

Design and Implementation of Battery Charger Using Ultrasparse Matrix Rectifier with Ann Control

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ABSTRACT: Artificial Neural Networks (ANN) is introduced by McCulloch and Pitts in 1943. It is an interconnected group of nodes. Neural networks models in artificial intelligences are usually referred to as artificial neural network. A novel unity power factor battery charger conception based on an Ultrasparse Matrix Rectifier (USMR) with Artificial Neural Network (ANN) is presented in this paper. Ultrasparse matrix converter topology can be derived from Indirect converter topology having a reduced number of input switches. The circuit has only three switching components and low-energy- conversion loss. This reduces the cost and enhances the system's efficiency for high voltage battery. Thus, the proposed ANN controller improves the line power quality and delivers admissible output power to the battery. The charging method chosen is the Constant Current (CC) or Constant Voltage (CV) method. The ANN control and space vector modulation algorithms are implemented with the Digital Signal Processor.

KEYWORDS: ANN controller, battery chargers, fuzzy logic controller (FLC), space vector modulation (SVM), ultrasparse matrix rectifier (USMR), unity power factor.

1. INTRODUCTION

Due to the popularity of battery charger in many areas of application, it is essential to design a battery charger to provide high performance and high power demands while meeting low cost requirements [1]. Charging battery may seem like an easy and simple task, however, it could involve complicated control algorithm. The control algorithm must be able to provide the means to protect the battery from over-charging, which leads to the destruction of the battery. Thus a proper battery charger with the ability of fast charging and efficient control topology is required to ensure the adequacy of the battery system throughout its life [2].

The conventional battery charger experiences a highly distorted current harmonic waveform and low power factor due to the presence of high ripple in the charging current. Thus the battery storage system requires an additional charging circuit for reducing the ripple and extending the battery life. Several methods for charging battery [7] have been proposed depending on the battery chemical composition and the capacity, construction techniques and application of the battery. The efficiency of the charging methodology is measured by the charging current and voltage level, the charging current oscillation, and temperature fluctuation during charging process, also the total charging time.

Constant voltage (CV) and constant current (CC) charging are the usual battery charging techniques. The CV charging method keeps the battery voltage constant by using an equivalent series resistance to control the battery current. The CC charging technique maintains the charging current constant, until the battery voltage achieves a designated value. Existing system consists of double control loop based on the fuzzy logic controller to charge the battery [5]. The main drawback of using fuzzy logic controller is that there is no standard and systematic method for the transformation of the human knowledge or experience into the rule base of a fuzzy inference system, it is not guaranteed that rules are coherent, it is possible to have mismatch between the rules, Computing time could be long because complex operations and even when human operator exists, their knowledge is often incomplete or episodic.

In this paper the FLC with an ANN controller [6] to overcome the above mentioned disadvantages and to design a better battery charger. ANN control is based on Artificial Neural Network. Basically ANN is an observer. It can behave

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like controllers such as P, PI, PID, FLC etc and can provide better dynamic response. Artificial neural networks can be most adequately characterized as computational models with particular properties such as the ability to adapt or learn to generalize or to cluster reorganize data and which operation is based on parallel processing. In this paper ultraspase matrix three- phase ac-dc converter topology, for ANN regulator based battery charger applications, is developed. The converter topology use a reduced number of power-controlled switches [4] (IGBTs) as compared to the four-quadrant matrix rectifier or to the PWM current rectifier. This structure needs only three IGBTs and 12 diodes and ensures the operation with unity power factor. Matrix converter has been frequently presented as future converter for AC drive application.

The Matrix converter circuits offer the following advantages as compared to conventional circuits.

1. Suppression of power harmonics: Realizes less than 7% THD of input current and more than 98% input power factor without any specific measures taken.
2. Longer operating life: The main circuit does not have endurable parts such as an electrolytic capacitor. This makes the operating life of the main circuit longer and the maintenance interval longer.
3. Elimination of derating: With the elimination of current constriction on any specific device, the reduced operation during low-frequency operation is unnecessary.
4. Power regeneration: Unique bi-directional switches for directly connecting the power supply and loads enable continuous regeneration.
5. High-efficiency: Only the bi-directional switches are used to connect the power supply and loads, allowing higher-efficient operation than as in conventional AC Drives.

