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Comparative Analysis of Li-Ion Battery Charging with Different Rectifier Topologies

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Abstract: ***Now a days the rechargeable batteries are used in many applications. There are many types of rectifiers like Diode bridge rectifier, SCR based rectifier, PWM based rectifier, etc. The rectifier is basically used to charge a battery. This paper discusses front end PWM rectifier based battery charging technique with its performances and for generation of gate pulses using modulation technique namely sine pulse width modulation (SPWM). This paper also features the description of 2-level front end PWM rectifier, Diode bridge rectifier, Thyristor based rectifier based battery charging and control strategy. Simulation models of two level SPWM based front end rectifier, Diode bridge rectifier and Thyristor rectifier based Li-Ion battery charging model is developed and simulated in MATLAB / SIMULINK platform and a comparative analysis is presented..***

Index Terms**: *Battery, Diode, IGBT, Li-Ion, Rectifier.***

I. INTRODUCTION

The batteries are small portable storage devices.. This paper discusses about the rechargeable battery charging techniques using diode bridge rectifier, thyristor rectifier and IGBT rectifier based battery charging technique. Three phase voltage fed rectifier are used as input supply in this technique. Basically batteries are used in the portable devices like clocks, remotes, vehicles which need less voltage requirement, the voltage for charging battery is to be stable.

The diode bridge rectifier is having a flow in only one direction and also the output voltage which acts as input to the battery charging is not controlled in this diode bridge rectifier based battery charging technique. The model of diode bridge rectifier circuit is discussed in the coming sections. Li-ion batteries are rechargeable batteries in this paper the testing done with Li-Ion battery. This paper discusses about the Li-Ion battery charging topologies. The diode bridge rectifier is a unidirectional topology where the current flow is from input to output side. Also the output voltage cannot be controlled in this configuration. Input current and voltage waveforms are not in phase due to large harmonics and thus have poor power factor.

The thyristor based rectifier based technique is also a unidirectional flow but in this case the output voltage can be controlled. To turn off the thyristor, there is a need to implement forced commutation circuit which makes circuit complexity more and cost more which is a major drawback of this technique. The phase controlled rectifiers are also having disadvantage of the lower order harmonics which makes the cost and size of the filters to increase.

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On comparing with the diode bridge rectifiers and thyristor controlled rectifiers, the IGBT based PWM rectifiers obtained bidirectional power flow. IGBT based PWM rectifiers are used in many applications in industrial sectors and also in many manufacturing companies. The major advantage of using the IGBT based PWM rectifier techniques results in less harmonic content by using appropriate number pulse to their respective switches. By using various pulse width modulation techniques the output voltage can also be stabilized through variation of modulation index. The power factor gets unity, when both the input currents and input voltages are in phase with each other this happens mostly in using of switches as IGBT's [1]. In the diode bridge rectifier and thyristor controlled rectifier, are having the disadvantage of higher order harmonics to reduces harmonics an additional filters are required which is not the case with IGBT based PWM rectifier [2]. To charge the battery, there are four stages of charging like constant voltage control, constant current control, pulsed charge and taper current. The Li-Ion batteries are having a high energy density and mostly they are used in electronics area. In this paper, the analysis of battery charging constraints as above discussed are all simulated in the Simulink/MATLAB. The diode bridge rectifiers based battery charging technique is discussed in section II. Thyristor based rectifier battery charging technique is discussed in section III. IGBT based PWM rectifier battery charging technique is discussed in section IV.

II. ANALYSIS OF DIODE BRIDGE RECTIFIER BASED BATTERY CHARGING TECHNIQUE

The circuit diagram of a three-phase two pulses six pulse diode bridge rectifier based battery charging is illustrated in Fig.1. The three phase AC supply is fed to the rectifier input side and the output is getting a rectified DC with filtered by a capacitive filter connected at the output side. The output from the rectifier is fed to single phase IGBT based front end inverter that is regulated using a current control loop. This current controller loop operates on the currents flowing at battery side. The control loop values, determines the switching signals to be applied to the single-phase PWM inverter.

