



# A DIGITAL DRIVER FOR THYRISTOR BASED EMERGENCY BATTERY CHARGER FOR IMPROVED RELIABILITY FOR RAILWAYS

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## ABSTRACT

The Indian Railways has always been attempting to make rail journey more pleasant and comfortable. Integral Coach Factory (ICF) is the conventional railway bogies, now being replaced by Linke-Hofmann-Busch(LHB) Rail Coach Factory(RCF) bogies . The RCF coaches have advanced-pneumatic disc brake system, modular interior with better ac, fans and lighting systems powered by main (IGBT) based battery charger. In case of the failure of the main battery charger, the thyristor based emergency battery charger connected in parallel to the main battery charger supplies the load as well as charge the battery in the Parallel Standby Mode. The conventional thyristor based emergency battery chargers used in the LHB coaches are equipped with the analog controller to obtain a regulated dc output to charge the valve regulated lead acid (VRLA) battery in the constant voltage mode (CVM). The paper presents the design and implementation of the digital driver for thyristor based emergency battery charger for improved power reliability in railway coaches. The circuit simulation is carried out in the MATLAB software .The DSP processor is programmed using the code composer studio to generate the required pulses to trigger the thyristor. The prototype hardware model is also tested.

**Keywords:** Coaches , Passive filter , Railways, , Semi - controlled converter,. Transformer.

## I. INTRODUCTION

The rapid technological advancement across the globe has led to the 'Digital Revolution'. The mechanical and analog electronic technologies are growing obsolete. The DSP processors are now the substitute for the analog circuits. Unlike the analog circuits, the DSP processor is more reliable, faster and consumes comparatively lesser power.

The Indian Railways is also replacing its conventional ICF coaches with the new LHB RCF coaches equipped with technologies using DSP processor for air conditioning and lighting .The LHB coaches are classified into three main categories Self Generating (SG), Head-on-Generation (HOG) and End-on-Generation (EOG) coaches based on the existing overhead power supplies to provide illumination, fans, air-conditioning and other miscellaneous need during journey of the travelling passengers.

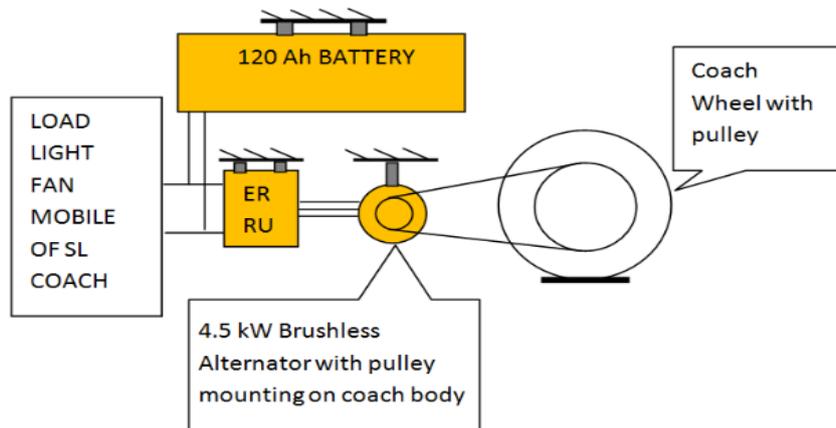
The express trains providing high speed and ambience to its passengers like Rajdhani, Shatabdi, Duronto and Gareeb-Rath has EOG LHB coaches. Since they are the highly expensive superfast trains, all possible provisions are made to prevent any discomfort to its passengers. Thus such coaches have thyristor based emergency battery chargers installed as the backup chargers, supplying power to the load and charging the battery when the main (IGBT) based battery charger fails to operate.

The digital firing driver circuit for faster and more reliable operation must replace the analog firing circuit for the thyristors in emergency battery chargers.

**II. METHODOLOGY**

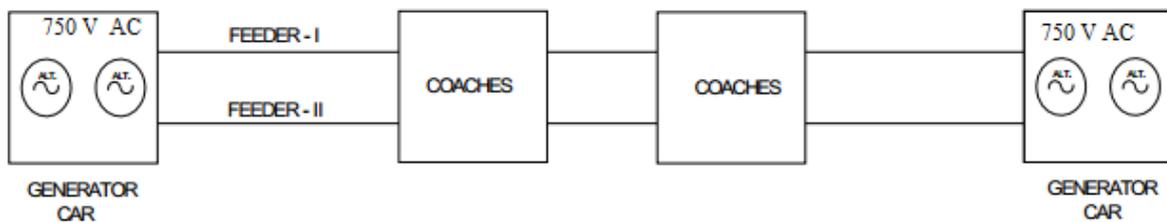
**A. Railway Coaches**

The conventional LHB coaches were either Self Generating (SG) coaches or Head-on-Generation(HOG) coaches. The SG coach is shown in Fig 1. The SG coach has a pulley-belt arrangement used to couple the alternator with the coach.



