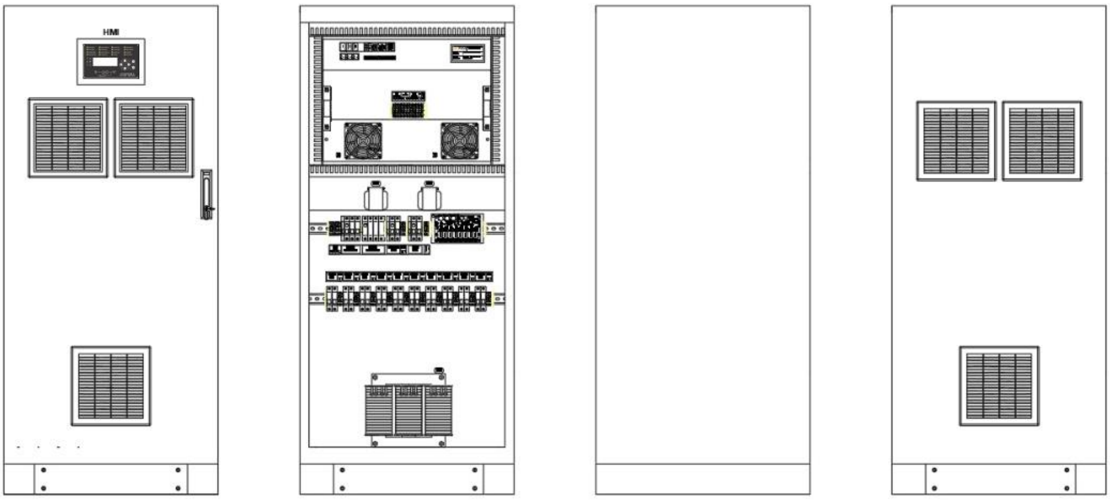
PESS

Power Electronic System Solutions

WHITE PAPER FOR RBC-12 BBC 12P 380VAC / 110VDC/ 30A INDUSTRIAL BATTERY CHARGER

REV-0722



380AC/110VDC/30A

3 PHASE BATTERY CHARGER DESIGN GUIDE

USING RBCM_12_BBC RECTIFIER POWER MODULE

WITH BUCK-BOOST CONVERTER

JULY 2022

AIM & SCOPE:

Main purpose of this paper is to be guide for battery charger producers to design a good quality three-phase industrial type battery charger product. This paper explains; how to design an example three-phase 12 pulse thyristor-switched galvanically-isolated battery charger rectifier with buck boost converter how to do wiring selections, MCB or MCCB selections, transformer and inductor design parameters, filter capacitor selections, cabinet selections and IP standards, how to use PESS power control modules, how to test battery charger products with technical specifications.

CONTENTS:

1. TRANSFORMER DESIGN GUIDE & EXAMPLE DESIGN

In this section we will explain to how you can the design a good quality three-phase 12 pulse rectifier transformer and calculations.

12 pulse transformers have a special structure because of its nature. It has 1 primary and 2 secondary windings. Figure 1.0 shows the physical structure of the 12 pulse transformer.

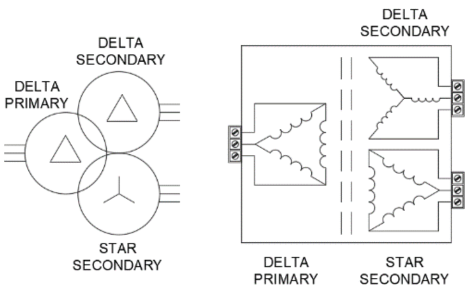


Figure 1.0. 12 pulse transformer structure.

1.1. Calculation of power transformer turn ratio

A three-phase rectifier output voltage versus input ac voltage can be define as eq.1.1;

$$V_{dc} = \frac{3\times V_{max}}{\pi} = \frac{3\sqrt{2}\times V_{rms(ac)}}{\pi} \qquad (1.1)$$

Because there is a step-down input isolation transformer at the input of rectifier, secondary voltage of transformer can be calculated as eq.1.2;

$$V_{rms(sec.)} = V_{dc<max>} \times \frac{\pi}{3\sqrt{2}} = 0.75 \times V_{dc} \qquad (1.2)$$

This voltage should be minimum secondary voltage at maximum allowable output voltage. A 110VDC battery charger has 122Vdc float and 128 Vdc boost voltage, sometimes this voltage can be 140Vdc. Thus, minimum secondary voltage of transformer should be in eq.1.3, and nominal secondary voltage should be in eq.1.4, and turn ratio is in eq.1.5.

$$V_{rms(sec.)(min.)} = 0.75 \times V_{dc} = 0.75 \times 140 = 105V_{ac} \qquad (1.3)$$

$$V_{rms(sec.)(nom.)} = 1.15 \times V_{rms(sec.)(min.)} = 1.15 \times 106 = 121V_{ac} \qquad (1.4),$$

if we consider 1 or 2 volts drop on the system, 122VAC is suitable for secondary voltage.

$$\frac{V_p}{V_s} = \frac{380}{122} = 3.11$$

(1.5)

1.2. Transformer design parameters

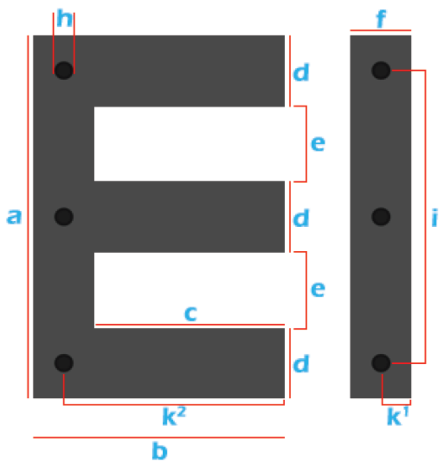
To produce a good quality three-phase , twelve pulse 380VAC/110VDC/30A battery charger, input isolation transformer of charger should be designed as follows. Table 1.1 shows the transformer design parameters, primary and secondary wiring details. Table 1.2 shows the core material details of transformer packet.

	Primary	Secondary	Secondary
	Delta (Δ)	Delta (Δ)	Star (Y)
Base Voltage	380V (Ph-Ph)	122V (Ph-Ph)	122V (Ph-Ph)
Power	6 KVA	3 KVA	3 KVA
Wire Area (cross section)	3.14 mm^2 (Ø=2.0 mm)	4.52 mm^2 (Ø=2.4 mm)	8.03 mm^2 (Ø=3.2 mm)
Wire Type	Aluminum Enamel	Aluminum Enamel	Aluminum Enamel
Turn	250 turns	81 turns	47 turns

Table 1.1. Transformer Primary & Secondary Parameters

Material	iron core
Type	EI250*250
B(max)	10000 gauss (1 Tesla)
Ae	50 mm×120 mm (d) x (thickness)
Dimensions (EI350 packet)	250 mm×250 mm×120 mm (a) x (b+f) x (thickness)

Table 1.2. Transformer packet details, materials, dimensions.