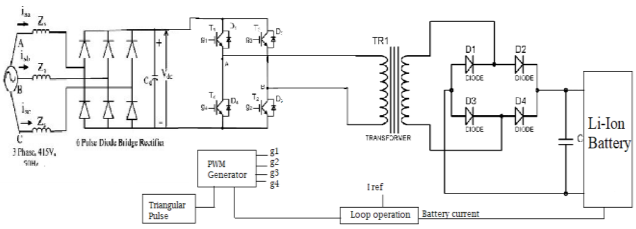

Fig.1 Block diagram of diode bridge rectifier based battery charging

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The inverter output is fed to the linear transformer 1:1. The output of the transformer acts as input to the single phase diode bridge rectifier, the rectified single phase DC output is filtered with a capacitive filter and fed to charge a battery. In closed loop operation, the battery current is compared with a constant of 100A and the error is acts as the input to PI controller. The controller output voltage is compared with a repeating sequence with a carrier frequency of 20 KHz and the respective pulse are generated and fed to the respective IGBT's switches of the single phase inverter The closed loop operation is used to stabilize the inverter voltage. Sine PWM technique is operated with a 20KHz carrier waveform switching frequency [3]. The analysis also done with the instability test of the input voltage with the variation of (0-0.5) seconds normal input voltage, (0.5-1) seconds the voltage of 10% less of normal voltage and again (1-1.5) seconds 10% more of normal voltage and the results of input voltage and battery waveforms shown in Fig.2 and Total Harmonic Distortion (THD) are shown in Fig.3.

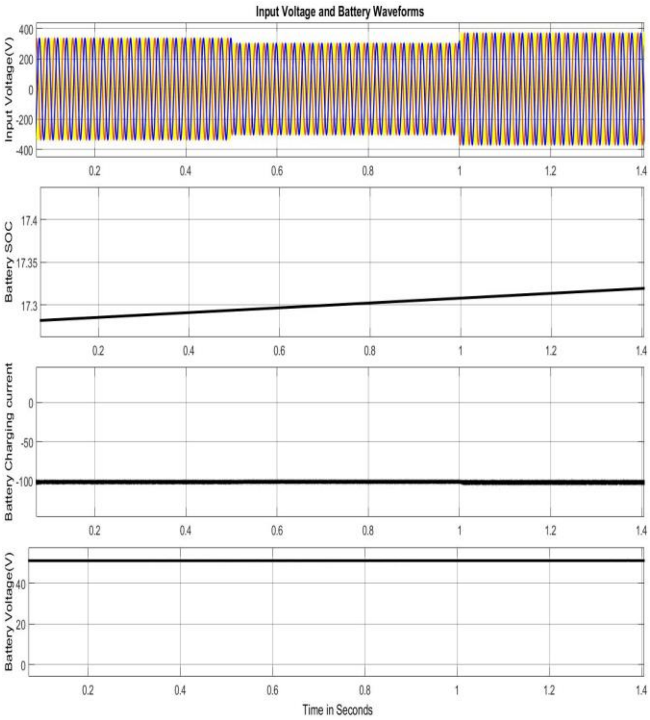

Fig.2 Input Instability AC voltage with battery output

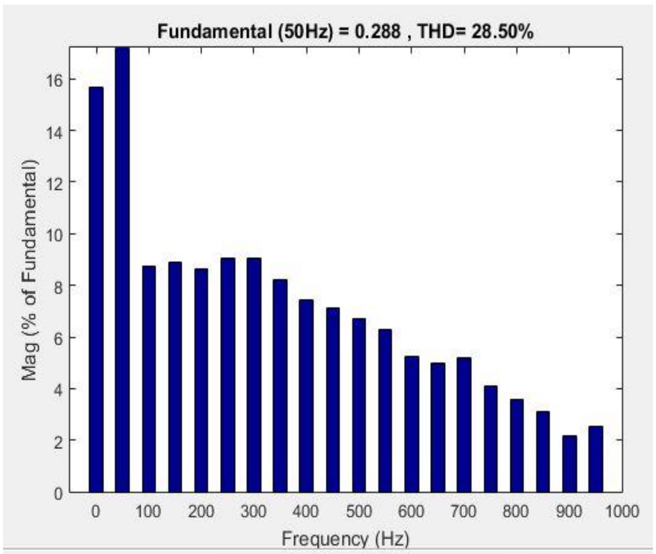

Fig.3 Total harmonic distortion results

The THD obtained with the instability voltage analysis with diode bridge rectifier based battery charging technique is 28.50%

III. ANALYSIS OF THYRISTOR BASED RECTIFIER BATTERY CHARGING TECHNIQUE

In this technique, the three phase voltage is fed to the thyristor based rectifier. Because, in the diode bridge rectifier it is a unidirectional flow rectifier that makes the more distortions in the circuit and also not controlled DC output is obtained. The gate pulses are generated by using sine pulse width modulation technique with a closed loop operation based on the rectifier out DC voltage [4]. The rectified DC output voltage is compared with a constant of 800V and the error is connected to the PI controller. The controller output I_d is again compared with I_{drefd} obtained from the transformation techniques applied from the input three phase currents and the error is connected to the PI controller. The controller output V_d. The I_q is compared with zero reference to maintain the power factor unity [5]. The error is connected to the PI controller, the controller output V_q and the output V_d is transformed to abc by dq-abc transformation technique, refer (1) - (5). The block diagram of thyristor rectifier based battery charging technique is shown in Fig.4.

