strategy to utilize all available sources and storage units efficiently without compromising load requirements of the system.

In this project DSM-PI controller is used for Plug-in hybrid electric vehicle. This paper presents the methods of charging. The charging systems are simulated in MATLAB/SIMULINK. The problem of EV charger with DC output voltage settling & higher charging time required for battery charging is minimized with this paper. The expected charging has been simulated and presented in this project using MATLAB.

Key Words: —Electric vehicle battery charging, CC/CV control, RT-Lab simulation

1.INTRODUCTION

Plug-in Electric vehicles (PEVs), the use of electric motors instead of internal combustion engines has become really popular. Those who seek to preserve the environment and go green appreciate electric vehicles. But most of us would be shocked to know that the EV is not a recent innovation. While history remains unclear as to who literally invented even the first EV, It has been said that electric motors have been in use as long ago as the early 1800s. One documented electric motor had been developed in 1828 by Anyos Jedlik. He built a small model of car that can move by itself with a modest electric motor. Between 1832 and 1839, a bigger electric motor produced by the Scottish scientist Robert Anderson has been used to drive a vehicle. Although such EVs did not achieve pervasive adoption, they ignited the imaginations of others. Two small-scale EVs had been produced in 1835, one in the Holland and one in the United States by Thomas Davenport. Davenport and later others introduced the first electric car to powered by batteries, since those batteries seemed to be non-rechargeable and could not give the car a lot of range.

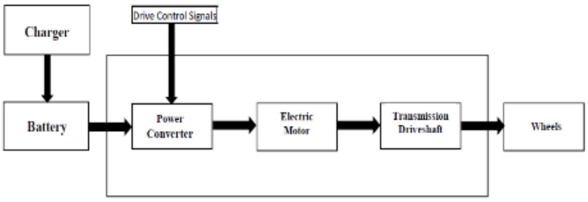

Fig 1: Block diagram of EV charging system

Along with French inventor Gaston Plante, others worked on battery technology, but were still short to producing a quality. As in 19th century, United states inventors returned to Electric Vehicle. At this period, William Morrison developed what others perceive the first practical electric car, even though it still lacked range. Hybrids have also been developed during that same era to fix a number of problems with the EV. Nowadays, electric vehicles are in mainstream than they've ever been, and are mostly able to drive their power packs relatively for longer ranges.

2. LITERATURE REVIEW

In the early period of automotive industry Competition between the three automotive technologies i.e. Electric Vehicles (EVs), steam cars and Internal combustion engine vehicles (ICEVs) takes place for market domination [1].

Steam cars had two major issues: they needed to be heated about 20 minutes before driving, and they required huge quantities of water causing it to disappear in 1920 from market [2].

The downsides of the ICEVs were the struggle of engine starting, the noise, the low top speed and the short range [3].

The drawback of electric vehicle (EV) was linked to poor battery performance: low top speed, limited driving range and not able to climb hills. From year 1900 onwards, a number of developments enabled ICE vehicles to enhance the top speed and range of driving, solve the problem of start-up offering a wide range of sales volume till now [4].

In today's world, due to technological advancement, environmental needs and the unavoidable decline of fossil fuels, it seems that the EV market is starting to rise. For a variety of ecological and economical factors, the EV industry is expected to have a major effect on the global automotive market. EVs (plug-in electric vehicles) draw whole or portion of their energy from the electrical grid. Two types of EVs are, a) All-electric vehicles (AEVs) - It comprises Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs). They collect energy by connecting it to the grid and storing it in the batteries. Most have ranges from 80 to 100 miles except for luxurious models have range up to 250 miles. When battery has been drained it can take 30 minutes for fast charging and up to 1 day for level 1 charging to recharge it. b) Plug-in hybrid electric vehicles (PHEVs) - It runs on electricity for shorter range from 6 to 40 miles then switched with ICE and can be used for higher ranges [5].

3. Body of Paper

As previously discussed, the main purpose of this dissertation work is to decrease charging time & reduce the settling time & oscillations of DC link voltage by using DSM-PI control strategy. In this section of system development, the block diagram of proposed system and performance analysis of each system in MATLAB/ Simulink are carried out. The charging systems are summarized in the block diagram 1 and table 3.1

A single-phase AC input is used for Level 2 charging. The charging circuit includes a diode rectifier, followed by a PFC boost DC/DC converter, and a dual bridge DC/DC converter. The dual bridge DC/DC converter consists of a full bridge DC/AC converter, an LLC resonant converter, a high frequency transformer, and a diode-bridge rectifier.

