BRAC UNIVERSITY

Inspiring Excellence

Project

EEE422 Power Electronics Lab

Design of a hypothetical IPS

Group 07

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Declaration: We certify that this assignment is entirely our own work except where we have fully documented references to the works of others, and that the material contained in this assignment has not been submitted previously for assessment in any formal course of study.

Objective:

The main objective of this project is to implement a circuit for hypothetical IPS(Instant Power Supply). We have been given an AC Supply as input (220V Peak AC at 50Hz) of the system. Due to the severe load shedding situation, we need to design a hypothetical IPS. This IPS will take input from the main outlet (220V Peak AC at 50Hz) to charge its battery.. This battery must be charged with a DC voltage of 17 Volts (+/-1V). Thus, we need to design a converter for charging this IPS battery. The design of the components of the converter must have the values of at least 10 times the minimum requirement. The circuit will have to be able to change the duty cycle on its own, depending on input voltage level. Finally, we need to produce 220V, 50 Hz square wave as output of the IPS for running several appliances of our house.

Introduction:

In the designed circuit we are asked to design an IPS with an input of 220V AC and output of 220V 50Hz square wave.

Requirements	
Input of the system	220V AC sin, 50Hz (May vary)
Battery charging voltage	17V(+/-1V)
Output of the system	220V square wave, 50Hz

But the battery of the designed circuit will have a battery of 17V. As we can't charge the battery with AC input so we will need to convert it to DC.

AC-DC converter: If we choose an AC-DC regulator the output will still have sharp peaks of 220V. Here using a regulated AC-DC converter though the output's average voltage can be controlled, but we won't get 17V DC. Again using a regulated AC-DC converter will require more complex circuitry like pulse generator. So we opted for using a non regulated AC-DC converter. But to make the output completely smooth DC we will need a filtering capacitor. This will output close to 218.5V due to the two diode's voltage drop across each half cycle.

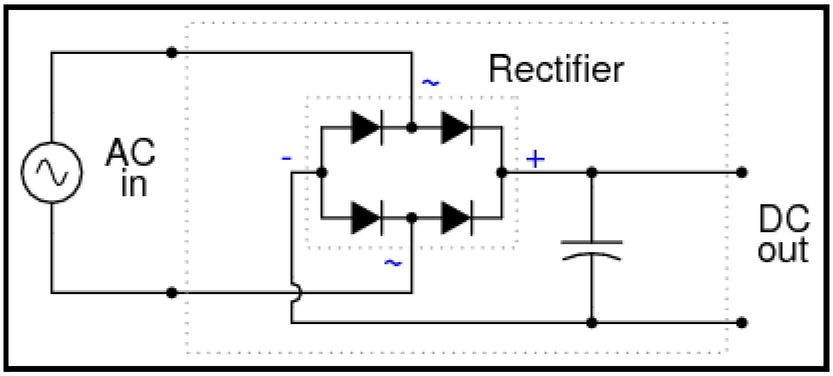


Figure: AC-DC converter

DC-DC buck converter: Then we will use a DC-DC buck converter to step-down the voltage to around 17V DC. We could've used a buck-boost/sepic/cuk converter but we don't need the boost operation and buck converter has an added advantage of no polarity reversal. So we chose the buck converter in our design. In our specification it's given that the output might vary. So to make the output of the buck converter stable we will use a feedback system. The feedback will generate a pulse with modulated width to output approximately 17V. This 17V can be used to charge the battery. A circuit diagram of a buck converter is given.

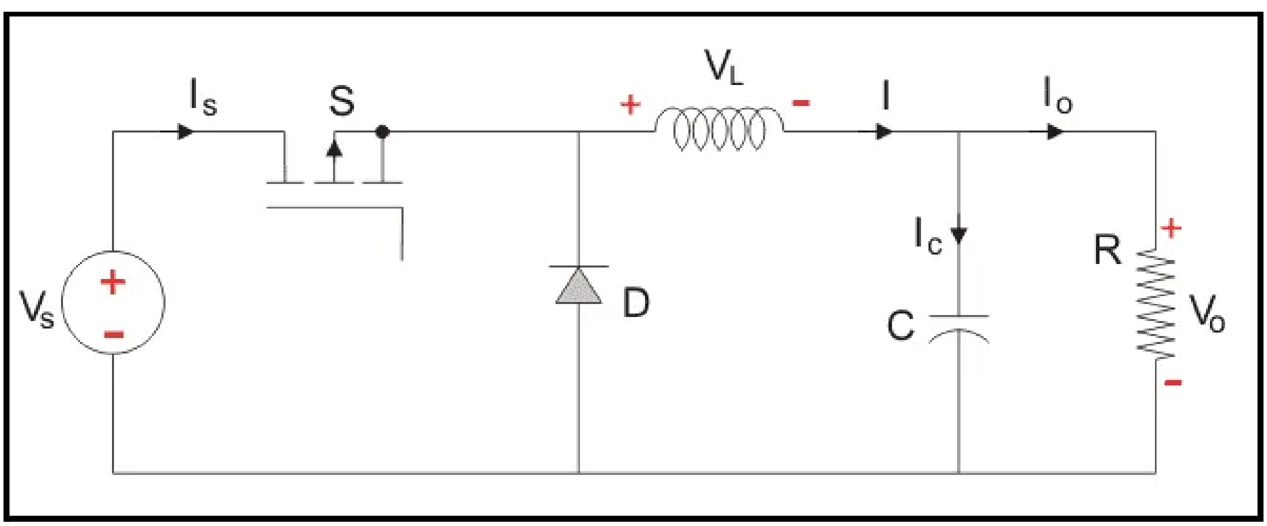


Figure: DC-DC buck converter

Equations for design,

Duty cycle $D = \frac{V_o}{V_s}$

Inductor $L_{min} = \frac{(1-D)R}{2f}$, where R=Load resistance and f=Frequency of the system.

Capacitor $C = \frac{(1-D)V_o}{8\times L\times V_r\times f}$.

A zener diode of 17.5V is used at the output of the buck converter to get a regulated output. This regulated voltage is used to charge the battery.

Battery: The battery has a nominal voltage of 17V and a capacity of 25.4Ah.

When the mains are turned off the switching will make sure that the battery doesn't discharge and flow back to the DC-DC buck converter. For an extra protective layer a diode is used at the output terminal to stop the flow of reverse current.

DC-DC boost converter: The battery is 17V. But we need an output of 220V squarewave. So we need to boost it to generate a 220V AC. The buck-boost,sepic and cuk require more components compared to the boost converter. So we chose a boost converter in our case. The boost converter's input will have a 17V zener and output will have a 220V zener to regulate the output of the circuit to 220V DC. The circuit diagram of a DC-DC boost converter is shown below.

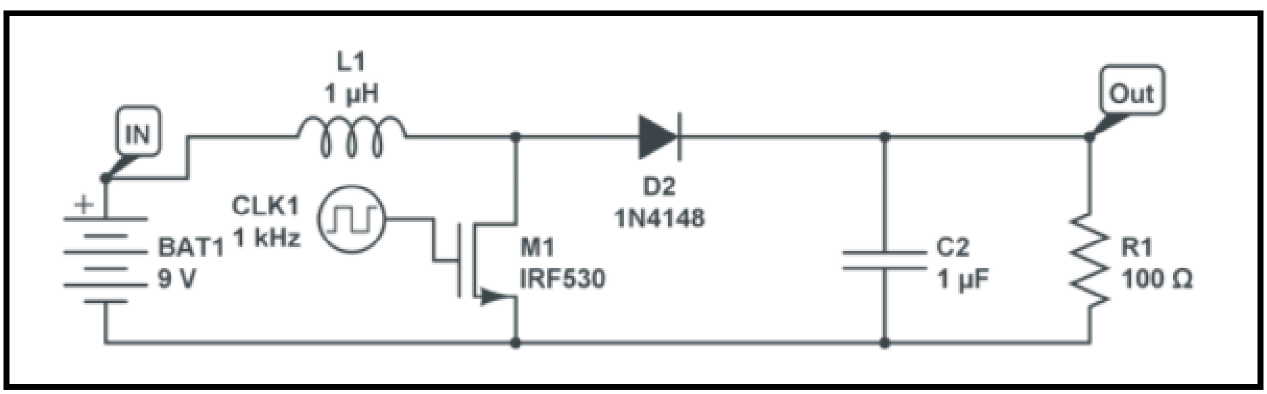


Figure: DC-DC buck converter

Equations for design,

Duty cycle $D = \frac{V_o - V_S}{V_o}$

Inductor $L_{min} = \frac{D(1-D)^2 R}{2f}$, where R=Load resistance and f=Frequency of the system.

Capacitor $C = \frac{D \times V_o}{R \times V_r \times f}$.

A zener diode of 220V is used at the output of the buck converter to get a regulated output. This regulated voltage is used in the inverter.

DC-AC inverter: The 220V DC output of the boost converter needs to be used as input of the inverter. Here we have a specification to generate a 220V square wave. So rather than choosing a multilevel converter we used a simple DC-AC converter as it requires less components and circuitry is also simpler than the multilevel design. The circuit diagram is given below.