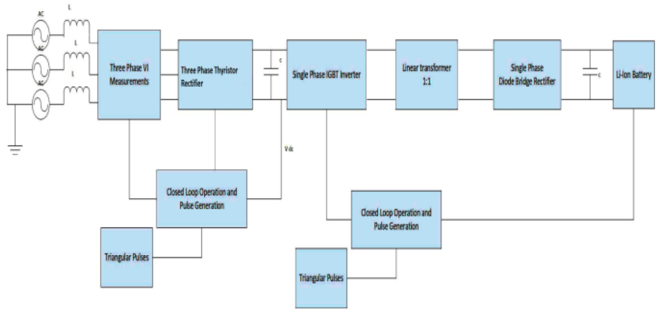

Fig.4 Block Diagram of Thyristor rectifier based Battery Charging Technique.

$$V_a = V\alpha \quad (1)$$

$$V_b = (-V\alpha + \sqrt{3} * V\beta)/2 \quad (2)$$

$$V_c = (-V\alpha - \sqrt{3} * V\beta)/2 \quad (3)$$

$V\alpha$ and $V\beta$ are obtained from equations (4) and (5)

$$V\alpha = V_d * \cos(\theta) - V_q * \sin(\theta) \quad (4)$$

$$V\beta = V_q * \cos(\theta) + V_d * \sin(\theta) \quad (5)$$

The three phase voltage V_{abc} is compared to the carrier wave frequency of 20 KHz, the respective pulses are fed to their respective thyristors [6]. The rectified output voltage is fed to IGBT based inverter and also the closed loop operation same as like diode bridge rectifier. By the thyristor based rectifier battery charging technique the THD is improved and the power factor gets improved with stability analysis also.

The rectified output is connected as input supply to the single phase IGBT based PWM inverter [7]. The inverter output is fed to the linear transformer 1:1.

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The output of the transformer is connected to a single phase diode bridge rectifier, the rectified single phase DC output is filtered with a capacitive filter and fed to charge a battery. In closed loop operation, the battery current is compared with a constant of 100A and the error is connected to the PI controller. The controller output voltage is compared with a repeating sequence with a carrier frequency of 20 KHz and the respective pulse are generated and fed to the respective IGBT's switches of the single phase inverter [8]. The analysis also done with the instability test of the input voltage with the variation of (0-0.5) seconds normal input voltage, (0.5-1) seconds the voltage of 10% less of normal voltage and again (1-1.5) seconds 10% more of normal voltage. The results of the input voltage and Battery waveforms and Total Harmonic Distortion (THD) are shown in Fig. 5 and 6.

The total harmonic distortion content is obtained with the instability voltage analysis with thyristor bridge rectifier based battery charging technique is 17.41%

