A Novel Economical Single Stage Battery Charger with Power Factor Correction

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***Abstract* – A single stage AC-DC topology with power factor correction is proposed for battery charger applications. Desired features for battery charger such as low cost, fast charging, charge profile programmability, high efficiency and high reliability are fully achieved by means of proposed solution. Additionally, its multiphase operation configuration provides easy power scaling. The proposed approach is superior to conventional ferro-resonant regulation widely used for EV (Electrical vehicle) charger applications. It is especially suitable to low cost and high power applications. The feasibility and practical value of the proposed approach are verified by the experimental results from a 1 kW product prototype.**

I. Introduction

Battery chargers for consumer and industry markets must be precise in function and reliable in operation at reasonable manufacturing cost. As a low cost and simple solution, ferro-resonant voltage regulation technology has been widely used in battery charger for EV for decades. This solution relies on the magnetic properties of transformer to regulate AC voltage. Regulating transformers operate on a resonant principle. The resonant network added to the transformer consists of a capacitor and inductor connected in parallel, which in turn is connected in series to the load. The semi-square wave output of the transformer is well suited to rectification. The inherent current limitation also guarantees safe operation of battery charger. However, the ferro-resonant transformer is much larger physically than an equal power rate 2 winding transformer, the price also, is more than a nominal type transformer. The ferro-resonant battery charger is inefficient and particularly sensitive to frequency changes. It produces acoustic noise, can interact with SMPS to produce transients and electrical noise on the output, and distort AC power to extremely high levels. Moreover, traditional ferro-resonant battery chargers tend to excessively overcharge the battery banks due to an old formula of change in voltage over change in time.

To develop a high performance battery charger with a competitive cost to ferro-resonant charger, this paper introduces a novel power-factor-corrected single stage economical AC-DC topology for lead-acid battery charger applications. It is a micro-controlled boost-driven AC-DC power factor rectifier. Desired features for battery charger such as low cost, fast charging, charge profile programmability, high efficiency and high reliability are fully matched by means of the proposed solution. This topology is superior to conventional ferro-resonant regulation technique in the following points of comparison: (a) competitive manufacture cost; (b) programmability enabling optimum charge profile implementation leading to high battery energy throughput and long service life; (c) quiet, neither acoustic nor electrical noise, it complies with IEC555 harmonic current standards; (d) multiphase-able operation providing easy power scaling and fast charging.

II. Single Stage Power-Factor-Corrected Charger

A. Proposed Approach

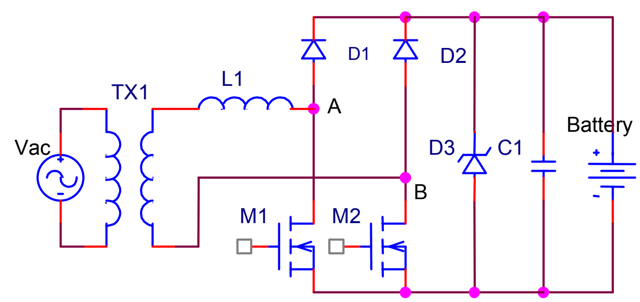

Fig. 1. Proposed single stage power factor corrected battery charger

Fig. 1 illustrated the proposed single stage charger approach. In this approach, a LF line transformer is used to provide safety isolation and step down the line voltage. A unity power factor rectifier [1] then is adopted to charge the battery with rectified sinusoidal waveform current. With step-down line transformer, conventional two-stage topology, PFC plus DC-DC converter, is no longer necessary. A single stage two-switch-type power factor rectifier can be implemented for battery charger application to achieve high efficiency. Furthermore, Schottky diodes and relatively low voltage MOSFETs can be used for the secondary power factor rectifier, resulting in low conduction losses. Since all power parts and control circuits are referenced to the low voltage

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secondary side of transformer, it also relieves the tough design restraint required by UL1564 standard for industrial battery charger [2]. Therefore, all these merits lead to a cost effective high-performance battery charger, which is competitive to traditional ferro-resonant charger. The other advantages of the proposed approach are as follows:

1. Unit input power factor
2. AC boost inductor contributes to EMI reduction
3. Very low conduction losses because the current always flows through only two semiconductors

The volume and weight of the line transformer are the downsides for this approach. However, a charger designed with the proposed approach is still smaller and lighter than a conventional ferro-resonant charger with same power rating.