**Fig.1 LHB SG coach**

In the HOG coach, the power is tapped from the locomotive and is fed to the train through inter coach coupler. But the EOG coach as shown in Fig.2 is replacing the conventional SG and HOG coaches.

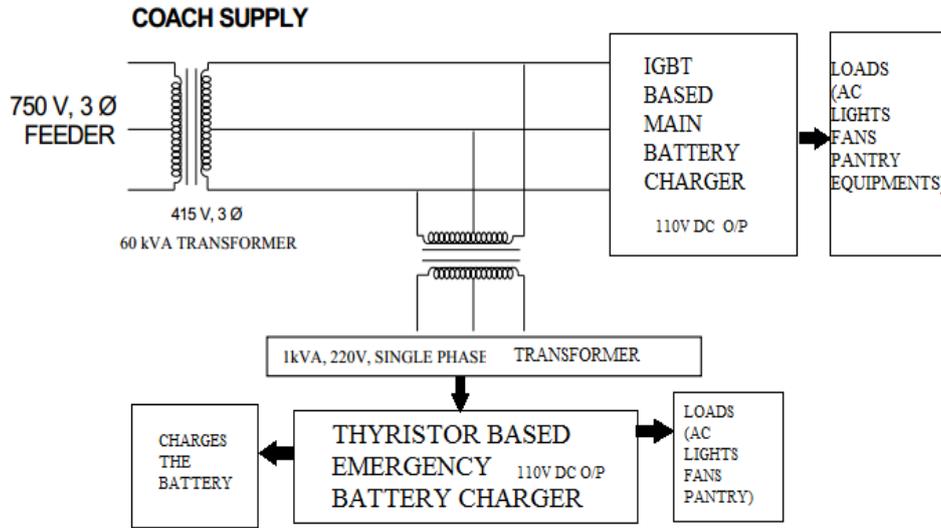


**Fig.2 EOG coach**

It is equipped with two power cars(Diesel-Generator) one at each end supplying a 3Φ , 50Hz ,750V AC to all the coaches two parallel inter-vehicle coupler.

In the LHB EOG coach, 750V is stepped down to 415 V AC and supplied as an input to 3 Φ IGBT based battery charger(main charger) that supplies the load.

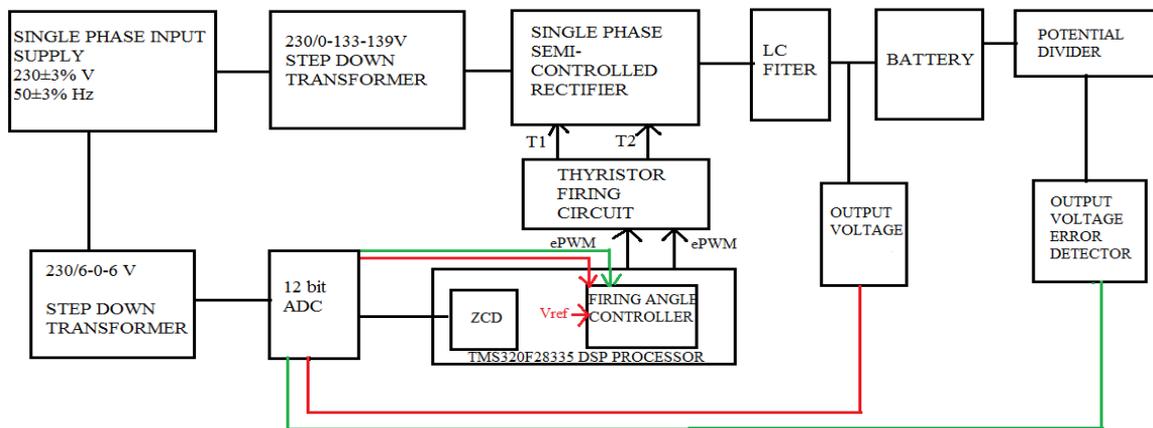
The coach also has 1Φ, 50Hz, 230V AC being fed as input to the emergency battery charger as shown in Fig. 3.



**Fig. 3 Power supply in a LHB EOG coach**

**B. Digital driver based thyristor controlled emergency battery charger topology**

The block diagram of the thyristor based emergency battery charger using DSP controller is shown in Fig.4. The 1 $\Phi$ , 230V, 50Hz supply is fed to the 230/133 V transformers. The 133 V AC input to semi-controlled converter is rectified to obtain a 110 V DC. The DSP processor is programmed using CCStudio to obtain required duration gate pulse



**Fig.4 Block diagram of thyristor based emergency battery charger**

A TI device AMC1100EVM is used to sense the output voltage and provide voltage feedback to the DSP controller. The passive LC filter at the output reduces the ripple content in the output voltage and the output current.