II. PROPOSED SYSTEM

Neural networks models in artificial intelligences are usually referred to as artificial neural network. It is an interconnected group of nodes. ANN is actually not a controller but an observer. It can behaves like controllers like FLC, PI, PID etc by training properly. But ANN is capable of giving output faster than the controllers. Artificial neural networks can be most adequately characterized as computational models with particular properties such as the ability to adapt or learn to generalize or to cluster or organize data and which operation is based on parallel processing. A neural network has to be configured such that the application of a set of inputs produces either direct or via a relaxation process the desired set of outputs. Various methods to set the strengths of the connections exist. One way is to set the weights explicitly using a priori knowledge. Another way is to train the neural network by feeding it teaching patterns and letting it change its weights according to some learning rule. A feed-forward network is adopted here as this architecture is reported to be suitable for problems based on pattern identification. A network first needs to be trained before interpreting new information. Several different algorithms are available for training of neural networks, but the back-propagation algorithm is the most versatile and robust technique for it provides the most efficient learning procedure for multilayer neural networks.

Also, the fact that back-propagation algorithms are especially capable to solve problems of prediction makes them highly popular. During training of the network, data are processed through the network until they reach the output layer. In this layer, the output is compared to the measured values (the "true" output). The difference or error between the two is processed back through the network (backward pass) updating the individual weights of the connections and the biases of the individual neurons. The input and output data are mostly represented as vectors called training pairs. The process as mentioned above is repeated for all the training pairs in the data set, until the network error has converged to a threshold minimum defined by a corresponding cost function, usually the root mean squared error.