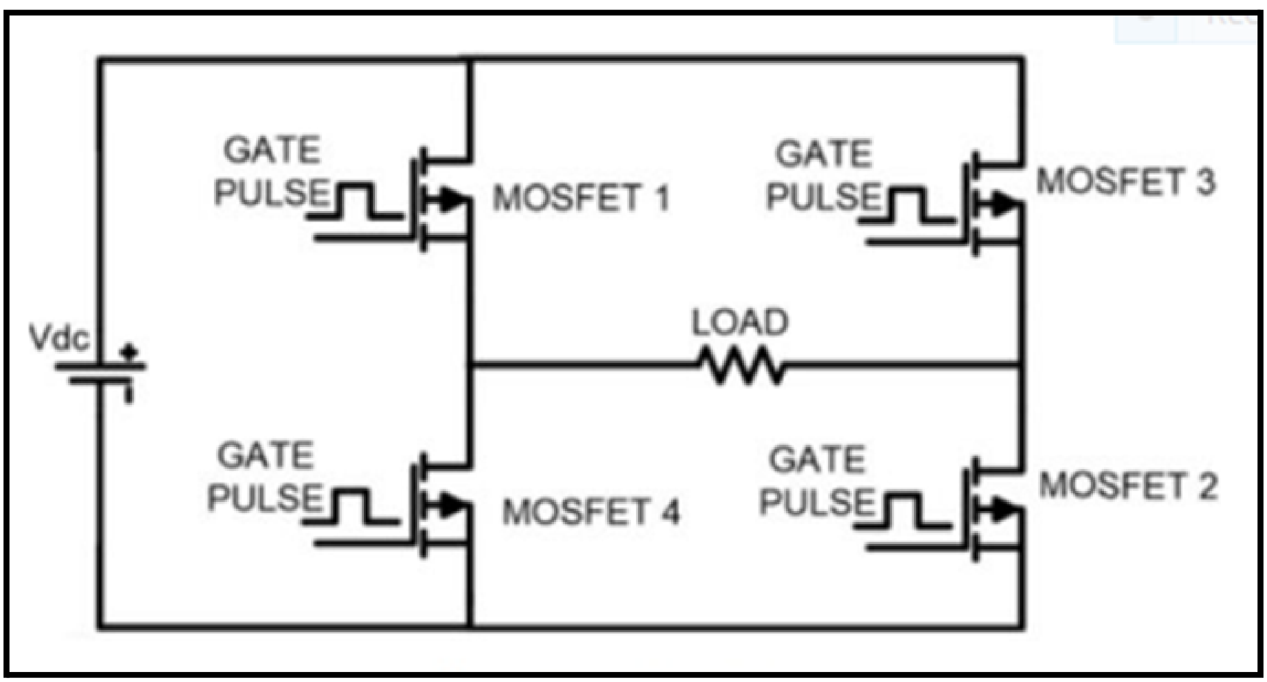


Figure: DC-AC converter

The whole system and the process is modelled by a simple block diagram. From the diagram the whole process can be easily visible step by step.

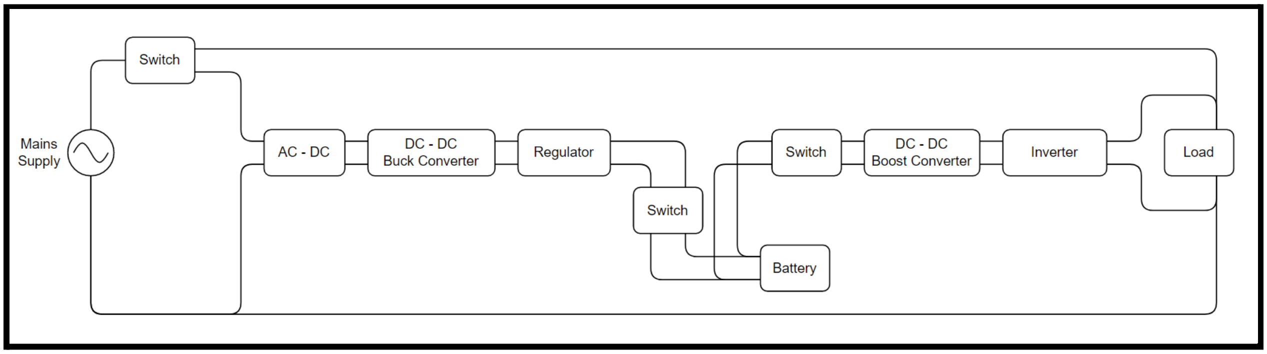


Figure: DC-AC converter

Software requirements:

- Matlab simulink

As we were asked to implement the circuit hypothetically, So we used the simulink tool to implement and test the result of the output of the circuit.

Circuit diagram:

The designed circuit diagram is as below:

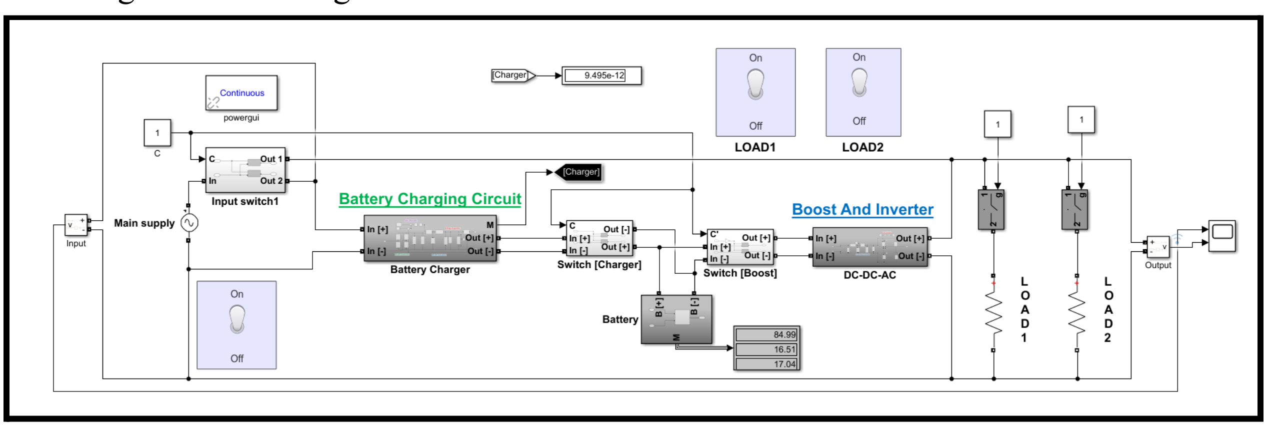


Figure: Simulink whole circuit diagram

Inside the “Battery Charging Circuit” block the following circuit is implemented. The implemented circuit is made into a block to make the circuit look more simple to understand.

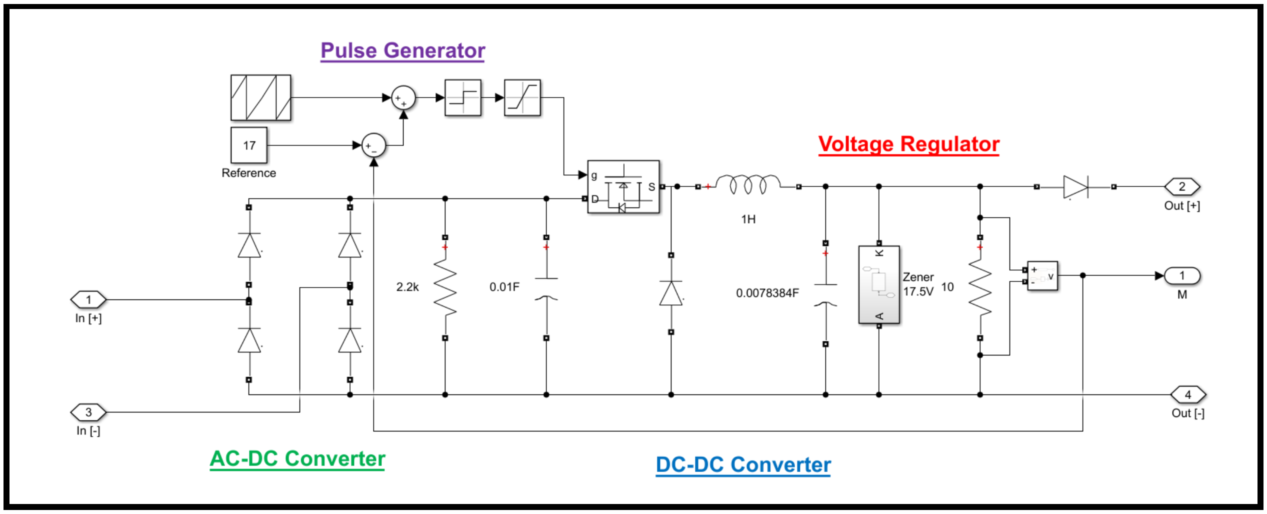


Figure: Simulink inside of "Battery Charging Circuit" block

Inside the "Boost And Inverter" block the following circuit is implemented. This is also converted into a block, making the whole circuit very simple to understand.