B. Principle of Operation

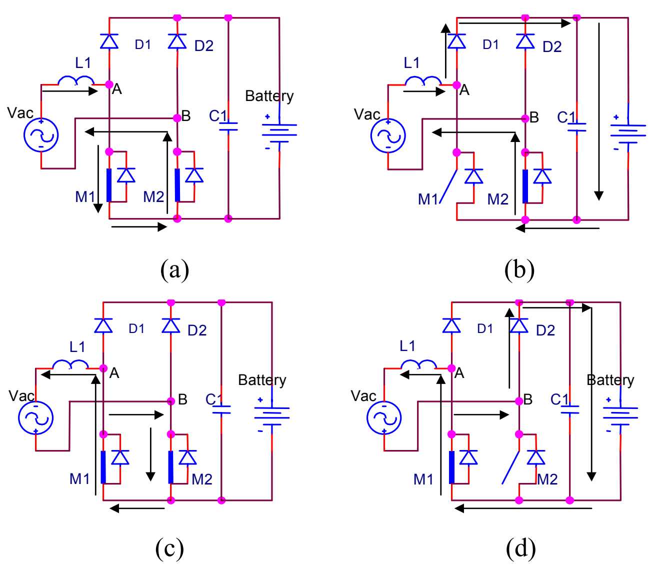

Fig. 2 Operation Modes

Fig. 2 illustrates the various operation modes for the proposed topology. At any given instant, only two semiconductor device drops exist in the power flow path. When the input AC voltage is positive, inductor L1, switch M1 and diode D1 constitute the conventional boost PFC circuit (Fig. 2 (a) & (b)). M2 is always on during this interval to decrease the conduction losses. Fig. 2(a) shows the current flow when the input AC voltage is positive and the switch M1 is closed. Input current flows through switch M1 and back through switch M2. At the same time, the bulk capacitor discharges and supplies current to the load. Fig. 2(b) shows the situation when input AC voltage is positive and the switch M1 is open. Current flows through Diode 1, the capacitor and load, and back through switch M2. Similarly, when the input AC voltage is negative, inductor L1, switch M2 and diode D2 constitute the PFC circuit (Fig 2 (c) & (d)), and M1 keeps on during this negative AC voltage interval. To achieve high efficiency further, some ZVT network [3,4] can be implemented to reduce the switching losses. These types of PFC circuits, however, are not used here because of the increased cost.

C. Control Strategy

Instead of working as a voltage source, the proposed circuit is configured to work as a current source. The input current, input voltage and output voltage are measured and presented to a micro-controller, which provides a voltage control reference accordingly to the control chip L4981B from ST microelectronics. By this control strategy, the output current can be controlled by the micro-controller. Thus, customer desired charging profiles can be easily implemented with embedded software. Fig. 3 shows the block diagram of the control circuit, along with the power stage. Average current control is adopted for the power factor rectifier.

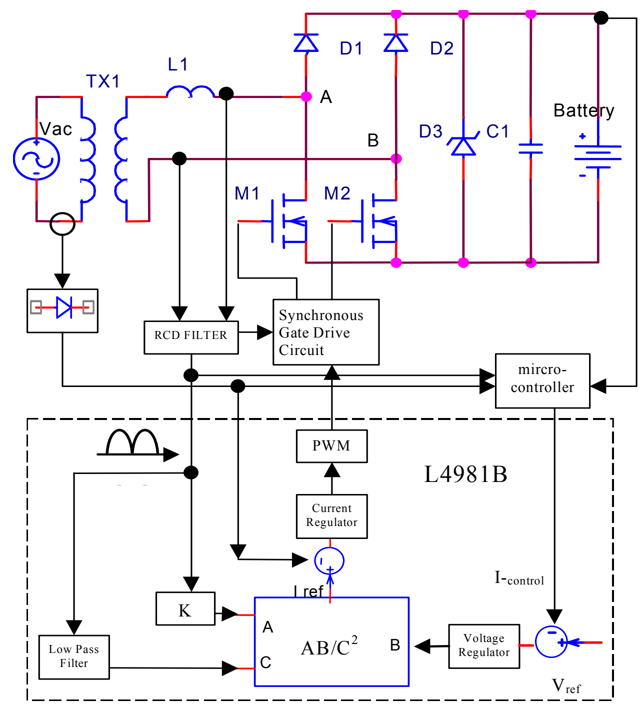

Fig. 3 Simplified power stage and control block diagram

In order to obtain unity power factor, a synchronous signal must be provided to the PFC controller for voltage scaling and current shaping. The synchronous signal must be a rectified sinusoidal waveform referenced to the negative terminal of the output capacitor. Instead of using isolated voltage sensor [4] or a small insulation transformer [1,3], a simple low pass RCD filter (Fig. 4) can retrieve the synchronous signal from the Drain to Source voltage of MOSFET M1 and M2. The retrieved synchronous signal is also sent to the micro-controller for input voltage measurement.