TRIFAZE EI Teknik Özellikleri

	a	b	c	d	e	f	h	i	k1	k2	kg/1000 0.5mm
EI 250x250	250	200	150	50	50	50	11	200	25	175	183

Figure 1.1. EI250 core datasheet details (All dimensions are *in millimeters)

Figure 1.1 shows the EI250 core material details.

1) One piece of this EI250 material is 183 gram and 0,5 mm thickness.
2) To get 120 mm thickness for transformer, it should be used 240 pieces.
3) To get good performance with transformer, it should be used, primary winding is outer, secondary wiring is inner, like as Figure 1.2.

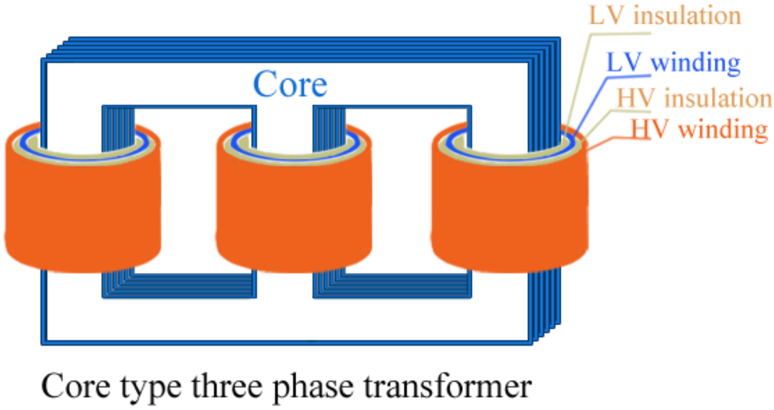


Figure 1.2. Three phase transformer winding details.

2. LC FILTER DESIGN GUIDE & EXAMPLE DESIGN

Output LC filter is necessary to achieve good ripple factor (RF) at the rectifier output. Capacitor should be selected as 20mF (2 x 10.000UF/200V), and inductor value should be higher than 4mH to achieve ripple factor less than 1 percent. To make ripple factor lower than 1 percent is important for batteries. If ripple factor is bigger than 1 percent, batteries could see high ripple current and they may be fail.

2.1. Inductor design parameters

There is a output filter inductor as mention at above and this inductors should be identical. Following tables shows the inductor design parameters and wiring details. Table 2.2 shows the core material details of inductor packet.

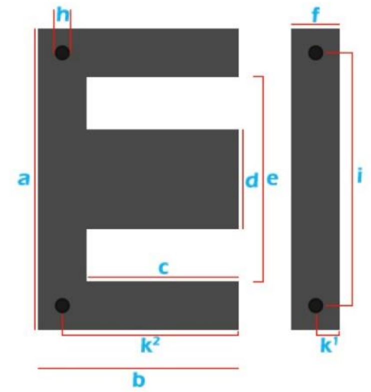
Inductor Value	5 mH
Current	20A
Wire Area (cross section)	12.56mm^2 (Ø=4.0 mm)
Wire type	Aluminium Enamel
Turn	43 turns
Air gap	6 mm

Table 2.1. Output filter inductor & wiring parameters

,

Material	iron core
Type	EI133.2
B(max)	10000 gauss (1 Tesla)
Ae	44 mm×50 mm (d)x(thickness)
Core Dimensions (EI133 packet)	133.2mm×117 mm×50 mm a x (b+gap+f) x (thickness)

Table 2.2. Inductor packet details, materials, dimensions.



MONOFAZE EI Teknik Özellikleri

	a	b	c	d	e	f	h	i	k1	k2	kg/1000 0.5mm
EI 133.2	133.2	88.8	66.6	44.4	88.8	22.2	7	111	11.1	77.7	45,4

Figure 2.1. EI133.2 core datasheet details (All dimensions are *in millimeters)

Figure 2.1 shows the EI133.2 core material details.

1) One piece of this material (EI133.2) is 45.4 gram and 0,5 mm thickness.
2) To get 50 mm thickness for inductor, it should be used 100 pieces.
3) To get good performance with inductor, it should be used, with air gap like as Figure 2.2.

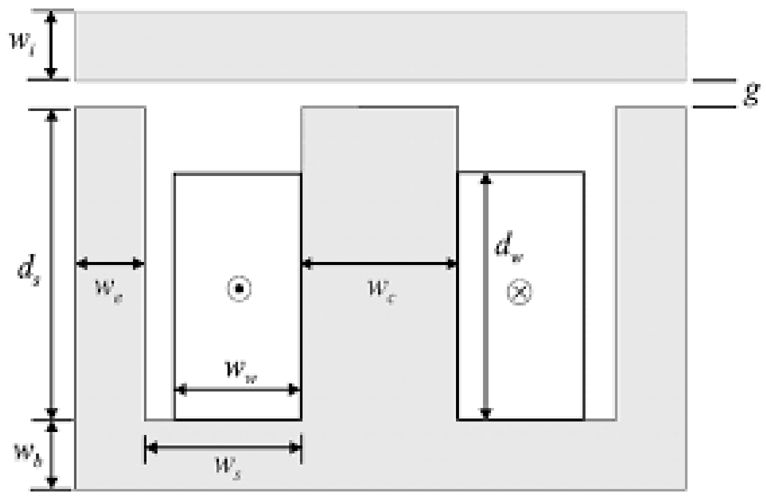


Figure 2.2. Output filter inductor winding and gap details for EI lamination.

3. MCB/MCCB/CABLE SELECTION GUIDE & EXAMPLE

MCB, MCCB and Wiring cables of rectifier should be selected properly to get secure performance. Example selection of 380AC/110VDC/30A charger can be seen the below in Table 3.1.

