

**MIDDLE EAST TECHNICAL UNIVERSITY**

**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**

**EE 463- Hardware Project – 2023 Fall**

**Final Report**

Wind Turbine Battery Charger

**Göklerde Charger Gibiydim**

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# INTRODUCTION

In this project, we are making a Wind Turine Battery Charger. We will implement a design for the given varying voltage input (15-25 Vll) and output of 10 A current with the 20 percent of ripple. The design specificiations are given in the [Github repository](https://github.com/onurtoprak1/EE463_PROJECT) of the hardware project.

We investigated the possible topologies that we might implement. We decided based on our calculations and other parameters like feasibility, easy to implement and cost. Throughout this report, we will investigate the toplogy selection, rectifier, converter, loss and thermal calculations, analysis of the simulations and implementation process.

# Project Description and Specifications

metin, genel ikmal maddesi, konteyner, iç mekan içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure 1. Battery that we used for charging

Battery Characteristics:

* 12V
* 100Ah
* 0.1 Ω internal resistance

Our design:

* 15-25 line-line Volts input from 3-phase variac
* Rectifying AC to DC
* DC to DC Converter to fix current to 10A output

# TOPOLOGY SELECTION

## 3 Phase Thyristor Rectifier

For the 3 Phase Thyristor Rectifier, we researched for this project. The advantages for this topology are;

* High power usage availabilty
* There is no need to have a DC/DC converter, since its output is controllable.

However, for this topology the disadvantages are more dominant;

* It cannot be used with high frequency, which will result in a high volume.
* Its turn-on circuitry is not easy to implement.
* Low switching speed, which will increase losses.

## Centre-Tap Rectifier + Buck Converter

For the 3 Phase Thyristor Rectifier, we researched for this project. The advantages for this topolpgy are;

* Good voltage regulation
* Less ripple
* High efficiency

However, for this topology the disadvantages are more dominant.

* Cost
* Complexity
* High switching losses

## 3 Phase Full Bridge Diode Rectifier + Buck Converter

For this project we decided to choose this topology since it provides a simple solution and cheaper compared to other topologies.

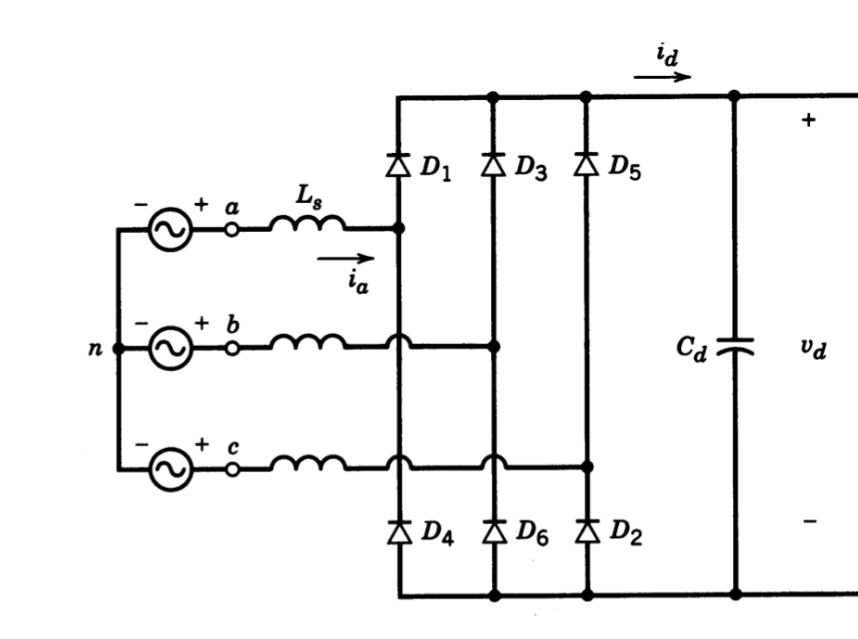
Here are advantages of the selection of this topology;

* Compact Design
* Cost Effectiveness
* Open to more applications
* Reliability

However, we should consider the disadvantages and the major disadvantage we should consider is the efficiency. Buck converter is not efficient due to the components of the circuit. By selection of circuit components, we will try to be as efficient as possible.