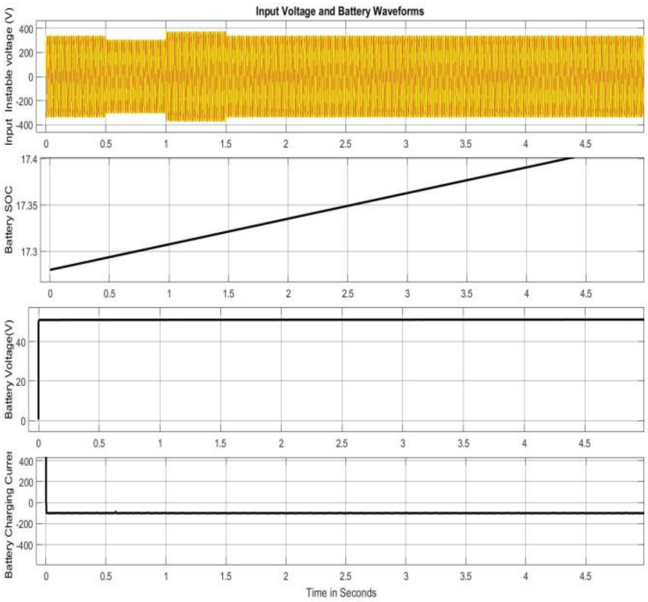

Fig.5 Input voltage and battery output

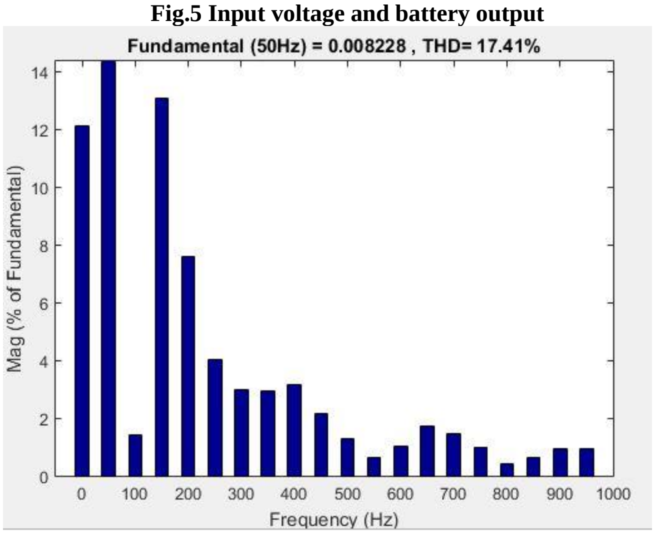

Fig.6 Total harmonic distortion of thyristor based rectifier battery charging technique

IV. ANALYSIS OF PWM BASED IGBT RECTIFIER BATTERY CHARGING TECHNIQUE

In this section the rectifier is operated with IGBTs to maintain the unity power factor and also from the above two rectifier topologies having some disadvantages like harmonic content, switching losses, unidirectional flow and stable supply to battery charging. In this topology the switches IGBT's are having advantages of bi-directional flow [9]. The diagram of 3-phase IGBT based PWM rectifier battery charging is shown in Fig.7.

The diode bridge rectifier based technique has disadvantages such as unidirectional flow and also the controllable voltage is not obtained stable.

By the thyristor based rectifier, the controllable output voltage can be obtained but the commutation problem is more in this technique. The thyristor are not having self commutation. For controlling the thyristor another commutation circuit is to be installed in the circuit, it makes circuit complexity and also more cost. To reduce all this disadvantages in this technique, the switches as IGBT's are used. It has self commutation property, bidirectional flow, unity power factor and less switching losses [10].

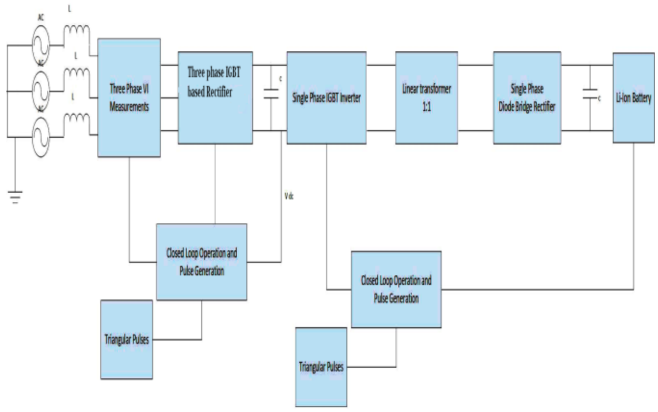

Fig.7 Block diagram of 3-phasel IGBT based rectifier battery charging

The three phase voltage fed to the IGBT based PWM rectifier [11], the rectified DC voltage is compared with the DC voltage constant of 800V and the error is connected to the PI controller. The controller output I_d is again compared with I_{drefd} obtained from the transformation techniques applied from the input three phase currents and the error is connected to PI controller. The controller output V_d. The I_q is compared with zero reference to maintain the power factor unity. The error is connected to the PI controller, the controller output V_q and the output V_d is transformed to abc by dq-abc transformation technique, refer (6) - (10).

$$V_a = V\alpha \quad (6)$$

$$V_b = (-V\alpha + \sqrt{3} * V\beta)/2 \quad (7)$$

$$V_c = (-V\alpha - \sqrt{3} * V\beta)/2 \quad (8)$$

$V\alpha$ and $V\beta$ are obtained from equations (9) and (10)

$$V\alpha = V_d * \cos(\theta) - V_q * \sin(\theta) \quad (9)$$

$$V\beta = V_q * \cos(\theta) + V_d * \sin(\theta) \quad (10)$$

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The three phase voltage, V_{abc} is compare to the carrier wave frequency of 20 KHz the respective pulses are fed to triggering the switches in such a way that follows the input voltage and current in a closed loop operation by using a Phase Locked Loop (PLL). The rectified output voltage is fed to IGBT based inverter and also the closed loop operation same as like diode bridge rectifier. By the thyristor based rectifier battery charging technique the THD is improved and the power factor gets improved with stability analysis also.