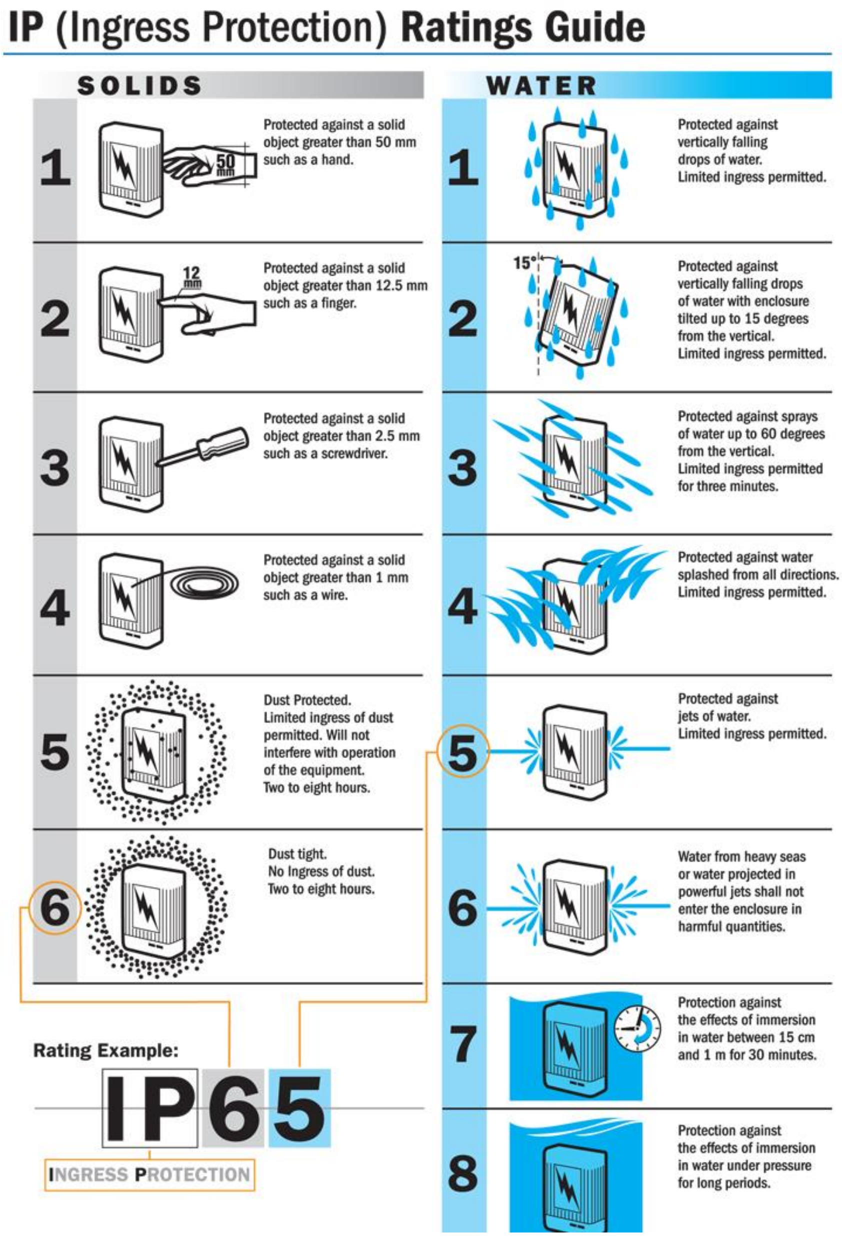
	AC side			**DC side**		
	Primer 380 VAC	**DELTA 133 VAC**	**STAR 133 VAC**	**Inductor Capacitor**	**Battery Output**	**Load Output**
POWER CABLES (NYAF COPPER)	6 mm^2	6 mm^2	6 mm^2	10 mm^2	10 mm^2	10 mm^2
MCB	3×16A		-	-	2×32A	2×32A

*All electronic cables (feedback, measurement and control) should be 0,75 mm^2 NYAF-type.

Table 3.1. 380AC/110VDC/30A battery charger MCB and cable selection table.

4. CABINENT SELECTION GUIDE & IP STANDARTS

The IP Code (or Ingress Protection Rating, sometimes also interpreted as International Protection Rating) consists of the letters IP followed by two digits. First Numeral Protection against the ingress of solid particles and Second Numeral Protection against the harmful ingress of water



5. HOW TO USE PESS 12 PULSE RECTIFIER WITH BBC

The main advantage of PESS rectifier power module is to make easy to produce battery charger products for suppliers. PESS rectifier power module contains all necessary power electronic control equipment like PCB, thyristor blocks, heatsinks, fan, user panel, communication panel etc. Using PESS rectifier power module, any suppliers can produce their own battery charger cabinets. All necessary equipment except PESS rectifier power module could be assembled as offshore in supplier side, like cabinet, transformer, inductor, capacitor, power wirings, MCB etc. A PESS rectifier power module comes with user HMI front panel, Automation relay and communication board and two DC current sensor.

Figure 5.1. PESS RECTIFIER POWER CONTROL MODULE

5.1. Connections of PESS RECTIFIER WITH BUCK BOOST CONVERTER

PESS rectifier power module terminals consists of AC power inputs, DC power outputs to LC filter, AC voltage monitoring input from the primary of transformer, DC voltage feedback input from DC capacitors, two LEM DC current sensor input from the battery and load lines, digital inputs from MCB auxiliary contacts, thermistor input from battery room, 24VDC supply output for relay board and one more 24VDC supply output for extra cabinet fan.

Single-line diagrams (SLD), sample battery charger power wirings, module wirings can be seen from wiring documents that comes with power module. Basic diagram about power module and charger wiring can be seen in Figure 5.3 and Figure 5.4.