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A. BLOCK DIAGRAM

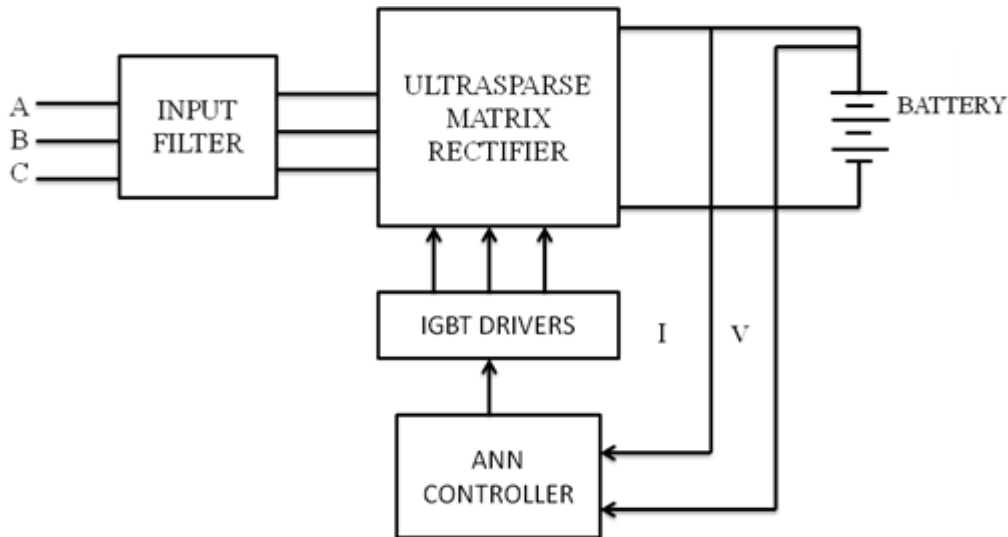


Fig.1. Block diagram for the proposed system

Block diagram of the proposed battery charger is shown in fig. 1. It consists of an ac source, input low pass LC filter, Ultrasparse Matrix Rectifier, battery bank, ANN controller, and IGBT drivers. The LC filter is connected to the input side of the rectifier to filter out the switching frequency harmonic components in the line. Ultrasparse matrix rectifier is indirect matrix topologies which consists of only three IGBTs and twelve diodes and ensure the operation at unity power factor. Diodes used are fast recovery diodes resulting in reverse voltage blocking capability and unidirectional current flow. The ANN controller is used for creating a feasible electro power for rechargeable battery and it must identify the point that is stopping charging to avoid rechargeable battery explosion. It also offers one of the most advantageous solutions to evaluate the charging conditions and to determine the ideal point of charging. The ANN controller continuously monitors the battery charging current, state of charge and battery voltage. According to the monitored values of the above mentioned parameters charging occurs in CC or CV mode. The ANN is actually not a controller but an observer. It can behaves like controllers like FLC, PI, PID etc by training properly. In this project ANN is trained to imitate the PI controller. But the ANN is capable of giving output faster than the PI controller. That is dynamic response is improved considerably.

B. CIRCUIT DIAGRAM

The circuit diagram of the proposed battery charger which supplies power to the battery bank is shown in Fig .2. It consists of an ac source, synchronizing circuit, low pass LC filter, ANN controller, analogue interface circuit, IGBT drivers, ultra sparse matrix rectifier, output inductor to minimize the switching losses in the output stage and the battery bank.

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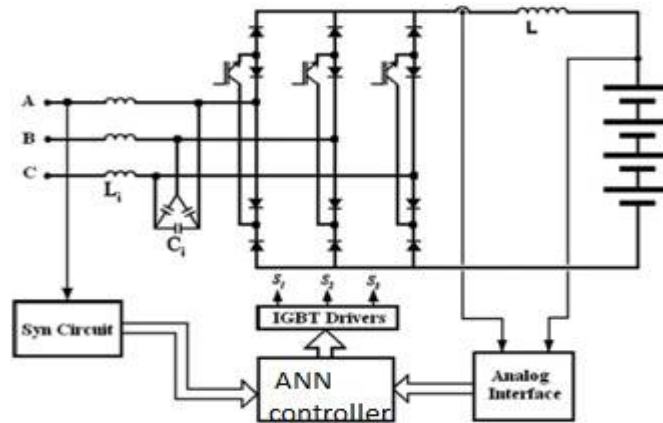


Fig.2. Circuit diagram of proposed battery charging system

A low pass LC filter is connected to the input side of the rectifier to filter out the switching frequency components in the line currents. LC circuit is also called a resonant circuit, tank circuit, or tuned circuit. Filters are generally used to picking out a signal at a particular frequency from a signal and to enhance the wanted ones. ANN controller monitors the charging current, battery voltage and battery state of charge. Then it compared with the reference values. The output from the ANN controller determines the switching states of the ultrasparse matrix rectifier. The circuit diagram of USMR as shown in fig 3.