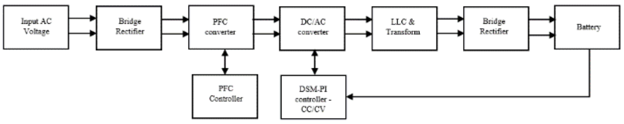

Figure 3.1 Block diagram of EV

Charging level	Supply Voltage	Charging Current	Rating Power
Level 1	120 Vac	Up to 16A	Up to 1.92 kW
Level 2	230 Vac	Up to 60A	Up to 14.4 kW
Level 3	400 Vac	Up to 60A	Over 20 kW

Table.3.1 Charging Systems

The circuit is shown in Figure 3.1. Dual bridge DC/DC converters have been adopted due to its capability of avoiding dead time and reducing current ripples. In this paper, we also adopt LLC resonant converter in the dual bridge DC/DC converter. The LLC resonant converter ensures a nearly sinusoidal waveform.

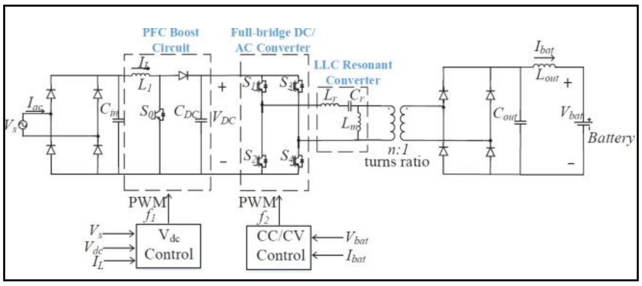

Figure 3.2 Circuit diagram of 230V level 2 charging system using DSM-PI controller

3.1 Working principle of level 2 charging system

The proposed charging system circuit for level 2 is shown in figure 3.2. In case of level 2 single phase AC input is converter into dc voltage using bridge rectifiers then this rectified voltage is boosted up to 300V using PFC boost circuit. The operation of PFC is controlled using PI controller by controlling switch S_0. Then this boosted voltage is converted into AC voltage using an inverter. This inverter operation is controlled using DSM-PI controller by controlling switch S_1S_3 &S_2S_4. Then this ac voltage is given to high frequency transformer. The main purpose of this transformer is for isolation purpose, itsacting as protection circuit for battery & grid side. Then again voltage is rectified using rectifier & finally given to the battery.

3.1.1. PFC boost circuit

The Level 2 charging can take place at home, so the charger should be able to deliver the single-phase residential source (120 Vor 240 V) to the battery pack with 200 V to 400 V. The charger should also be capable to allow input current up to 60 A when maximum output power occurs.

Since the battery voltage is up to 400 V, we can choose this value as the PFC boost circuit output. According to the Table I, the maximum rating power is 14.4 kW. Hence, the DC current is 14.4 Kw = 36A

Assuming unity power factor, the single-phase ac circuit will have the following form of instantaneous power.

$$p(t)= P + P \cos(2\omega t)(1)$$

where ω is 377 rad/s and P is the active power.

The second harmonic ripple component is expected to be absorbed by the capacitor C_{DC}. Further, the DC voltage is assumed to be constant at V_{DC}. The DC current can then be found as $I_{out} = P/V_{DC}$

The current through the capacitor should be a second harmonic ripple as:

$$ic(t)=P\cos(2\omega t) /V_{DC}$$

The PFC controller aims to achieve unity power factor by ensuring the input AC current and the input AC voltage have the same phase shift. The charging system is expected to behave similar as a pure resistor. The PFC controller has a cascaded control loop: inner loop is for inductor current control and outer loop is for VDC control. Fig. 3.3 shows a PFC controller block. The DC bus voltage V_{DC} of the boost circuit is compared with a fixed reference voltage. The error goes to a PI controller and then is multiplied with the rectified voltage to generate a reference inductor current. The reference current is proportional to the rectified voltage. The inner loop regulates the current to follow the reference current. The error between the reference current and the measured current is the input to a PI controller. The output is the duty cycle of the PFC boost converter. This signal is compared with a triangle waveform to generate pulse width modulation (PWM)-based switching sequences for the switches.