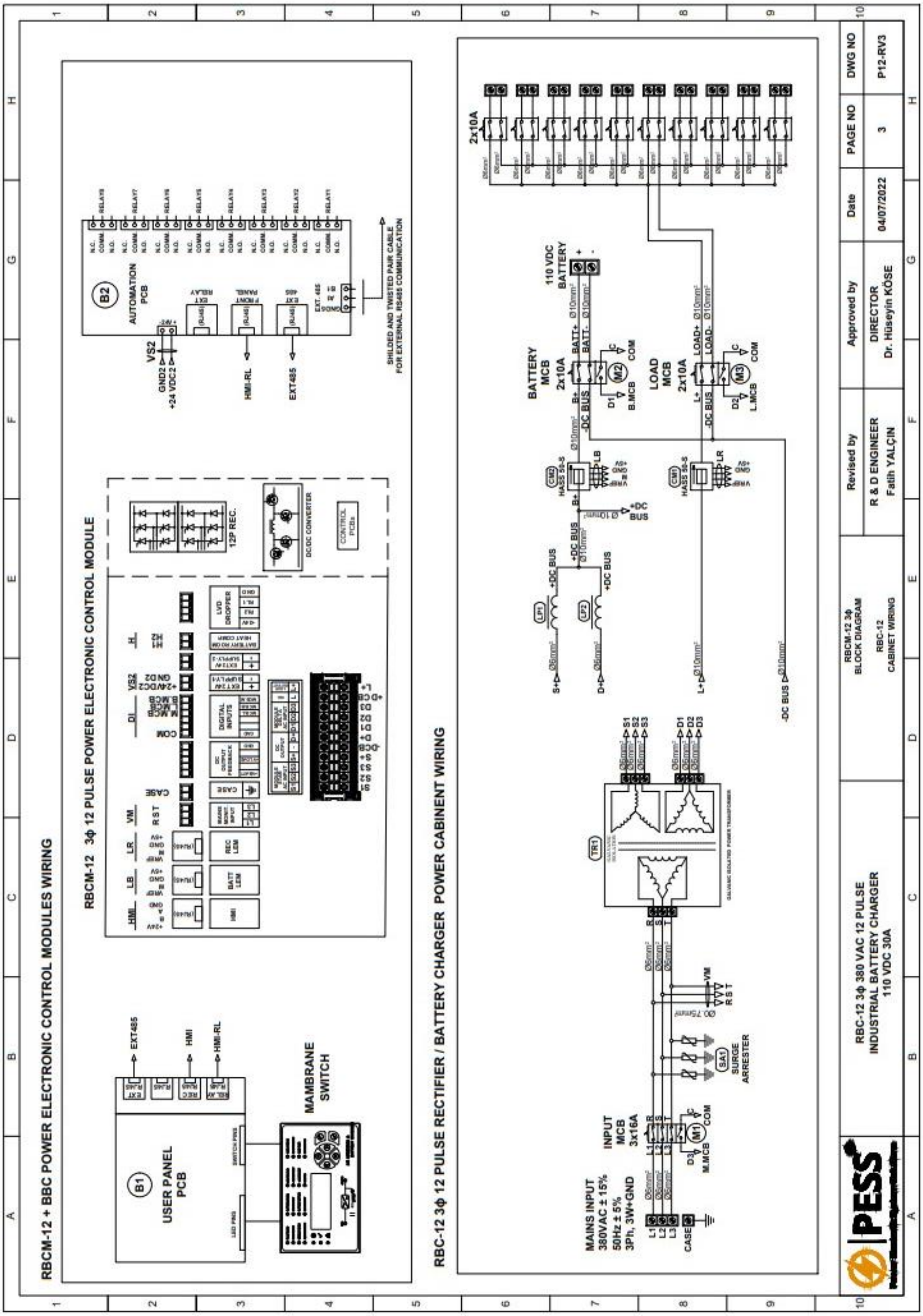

RBCM-12 + BBC POWER ELECTRONIC CONTROL MODULES WIRING
RBCM-12 3Φ 12 PULSE POWER ELECTRONIC CONTROL MODULE
RBC-12 3Φ 12 PULSE RECTIFIER / BATTERY CHARGER POWER CABINENT WIRING
USER PANEL PCB
MAMBRANE SWITCH
AUTOMATION PCB
SHILDED AND TWISTED PAIR CABLE FOR EXTERNAL RS485 COMMUNICATION
12P REC.
DC/DC CONVERTER
110 VDC BATTERY
BATTERY MCB 2x10A
LOAD MCB 2x10A
INPUT MCB 3x16A
SURGE ARRESTER
MAINS INPUT 380VAC ± 15% 50Hz ± 5% 3Ph, 3W+GND
2x10A
DWG NO
P12-RV3
PAGE NO
3
Date
04/07/2022
Approved by
DIRECTOR Dr. Hüseyin KÖSE
Revised by
R & D ENGINEER Fatih YALÇIN
RBCM-12 3Φ BLOCK DIAGRAM
RBC-12 CABINET WIRING
RBC-12 3Φ 380 VAC 12 PULSE INDUSTRIAL BATTERY CHARGER 110 VDC 30A

Figure 5.3.