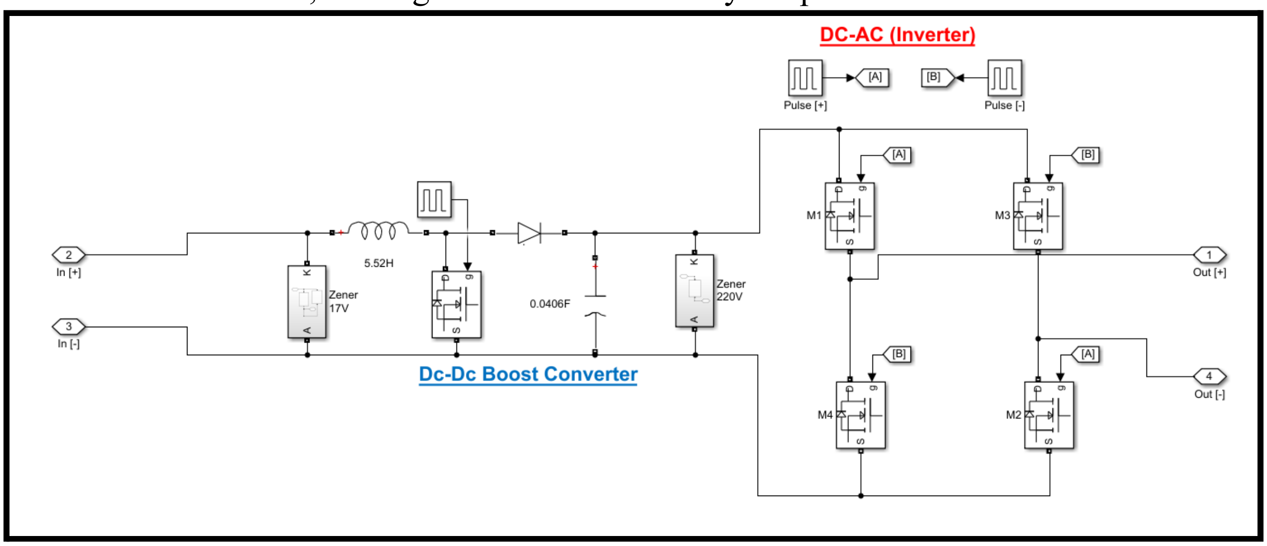


Figure: Simulink inside of "Boost And Inverter" block

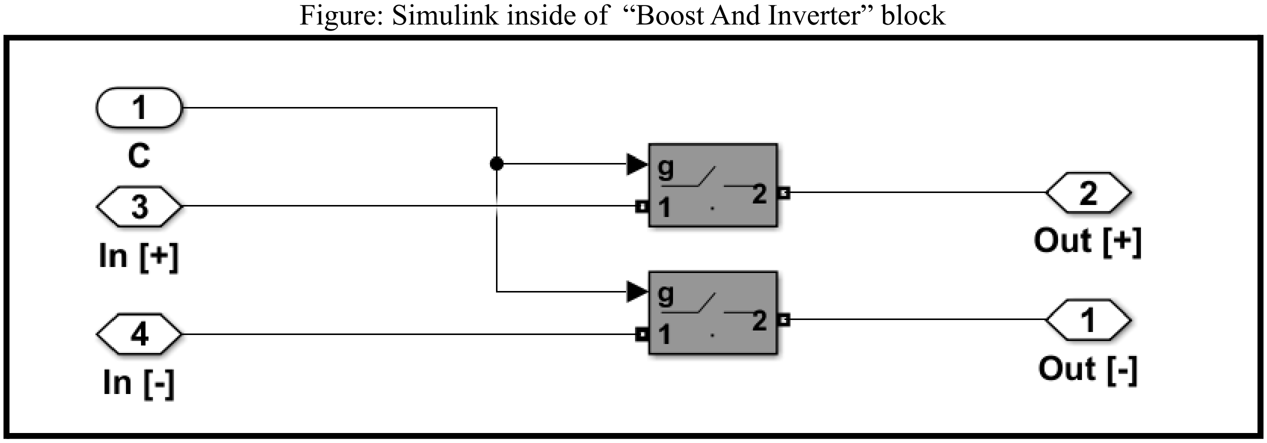


Figure: Simulink inside of "Switch [Charger]" block

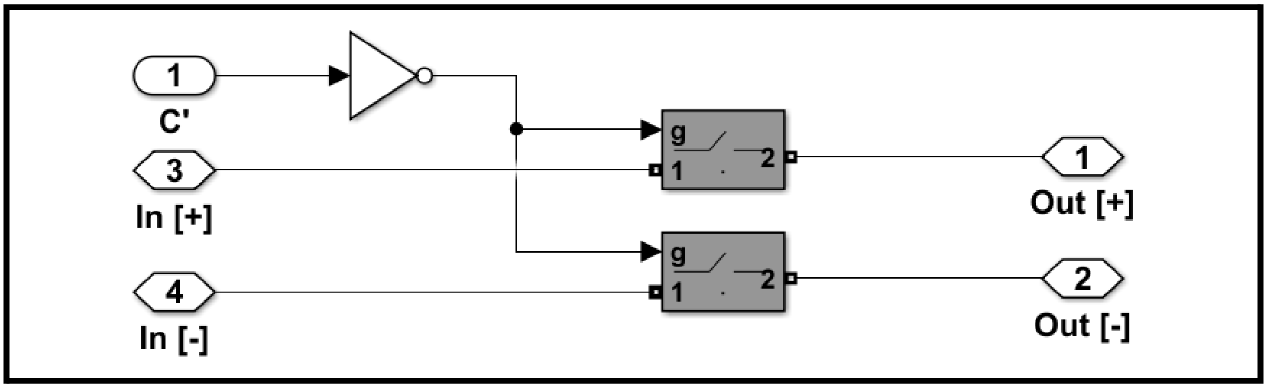


Figure: Simulink inside of "Switch [Boost]" block

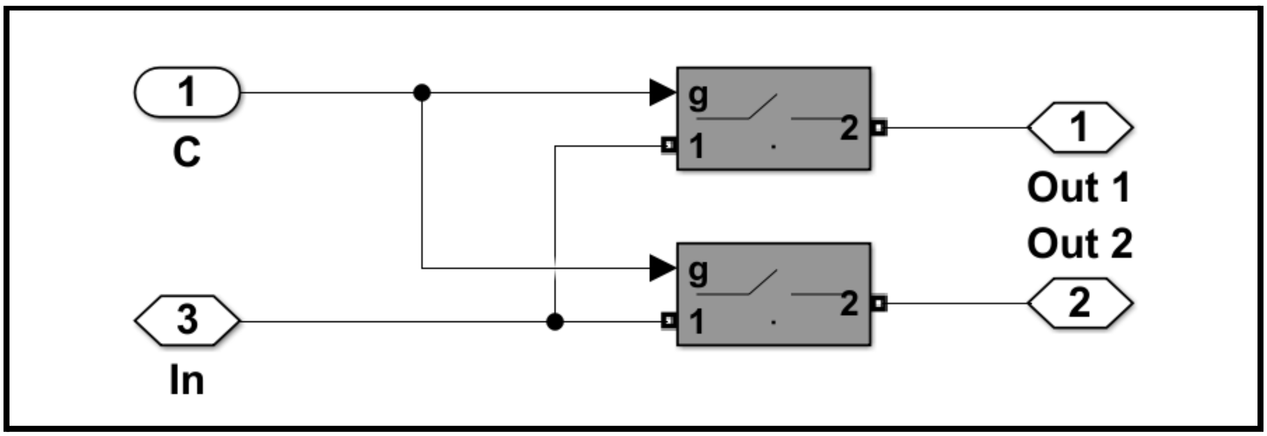


Figure: Simulink inside of AC disconnection block

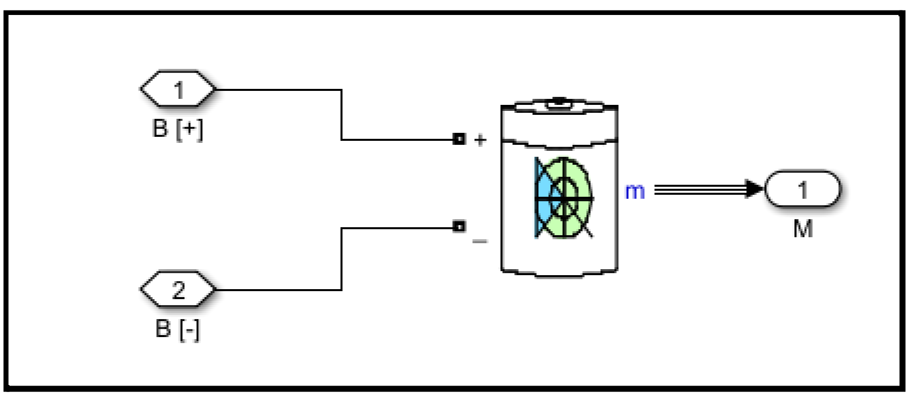


Figure: Simulink inside of "Battery" block

Design:

According to the block diagram of the system, first we need to implement the AC to DC converter. The unregulated AC-DC converter is shown below.