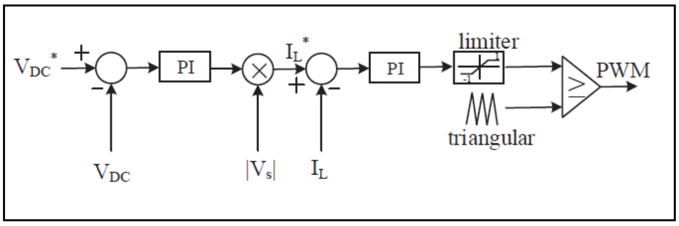

Figure 3.3 PFC boost circuit control block diagram

3.1.2 Battery modeling

The battery model used for this project is adopted from MATLAB/Simulink library. According to, there are three categories of battery models: experimental, electrochemical, and electric circuit based model. The electrochemical model is complex and time consuming due to its time-varying partial differential equations. The experimental and electrochemical models need high computation ability to solve partial differential equations. The electric circuit model is the most intuitive for simulation. In this paper, a lithium-ion (Li-ion) battery is used and its electric circuit model is adopted for simulation.

The parameters used for battery are 250V battery nominal voltage, 0,0625Ohm internal resistance, 40 Ah rated capacity and 325V Constant voltage.

3.1.3 CC/CV algorithm-

There are several charging methods that can be applied in EV battery charging. The three basic methods are constant-current (CC), constant-voltage (CV) and taper-current (TC) charging. The CC method charges a battery using a constant charging current while voltage varies. When the voltage reaches a preset value, the charging process will stop. However, the charging current level needs to be considered carefully because low current is not suitable for fast charging while high current may cause excessive damage. The CV method limits the voltage to a septic level by varying current. The charging stops until current drops to almost zero. The CC method charging a battery with a decreasing current while the voltage is rising. The method rarely used since batteries have different characteristics in real application.CC/CV charging is combination of CC and CV, and intends to enhance the reliability and efficiency. The CC method is usually used in the initial stage of charging to avoid over current. The CV method is used following the initial stage. Figure 3.4 shows a simple illustration of CC/CV charging.

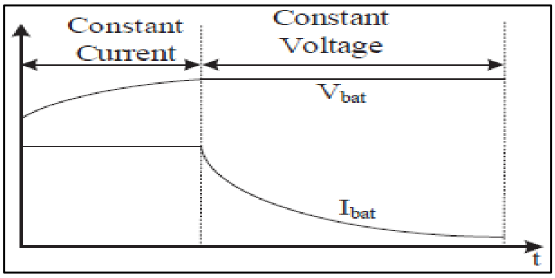

Figure 3.4 CC/CV charging illustration

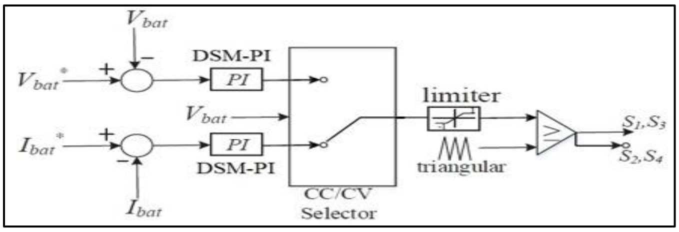

Figure 3.5. CC/CV charging structure using DSM-PI Controller

3.1.4 DSM-PI Controller

The main agenda of using DSM-PI controller is to reduce the selling time of output. To reduce this settling time this controller will always compare the output value & reference value. To fulfil this requirement controller will always compare K_p& K_i values with K_{pavg}. In DSM-PI controller K_p&K_i values are always equal to K_{pavg}& whenever this values are not equal that means there is error in system then controller will act as sliding mode & try to match this values. The DSM-PI working is based on following equation,

$$\tilde{kp}=[(1+sgn(\sigma))kp^{+}-(1-sgn(\sigma))kp^{-}]+k_p{}^{av} \qquad (1)$$

$$\tilde{ki}=[(1+sgn(\sigma))ki^{+}-(1-sgn(\sigma))ki^{-}]+k_p{}^{av} \qquad (2)$$