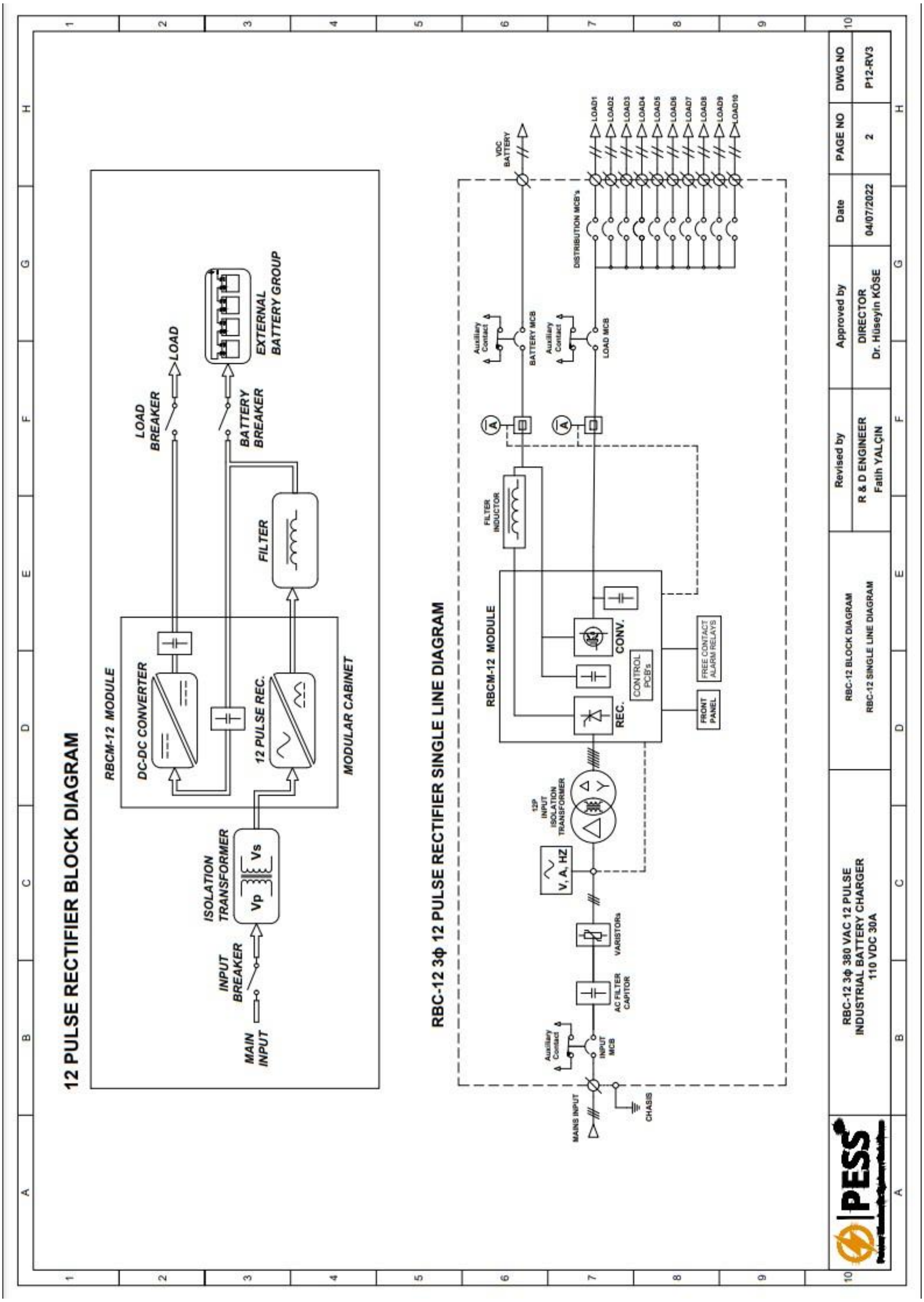

12 PULSE RECTIFIER BLOCK DIAGRAM
RBCM-12 MODULE
DC-DC CONVERTER
12 PULSE REC.
MODULAR CABINET
FILTER
LOAD BREAKER
LOAD
BATTERY BREAKER
EXTERNAL BATTERY GROUP
ISOLATION TRANSFORMER
Vp
Vs
INPUT BREAKER
MAIN INPUT
RBC-12 3ф 12 PULSE RECTIFIER SINGLE LINE DIAGRAM
RBCM-12 MODULE
REC.
CONV.
CONTROL PCB's
FRONT PANEL
FREE CONTACT ALARM RELAYS
FILTER INDUCTOR
BATTERY MCB
LOAD MCB
Auxiliary Contact
DISTRIBUTION MCB's
VDC BATTERY
LOAD1
LOAD2
LOAD3
LOAD4
LOAD5
LOAD6
LOAD7
LOAD8
LOAD9
LOAD10
12P INPUT ISOLATION TRANSFORMER
V, A, HZ
VARISTORs
AC FILTER CAPITOR
INPUT MCB
MAINS INPUT
CHASIS
RBC-12 3ф 380 VAC 12 PULSE INDUSTRIAL BATTERY CHARGER 110 VDC 30A
RBC-12 BLOCK DIAGRAM
RBC-12 SINGLE LINE DIAGRAM
Revised by
R & D ENGINEER
Fatih YALÇIN
Approved by
DIRECTOR
Dr. Hüseyin KÖSE
Date
04/07/2022
PAGE NO
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Figure 5.4

6. HOW TO TEST BATTERY CHARGER WITH PESS RECTIFIER MODULE

6.1. How to test Power Module

It is the most important procedure for producing battery charger product. PESS rectifier power modules come with user HMI panel, relay PCB and two LEM current sensors. All power modules are tested at factory.

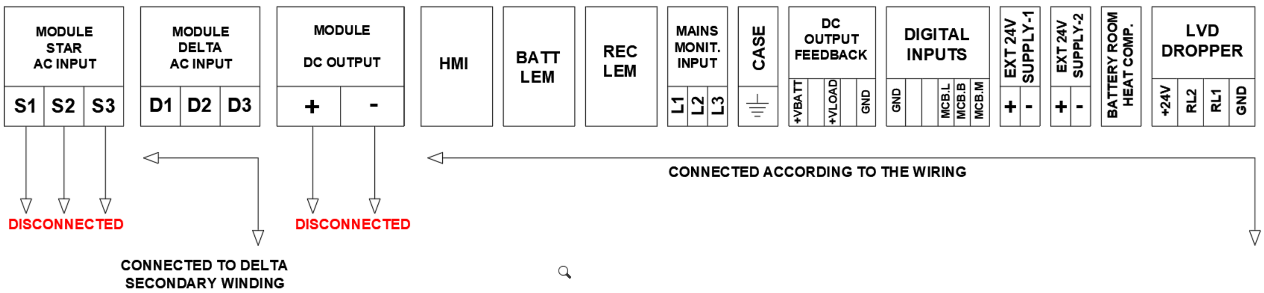
6.2. Transformer Synchronous Connection Check

Transformer output voltage should be checked before install. One of important part before the energize system, find out synchronous phases between transformer primary/secondary. Sometimes transformer manufacturers may be connect phase coils randomly. Please ensure that transformer phase order and connections is correct !

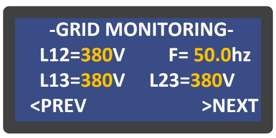
6.3. Test Steps

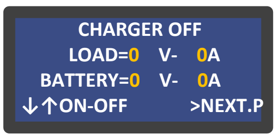
Check all the connection again according to wiring diagram!!!

Step 1: Disconnect DC output cables (+/-) from module.



Step 2: Energize system from input breaker and check input and output voltage and current values on HMI front Panel.



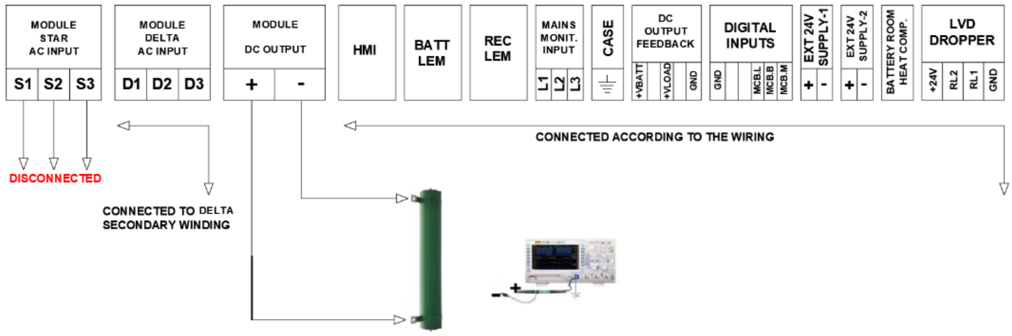


After you observe values shown above **Turn OFF input breaker**. (Any different situation for values you should check wiring and connections again).

Step 3: If there is any misconnection or wrong sequence to input, there may be a false working for thyristor triggering, so that there may be an explosion for output LC capacitors.