A current sensing transformer AC-1015 from Talema is used to monitor the input current. Transient Voltage Suppressor D3 in Fig. 3 is used to clamp the output voltage if the batteries under charging are unplugged during charging operation. For briefness, other misc. circuits, such as over-voltage and over-current protection circuit are not discussed here.

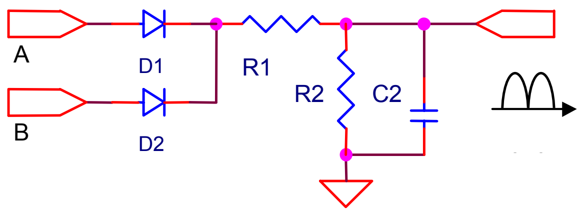

Fig. 4 Simple RCD filter retrieves synchronous signal

D. Further Improvement:

The proposed topology provides us a low cost solution for battery charge applications. Some additional work can improve the approach further in terms of cost. By winding primary and secondary windings spaced apart on a bobbin with 2 chambers, a leakage-field-transformer [5] can be applied to integrate the normal line transformer TX1 and boost inductor L1 (Fig. 1). This approach will reduce the cost and make charger more compact. For the control circuit, the function of the PFC chip L4981B also can be implemented in micro-controller, thus reducing the cost further. Due to developing time limitation, these two cost saving solution are not accomplished with our prototype and left for future development.

III. Experimental Result

A. Experimental Verification

Fig. 5. 36V Battery Charger Prototype

To verify the operation and performance of the proposed approach, a 1kW 36V battery charger prototype was built and tested (Fig. 5). The prototype was used to charge 6×6V lead-acid batteries. The measured efficiency at 115V_{ac} input voltage was 87%. The measured PF was 0.99. The main component specifications are as follows:

TX1,	Input 115V_{ac}, output 22.5V_{ac}
M_1, M_2,	IRFP2907
D_1, D_2,	MBR4060WT
D3,	1.5KE51A
C1,	6X22uF/63V_{dc}(polyester)
L1,	100uH

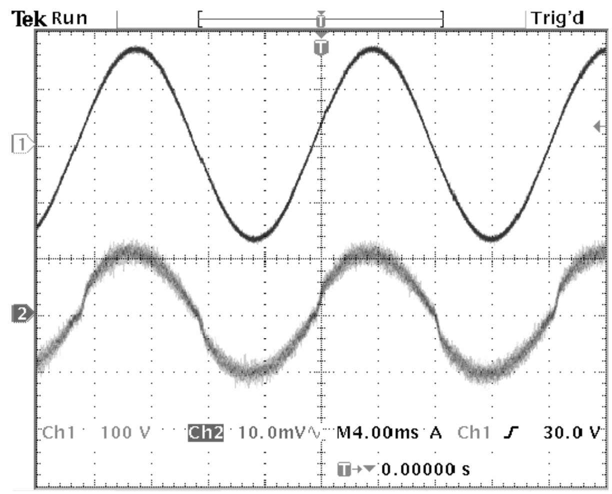

Fig. 6. Waveforms for input voltage (cha. 1) and current (cha. 2, 10A/div)

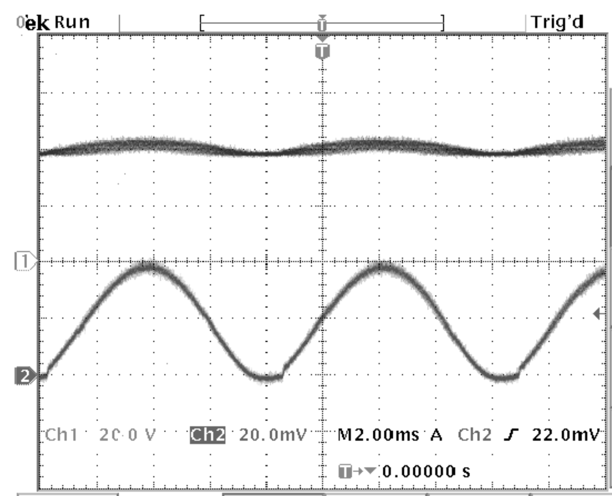

Fig. 7. Waveforms for output voltage (cha 1) and current (cha 2, 20A/div)

Fig. 6 shows the input voltage and current at full load. Fig. 7 shows the output voltage and current, and Fig. 8 shows the implemented optimum charging profile for lead acid battery, which leads to high battery energy throughput and long service life. The battery bank was discharged about 150Ahrs. The charger returns 170Ahrs to the battery bank in less than 11 hrs. These figures simply confirm the superiority of the developed charger with the proposed approach to ferro-resonant charger.