**III. OBJECTIVES**

The major objectives of the presented work are as listed:

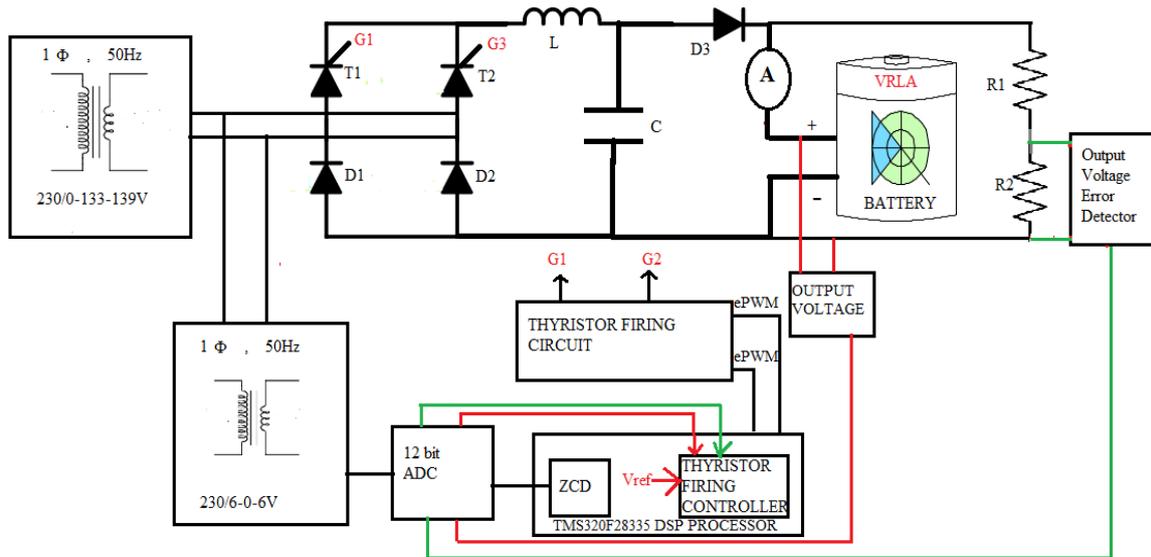
- To design a 2.5KW, 110V,70AH Thyristor Based Emergency Battery Charger for railway application
- To obtain a regulated output of 110V DC with output regulation  $\leq 2.5\%$

- To obtain an overall system efficiency  $\geq 80\%$
- To supply the load and charge the primary battery in the case of failure of the main battery.

#### IV. COMPONENTS SELECTION

The various components of the thyristor controlled emergency battery charger are chosen to fulfill all the stated objectives. The circuit diagram is shown in Fig.5.

The valve regulated lead acid battery (VRLA) battery is charged in the constant voltage mode.



**Fig.5 Components of thyristor controlled emergency battery charger**

The selection process of the various blocks that has been incorporated in the thyristor controlled emergency is as:

- **Transformer**

A rectified output of 110V is required. Considering the voltage drops across the diode, thyristor, inductor resistance and electrostatic resistance (ESR) in capacitor, a 230/0-133-139V centre tap transformer is selected. The double winding transformer has EI core.

- **Rectifier bridge**

A thyristor–diode bridge module SKKH 57/16E is used. The thyristor has 150 mA holding current ( $I_H$ ) 300mA latching current ( $I_L$ ). The minimum gate to cathode voltage ( $V_{AK}$ ) for turning on the thyristor is 3V.

- **Passive filters**

The capacitor and inductor is selected to minimize the ripple content in the output voltage and the output current.

- **Capacitor**

A 4700µF, 350V DC, Large Can Electrolytic Aluminium Capacitor is used to minimize the ripple content in the output voltage.

• **f. Inductor**

A 18mH allowing maximum permission current of 30A is used. It is of Type 43 with single core EI laminations. The ripple content in the output after using the LC filter circuit is calculated using equation -

Ripple factor (RF) =

$$\frac{1}{6 \cdot \sqrt{2} \cdot W^2 \cdot L \cdot C} \cdot 100$$

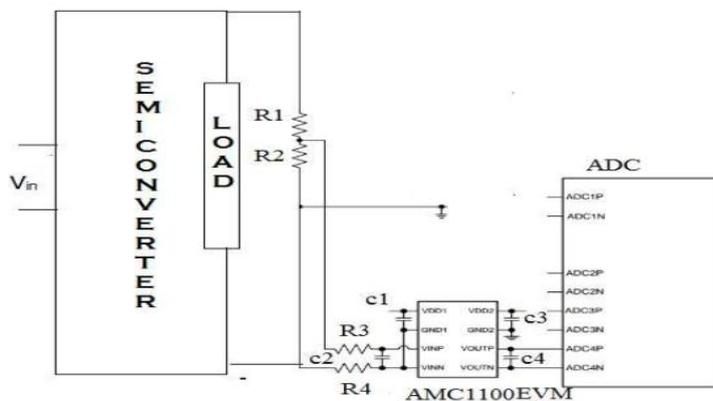
$$RF = 1.411 \% \leq 2.5\%$$

• **Output Voltage Error Detector**

R1 and R2 at the output forms the potential divider circuit. The resistance values are selected as 45.3kΩ and 100Ω respectively.