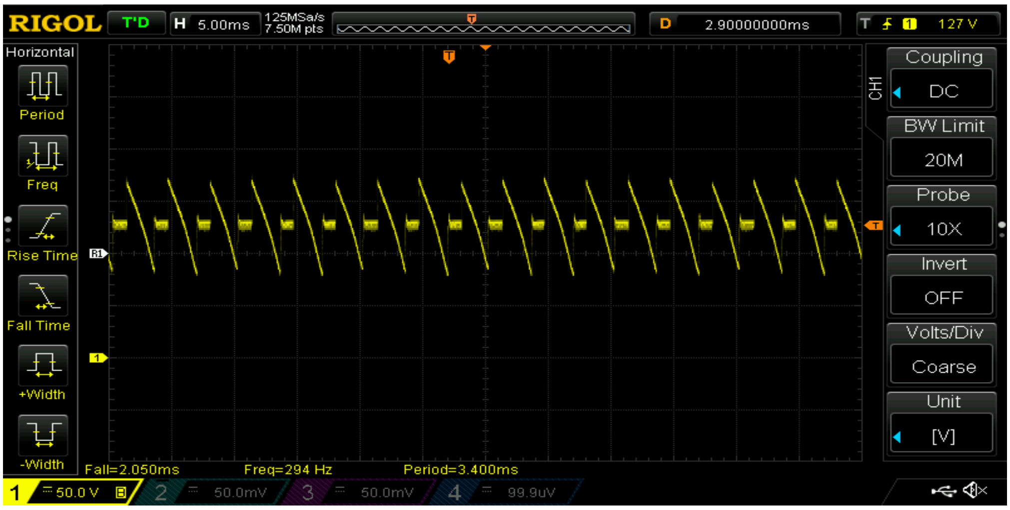
Because of this risk, there is a resistor test method for initial stating the rectifier. Please connect a 1k/400W or 470R/400W resistor across between +DC and -DC connection terminal as a parallel. Test resistor setup is shown below.

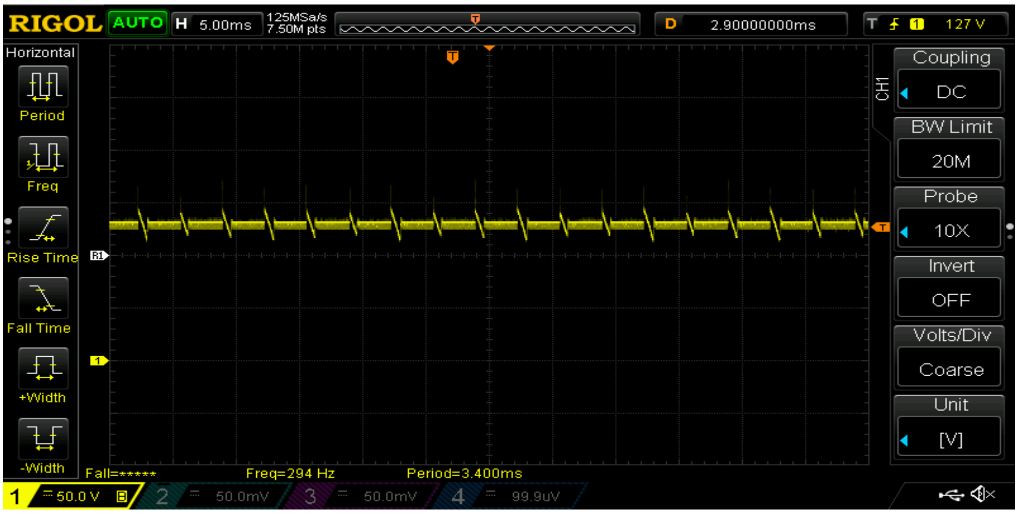
This test resistor will limit the current and you can see thyristor pulses are true or not.



Step 4: Set oscilloscope parameters volt/div 100V, time/div 5ms and trigger

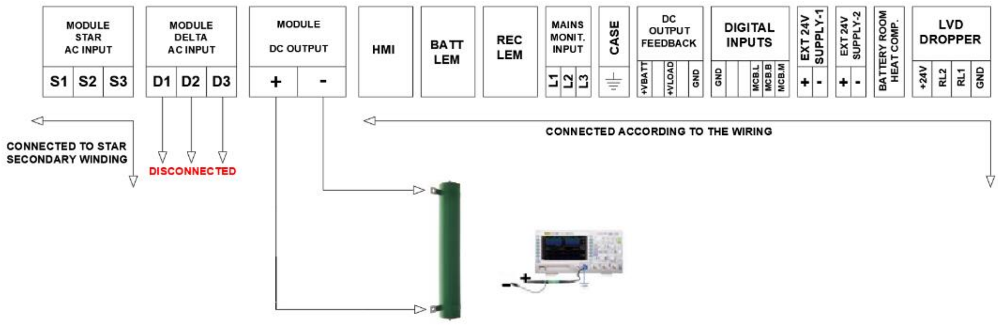
- Turn ON input breaker and keep looking oscilloscope screen to observe soft start and similar view below.
- If you observe soft start and oscilloscope screen **Turn OFF input breaker**.