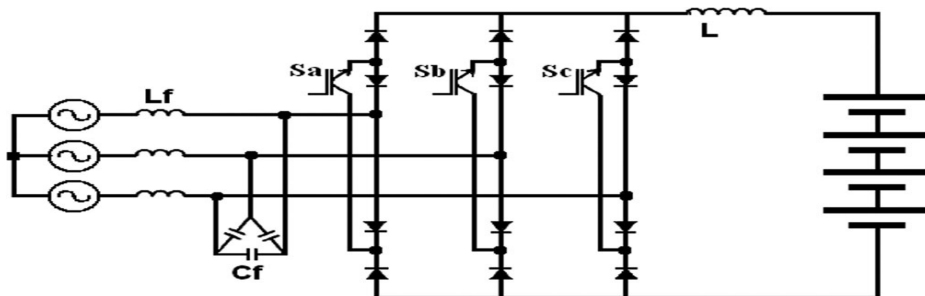


Fig. 3. Ultrasparse Matrix Rectifier

The ultrasparse matrix rectifier consists of only three switching components. That is it consists of only three IGBTs in series with an ultrafast recovery diode, resulting in reverse voltage blocking capability and unidirectional current flow. Its circuit has only three switching components and low-energy-conversion loss. This reduces the cost and enhances the system's efficiency for high voltage. Due to the decreased number of switching operation the losses are reduced [3] in this rectifier compared to the conventional three phase rectifier. In the rectifier stage, each combination of one semiconductor device and four diodes functions as a bidirectional switch. The inverter stage is the same as the convectional six-switch inverter. The aim of the modulation in rectifier stage is to produce the maximum voltage in the dc-link as well as to maintain the sinusoidal input current and unity input power factor. The converter synthesizes a positive voltage in dc-link stage by selecting a switching state in the rectifier stage. USMR permits only unidirectional power flow due to the arrangement of input switches as shown in fig 4.

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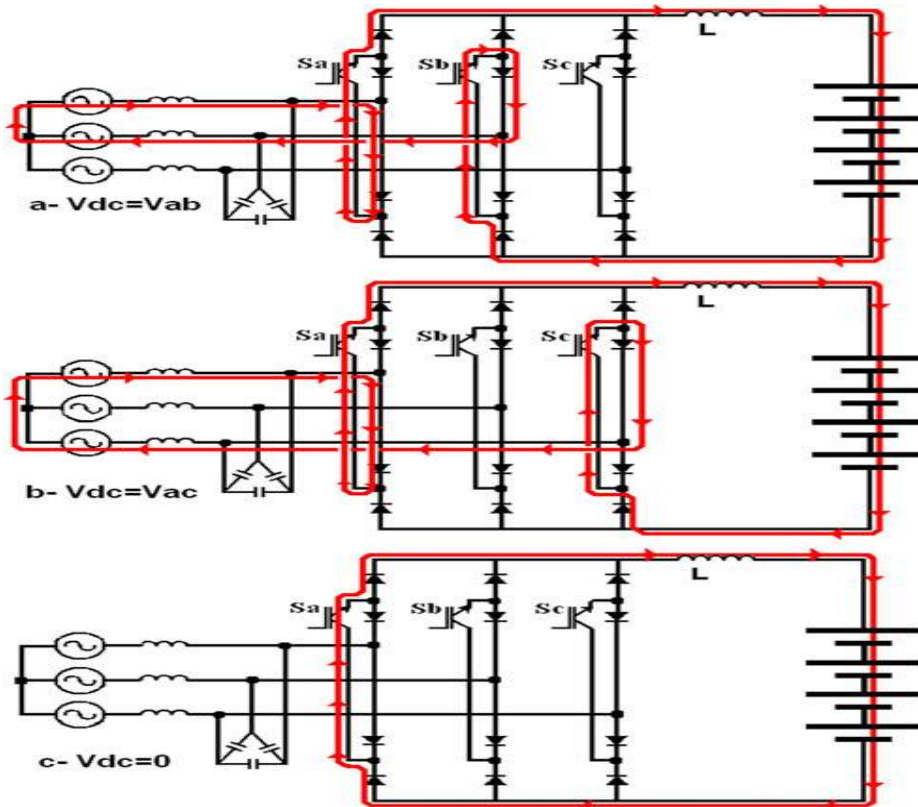


Fig. 4. Current flow during operation

Current flow in different modes of operation is shown in fig.4. During the first diagram only two IGBTs that is S_a, S_b are in conduction along with four diodes. In the second mode IGBTs S_a, S_c are on along with four diodes. In the Third mode only one switch S_a and two diodes are in conduction.

A space vector modulation is used to provide sinusoidal input currents for the USMR.

C. BATTERY CHARGING PROFILES

The battery charger must have most efficiency, fast charging mode, and guarantee the safe of battery from probably damage of undercharge or overcharge and the cost must be reasonable. The basic essential item designer of battery should have to check included factor, voltage, energy density, temperature performance, drain rate, and cycle life and it must have minimize size and weight and no memory accumulation .Battery life is also one of important properties. Rechargeable battery life is not related only charger times, But overcharging control and charger way. The life cycles of Li-Ion batteries are simply is influenced by overcharge or undercharge, because overcharge can damage the physical elements of the battery and undercharge can decrease the energy capacity of the battery. The Charger controller has duty of creating a feasible electro power for rechargeable battery and it must identify the point that is stopping charging to avoid rechargeable battery explosion. The Constant-Current and Constant-Voltage (CC-CV) is used most broad, but its function is cannot give the customer all of their need. Therefore an additional controller is needed.