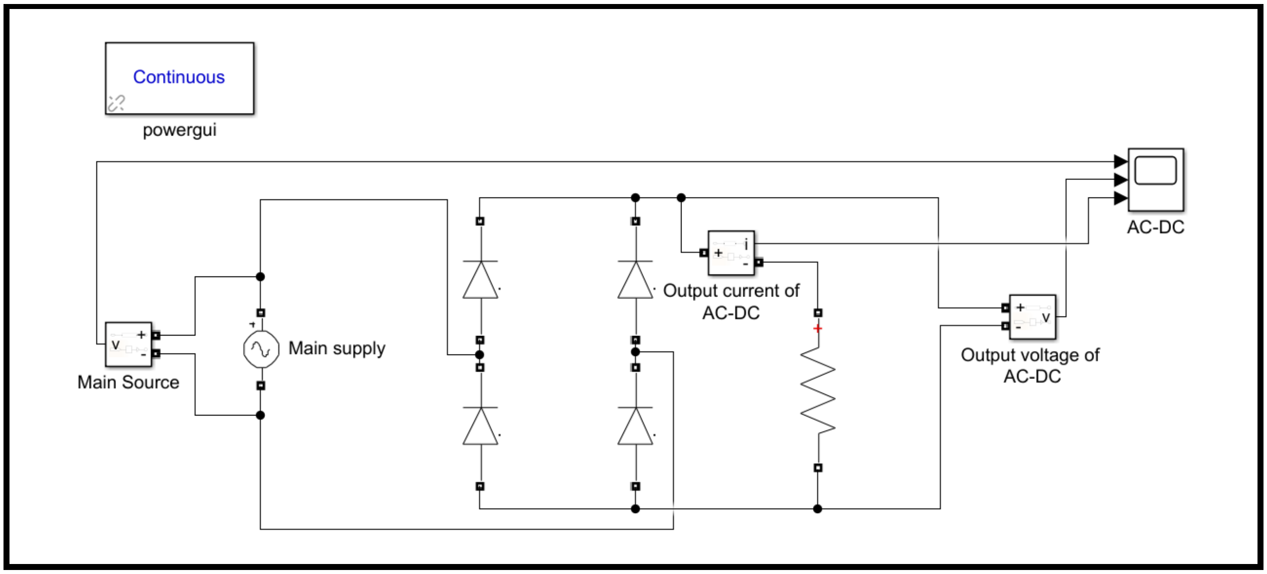


Figure: Simulink AC-DC converter

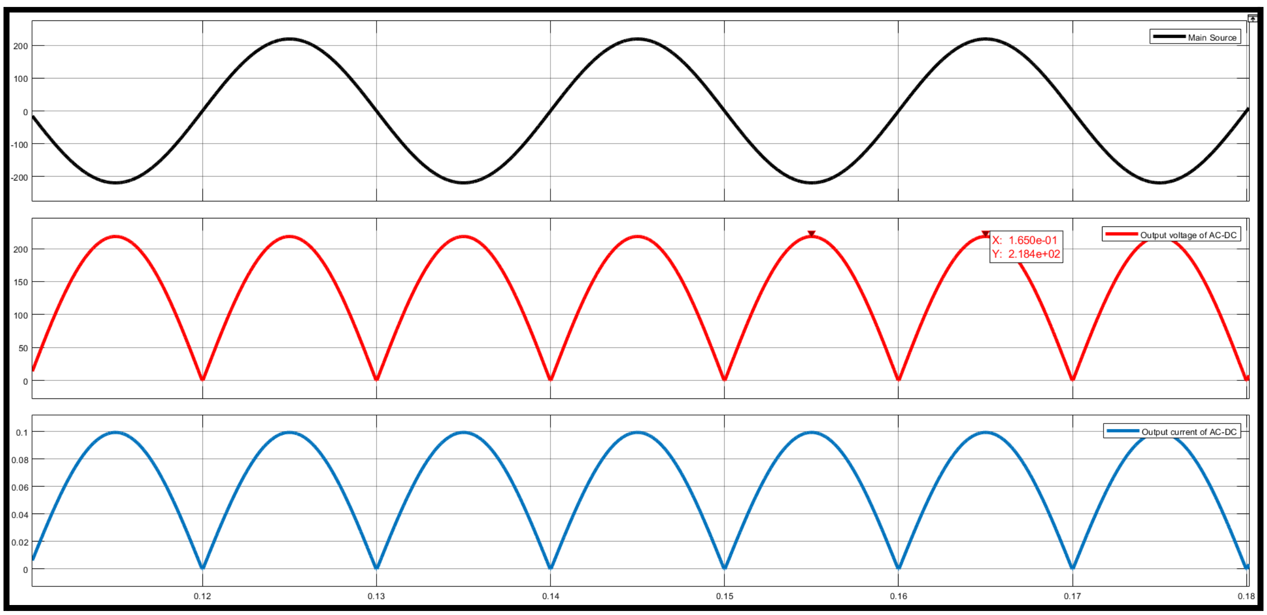


Figure: Output graph of the circuit(No filter capacitor)

Filter capacitor: Here due to two diodes per half cycle are turned on, so the output has a voltage drop of 1.6V. But the output is not pure DC. So we had to insert a filter capacitor in the circuit.

Ripple voltage $V_r = 0.1V$.

Load of the circuit is R = 2200Ω.

Peak voltage $V_p = 218.4V$.

Time between two consecutive peaks $\Delta t = 0.01\, second$.

So the filter capacitor, $C = \frac{V_p \times \Delta t}{R \times V_r} = \frac{218.4 \times 0.01}{2200 \times 0.1} = 0.009927 = 0.01F$.

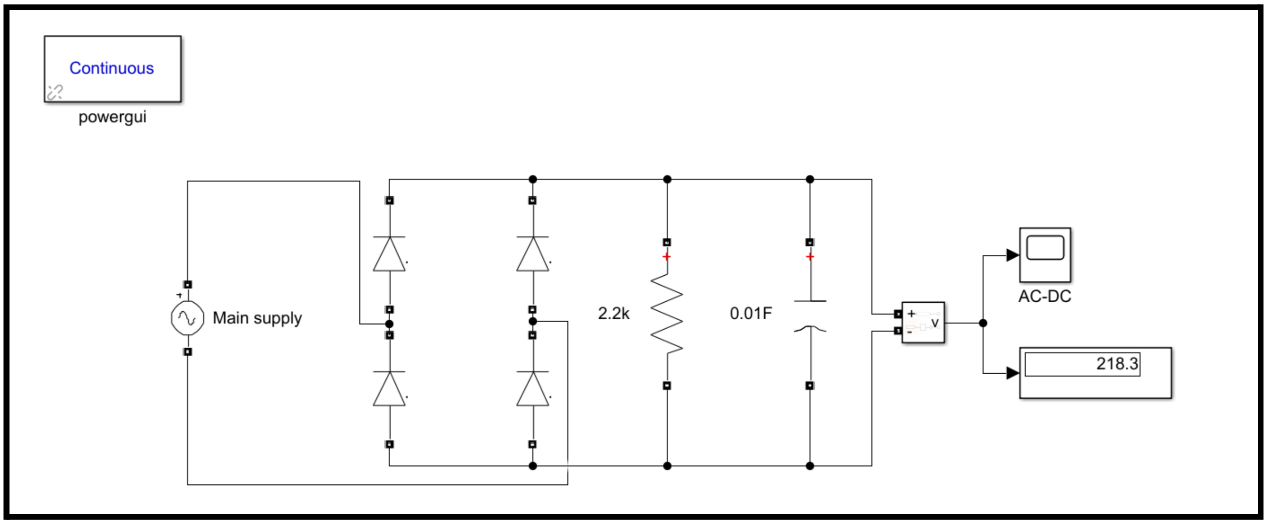


Figure: Circuit with filter capacitor

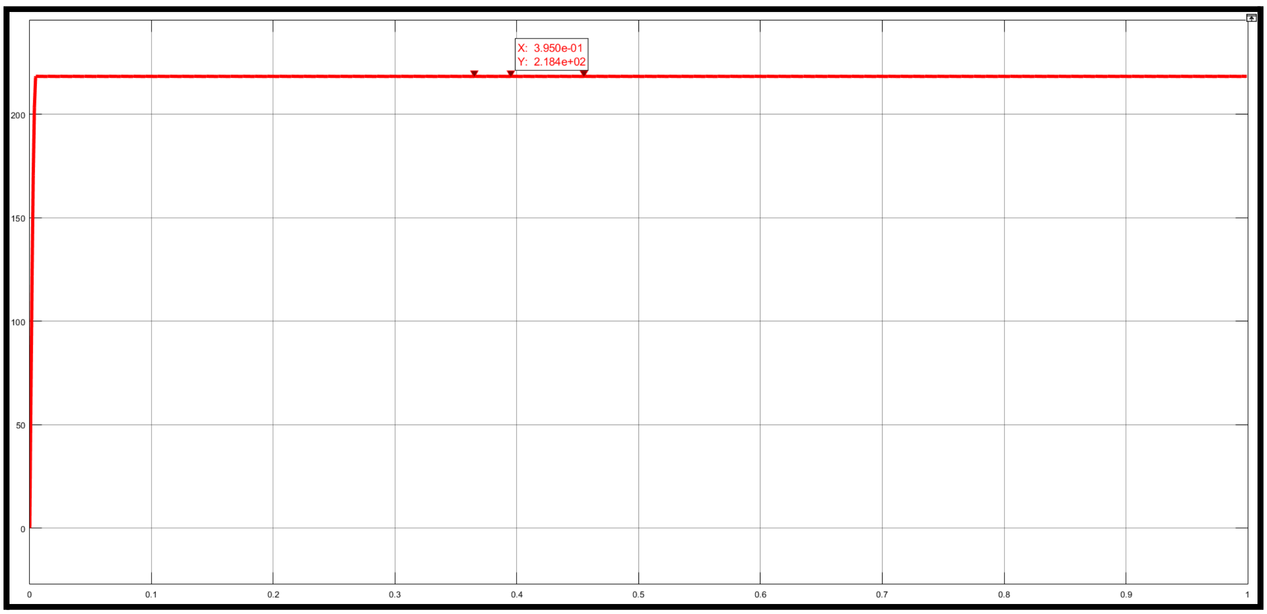


Figure: Output graph of the circuit (With filter capacitor)

Buck converter: According to the block diagram now we need to step down the output to 17V.

So input $V_S = 218.4V$. Output $V_o = 17V$. System frequency f = 50Hz. Load R = 10Ω.

Duty cycle $D = \frac{17}{218.4} = 7.7838\%$

Inductor $L_{min} = \frac{(1-0.0778338)\times10}{2\times50} = 0.09216H.$

10 times the minimum value ≈1H

Capacitor $C = \frac{(1-0.0778338)17}{8\times1\times0.1\times50} = 0.0078384\text{F}.$

