# An Efficient Unity Power Factor Battery Charging/Discharging Unit

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**Abstract— Rechargeable battery is considered to be one of the main electric energy storage devices. Due to the problem of posible shortage of energy resources, cost or enviromental cosiderations, a power saving and energy efficient devices become frequent request and important need. Therefore, within this apaer a single phase battery charger / discharger set is proposed, which operates in two different modes. An empty battery is charged directly from ac source through the control of a PWM rectifier converter, followed by a dc/dc buck regulator in the first mode, which is called charging mode. Second mode is discharging mode, as the set is utilized to discharge and transfer the energy from a charged battery to charge another empty battery, hence a power saving has been obtained. Such charging and discharging operations could be frequently required, particularly during batteries manufacturing, tests, maintenance and also can be adopted to be utilized withn recent vechicle to grid applications. The proposed PWM rectifier offers a sinusoidal supply current at unity power factor and improves the total harmonic distortion during the two modes of operations, hence providing high power quality operating conditions. The proposed set is simulated using PSCAD software to evaluate the system performance. Furthermore, experimental setup of the proposed system is implemented and experimental results have been agreed with simulation results, validating the proposed set for practical applications.**

***Index Terms--*** **implementation, power electronics, PSCAD, PWM and simulation.**

## I. INTRODUCTION

Since rechargeable batteries are used for storing electrical energy, they are vital components in electrical and electronic devices ranging from portable electrical shavers to satellites in space [1] and [2]. Before rechargeable battery is utilized by consumers, it should be tested by manufacturers to guarantee of battery cycle time, furthermore there are several tests are necessary for maintenance and testing, such as the annual performance tests [3]-[4] and energy performance test [5]. These tests may require charging the battery to full charge state and then discharging it to full discharge state [6]. This process could be repeated several times [6]-[8]. So, it can be appreciated how much energy could be wasted in the charging and discharging processes in these several tests. This wasted energy is considered as additional cost with respect to the manufacturers and consumers. Different battery charging techniques are scattered in literature [9]-[16],which could have different criteria such as fast charging, economic, simple, good power factor, capability to grid connection and etc. The goal of the proposed technique, in this paper, is to save the energy during battery tests. The basic idea presented, here, depends mainly on the utilization of the existing energy in a charged battery to charge another empty one directly during the battery tests. Realization of this idea will help in reducing the energy and the time required to test a number of batteries, since the two processes of charging and discharging the two batteries are accomplished in one step at the same time. In this paper, a set is proposed that can realize a battery charger and discharger processes. The proposed configuration has a simple and efficient operation, with low cost. Moreover, it exhibits close to unity power factor regarding the ac supply side. The proposed setup provides two modes of operation, first is a normal charging of an empty battery. Second is a discharging of the full battery and transferring its energy to charge another empty battery.

## II. PROPOSED BATTERY CHARGER / DISCHARGER SET

The proposed battery charger / discharger unit (CU/DU) is illustrated in Fig. 1, which is mainly based on two modes of operations; Charging and Discharging. The proposed system has been supported by a controlled selector (*S*) to be able to select and perform one of the two modes of operations.

a) ***First mode;*** Charging as (S) is in position (1) and only one empty battery is directly connected while the unit keeps the charging applied voltage ($v_{charger}$) at suitable values to feed the battery with the required charging current.

b) ***Second mode;*** Discharging as (S) is in position (2) and the empty battery is connected in series with the pre-charged one, while the control scheme of the unit in battery-series configuration aims to maintain the voltage of the required charged battery ($v_{b2}$) at its suitable value through discharging of the other battery by adapting the unit output voltage ($v_{charger}$) to realize the following equation,