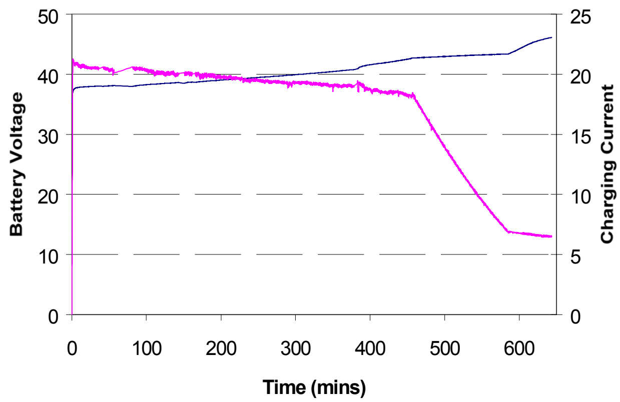

Fig. 8. Implemented charger profile for 36V lead acid battery bank

B. Multiphase Operation

The last advantage of the proposed topology is that the developed charger can be operated in parallel to provide high charging capacity. Distributing chargers evenly on each phase of a 3ϕ power line and tying the output terminals together comprise a three-phase power factor corrected low cost charger station with triplen charging capacity. Thus multiple-triple configurations can provide high level easy power scaling and fast charging. The load of each charger is automatically balanced since the charger works as a micro-controlled current source. Therefore, the balance of each power line phase is guaranteed. Fig. 9 shows the charger current of a 3kW 3ϕ charger station, which consists of three proposed battery chargers. Fig. 10 shows the programmed charging profile for the charger station.

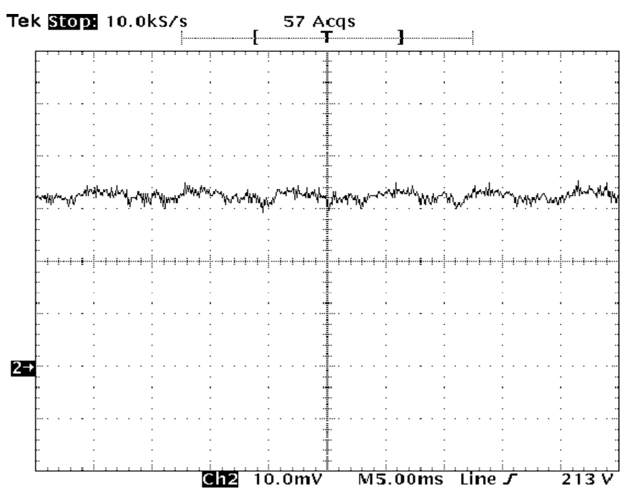

Fig. 9. Output current of 3ϕ charger station (3kW, 20A/div)

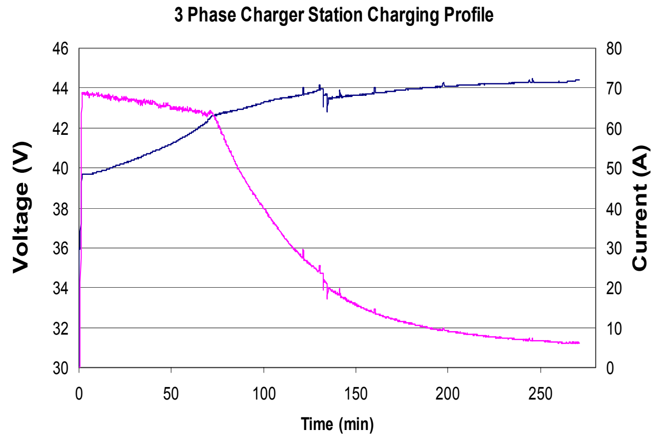

Fig. 10. Implemented 3ϕ charger station (3kW) charging profile for 36V lead acid battery bank

IV. Conclusion

A novel economical single stage power factor corrected charger topology has been presented. Operation, features, and practical values of the proposed approach were illustrated and verified by the experimental results from a 1kW prototype. Distinctive advantages make the proposed approach very suitable for high power EV battery charger applications.

The proposed topology only consists of a normal line transformer followed by a two-switch-type power factor rectifier. Desired features for battery charger such as low cost, fast charge, charging profile programmability, high efficiency and high reliability are fully achieved by means of proposed solution.

Reference:

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