The charging method chosen is the CC/CV method. CC/CV is the best method in battery charging, because it offers the fastest charging time to fully charge the battery. Charging starts with CC mode until the battery has reached the maximum voltage. In this mode, the CC value is applied. The voltage across the battery terminal is monitored to prevent overcharging, and the CC mode is then switched into the CV mode once the maximum voltage is reached. At this stage, the battery is about 75% of its full capacity.

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However, when the battery is deeply discharged or damaged, it may not accept an immediate application of the CC/CV charge profile. As an alternative, a “trickle-charge” must first be applied to charge any battery that is below the minimum charge voltage until it is ready to receive a CC/CV charge. If the battery fails to reach the required minimum voltage after a trickle charge is applied, then the cell is declared damaged. The full charging profile for the battery string is shown in Fig. 5.

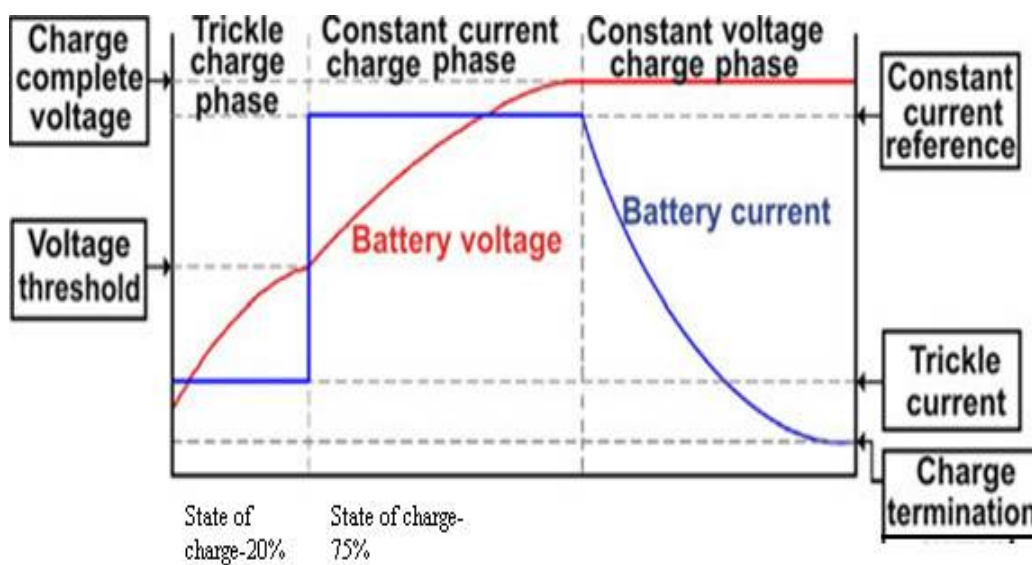


Fig.5. Battery charging profile

As shown, the trickle current I_t must be applied until a voltage above the threshold voltage V_{th} is measured. Then a CC/CV charge profile is applied.

This strategy applies basic operations with current and voltage detection, end of charge detection and automatic charging speed control. This charger uses mixed method and it is supported from trickle large CC to CV mode. According to the internal parasitic resistance of the Li-Ion battery pack system, without fully charging the cell to the rated voltage value, the charger circuit switches from the CC stage to the CV stage. Degrading current at the CV stage causes the longer the charging time. Dynamic estimate the internal resistance of the battery pack system is possible by this proposed technique due to enlarge the period of the CC stage to achieve faster charging response. The period of the CC stage may increase to 40% that of the original design in practice. The operational mode of charger is dependent on

the internal resistance of battery and it is affective for reducing the damage of Li-Ion battery and improves the power efficiency of charger.