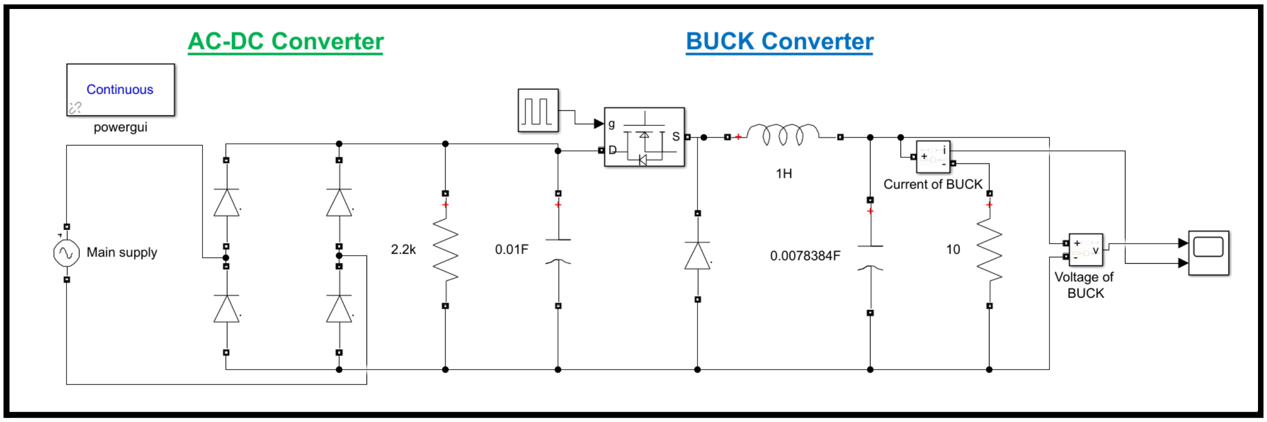


Figure: Circuit of buck converter cascaded with AC-DC converter

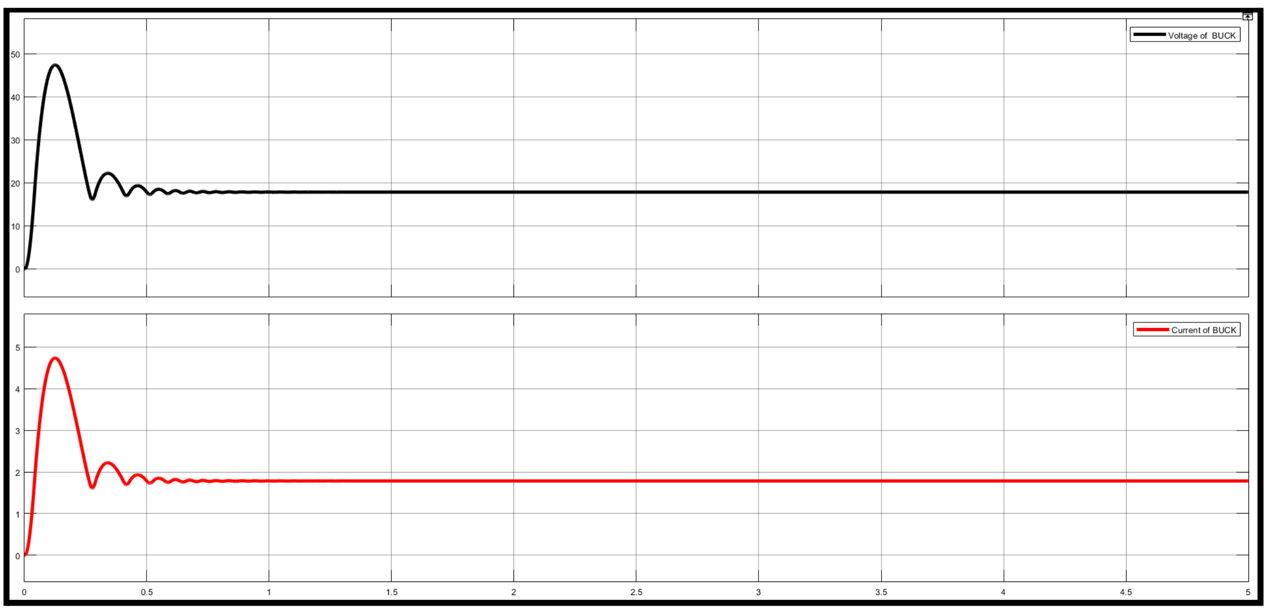


Figure: Output of the graph

Feedback: According to our specifications the input can vary, So we changed the input and simulated the circuit. According to our observations the output varied whenever the input was varied. When the input was 250V the output was 18.5V which is not in +/-1V acceptable range. When the input was 200V the output decreased and became 14.63V. These results can be seen from the attached following figures.

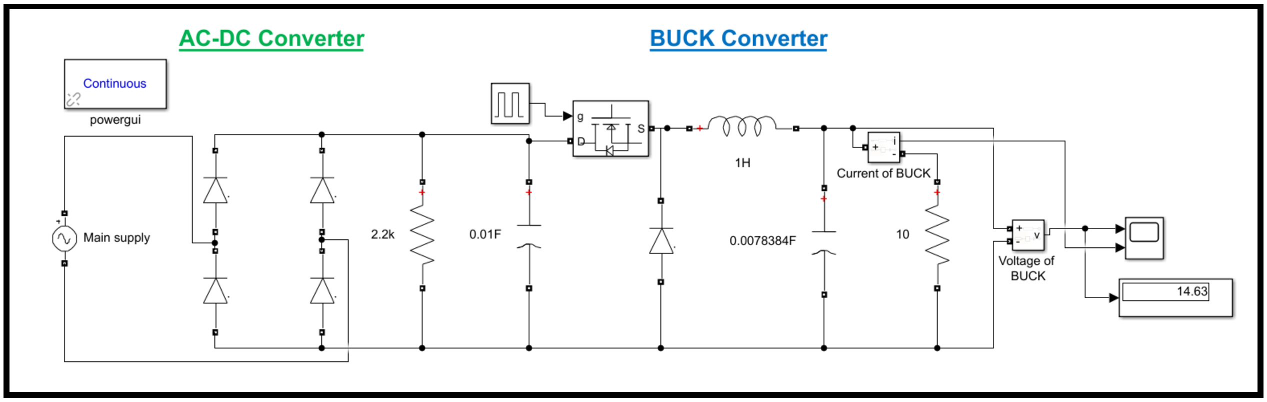


Figure: Output of buck converter 14.63V when input 200V

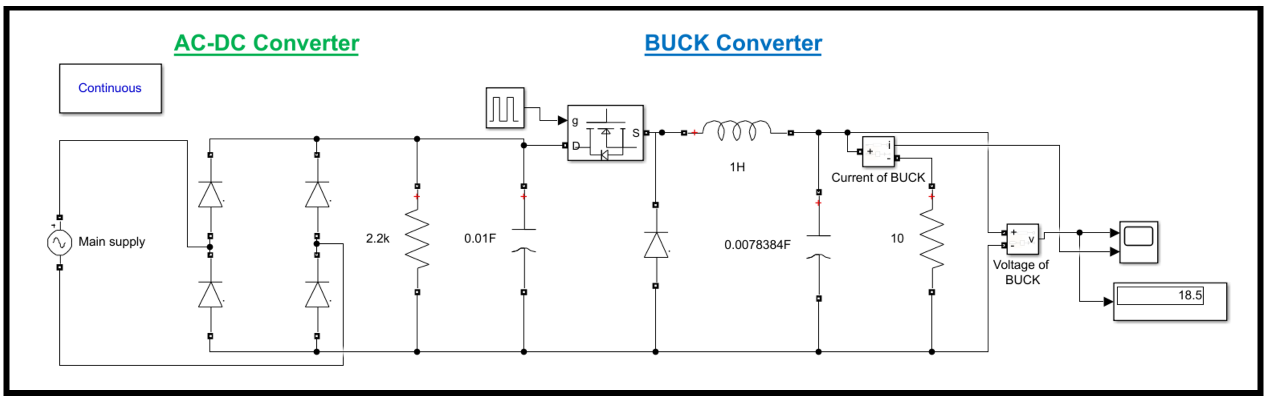


Figure: Output of buck converter 18.5V when input 250V

To correct the output close to 17V with an acceptance rate of +/-1V we used a feedback system. We generated the same pulse signal with a sawtooth generator. The output of the circuit is compared to a constant 17V and according to that the pulse was generated using zero crossing detection technique.

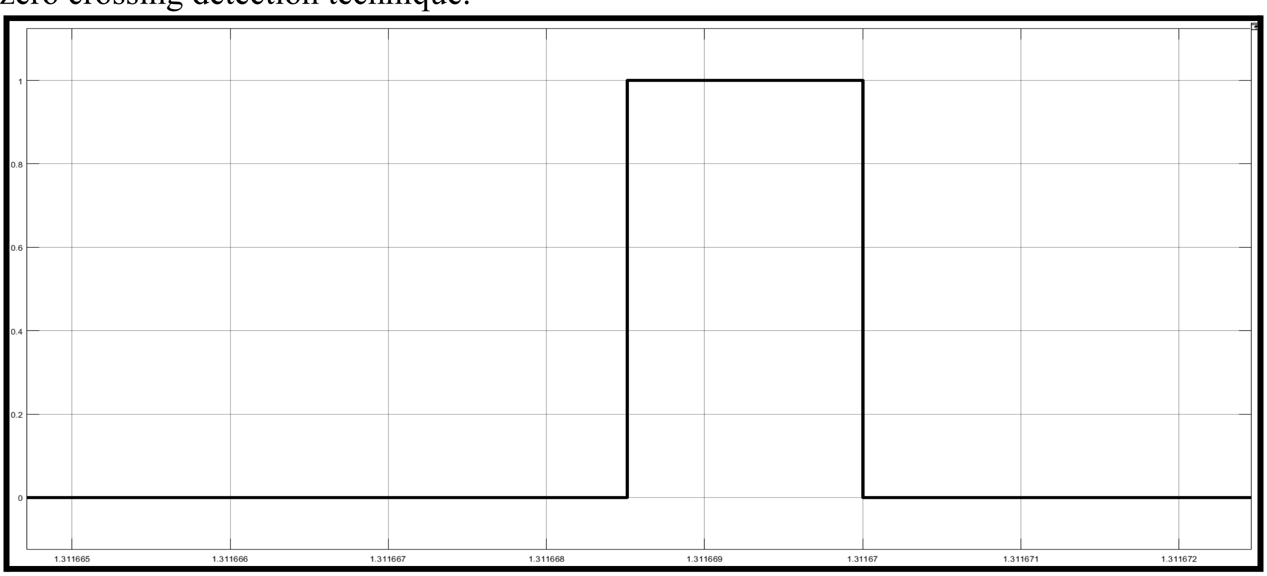


Figure: Gate pulse when input 250V

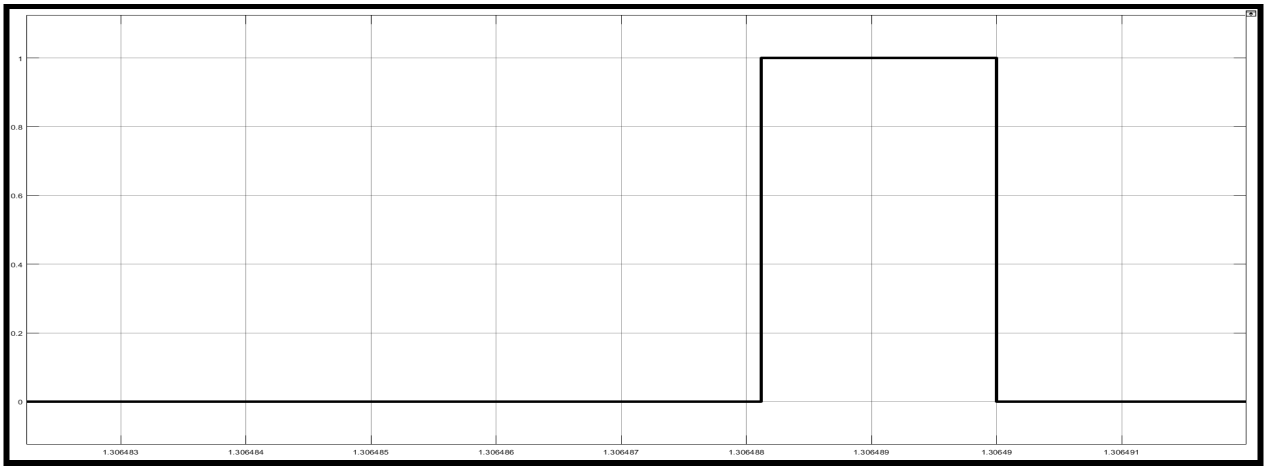


Figure: Gate pulse when input 200V

When input is 250V gate pulse time = 1.3167-1.3116685=0.005s.
When input is 200V gate pulse time = 1.30649-1.306488=2e-6s.
So, feedback is working perfectly to correct the output.

