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Harmonic distortion caused by EV battery chargers in the distribution systems network and its remedy

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HARMONIC DISTORTION CAUSED BY EV BATTERY CHARGERS IN THE DISTRIBUTION SYSTEMS NETWORK AND ITS REMEDY

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ABSTRACT

An effective way to minimise harmonic pollution in power systems is by careful design of the equipment connected to them. It is important for designers of equipment associated with emerging technologies to be aware of the potential impact of their designs on power system quality. One such upcoming technology is Electric Vehicle (EV) battery charging which may contribute to high harmonic distortion in the power system during the charging period. The literature notes total harmonic distortion of up to 50%. These findings are the impetus behind the present paper, where an EV battery charger has been designed, with an inherent power quality control feature. A parallel power circuit topology has been proposed on an existing ferro-resonant charger, which ensures that the THD of the input current remains within the acceptable harmonic distortion limits of the distribution system. The design and control of the battery charger are elaborated in the paper and simulation results are presented which confirm the performance of the charger.

Keywords: battery charger, harmonic distortion, power quality

INTRODUCTION

California Air Resource Board's guideline to successively increase Zero Emission Vehicle (ZEV) production over the coming years has been globally accepted as a norm to switch towards eco-friendly sustainable transport systems. The progress towards alternative vehicle technology gives rise to the need for the development of certain auxiliary technology, without which the evolution of green car technology would remain incomplete and unsustainable. Batteries and other power sources remain critical factors for the techno-economic feasibility of ZEVs so their charging procedure naturally gains significant importance.

Unfortunately the environmental cleaning process could create an additional burden for electric utilities. What is clean for the atmosphere may not necessarily be clean for the electrical environment! The effect of chargers for EV batteries on the distribution system would result in power quality (PQ) problems, which have already been studied [1-5]. It has been found that EV chargers contribute to power quality (PQ) degradation. This needs correction in order to ensure the required performance and safety of other equipment connected to the power system.[1].

A Public Interest Energy Report, published by California Energy Commission [4] reported battery charger input current THD variation from 2.36% to 28% over the charging cycle. In another study [7], Ford-Escort's station wagon on-board battery charger measured input current THD of 59.6% at an output current of 15.7 A. It is clear that simultaneous usage of many chargers on a distribution network could cause significant increase in system THD.

With this in mind, the present paper proposes a novel battery charger topology, with parallel PQ correcting facility. The design modifications have been made to an existing ferro-resonant charging scheme [6, 7] and the new design remains a commercially feasible option. The control techniques are described and simulation results are presented in support of the design.

EV BATTERY CHARGERS

EV battery chargers can be categorised as on-board chargers and off-board chargers depending on whether the installation of the charger is within the vehicle or outside the vehicle. Generally off-board chargers have higher charging rate and higher charging capacity. To keep vehicle weight down and maintain electrical safety on-board chargers are limited to a few kWs and are designed for lower charging rates, typically 5-8 hours. Irrespective of the position/installation of chargers, they can be further classified as conductive or inductive based on their mode of energy transfer. As the name suggests conductive chargers have a direct plug-in connection to the supply. They are simple in design and higher in efficiency and hence more popular. Inductive chargers use magnetic induction coupling as mode of energy transfer and the main advantage is electrical safety under all weather conditions.

This paper looks at a conductive charging technology and its effect on the electric utility. For most batteries the rate of charging is determined by the state of charge (SOC) of the battery so the power consumption of the charger varies widely from lowest initial SOC to full SOC. Therefore, during a charging process, the current demand varies and based on the charger configuration the THD of the input current can vary from more than 50% to less than 5% [1, 4, 6].

Ferro resonant chargers are a well established commercially available technology with many benefits including simplicity, cost effectiveness and good efficiency at high load. This kind of charger uses inductor-capacitor resonance to keep a transformer in saturation producing a reasonably regulated square wave over a wide range of input voltages and output currents. The square wave is ideal for applications that require rectification. It has been reported [7] that the input current THD from no load to full load is quite severe (as high as 40%).

GENERAL EFFECTS OF CHARGERS ON THE DISTRIBUTION SYSTEM

Power quality issues in distributed power systems due to non-linear loads have been well documented. A number of surveys have been conducted to estimate the particular effects of EV chargers [3-5].

In considering the effect of home EV battery chargers, which draw significant distorted currents from the utility, co-incidence of charging start time during the evening load peak-period (which varies with customer and country), needs to be considered. Charger THD varies due to SOC and that can influence peak and off-peak conditions.

The net effect of EV chargers is not merely the numerical sum of THD because harmonic phase cancellation also takes place. The resulting harmonic currents affect the shared network components such as distribution transformers, cables and circuit breakers.