The voltage across R1 is 109.75V and that across R2=0.24V if an output of 110V is obtained.

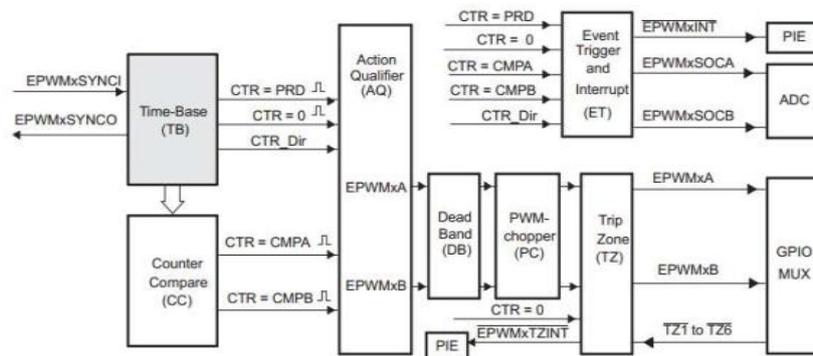
The voltage across R2 (V<sub>R2</sub>) vary in the range of 0.25V to 3.3 V as the output varies between 106V to 112V due to fluctuations in the AC supply. The voltage V<sub>R2</sub> is fed to AMC1100EVM, a TI device generating the error voltage in the output and feeding it as input to the ADC as shown in Fig.6.



**Fig.6 AMC1100EVM detecting the error in output voltage**

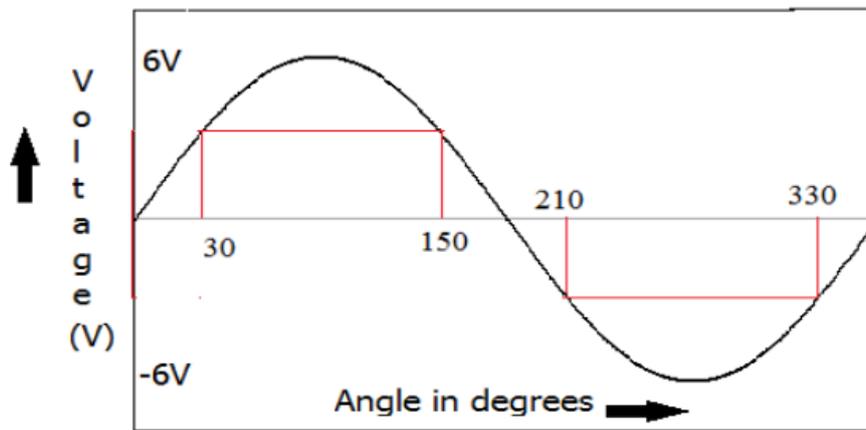
• **DSP Processor**

TMS320F28335 processor is used to generate the required gate pulses to fire the thyristor. The block diagram is shown in Fig. 7.