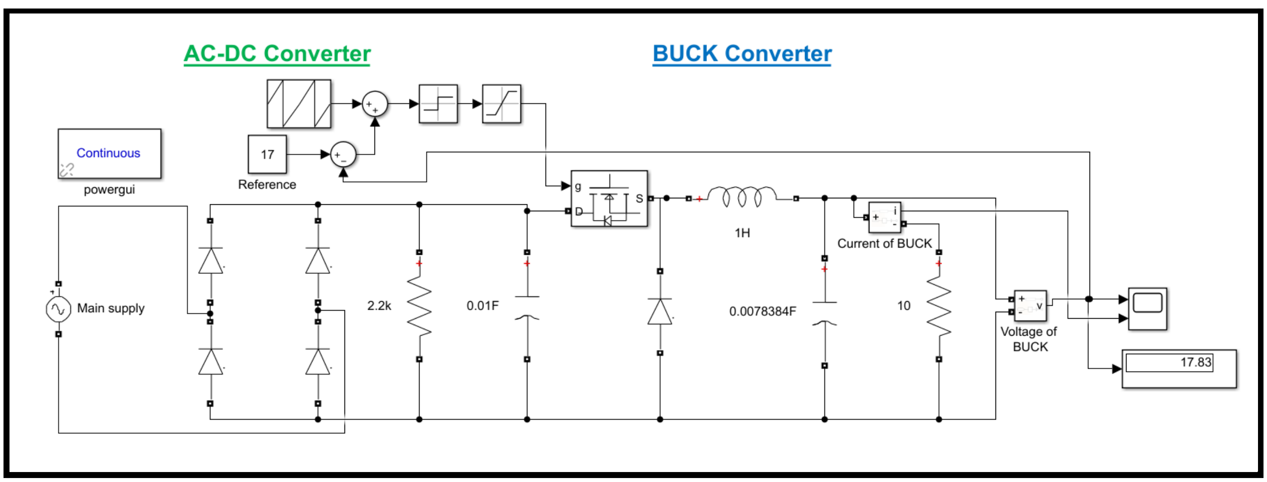


Figure: Output of buck converter 17.83V when input 220V with feedback

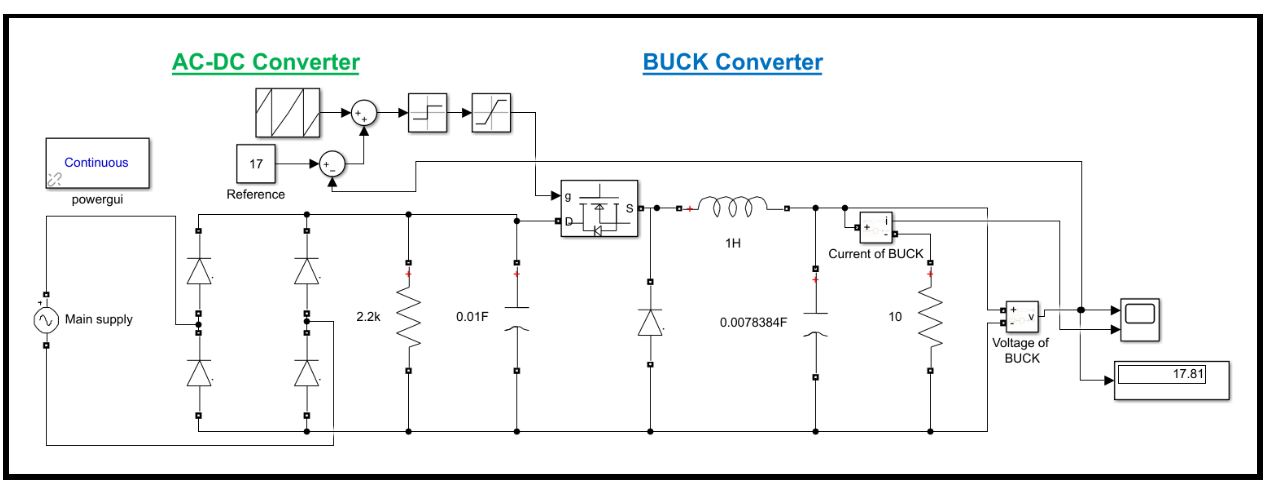


Figure: Output of buck converter 17.81V when input 200V with feedback

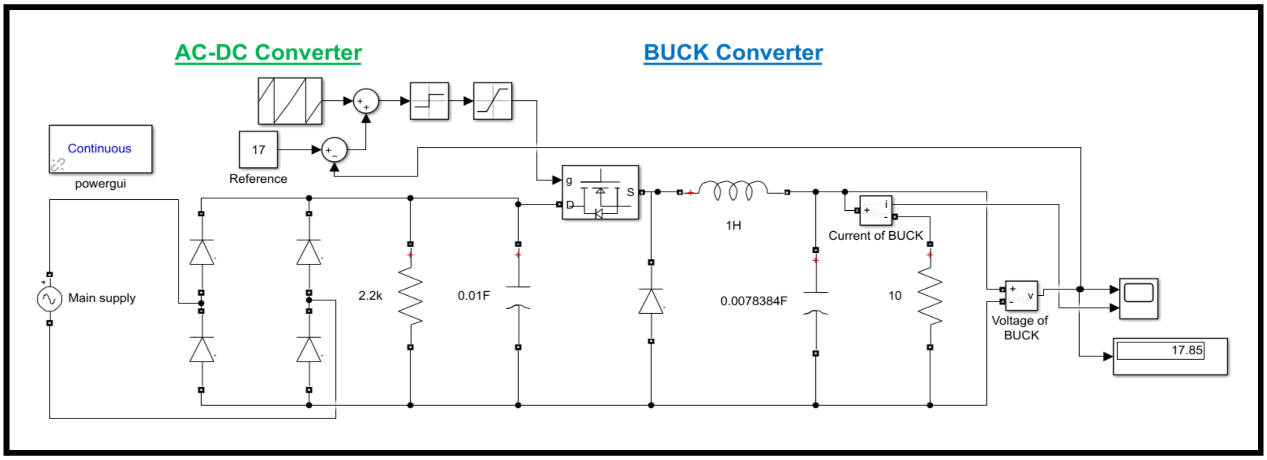


Figure: Output of buck converter 17.85V when input 250V with feedback

Voltage regulation of buck converter:

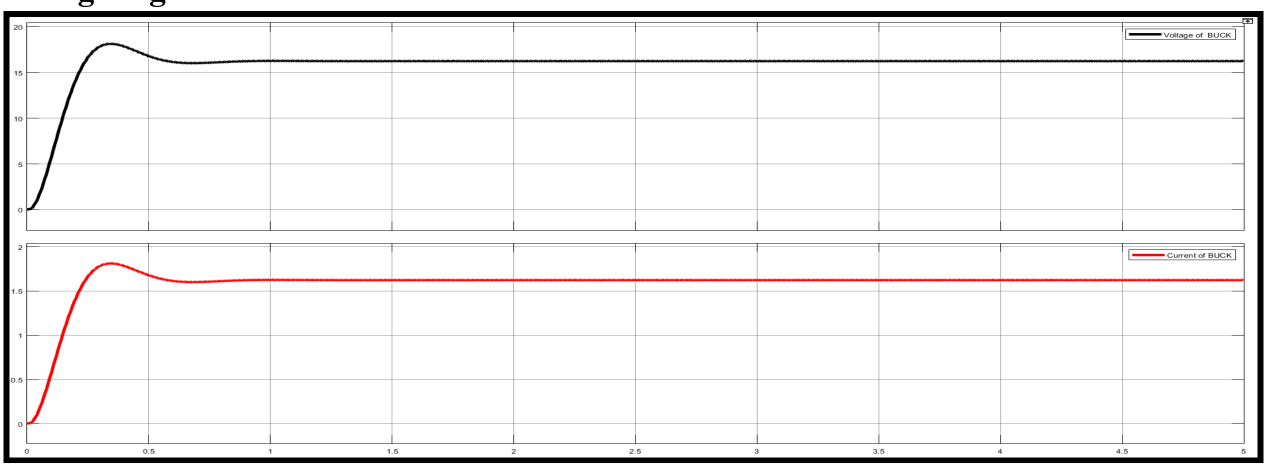


Figure: Output of buck converter 17.81V when input 220V with feedback

In the circuit initially we see voltage a little bit higher than expected. So here we will use a 17V zener diode to chop the excess voltage and get a voltage always less or equal to desired.