Gomez and Morcos [1] point out that the additional heating caused by harmonic currents would force derating of equipment to avoid thermal effects and reduced service life. For cables, excessive neutral currents would flow due to triplen harmonics. A doubling of the cross section of the neutral conductor would be required in order to avoid excessive heating.

CHARGER CONFIGURATION

This design has been proposed as a modification to a cost effective design [6] of ferro-resonant charger, and can be applied as a general solution to other designs (residential and fast charging). Fig. 1 shows the original schematic of the charger, on which the design modification is suggested. The power circuit schematic of the battery charger shows the battery pack connected to the rectified output of the secondary winding of a transformer. A third winding (not shown) is connected to a capacitor, which creates resonance with the inductance of the transformer. The microprocessor-based control uses a triac as a power electronic switch with a voltage monitoring circuit for gassing point detection to determine the end of charge [6].

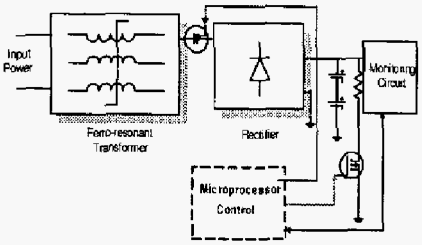

Fig. 1 Standard battery charger circuit [6]

Fig.2 shows the modified power circuit schematic of the battery charger. From the supply side of the transformer a parallel connection is made to a current controlled voltage source inverter (VSI) through a link inductor. This inverter shapes the input current of the transformer, irrespective of the secondary loading. The inductor helps in boosting the charge to the dc link of the VSI, but at the same time reduces the current response of the inverter. The trade-off should be considered based on the maximum switching frequency desired by the inverter and the maximum current to be supplied by it. The control can be integrated with the charging scheme.

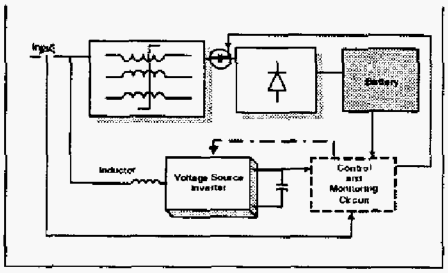

Fig. 2. Schematic of battery charger with active wave shaping

The dc side of the VSI contains a self-charged capacitor, whose reference is selected based on SOC of the battery. The inverter switches operate in accordance with hysteresis current control to shape the input current waveform. This results in the inverter supplying almost all of the harmonic current drawn by the charger, so the input (utility interface) needs only to provide the active power component of current.

CONTROL

Fig. 3 shows the schematic control block diagram. The charger is controlled in dual mode. From the estimated SOC of the battery, an appropriate dc link reference (V_{dc}^*) is selected for the VSI. From its dc link feed back, the difference voltage $(V_{dc}^* - V_{dc})$ is processed through a PI controller, which yields an estimate of the amplitude $(|I_{ref}|)$ of the supply current required for the charger. This multiplied by a synchronised sine-template generates the reference current signal (i_s^*) for the hysteretic comparator. The input current of the charger (i_s) is compared with i_s^* in a hysteretic comparator, and the output signal is sent to the driver circuit of the VSI for appropriate triggering of the switches. The hysteresis band-width is a certain percentage of the reference current generator which determines the quality of the shaped current. A narrower band enforces better harmonic suppression of the supply current but increases the switching frequency.

The charging control scheme is simple. The output of the ferro-resonant charger is rectified and the output is connected to the battery module that is required to be charged. Typically charge is applied for 1 hour, after which the triac disconnects the supply, and microprocessor based control is implemented to identify and detect gassing which indicates end of charge [6]. From this point onwards repeated sensing for gassing detection is performed. All control can be integrated in the microprocessor.

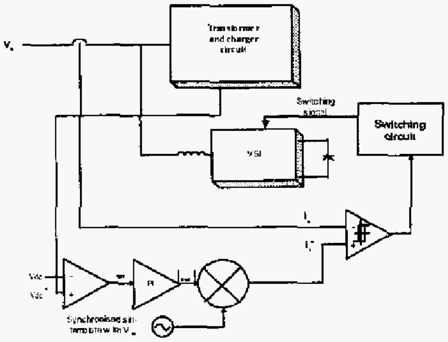

Fig. 3 Modified control scheme of the battery charger

SIMULATION RESULTS

A typical 4.5 kWh battery charger (150 V, 30A on the dc side) is simulated, for comparison with the standard technology. Some typical results are compared and analysed to establish the new control technique. Fig. 4 shows the simulated no load voltage of the ferro-resonant transformer, and the resonating capacitor current.