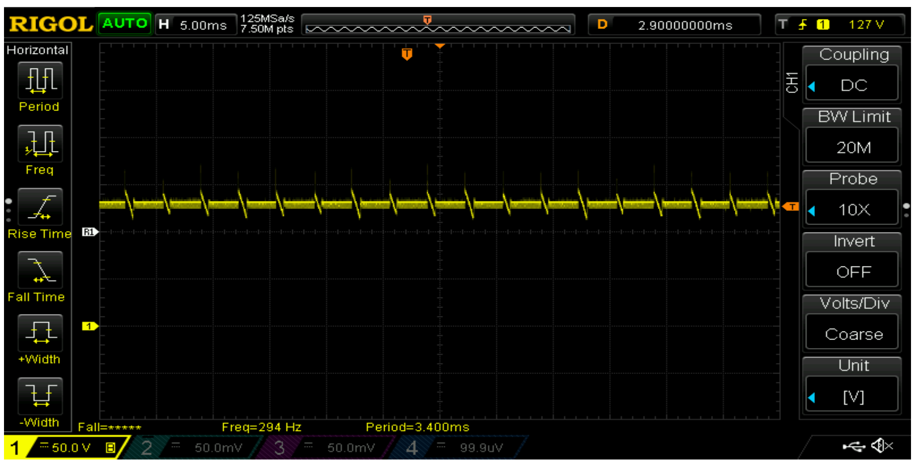


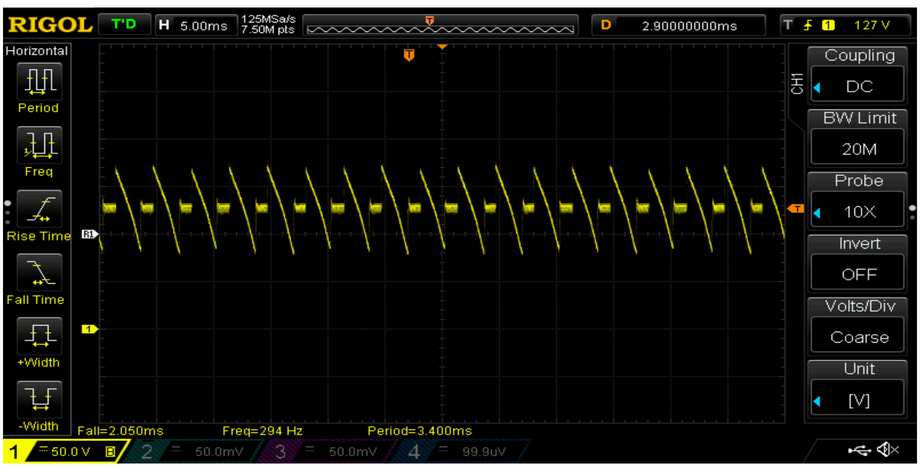
!!! If you cannot observe soft-start and similar view above this means there is a synchronous problem to input, this situation caused by “transformer output” or “mains monitoring input” connection. Go to “Transformer Synchronous Connection Check” again or check “mains monitoring input” connection sequence according to wiring!!!

Step 5: Change the connections according to the picture at the below and observe thyristor pulses



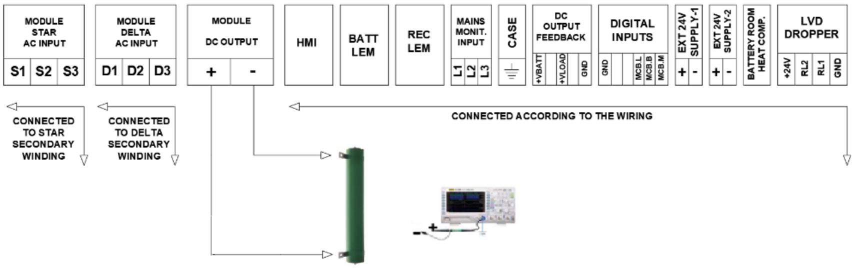
- Turn ON input breaker and keep looking oscilloscope screen to observe soft start and similar view below.
- If you observe soft start and oscilloscope screen **Turn OFF input breaker**.





!!! If you cannot observe soft-start and similar view above this means there is a synchronous problem to input, this situation caused by “transformer output” or “mains monitoring input” connection. Please make sure that the transformer phase order and synchronous or check “mains monitoring input” connection sequence according to wiring!!!

Step 6: Connect all terminals on the rectifier module and observe 12 pulse

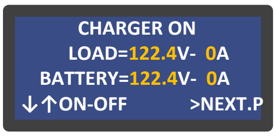


- Turn ON input breaker and keep looking oscilloscope screen to observe soft start and similar view below.
- If you observe soft start and oscilloscope screen **Turn OFF input breaker.**

According to the oscilloscope screen you should be see the 12 pulse in 20 ms period if you are all thyristor pulse is correct you can proceed to next step otherwise please check transformer synchronous or main monitoring input sequence according to the wiring

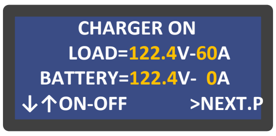
Step 7: Disconnect test resistor and connect directly +DC Cable to the module then turn ON input breaker. You will observe

same screen on HMI Front panel also you can connect a multimeter or oscilloscope output of rectifier.

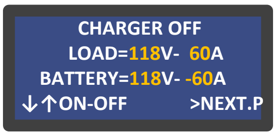


Step 8: Connect battery group and Load to the system.

Load %100 percent and check Rectifier Current Module from HMI front panel.



Turn OFF system and check Battery Current Module from HMI front panel.



Step 9: Turn ON system again and wait with load until Cooling Fans are started.

After these steps and rectifier connection test, module connection test and initializing procedures will be completed successfully.

6.4. Internal Buck Boost Converter of PESS Module

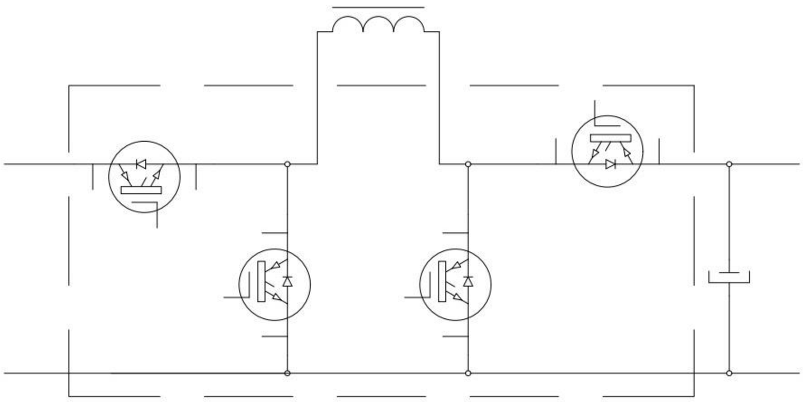


Figure 6.4

BBC is a powerful Buck-Boost transformerless converter, based on a small number of IGBT modules to be analyzed and experimentally verified. Such a solution has the potential to be used as a powerful (up to 30 kW) battery charging system based on a budget-friendly topology with high power density and efficiency. These requirements are feasible due to the simple structure, which this type of DC–DC converter usually has. Inherently, their power stages are based on a small number of semiconductors. In this case, an application of the currently available powerful silicon based IGBTs would allow for only two modules to be used.

PESS rectifier module contain two-switch buck - boost topology as mentioned above. The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. Two identical IGBT is used for a switch.

Grid is available when rectifier charge the batteries, load voltage value is expected smaller than float or boost charging rate for batteries, as an example for 110VDC charger float value is 122VDC but load is expected 110VDC +- 1%.And boost value is 128V while load output is expected 110VDC +- 1%. If the grid is not available during the battery discharge period,battery voltage value is between low battery and nominal DC BUS value like 90VDC ,110VDC.