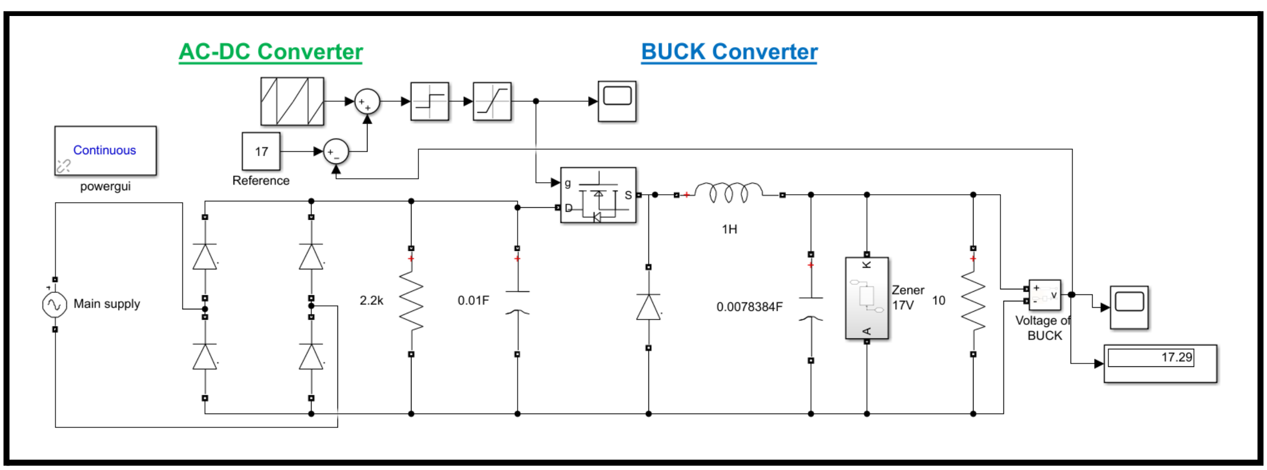


Figure: Output of buck converter 17.3V when input 220V with feedback and regulation

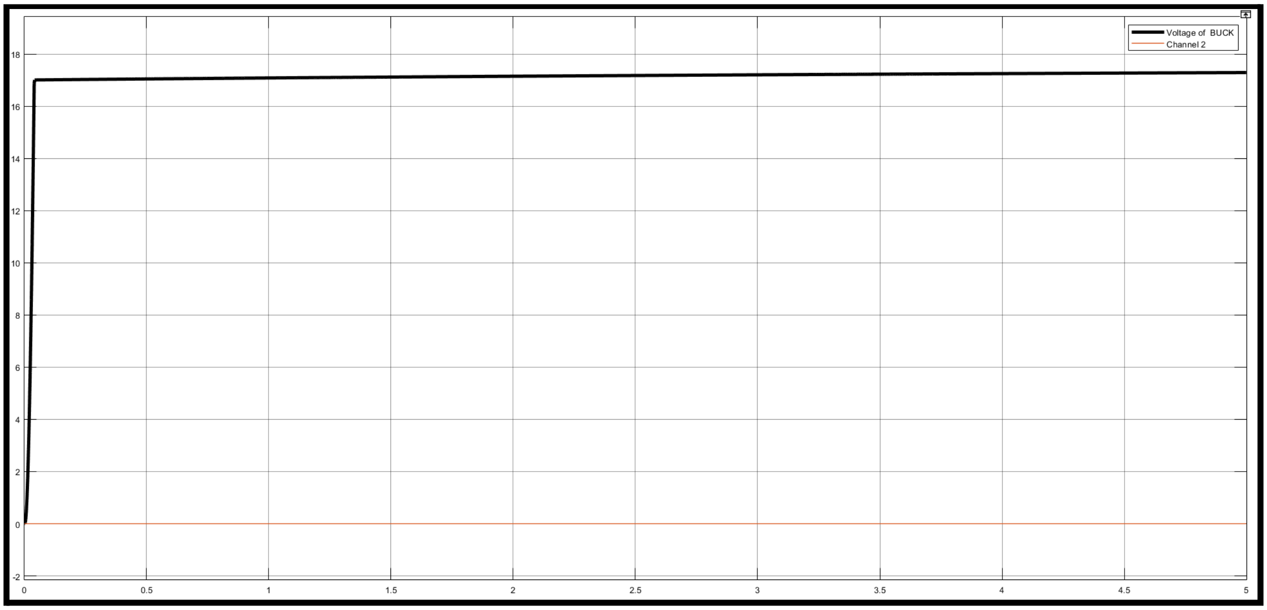


Figure: Output graph of buck converter with regulation

Here we can see with a use of voltage regulation the initial sudden high voltage can be avoided and we get smooth DC output.

Reverse current protection: To stop the battery from discharging itself and to stop reverse current a diode is connected in series with the output. This protects the buck converter from reverse current. Again the voltage drop across the diode is 0.3V and the battery needs a 17V input to charge itself. Without regulation the output was around 17.83V. So we increased the voltage regulator zener to 17.5V. Thus after the diode's voltage drop the output will remain more than 17V.

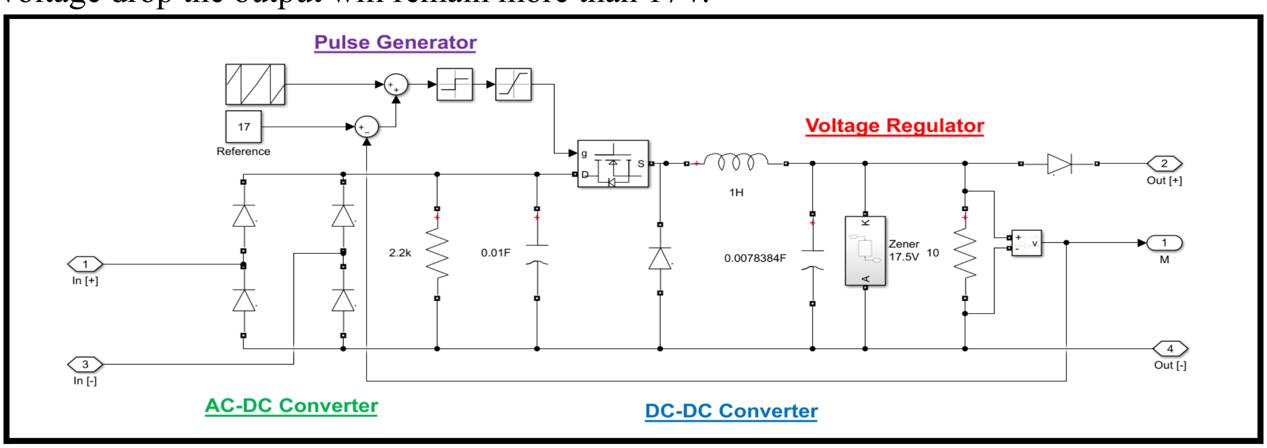


Figure: Circuit diagram with reverse current protection

DC-DC boost converter: This regulated voltage now needs to be stepped-up inorder to feed it to the inverter. Here the boost converter's input is 17V and output should be around 220V. The system frequency is 50Hz and R = 10000.

Duty cycle $D = \frac{V_o - V_S}{V_o} = 92.27\%$

Inductor $L_{min} = \frac{D(1-D)^2 R}{2f} = 0.5513H.$

10 times of minimum inductor value = 5.513H

Capacitor $C = \frac{D \times V_o}{R \times V_r \times f} = 0.04059F.$

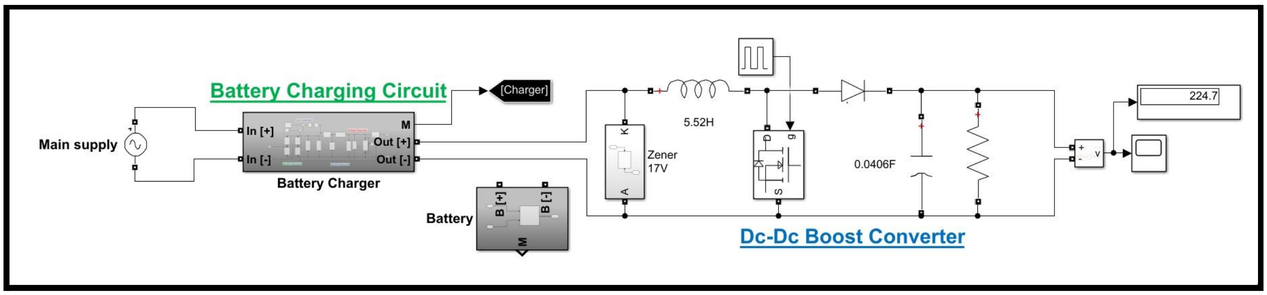


Figure: Boost converter output 224.7V

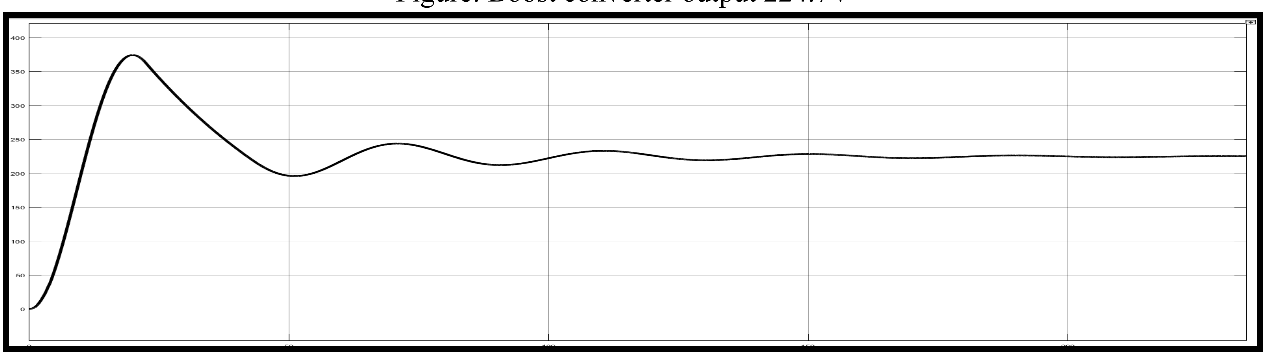


Figure: Boost converter output graph

Voltage regulation of boost converter: Initially the output has very high voltage peaks, To reduce it, we need voltage regulation. So, to cap input at 17V and output at 220V two zeners are used as regulators.