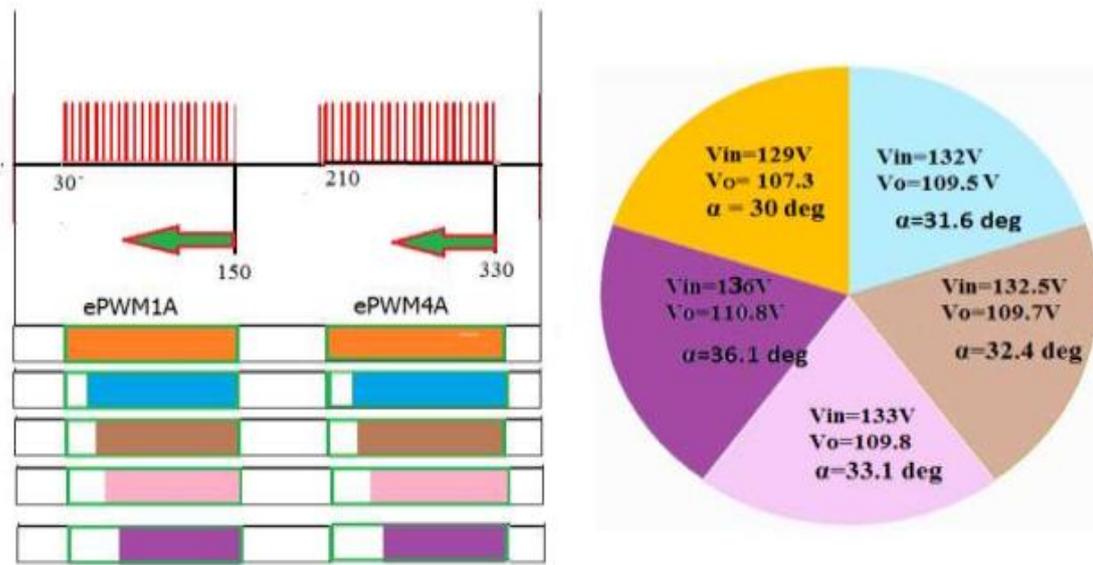


**Fig.7 Block diagram of TMS3220F28335**

The phase angle control logic is implemented as shown in Fig.8. The thyristor firing angle gets adjusted based on the error voltage input to the ADC. The slave ePWM signals ePWM1A and ePWM4A corresponds to the firing angle of thyristor T1 and T2 respectively where as ePWM6A is the master ePWM controlling the generation of ePWM1A during the positive half cycle and generation of ePWM4A during the negative half cycle.



(a)

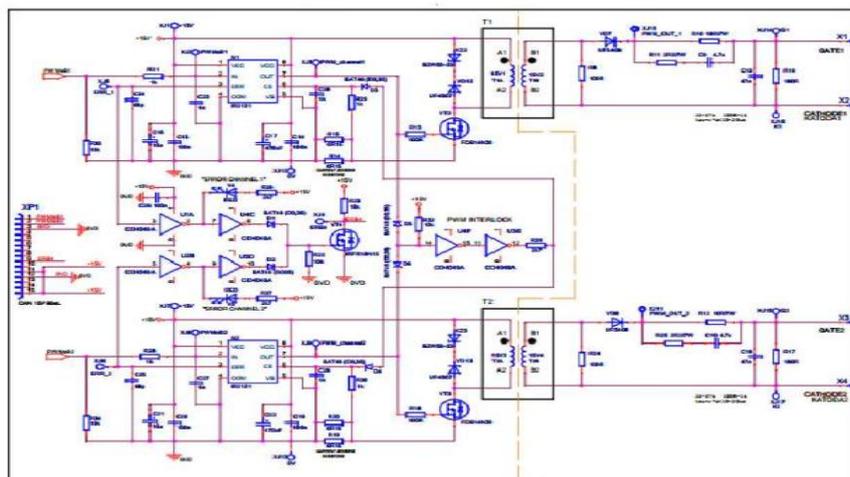


(b)

**Fig.8 Thyristor Firing Logic (a)Dead Band Generation (b) Firing angle adjustment**

### • Firing Control Circuit

The ePWM1A and ePWM4A is fed to the firing and control circuit shown in Fig 9. The IR2121 IC limits the inrush of huge current and shuts down the circuit in case of any fault detection. The high switching frequency MOSFET is synchronised with the ePWM pulses. A transient voltage suppressor diode BZW50-33 and a fast recovery diode UF4007 is used on the transformer primary for preventing the voltage from exceeding 15V .



**Fig. 9 Thyristor firing circuit**

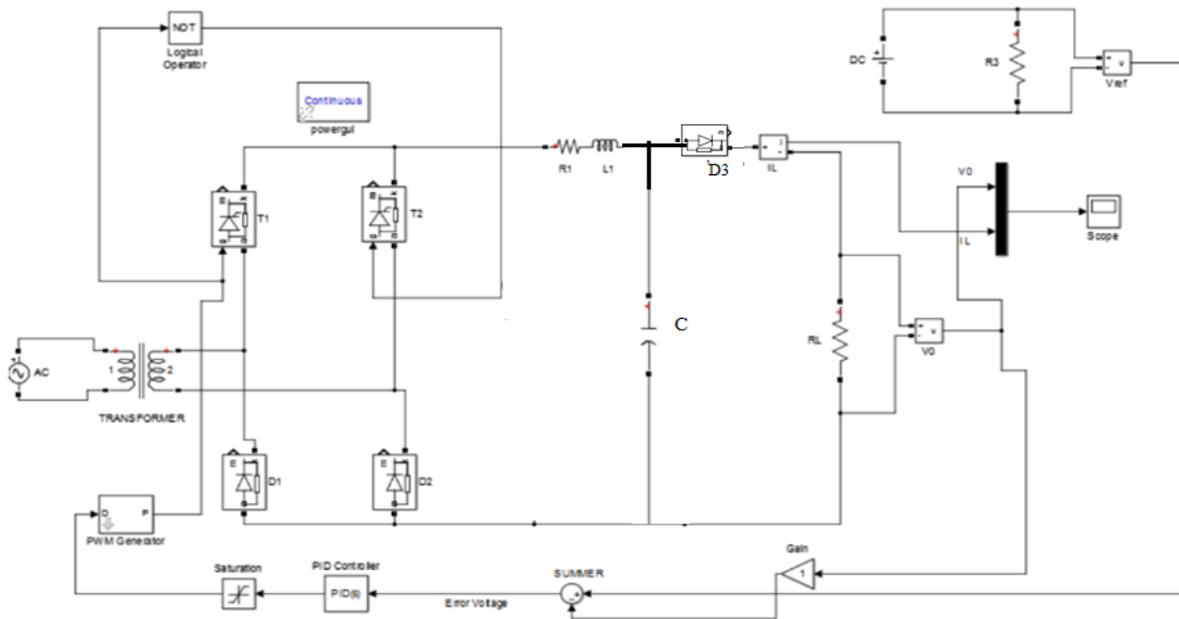
The secondary of 1:1 ,15V isolation transformer is fed to the gate and the cathode of the thyristor .