The rectified output is connected to the single phase IGBT based PWM inverter. The inverter output is fed to a linear transformer 1:1. The output of the transformer is acts as input to the single phase diode bridge rectifier, the rectified single phase DC output is filtered with a capacitive filter and fed to charge a battery. In closed loop operation, the battery current is compared with a constant of 100A and the error is connected to PI controller. The controller output voltage is compared with a repeating sequence with a carrier frequency of 20 KHz and the respective pulse are generated and fed to the respective IGBT's switches of the single phase inverter [12].

The Simulink model of three phase PWM based IGBT rectifier battery charging is carried out and the simulated results for instability input voltage and battery outputs are shown in Fig.8 and Total Harmonic Distortion (THD) are shown in Fig.9 respectively.

The analysis is also done with instability test of the input voltage with a variation of (0-0.5) seconds normal input voltage, (0.5-1) seconds the voltage of 10% less of normal voltage and again (1-1.5) seconds 10% more of normal voltage.

The total harmonic distortion content is obtained with the instability voltage analysis with PWM based IGBT rectifier based battery charging technique is 2.37%

The IGBT based PWM rectifier gives the less THD content and also the better performance on comparing with the above two techniques.

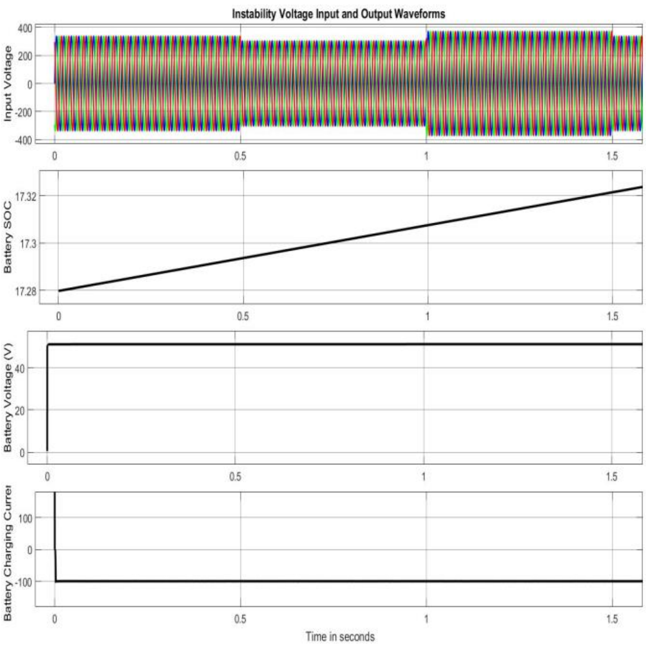

Fig.8 Input voltage and battery output

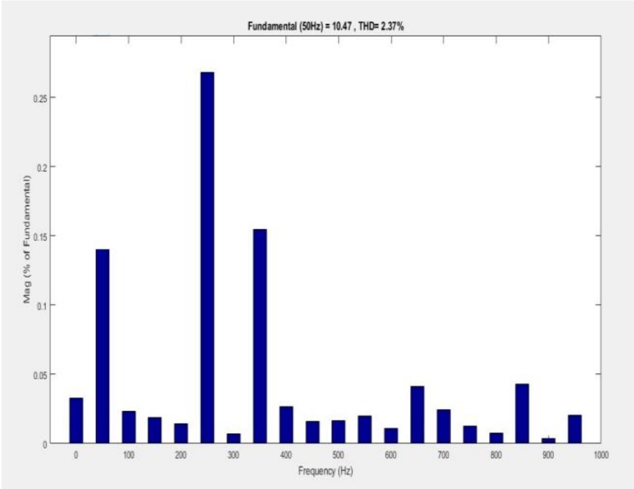

Fig.9 Total harmonic distortion of rectifier

V. RESULTS AND CONCLUSION

The results of THD for diode bridge rectifier, thyristor based rectifier and IGBT based rectifier battery charging circuits with instability test are listed in Table.I. By the following results, concluded that the IGBT based PWM rectifier battery charging topology yields effective outcome in terms of THD compared to the other two techniques. By this comparative analysis with respect to THD analysis concludes the IGBT rectifier is having very less THD on comparing with Diode Bridge rectifier and Thyristor Bridge Rectifier based Battery Charging Technique.

TABLE.I THD REPORT (%)

Topology	THD
Diode Bridge rectifier	28.50
Thyristor based rectifier	17.41
IGBT based PWM rectifier	2.37

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