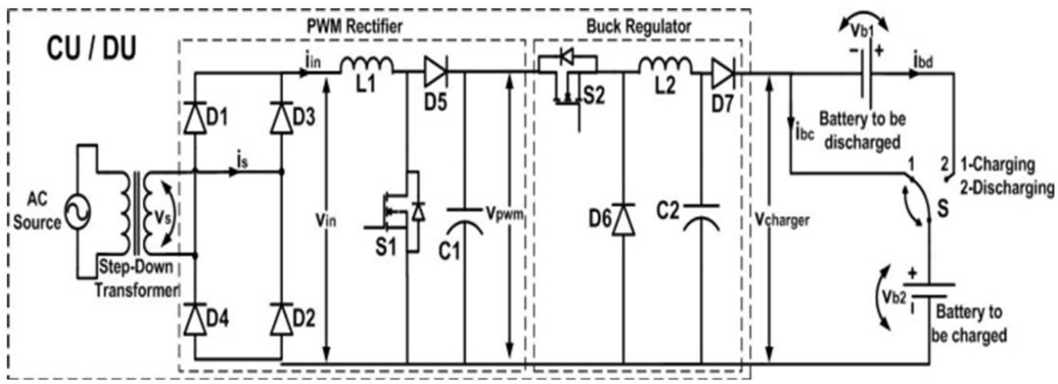



Fig.1. Proposed battery charger / discharger set

$$v_{b2} = v_{b1} + v_{charger} \qquad (1)$$

Where; $V_{b1}$ and $V_{b2}$ are voltages of battery to be discharged and battery to be charged respectively (see figure 1).

This configuration could achieve the best energy saving requirements during the discharging phase, since it transfers the energy from charged battery to another battery.

The proposed battery charger / discharger unit (CU/DU) also depends on the control of input ac current by making the charger / discharger system appears as a unity power factor load during the two charging and discharging modes. Such (CU/DU) unit consists of two main stages;

a) First one is the PWM rectifier converter, which operates as a booster for its output voltage ($v_{pwm}$) using the hysteresis current wave shaping technique in order to get a unity power factor input supply current **Error! Reference source not found.** and **Error! Reference source not found.**.

b) Second stage is the buck regulator to regulate the output voltage of the PWM rectifier converter to a suitable level of the battery to be charged ($v_{b2}$). Furthermore, this stage can limit the operating current during different modes of operation, as will be shown in next sections.

## III. System Control Techniques

The proposed system shown in Fig. 1 has two control techniques, one is dedicated to the PWM rectifier and the other control technique is for the buck regulator.

### *A. PWM Rectifier*

The power circuit of the PWM rectifier depends on a step down transformer, H-bridge uncontrolled diodes rectifier ($D_1$, $D_2$, $D_3$, $D_4$) and step-up converter, which consists of the power electronic switch ($S_1$), the inductor ($L_1$), the capacitor ($C_1$) and the diode ($D_5$), as shown in Fig. 1. When the boost switch ($S_1$) is turned on the inductor($L_1$) current is build up and energy is stored in the inductor, whereas the boost diode ($D_5$) is reverse biased, and the capacitor ($C_1$) supplies power to the load.

As soon as the boost switch is turned off, the power circuit changes modes, and the stored energy in the inductor, together with the energy coming from the input ac source, are pumped to the output circuitry (capacitor + load combination), so the inductor current is decreased.

In case of $S_1$ is on,

$$v_{in} - L\frac{di_{in}}{dt} = 0 \qquad (2)$$

Where in case of $S_1$ is off,

$$v_{in} - L\frac{di_{in}}{dt} - v_{PWM} = 0 \qquad (3)$$

In equations (2) and (3), $v_{in}$ is the full-wave rectified sinusoidal input voltage, $i_{in}$ is the current through the inductor, $v_{PWM}$ is the output voltage and $v_L$ is the voltage across the inductor $L_1$. It is accepted that the output capacitor $C_1$ should be large enough to be able to supply power to the load when the switch is on.

In order to obtain a sinusoidal input current in phase with input voltage, the control unit should act in such a way that $v_s$ sees a resistive load equal to the ratio of $v_s$ and $i_s$. This has been done by comparing the actual current passing through the inductor with a current reference, which is derived from multiplication of the sinusoidal supply voltage $v_s$ and the amplitude determined by the output of voltage controller as shown in Fig. 2. The current error has become the reference sine current of the hysteresis current controller to generate the necessary gating signal to control the boost switch operation (S1).