### • Battery

The thyristor controlled emergency battery charger is used to charge nine 12V valve regulated lead acid (VRLA) batteries connected in series.

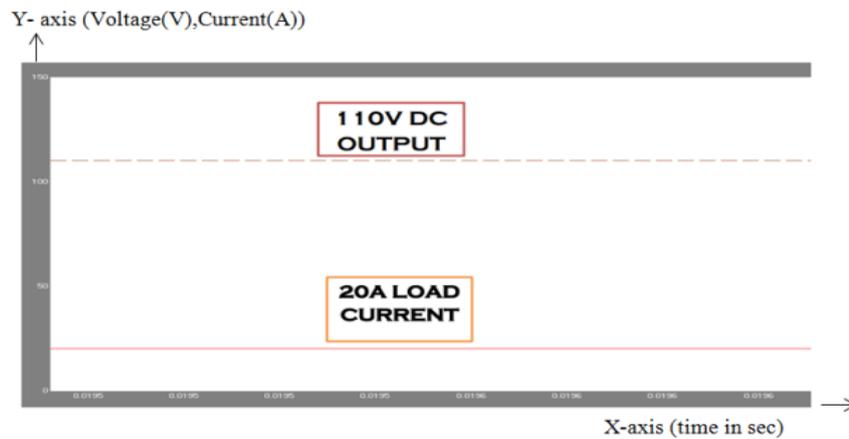
**V. SIMULATION**

The simulation is carried out on MATLAB R2013a version software and the results are observed for three different cases. The simulation circuit is shown in Fig. 10