D. BATTERY CHARGER CONTROL CIRCUIT

Fig.6 shows the block diagram of the battery charge control using a double control loop based on the fuzzy logic controller. Here fuzzy logic is used as a controller and ANN is as observer. The ANN monitors the charging current, battery voltage and battery state of charge. Then it compared with the reference values. The output from the ANN determines the switching states of the ultrasparse matrix rectifier.

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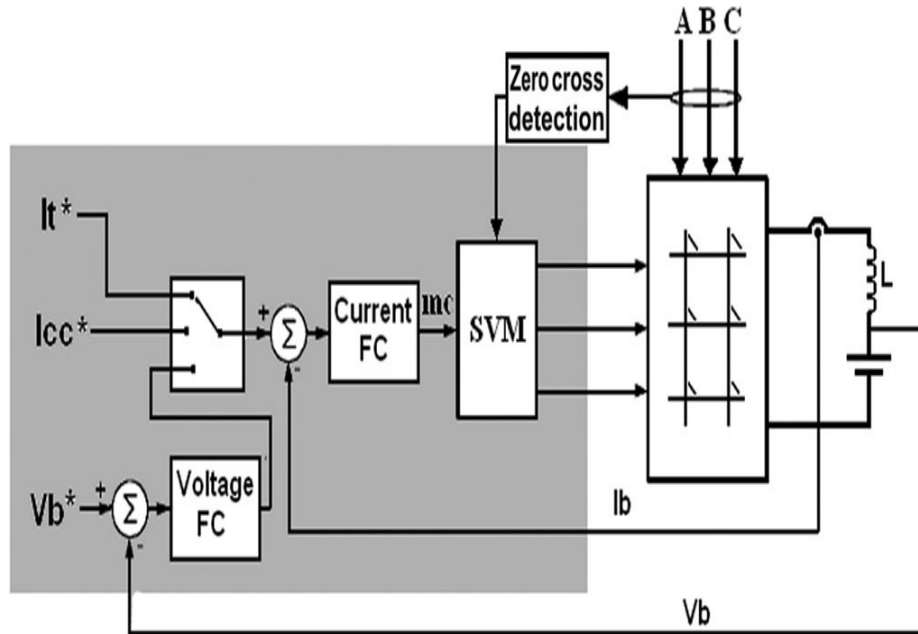


Fig.6 Closed loop voltage and current regulation

It consists of an external control loop, regulating the converter output voltage, and an internal control loop, regulating the inductor current. Fuzzy logic is used in both regulators. The controlled output voltage is detected and compared with reference voltage. The voltage error and its changing are considered as the fuzzy logic controller inputs. The output signal is used to generate the current reference. A space vector modulation scheme is used to provide the sinusoidal input currents to the converter. The fuzzy battery voltage and current regulation loop algorithm is implemented on the DS1104

Power PC master processor and the space vector modulation (SVM) algorithm is implemented in TSM320F240 DSP (DS1104 slave device).

III. CIRCUIT DESIGN

The main passive components in the design example are the inductor L , L_f , and capacitors C_f which are designed according to battery current ripple criteria and input current harmonic elimination. The inductance of the inductor L can be expressed as

$$L = \frac{U_{dc \max} - V_{batt}}{\Delta I_{batt} F_s} \tag{1}$$

Where, $U_{dc \max}$ is the converter maximum output dc voltage,

V_{batt} is the battery voltage, ΔI_{batt} is the battery current ripple and f_s is the switching frequency.

The input filter is designed to filter high harmonic components of the input current and to reduce the input voltage distortion supplied to the USMR. The input filter cutoff can be given by

$$F = \frac{1}{2\pi L F C F}$$

1
 $(2\pi F)^2$
 (2)

IV. SIMULATION RESULTS AND ANALYSIS

The simulation of battery charger using an ultrasparse matrix rectifier with ANN control is as shown in fig. 7. The result for both constant current (fig.8.) and constant voltage charge phase (fig. 9.) are given below. The charging starts with an initial state of charge 20%. It starts charging in Constant current mode. But the battery voltage and state of charge increases time by time.