### *B. Buck Regulator*

The output dc voltage ($V_{PWM}$), which has been provided from the PWM rectifier converter, is decreased by buck regulator to be suitable for battery charging. The output average voltage can be defined as,

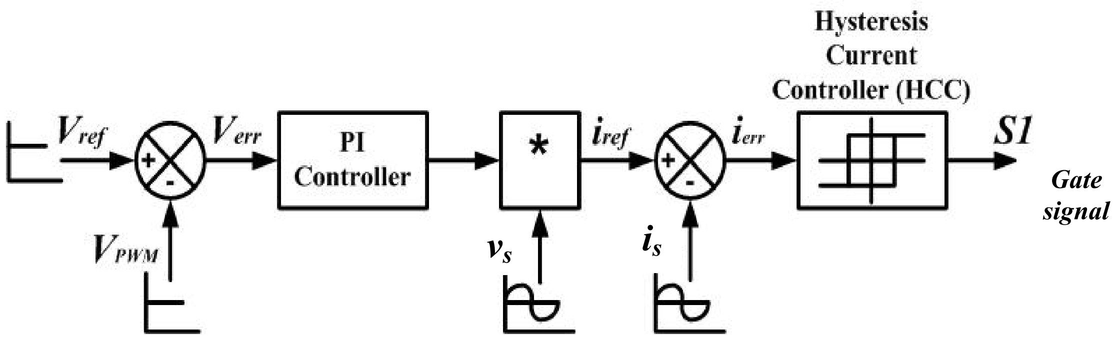



Fig.2. Proposed control loop of the PWM rectifier

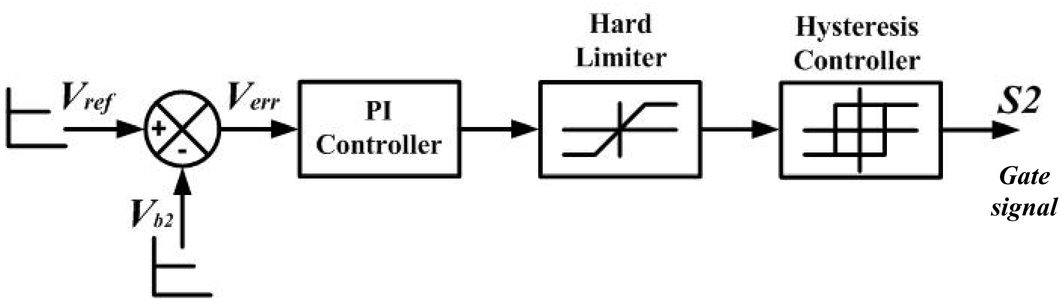



Fig.3. Proposed control loop of the buck regulator

$$v_{charger} = \frac{1}{T}\int_{0}^{t_{on}} v_{PWM}\, dt = K v_{PWM} \qquad (4)$$

Where, $K$ is the duty cycle = $t_{on}/T$ = 0 > $K$ > 1, $t_{on}$ is the on-period and $f_s = 1/T$ is the regulator switching frequency. Fig. 3 demonstrates the control block diagram of the buck regulator; the feedback of battery voltage is subtracted from the required charging voltage reference and the error signal is processed by a PI controller, then hard limiter controller is utilized to limit battery charging current and then gate signal of switch ($S_2$) is provided from hysteresis control.

These two control techniques (Fig. 2 and Fig. 3) have been realized through simulation in section IV by EMTDC/PSCAD software, while an experimental setup using a PIC microcontroller has been developed to implement these control techniques digitally in section V. In all cases, the controller parameters have been tuned by trial and error to get the most acceptable performance of the proposed set, while circuit components and rated values are as given in Table 1.