# Calculations of Rectifier and Converter

## Rectifier



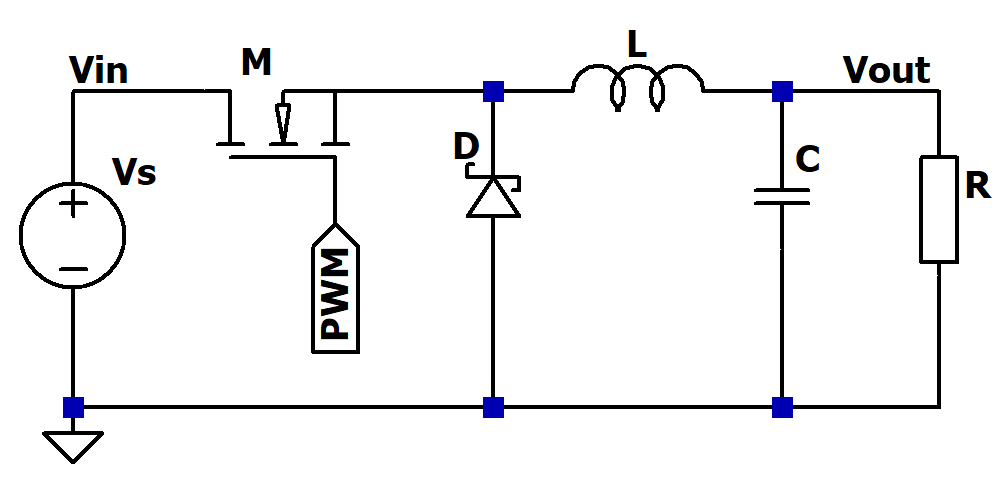
Şekil 2. 3-Phase Rectifier Circuit

The average of the output voltage of the rectifier can be found by:

It can be found that our output for diode is in between 20.26 - 33.76 .

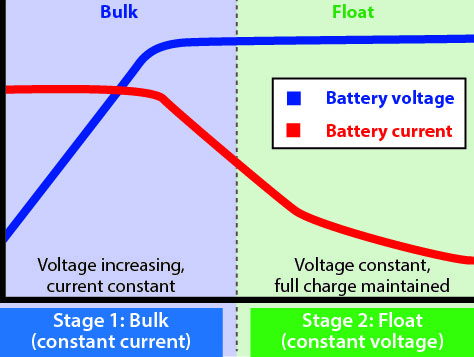
## Converter

This is also the input of the converter. We should have an output around 12 V; so we should use Buck(Step-Down) Converter to achieve this output voltage.



Şekil 3. Buck Converter Circuit Topology

In order to achieve our design characteristics to charge battery properly, we think that using Constant Current / Constant Voltage control mechanism should be applied.



Şekil 4. CC-CV Battery Charging Stages

To charge the battery, we need to apply this stages via controlling mechanism. The full charging battery reaches up to 13.8 V. So, we design our controller accordingly to reach constant current stage first, then constant voltage stage after certain value (13.5V).

If we look at the Duty Cycle that needs to be applied:

It can be found that Duty Cycle is around 0.4 – 0.67.

çizgi, diyagram, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, metin içeren bir resim

Açıklama otomatik olarak oluşturuldu

Şekil 5. Vo constant curve for Buck Converter

According to this curve, with values of;

* = 250 kHz
* L = 0.1 mH

We can found that, output of 10 A does not go into the discontinous mode with Duty Cycle around 0.4 – 0.67.

# Loss Calculations

## Bridge Rectifier

## MOSFET

* = 1.25 c/w
* = = 62 c/w
* = = 0.04 ohm
* = =55 ns
* = 57ns

**2.68W**

## Diode

**5.6W** (VF =0.85 WHEN 10A)

# Controller Schematic and Calculations

For PWM generating, TL494 integrated circuit is used. It has different operation modes. With this controller, CC / CV operation modes are provided. For this purpose, error amplifier pins are used. Moreover, TL494 contains a 5 V voltage regulator itself. 5 V output voltage is supplied at reference pin. This pin is used for adjusting PWM output according to adjusting voltages at pins 2 and 15 are used. Then pins 1 and 16 pins get feedback from the buck converter part. Frequency of the PWM generator adjusted with pins 5 and 6. Connected resistor and capacitor’s values adjust the frequency. Then, TL494 can work at the voltages between 7 and 40. It is big advantage for this project because system operates between 19 and 33 V. So, TL494 can be connected to input voltage directly, so extra voltage regulator is not needed.

metin, diyagram, plan, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Pin Connections of TL494*

From the information and application notes of this controller at the datasheet is got reference. Then, design of the controller was started. Firstly, for the schematics, KiCAD will be used.

Firstly, circuit diagram of the controller can be seen in Figure X.

diyagram, plan, teknik çizim, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Controller Schematic Design*

8 and 11 pins are directly connected to Vcc, which is input voltage of the buck converter. Internal PNP transistors’ collector pins are directly connected to input voltage with these connections. Then, 9 and 10 pins are again the collector pins of the internal PNP transistors. PWM signals are generated at these pins, and they will be connected to MOSFET driver circuit with serial 10 Ω resistor.

After that, for the adjusting the frequency of the PWM signal, pins 5 and 6 are used. Frequency value of the PWM signal formula is:

Then capacitor and resistor are grounded.