7.PERFORMANCE TESTS

7.1. Ripple Factor Test

To test ripple factor of rectifier, A true rms multimeter (like Fluke) should be connected to load-MCB terminals (+, -). Multimeter reads the DC voltage and AC voltage between the connected terminals. Ripple factor of the rectifier should be less than (1%) percent to get good-filtered harmless DC voltage for batteries (at full load).

$$RF = (Vac(rms))/(VDC\ (rms))\ \times 100\ (\%) \quad (7.1)$$

- This test should be done without battery and for all load conditions from 10% to 100% (at 380 Vac input).
- DC voltage ripple will be better with battery, but without battery RF is the real parameter to get as reference.

7.2. Input Voltage Limits Test

- To test input voltage acceptable limits for rectifier working, connect a variac to input of rectifier.
- Input voltage acceptable limits are important to get technical specifications for critical area. Full load working limits are tested with this voltage limit test. So that, this test should be done at full load, without battery.
- Open input MCB with 380 Vac input voltage, see the rectifier soft-start and going float voltage, open load MCB and give some loads 10%. Increase the load step by step up to 100%. In these steps battery MCB should be closed.
- At full load, play the variac and set the variac 380 Vac -15% = 315 Vac, and 380 Vac + 15% = 445 Vac, see the workings.
- Out of these acceptable limits, rectifier will stop working, and returning the acceptable limits rectifier starts automatically.
- Out of these voltage limits, rectifier will give line failure alarm, thick led will disappear, but there is a failure alarm, after retuning normal voltages, rectifier will work, thick led will appear and line failure alarms will disappear.

7.3. Current limits test

- Other specific test is current limitation test for rectifiers. PESS rectifier power module allows two current limitations, one is at the rectifier output as total output DC current, other is at the battery side to limit battery charge / discharge current.
- It can be tested easily with 380 Vac input conditions. Connect the load, open the load MCB when rectifier floating without battery.
- Give some loads, and increase the loads up to see current limit led appear on HMI and check the pens-ammeter current reding on load side.
- To test battery charge current limits, open the battery MCB at full-load, and close the input MCB for discharge battery, after some discharging about 2 minutes, close the load MCB, and open the input MCB again, see the current limit led appears on HMI and check the pens-ammeter reading on battery side.

7.4. Power Factor Testing

- Power factor testing should be done nominal conditions; where input is 380 Vac, without battery and at full load.
- Connect a power analyzer to input of rectifier, in power reading mode, check the VA, W, PF readings at nominal input conditions without battery and full load.

7.5. Calibration of voltage, current readings on HMI

There isn't any potentiometer on the anywhere of PESS rectifier modules. All measurements are made by high precision (%1 tolerance) components. However, if the customer's need to calibrate any values on HMI Module, all calibrations can be made over communication channel between PC and HMI Module. You can see the relevant section at the Figure 7.1 in the yellow squared section

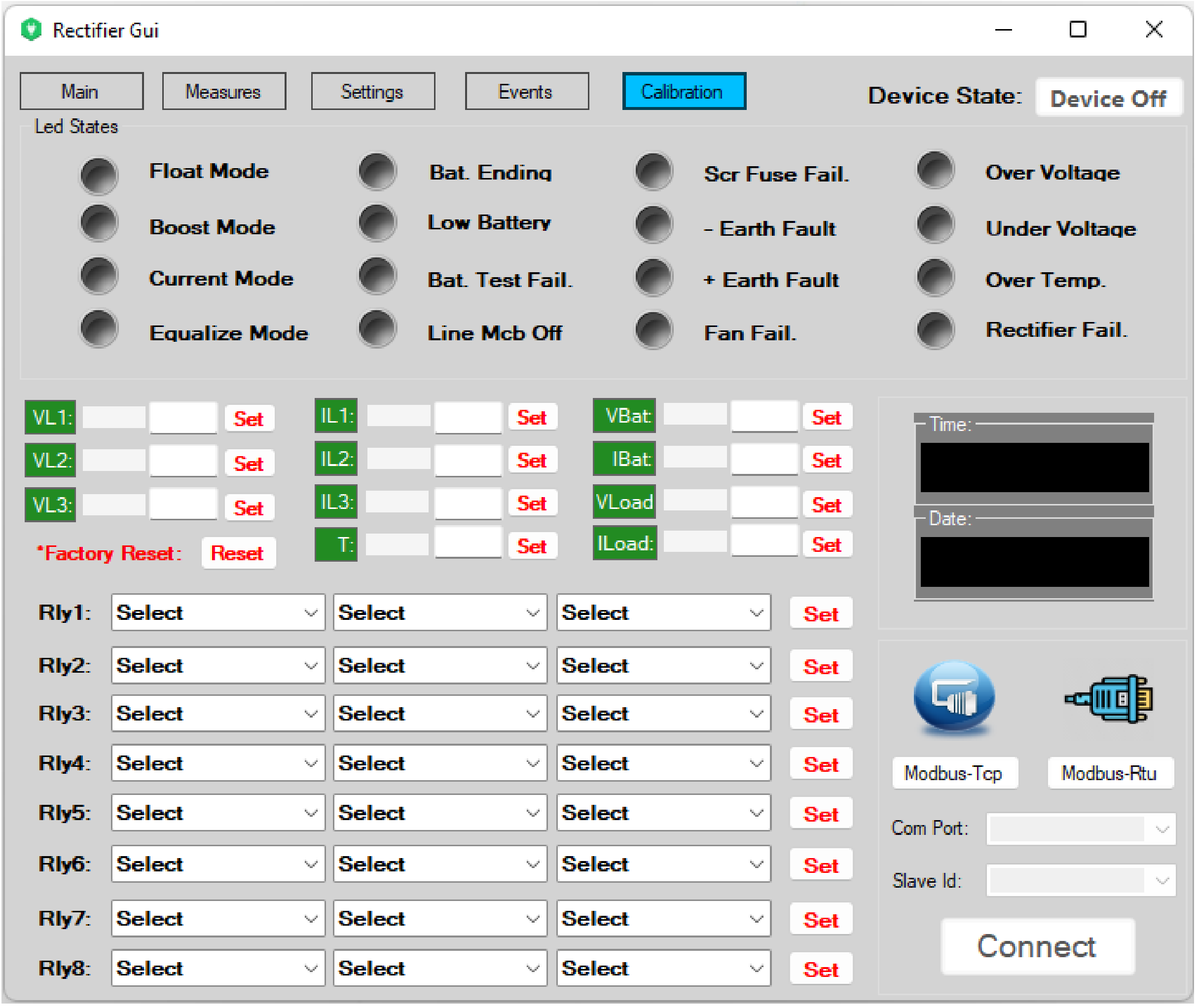


Figure 7.1.