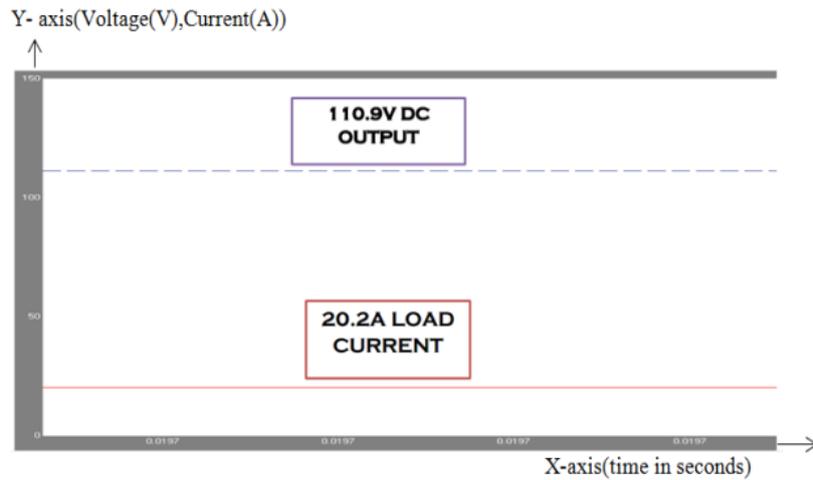
**Fig.10 Simulation Circuit**

**Case1.** AC input to the transformer is 230V. The DC voltage and current output is shown in Fig.11.



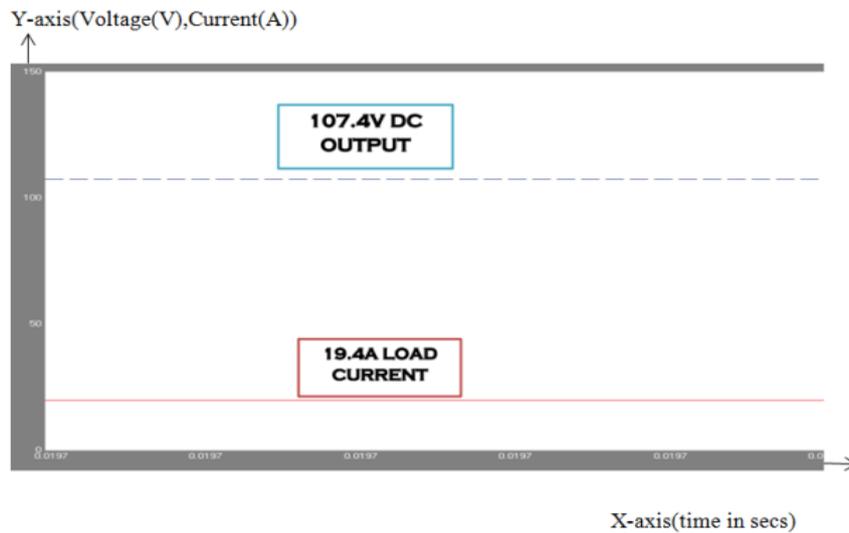
**Fig.11 Output V and I for Vin=230V**

**Case2.** AC input to the transformer is 236.9V. The DC voltage and current output is shown in Fig.12.



**Fig.12 Output V and I for  $V_{in}=236.9\text{ V}$**

**Case3.** AC input to the transformer is 223.1V. The DC voltage and current output is shown in Fig.13 .



**Fig.13 Output V and I for  $V_{in}=223.1\text{ V}$**

The simulation results are also tabulated in Table1.

**Table1.Simulation Results**

$V_{in}(\text{rms})$ (V)	$V_o(\text{dc})$ (V)	$I_o(\text{dc})$ (V)	$P_o$ (W)	Losses (W)	$\eta$ (%)
230	110	20.0	2200.00	300.00	88.00
236.9	110.9	20.2	2240.18	259.82	89.60
223.1	107.3	20.4	2190.96	309.04	87.60

Thus ,the simulation results ensure proper selection of the various components as efficiency  $>80\%$  and regulation  $<2.5\%$  is achieved for input varying in the range  $230\pm 3\%$  V. The efficiency can further be increased by adopting ways to minimize the losses.

## VI. HARDWARE IMPLEMENTATION

Considering all the safety precautions , the hardware circuit is set up as shown in Fig.14 .



**Fig. 14 Hardware set up of the battery charger**

The labels in Fig. 14 are as follows-

A - 230V AC input

B- Auto-transformer (0-230 V AC)

C-Step down transformer (230/6-0-6 V )

D-Regulated dc power supply(+12V,ground,-12V)

E-Analog to digital converter and TMS320F28335 dsp processor

F-Dual firing circuit for the thyristors

G- Semikron SKTH 56/16E thyristor - diode bridge

H-18mH inductor

I -4700uF capacitor

J- Current measuring device clamp meter

K -Multimeter

L,M-Cathode Ray Oscilloscope(CRO)

N- TI Device AMC1100EVM ,a precision isolation amplifier for error detection

O-Load (5.5Ω)

The input voltage is varied and the variation in the firing angle ,the output voltage is observed as shown in Fig.15.

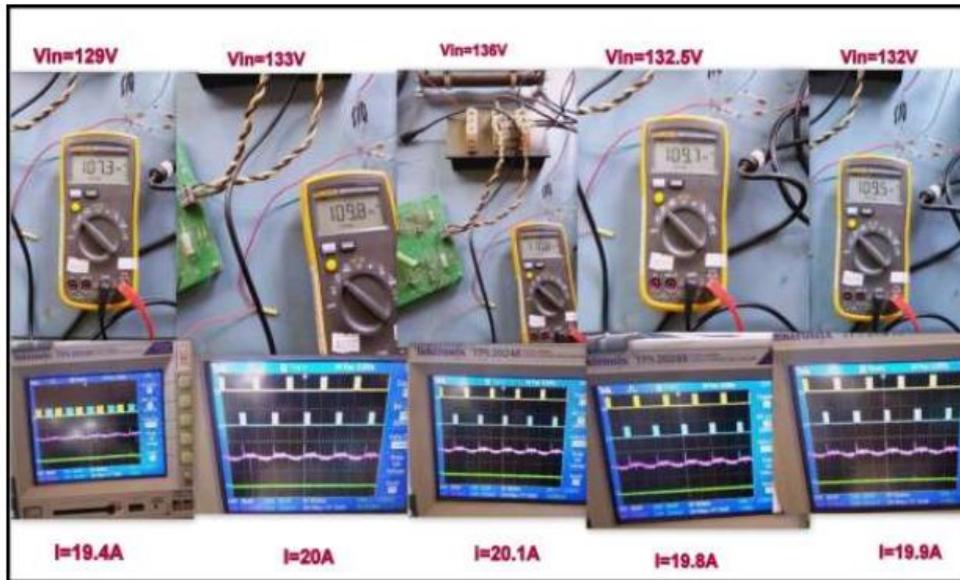


Fig.15 Gate firing pulse and dc output voltage

The hardware results showing the efficiency and regulation of the thyristor based emergency battery charger is tabulated in Table 2 and Table 3 respectively.