After these connections, voltage dividers are applied on the reference voltage pin, 14. 1K and 3.9K are used for the first voltage divider. With this voltage divider is got. Then this signal is connected to error amplifier 2’s inverting input, 15. Then, this error amplifier’s non-inverting pin is directly connected to shunt resistor which is serial connected directly to output of load and then goes to ground. These connections will be provided more detailed at other schematics. Then another voltage divider applied on the reference voltage pin. 2 x 10K Ω resistors are connected serial to the ground. Then obtained voltage level is connected serial with 560 Ω to error amplifier 1’s inverting input. From this connection, feedback pin is connected to this connection by 50K serially. Lastly, pins 4, 13 and 7 are grounded.

With this controller design, MOSFET is switched depending on input voltage and output voltage. TL494, keeps the output current constant at 10 A and duty cycle of the PWM signal is changing continuously depending on the feedback’s from the shunt resistor. For the project requirements, input voltage varies between 19 and 33 V and battery voltage level can be change between 11 V and 14 V according to State of Charge. Moreover, battery has internal resistance, so in summary, TL494 generate PWM signal according to these information. Simulation results will be provided in Simulation Results part.

# Gate Driver Schematic and Calculations

After getting the PWM signal from TL494, gate driver circuit must be used for switching the Power MOSFET IRF540. With the MOSFET driver circuit, gate signal’s current will be amplified and with gate driver resistor, switching time between the ON / OFF stages is decreased. With this operation, thermal and power efficiency is increased. Also, the oscillation in the opening situations is decreased, so total EMI which is harmful for the operation of device is reduced.

Gate Driver circuit is implemented with 2 power BJT’s. NPN BD139 and PNP BD140 transistors are used. Also, resistors 2 x 1K Ω, and 56 Ω are used.

metin, diyagram, çizgi, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Gate Driver Circuit Schematic*

So, implemented gate driver can be seen in Figure X. With this gate driver, oscillations which happened when MOSFET is opening, are reduced and total EMI on the design is reduced and gate signal is amplified. MOSFET can be opened more easily.

# SIMULATION Results

## Three-Phase Full Wave Rectifier Schematic

For getting DC voltage from the AC voltage, three phase full wave diode rectifier is used. For this purpose, 2 x KPBC5010 Bridge Diode are used. After that, for the decrease a ripple at the DC output, 1000 µF capacitor is used.

metin, ekran görüntüsü, diyagram, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Three Phase Full Wave Diode Rectifier Schematic*

## Buck Converter Design

According to calculations of the converter, buck converter design is implemented. IRF540N, Schottky Diode MBR20100CT, 50 µH inductor, 470 µF capacitor, 0.1 shunt resistor and 2 resistors are used. From the buck converter, feedbacks for TL494 are provided. For the current adjusting, 0.1 shunt resistor used and with this implementation, adjusted current is 1 / 0.1 = 10 A. Then, for CC / CV topology, voltage divider is used and signal from this divider connected to pin 1. Stone resistor with 10 W is used for the sensing current because total power on this resistor is 102 \* 0.1 = 10 W.

metin, diyagram, çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Buck Converter Schematic*

## Simulation Results

For the simulations, proteus simulation program is used. This program was preferred because it contains most of the components used in the circuit in its library and the simulation results are similar to real-life applications.

Full circuit schematic of the system is implemented at the proteus program. Firstly, 3-phase diode rectifier circuit is implemented at the input stage. With 1000 µF, input voltage ripple is decreased. Then from this input voltage TL494 controller is worked. After that controller circuit is designed. Then MOSFET Gate Driver circuit is implemented at output of the PWM signal of the TL494. Lastly buck converter is implemented.

çizgi, diyagram, paralel, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

*Figure X. Full Circuit Schematic of the Battery Charger*

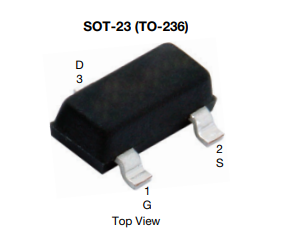
After the simulation setup is constructed, simulation is run.

# COMPONENT SELECTION

## Planned Components

### Buck Converter MOSFET Selection

From the critical compenent selection parameters, as seen in the github repository, we calculated the rating current value. Is>Iomax \* Dmax = 10\*0.68 = 6.8 A. We will charge our battery with 10 A in control current situation. So, it will be maximum current value for our charger. From the simulations output, we saw the maximum voltage which drops on the MOSFET. It is 33 V. From these informations, we should choose our MOSFET with safety margins. We put the diode with rating voltage is around 40 V and current rating is around 8 A. Our selection is SQ2318AES. Its Vds value is 40 V and Rds(on) is around 32 mΩ. Of course, it is a n-channel MOSFET. Moreover, stock situation and price is critical parameters for us.