where

$$sgn(\sigma)=\{1\ for\sigma>0\ -1\ for\sigma<0$$

Example, when error is more than 0 then

$$\tilde{kp}=[(1+1)k_p{}^{+}-(1-1)kp-]+k_{pav}$$

$$\tilde{kp}=k_{pav}+2k_p{}^{+} \quad (3)$$

when error is more less than 0 then

$$\tilde{kp}=[(1\text{-}1)k_p+-(1-(\text{-}1)k_p-]+k_{pav}$$

$$\tilde{kp}=k_{pav}\ \text{-}2k_p{}^{\text{-}} \quad (4)$$

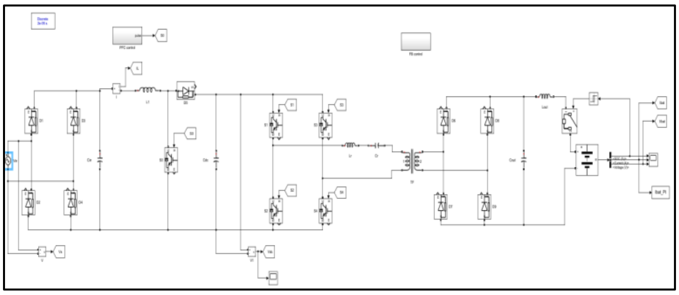

Figure 3.6 Charging circuit for level 1

3.1.2 Working principle of level 3 charging system

According to SAE, Level 3 charging system has a three-phase source as input. Thus,the system includes a three-phase AC/DC converter. In this level we adopt a bi-directional converter based on IGBT switches. Considering vehicle to grid (V2G) services, we apply VDC/Q control. The VDC/Q control can regulate the DC bus voltage and the reactive power from grid. The topology of Level 3 charger is shown in Figure 3.7.

The controller has two inputs: reactive power measurement and DC bus voltage measurement. Two PI controllers are used to make sure the measurements track their reference values. The outputs from the PI controllers are dq-axis current orders. This dq-reference frame is aligned with the input voltage space vector. Angle of the input voltage space vector (θ) is obtained through a PLL. This angle is used for abc–dq and dq–abc conversion.

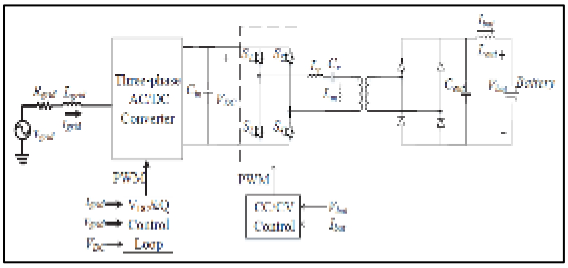

Figure 3.7 Circuit diagram of 400V level 3 charging system using DSM-PI controller

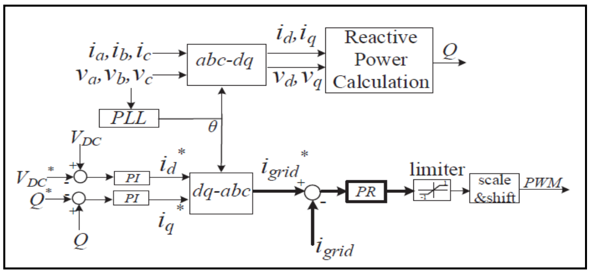

Figure. 3.8 V_{DC}/Q control method applied to the three-phase rectifier.

The transformed voltage and current are used to calculate three-phase reactive power as shown follows:

$$Q=\frac{3}{2}(V_qI_d-V_dIq).$$

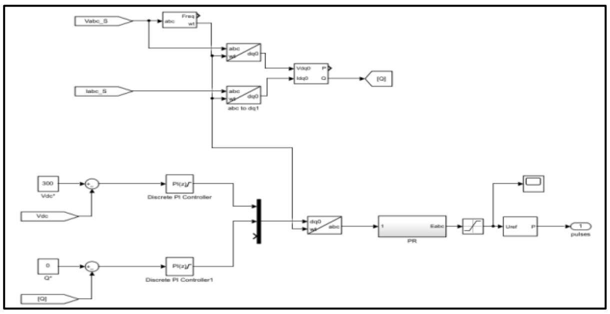

Figure. 3.9 V_{DC}/Q control method applied to the three-phase rectifier.

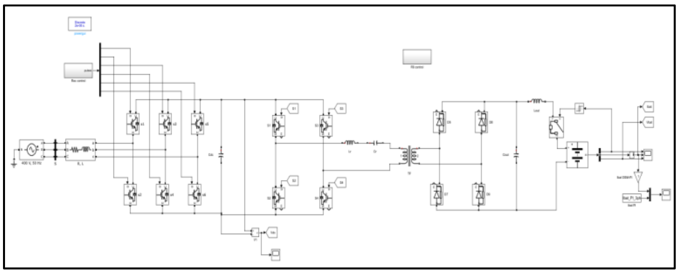

Figure 3.10 charging circuit for level 3 with 400V system

4. Results

The mode; is simulated for 3 seconds using PI & DSM-PI controller. The SOC of battery is increasing which implies that the battery is in charging mode. The current characteristics and the voltage characteristics are also shown. Charging characteristics using PI Controller is shown in figure below,