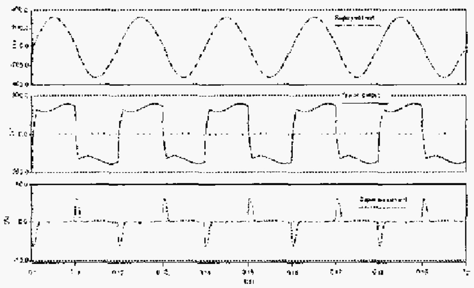

Fig. 4 Supply voltage, transformer output voltage, and resonating capacitor current

Initially, when the SOC of the battery pack is low, the charger has to deliver maximum current. It is to be noted that near full load condition the distortion of the input current is at its lowest and as the SOC increases the input current requirement reduces and THD increases. Fig. 5 shows typical current waveforms associated with the process of battery charging around 50% SOC.

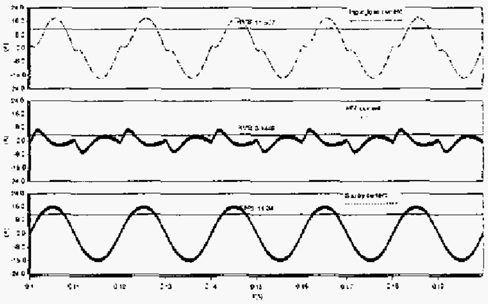

Fig. 5 Typical battery charger input current, compensator current and input supply current after the new control technique is applied

An FFT analysis of the waveforms is performed, and it is found that the THD of the charger current is 16.8%(3rd harmonic 15.2%, 5th harmonic 6.1%). The quality of the input current is greatly enhanced and it is found to have a THD of only 5.6% (3rd harmonic reduced to 2.7%, 5th harmonic 1.1%). This is a significant improvement over previously published results [6, 7] The typical ratio of the compensator current to charger current in the present case is found to be 0.27. It is interesting to note that this ratio may not vary uniformly from initial to final SOC. It would depend upon the percentage of higher order harmonics to be compensated. Also the compensator would always require some active component of current to maintain the voltage on the dc link and to compensate for the switching loss. . Therefore, it can be concluded that with moderate increase in the rating of the combined charger cum active filtering circuit, with no significant additional power consumption, the quality of the input current waveform can be greatly improved.

CONCLUSION

To eliminate harmonic distortion from power systems, the sources of distortion must be known. It is important for designers of emerging technologies to be aware of the impact that these will have on future power system quality so that appropriate measures can be implemented. Electric Vehicle (EV) battery chargers are an important new technology that could result in up to 50% harmonic distortion of the line currents during the charging period. This fact has been the impetus behind the present paper in which the design of a fast battery charger with inherent power quality control is presented. The novel design suggests low cost modification of existing topologies, where by enhanced quality of charger input current could be ensured. The design and control technique has been supported by extensive simulation, which establishes the superior performance of the new design.

REFERENCES

1. J. C. Gomez, M. M. Morcos, "Impact of EV Battery Chargers on the Power Quality of Distributed Systems", *IEEE Trans. Power Delivery*, vol. 18, no. 3, July 2003, pp. 975-981.
2. P. T. Staats, W. M. Grady, A. Arapaostathis, R. S. Thallam, "A Statistical Method for Predicting the Net Harmonic Currents Generated by a Concentration of Electric Vehicle Battery Chargers", *IEEE Trans. Power Delivery*, vol. 12, no. 3, July 1997, pp. 1258-1264.
3. P. T. Staats, W. M. Grady, A. Arapaostathis, R. S. Thallam, "A Procedure for Derating a Substation Transformer in the Presence of Widespread Electric Vehicle Battery Charging", *IEEE Trans. Power Delivery*, vol. 12, no. 4, Oct. 1997, pp. 1562-1568.
4. F. Lambert, "Secondary Distribution Impacts of Residential Electric Vehicle Charging", Public Interest Energy Res. (PIER), California Energy Commission, Project no. 373, 1999.
5. S. Rahaman, G. B. Srestha, "An Investigation into the Impact of Electric Vehicle Load on the Electric Utility Distribution System", *IEEE Trans. Power Delivery*, vol. 8, no. 2, Apr. 1993, pp. 591-597.
6. C. R. Mersman, N. G. Dillman, M. M. Morcos, "A Novel Microprocessor-Based Ferro resonant Battery Charger for Electric Vehicles", *Proc. Of Canadian Conference in Electrical and Computer Engineering*, vol. 1, 1996, pp. 327-330.
7. M. M. Morcos, C. R. Mersman, G. D. Sugavanam, N. M. Dillman, "Battery Chargers for Electric Vehicles", *IEEE Power Engineering Review, Nov. 2000,* pp. 8-11.

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