## IV. Simulation Results

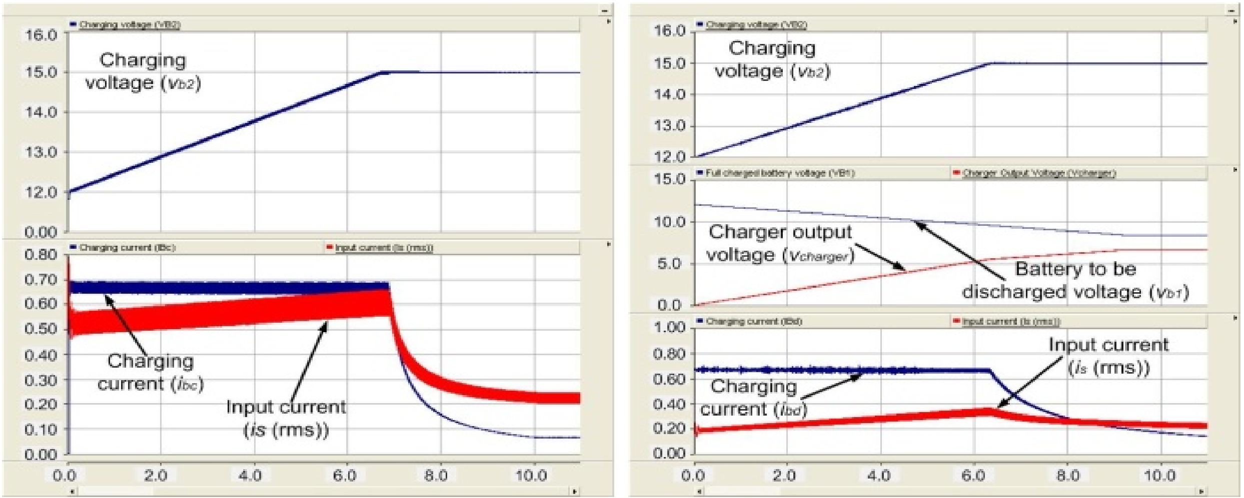
EMTDC/PSCAD software has been used to simulate the proposed configuration where, a lead-acid battery is modeled by a Thevenin circuit, (a voltage source representing the open-circuit voltage in series with a resistance representing both the Ohmic resistance within the electrodes and the electrolyte) [10].

Fig. 4a demonstrates the proposed system in charging mode process, as (S) is in position (1). It can be seen that the battery charging voltage ($V_{b2}$) is gradually increased up to 15V while the controller limits the charging current ($i_{bc}$) on the predefined limit value (0.69A). When the battery voltage reaches the applied charging voltage (≈15V), the charging current is totally reduced and could reach zero value.

Figure 4b illustrates the unit operation during the discharging mode while the pre charged battery is connected in series with the second battery needed to be charged.

TABLE1: COMPONENTS LIST OF THE PROPOSED TEST SETUP

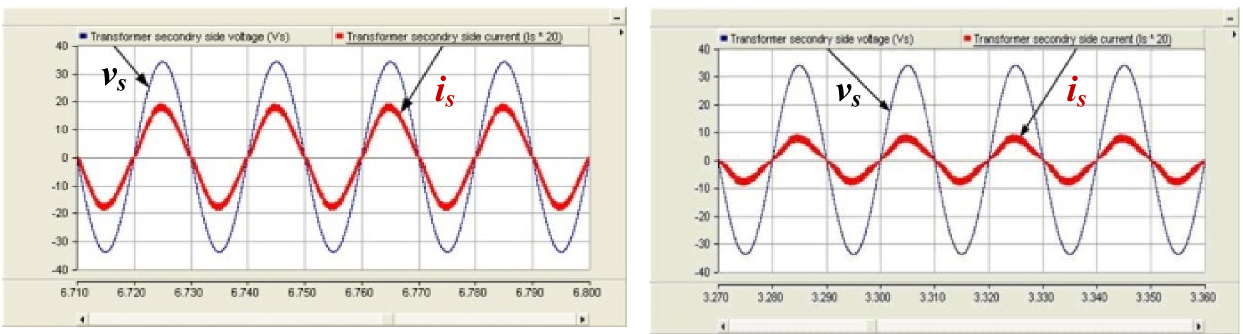
| Component Type | Value/No. |
|---|---|
| Step-down Transformer | 220/24V – 10A |
| Diode (D1:D7) | 6A4 |
| Inductor (L1) | 13 mH |
| MOSFET (S1:S2) | IRF740B |
| DC Capacitor (C1) | 6800µF/150V |
| Inductor (L2) | 15 mH |
| DC Capacitor (C2) | 2200µF/50V |
| Microcontroller Chip | 16F877A |
| Lead-acid batteries specifications | |
| Nominal voltage | 12V |
| Capacity | 2.3Ah |
| Max. charging voltage | 15V |
| Max. charging current | 0.69A |




(a) Charging mode

(b) Discharging mode

Fig.4. Simulation of proposed system process




(a) Charging mode

(b) Discharging mode

Fig.5. Simulation of the input supply voltage and current ($i_s$*20).