Level 2 output results

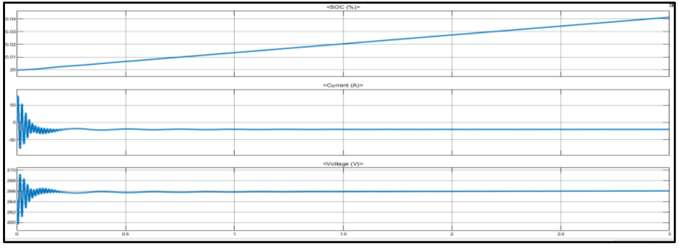

Figure 4.1 Charging characteristics of battery using PI controller for 230V level 2

Level 3 output results

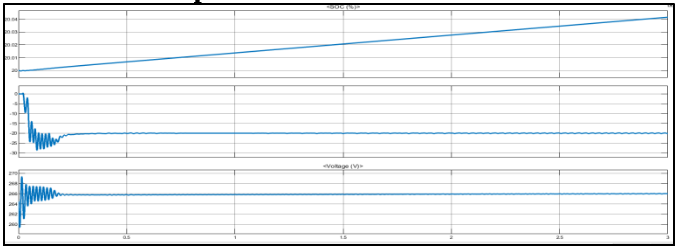

Figure 4.2 Charging characteristics of battery using DSM-PI controller for level 3

Comparison of battery current between PI vs DSM-PI controller

This model is simulated for 3 seconds in which the charger is controlled using PI & DSM-PI. The current taken by battery is higher in case of DSM-PI controller hence the time taken for the charging is less in case of DSM-PI controller hence much more reliable.

1. For level 2-230V system with CV mode run for the duration of 3 secs, the current taken by battery with DSM-PI is 18.7Aand with PI controller it is 11.8Amp. The current taken by the battery is more so the time taken for the charging is less in case of DSM-PI controller.
2. For level 3-400V with CC mode the settling time for DSM-PI controller is 0.3 sec while the settling time for PI controller is 1.6 sec. Refer figure 4.4 for CC mode comparison.
3. In case of DSM-PI we are getting higher current magnitude compare to PI controller.

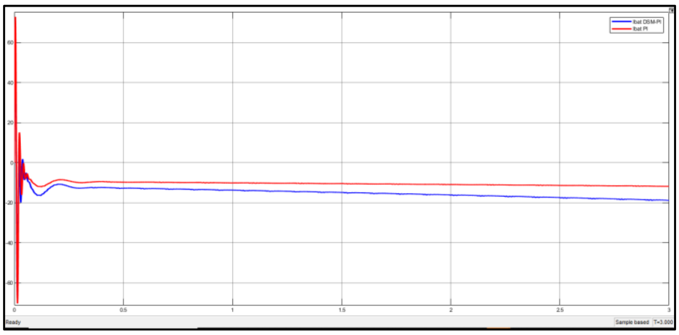

Figure 4.3 Comparison with PI vs DSM-PI controller for 230V level 2

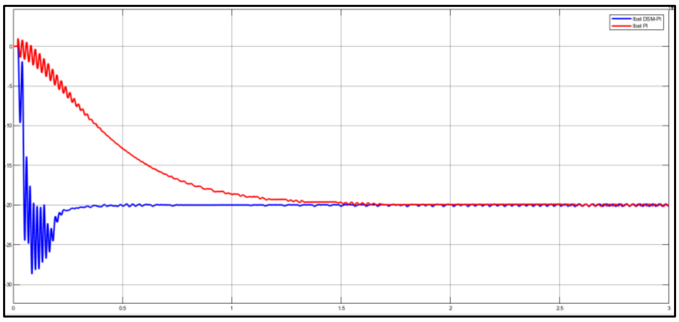

Figure 4.4 Comparison with PI vs DSM-PI controller for 400V level 3

3. CONCLUSIONS

In this dissertation two types of topologies with control strategy of DSM-PI controller is shown. DSM-PI selects cc/cv mode as per the battery SOC & improves the battery life and reduces the battery charging time. Using simulation PI and DSM-PI controller charging current compared with each other and it is observed that current taken by battery is higher in case of DSM-PI controller as compare to PI controller. Hence the time taken for the charging is less in case of DSM-PI controller. The gains of the PI controller are fixed while the gains of DSM-PI controller are updating as the error generated. Hence DSM-PI controller is used to increase the charging current of the battery pack due to which the charging time reduces and also settle the DC link voltage faster with reduced disturbances and oscillations.

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