Table 2. Output V,I and efficiency

V <sub>in</sub> (V)	$\alpha$ (deg)	V <sub>o</sub> (V)	I <sub>o</sub> (A)	P <sub>o</sub> (W)	Loss (W)	% $\eta$
133.0	33.23	109.8	19.8	2174.04	425.96	83.36
132.5	32.68	109.7	19.7	2161.09	438.91	83.11
132.0	32.30	109.5	19.9	2179.05	420.95	83.80
136.0	35.66	110.8	20.1	2227.08	372.92	85.66
129.0	31.76	107.3	19.4	2081.62	518.38	80.06

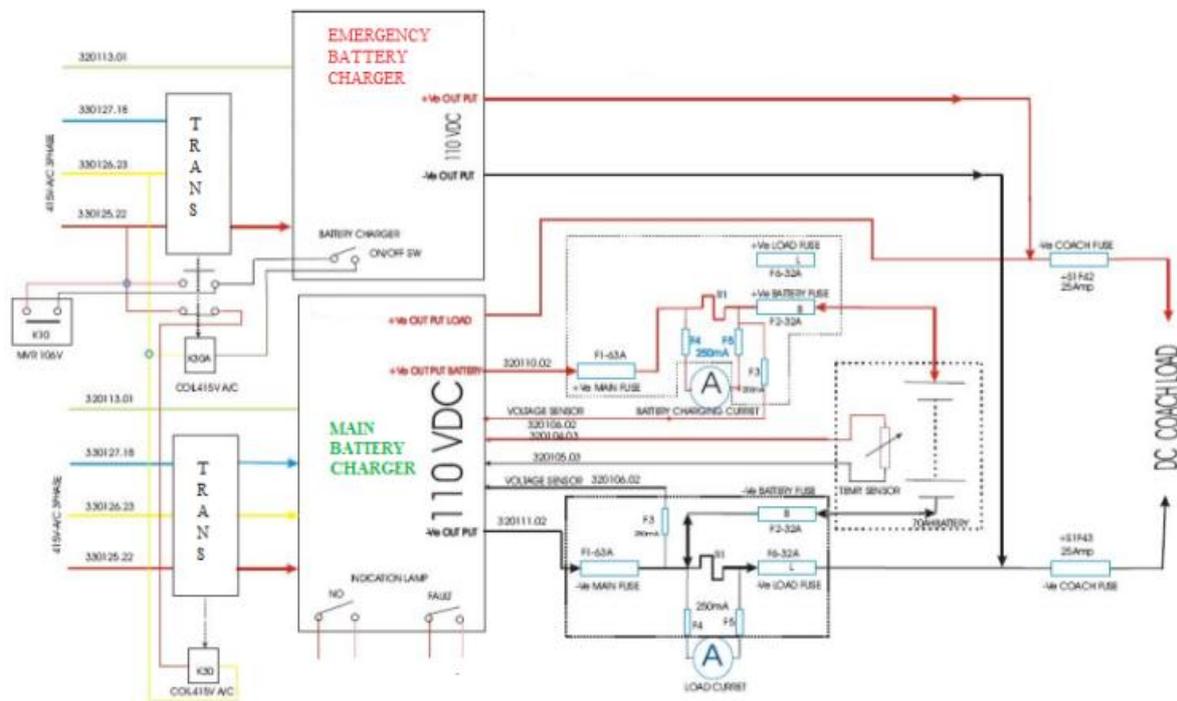
Table 3. Output V,I and regulation

$V_{in}$ (V)	$V_{NL}$ (V)	$V_{FL}$ (V)	$I_o$ (A)	%Voltage Regulation
133.0	111.1	109.8	19.8	1.18
132.5	111.7	109.7	19.7	1.80
132.0	111.3	109.5	19.9	1.64
136.0	113.4	110.8	20.1	2.34
129.0	109.4	107.3	19.4	1.95

The output result shows that the efficiency greater than 80% is achieved with voltage regulation lesser than 2.5%.

## VII. CONCLUSION

The emergency battery charger is connected in parallel to the main based battery charger as shown in the Fig.16. The DSP controlled firing circuits is more efficient, accurate and reliable compared to the analog firing circuit based battery charger used in the conventional bogies of trains.



**Fig .16 Thyristor based emergency battery charger in parallel with the main battery charger**

The DSP controller based battery charger consume lesser power and losses are also minimised to a greater extent .



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