SQ2318AES

Also, we propose a possiblity of selection these MOSFET’s in case of emergency. We will use a component in the list that fits well to our design **IRF540 N** Kanal Power Mosfet TO-220. It has a current rating of 30A which is little high if we think that our steady state current is 10A. However, if we think the thermal issues and transient, our MOSFET will be only sufficient to carry such current at high temperatures. We can also use a different MOSFET by looking at other parameters such as heating affect and heat sink. **SQJ942EP** this MOSFET has a 15A continous drain current, which seems okey and has a good resilient to temperature.

elektronik donanım, boru, tüp içeren bir resim

Açıklama otomatik olarak oluşturuldu 

IRF540 N SQJ942EP

### Buck Converter Diode Selection

From the critical component selection parameters, as seen in the github repository, we calculated the rating current value. If>Iomax \* (1-Dmin) = 10\*0.61 = 6.1 A. We will charge our battery with 10 A in control current situation. So, it will be maximum current value for our charger. From the simulations output, we saw the maximum voltage which drops on the diode. It is 33 V. From these informations, we should choose our diode with safety margins. We put the diode with DC reverse voltage is around 40 V and current rating is around 8 A. Our selection is SD2114S040S8R0. Its Vrr-max value is 40 V and Vf is around 0.5 V. It is a schottky diode.

tasarım içeren bir resim

Açıklama otomatik olarak oluşturuldu

SD2114S040S8R0

### Diode

We thinked that we can use a **Schottky Diode** since we are working on low voltage and we can increase efficiency bu using this diode. We can reduce the effect of Vf  by using a Schottky Diode. This is the one that is on the components list in the Github repository. We will build our full bridge rectifier by these diodes.

boru, tüp içeren bir resim

Açıklama otomatik olarak oluşturuldu

1N5822-HT

Another component possibility is a full-bridge rectifier. If we select a full-bridge rectifier, our efficiency will be low but we can use this if we can not achieve good results with shotcky diodes.

metin, ekran görüntüsü, diyagram, teknik çizim içeren bir resim

Açıklama otomatik olarak oluşturuldu

DBI20-08B

### Passive Elements

For inductors, we will use different sizes and capacitys for the circuits necessiy. So, we will use a variety to achieve a solution considering different parameters like filtering and heating. We will try to select a inductor by looking its design of circuitry and its capability to high current values.

For capacitors, we will use different sizes according to our design. We will try to select our capacitors based on peak voltage values in order to work in a safe limit. Another limit for the capacitor selection is the ripple value. We should consider the ripple while selecting a capacitor.

### PWM GENERATOR

diyagram, plan, çizgi, metin içeren bir resim

Açıklama otomatik olarak oluşturuldu

A digital signal is used in the pulse width modulation (PWM) technique to precisely control analog devices. A signal with pulse width modulation is made up of electronic pulses that replicate an analog voltage change. An astable oscillator using a 555 timer is demonstrated in the circuit above.

When capacitor C1 charges through resistors R1 and R2, the output is HIGH. On the other hand, if capacitor C1 only discharges through resistor R2, the IC's output is LOW. The square wave output signal's duty cycles and ON/OFF times can be altered by varying the values of any one of these three components. Adding two diodes to the circuit and substituting a potentiometer for the R2 resistor is a quick and simple way to achieve this. Under this setup, resistor R1, the potentiometer's left side, capacitor C1, and the potentiometer's right side will determine the On time and the Off time, respectively. Because the total resistance won't change during charging or discharging, the frequency and cycle period in this configuration will always be the same.

We will use LM555 for our timer which can be found in the component list because its supply voltage limits are between 4.5V-16V. It is adequate because we just use this component as the pulse for switching.

## Used Components

# Thermal Calculations

# Implementation

Summary of implementation and detailed explanation of each parts of the design on the hardware.

Difficulties we faced…

# Demo Day Results

# Conclusion

# Appendix

1. *TL494*. TL494 data sheet, product information and support | TI.com. (n.d.). https://www.ti.com/product/TL494?utm\_source=google&utm\_medium=cpc&utm\_campaign=app-hvp-null-44700045336317425\_prodfolderdynamic-cpc-pf-google-wwe\_int&utm\_content=prodfolddynamic&ds\_k=DYNAMIC%2BSEARCH%2BADS&DCM=yes&gad\_source=1&gclid=CjwKCAiA5L2tBhBTEiwAdSxJX0dTR8Tg0Avmt0iJCPrMx2zc88EI-acExI1JAIjcb5ATgYrENaZhEhoCa4AQAvD\_BwE&gclsrc=aw.ds