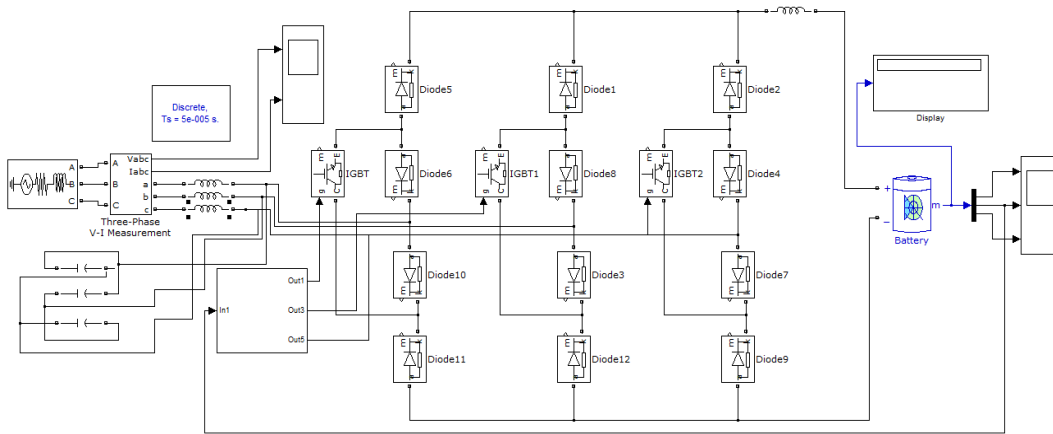


Fig.7.Simulink model of proposed system

As the time goes on, battery voltage and state of charge increasing but the charging current remains constant. The CC charging technique maintains the charging current constant, until the battery voltage achieves a designated value. It consists of ANN controller. The ANN controller is used for creating a feasible electro power for rechargeable battery and it must identify the point that is stopping charging to avoid rechargeable battery explosion. It also offers one of the most advantageous solutions to evaluate the charging conditions and to determine the ideal point of charging. It monitors the charging current, battery voltage and battery state of charge. Then it compared with the reference values. If the state of charge is less than 20% then the battery charged in the constant current phase. The value of the constant current is set as

5A. Constant current charging maintains the charging current constant until battery voltage reaches the designated value. In this mode CC is applied. The voltage across the battery terminal is monitored to prevent overcharging and the CC mode is then switched to CV mode once maximum voltage is reached. At this stage the battery is about 75% of its full capacity. When the battery approaches the 75% of the state of charge then constant current mode shifted to constant voltage mode.

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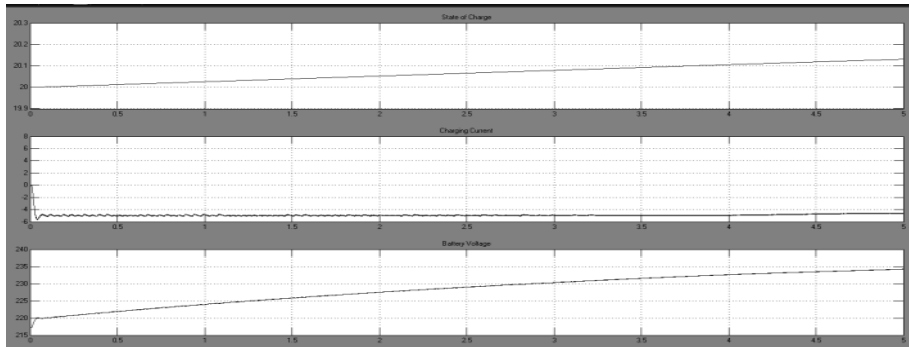


Fig.8. Constant current charge phase

In constant voltage mode battery voltage is constant but charging current and state of charge is varying. This will increase the efficiency of the charging procedure.