It can be seen that the charging voltage of the unit ($v_{charger}$) is gradually increased up to approximately 6.5V while the voltage of the battery required to be charged ($v_{b2}$) is gradually increased up to approximately 15V and the voltage of the battery required to be discharged ($v_{b1}$) is gradually decreased down to approximately 8.5V, fulfilling equation (1).

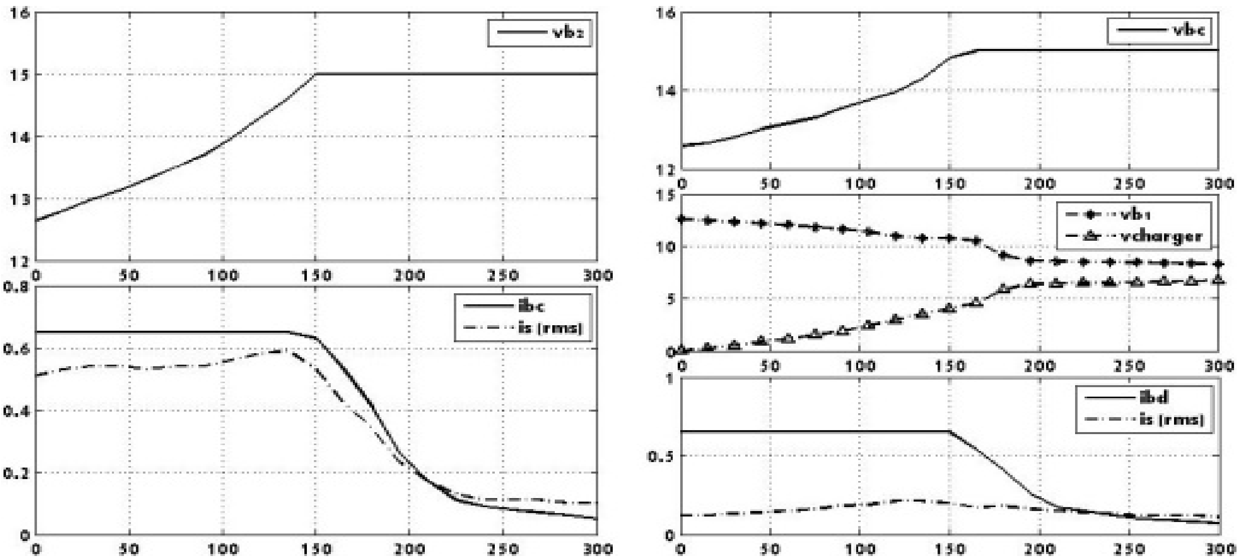
Figure 5 depicts the waveforms of the input supply voltage and currents during the two modes of operation, where the proposed set has successfully kept the input supply current sinusoidal in phase with the input supply voltage (unity power factor) within all modes of operation.

It should be pointed out that during the limiting period, the dc charging current could be higher than the rms value of the supply current due to the boosting action. While the input rms supply current is not reached zero at the end of the process, due to the required current to the PWM rectifier converter to boost its output voltage to the required value and make the ac current in phase with ac voltage (see Figures 4 and 5).

Comparing the supply current in both modes of operation, it is clear that its value during the discharging mode is totally reduced by to approximately 60% of the corresponding charging value, hence reduction of the input power by the same ration is achieved. Practical validation of the proposed set will be illustrated in the next section

## V. EXPERIMENTAL RESULTS

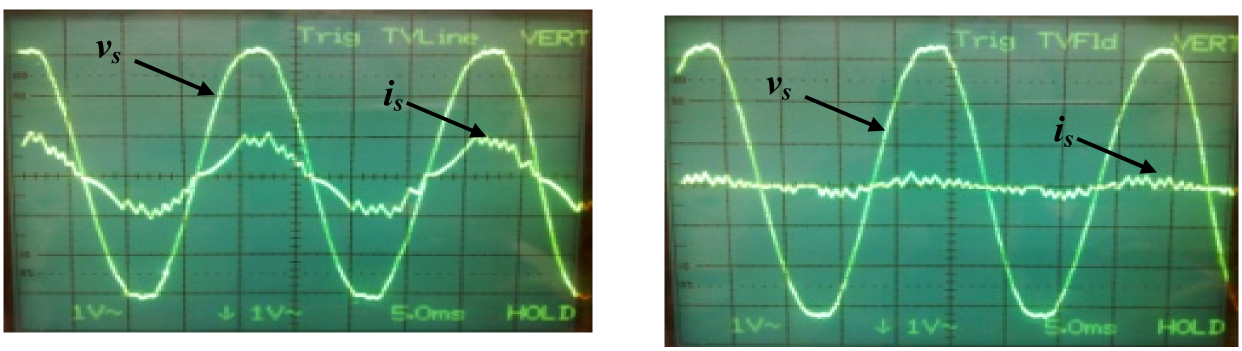
A prototype of the proposed charging/discharging unit has been experimentally implemented with the components values listed in Table1 in order to practically verify performance and operation of the setup. Control algorithms described in figures 2 and 3 have been realized within the microcontroller programs that has been provided with voltage and current sensing circuits to produce the suitable gate signals to the MOSFET switches through gate isolating circuits. Different experimental results have been obtained within different modes of operation as depicted in figures 6 and 7 (corresponding to the simulated results illustrated in figures 4 and 5 respectively).




(a) Charging mode

(b) Discharging mode

Fig.6. Experimental results of proposed system process




(a) Charging mode

(b) Discharging mode

Fig.7. Experimental waveforms of the input supply voltage and current (vs/10)

It can be seen that the experimental results have well matched and correlated with the simulated results, validating the unit for real and practical applications. Any variations and differences between simulation and experiments results could be due the variation between actual and simulated component parameters.

Table 2 summarizes the practical values obtained during the two modes of operation. Comparing the supply currents during the two modes of operation, current taken from supply during the proposed discharge mode has been reduced by a factor of (0.33-0.12)/0.33)= 60% of the charging mode. It confirms that most charging energy is transferred from the full battery to the other empty one, providing good utilization and manipulation of energy instead of wasting in a useless resistance unit, while also providing unity power factor for the input supply, i.e. good energy saving with power quality operation device.

## VI. CONCLUSIONS

A proposal of a single phase charger / discharger topology with improved power factor has been presented. Operation and features of the proposed approach were illustrated and verified by the simulation and experimental results. The idea of utilizing the energy of a charged battery to be transferred to charge another empty battery has been fulfilled through the proposed set, while keeping the input current drawn from the supply in phase with the supply voltage. Such configuration provides high power factor during the two modes of operation with energy efficient due to good utilization and manipulation of energy between the two batteries. The proposed set can be used in multi charging / discharging of batteries during tests, maintenance operations manufacturing process and culd be adopted for electrical vehicle applications.

TABLE 2: COMPARISON BETWEEN EXPERIMENTAL VALUES DURING THE TWO MODES OF OPERATION

| | Charged battery voltage ($V_{b1}$) in V Start/End | Empty battery voltage ($V_{b2}$) in V Start/End | Discharging current ($i_{bd}$) in A Start/End | Charging current ($i_{bc}$) in A Start/End | Supply current ($i_s$) in A Start/End |
|---|---|---|---|---|---|
| **Charging mode** | - | 12.64/15.0 | - | 0.65/0.05 | 0.53/0.10 |
| **Discharging mode** | 12.57/8.29 | 12.58/15.0 | 0.65/0.07 | | 0.12/0.11 |

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