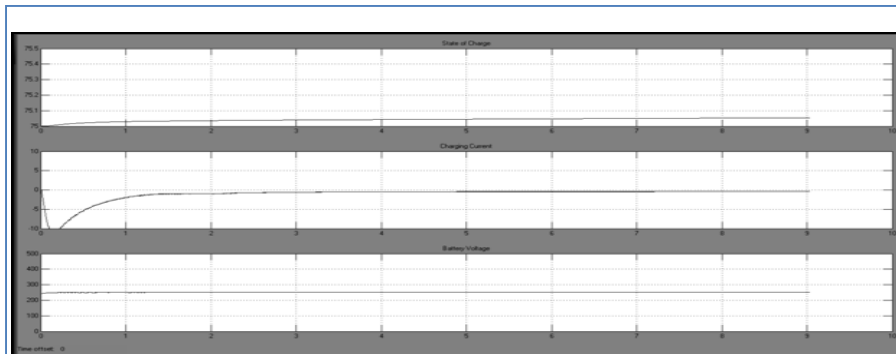


Fig.9. Constant voltage charge phase

Fig.10. shows the gating signal for the three IGBTs presents in the ultrasparse matrix rectifier.

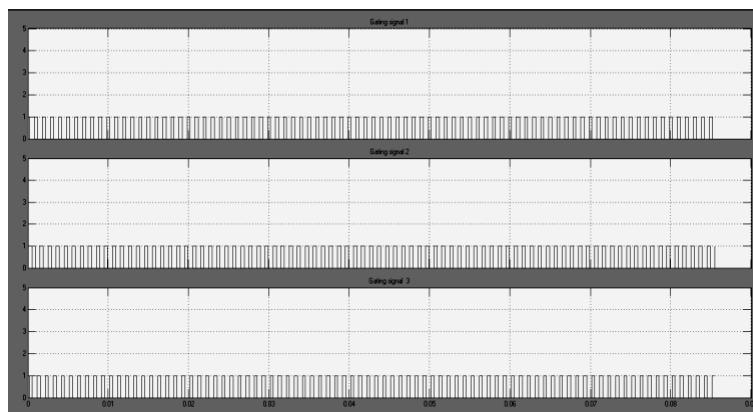


Fig. 10 Gating signals for IGBTs of USMR.

The gating signals are generated according to the ANN controller. This gating signal controls the turning on and off

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of the IGBTs.

The converter power factor, for the entire load range at 50–100 V input voltage, is provided in Fig. 11. As the input current from the space vector modulation to the matrix converter is purely sinusoidal, the input power factor is greater than 0.99 for current load variation.

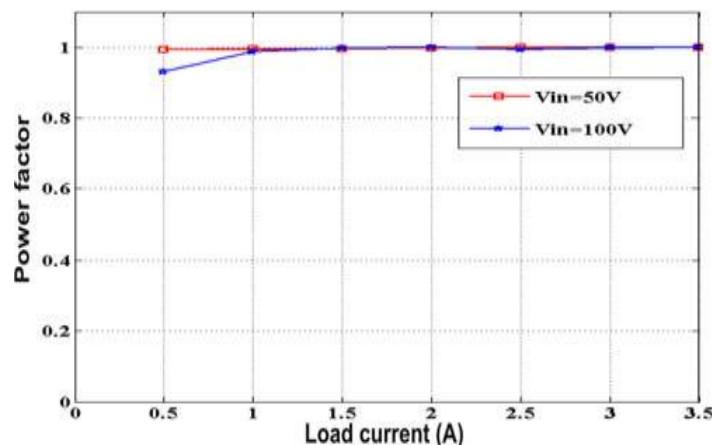


Fig.11. Input Power factor of the proposed battery charger.

V. CONCLUSION

A novel battery charger using USMR with ANN control was developed. ANN offers one of the most advantageous solutions to evaluate the charging conditions and to determine the ideal point of charging. Its circuit has low-energy-conversion loss and this reduces the cost and enhances the system's efficiency for high voltage battery. The efficiency of the battery increases due to the reduced charging time of the battery. Thus, the proposed controller improves the line power quality and delivers admissible output power to the battery.

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