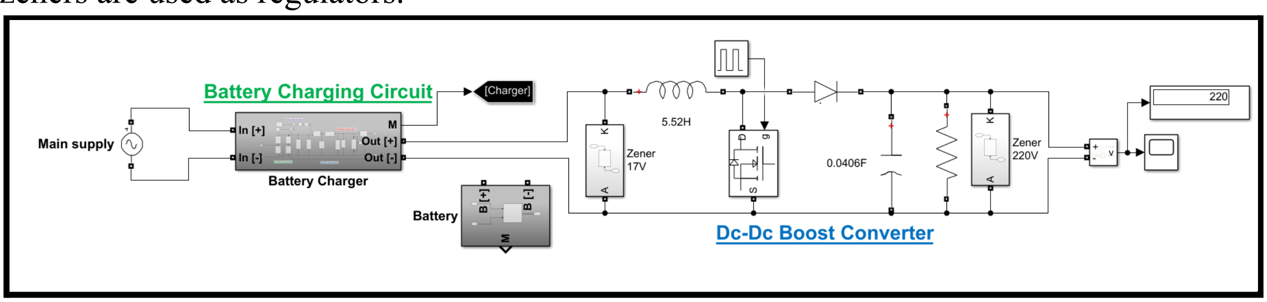


Figure: Boost converter output 220V with regulation

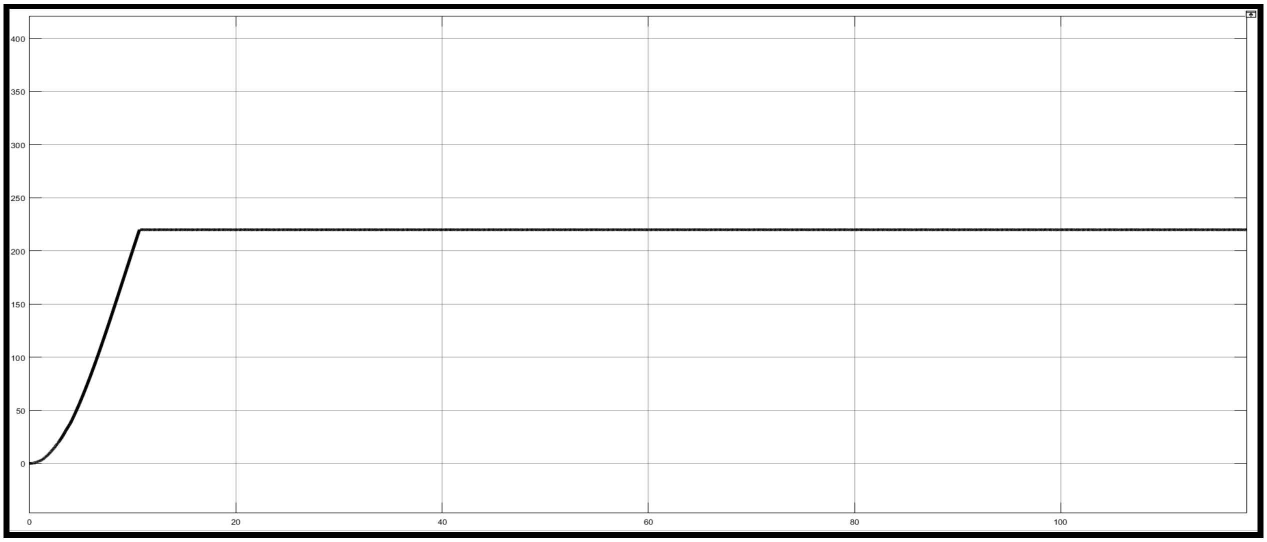


Figure: Boost converter output graph chopped at 220V with regulation

AC-DC converter: This 220V DC needs to be converted to 220V AC. For this we will need to use an AC-DC converter. In the circuit the four mosfets need to be turned on, For positive half cycle the M1 and M2 and for negative half cycle M3 and M4 needs to be turned on. So gate pulses were set accordingly.

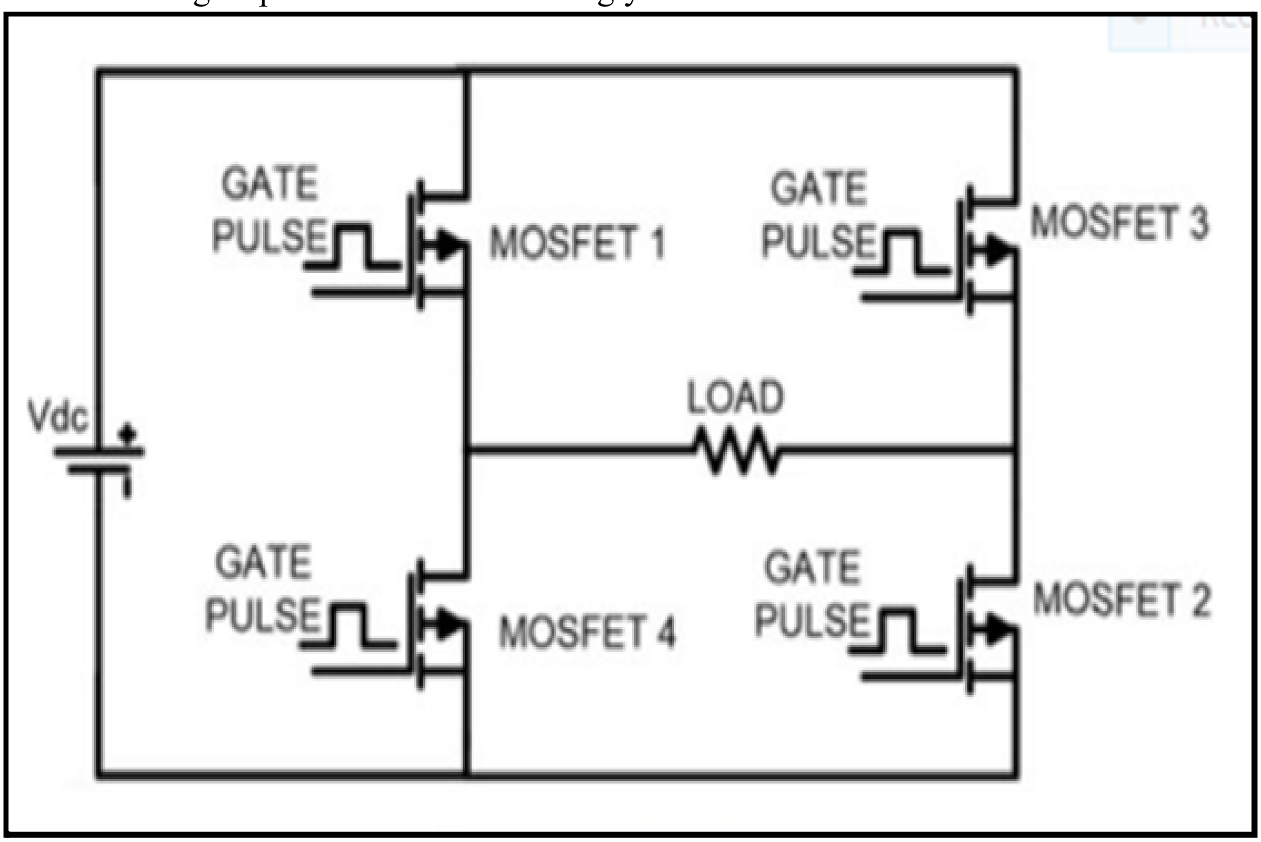


Figure: Circuit diagram of inverter

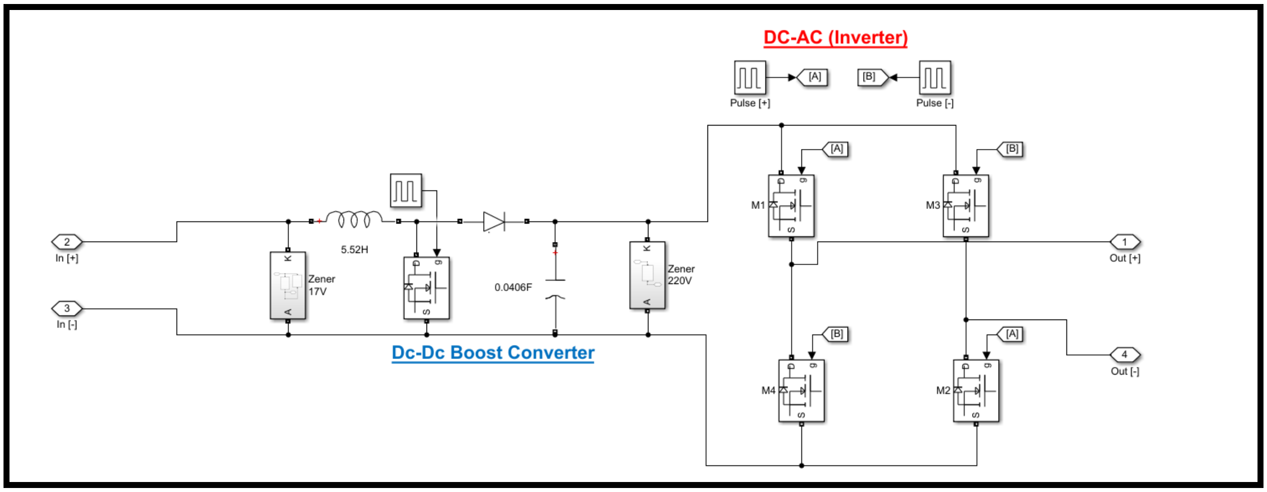


Figure: Simulink circuit diagram of inverter

The load is shifted to the inverter's output terminal.

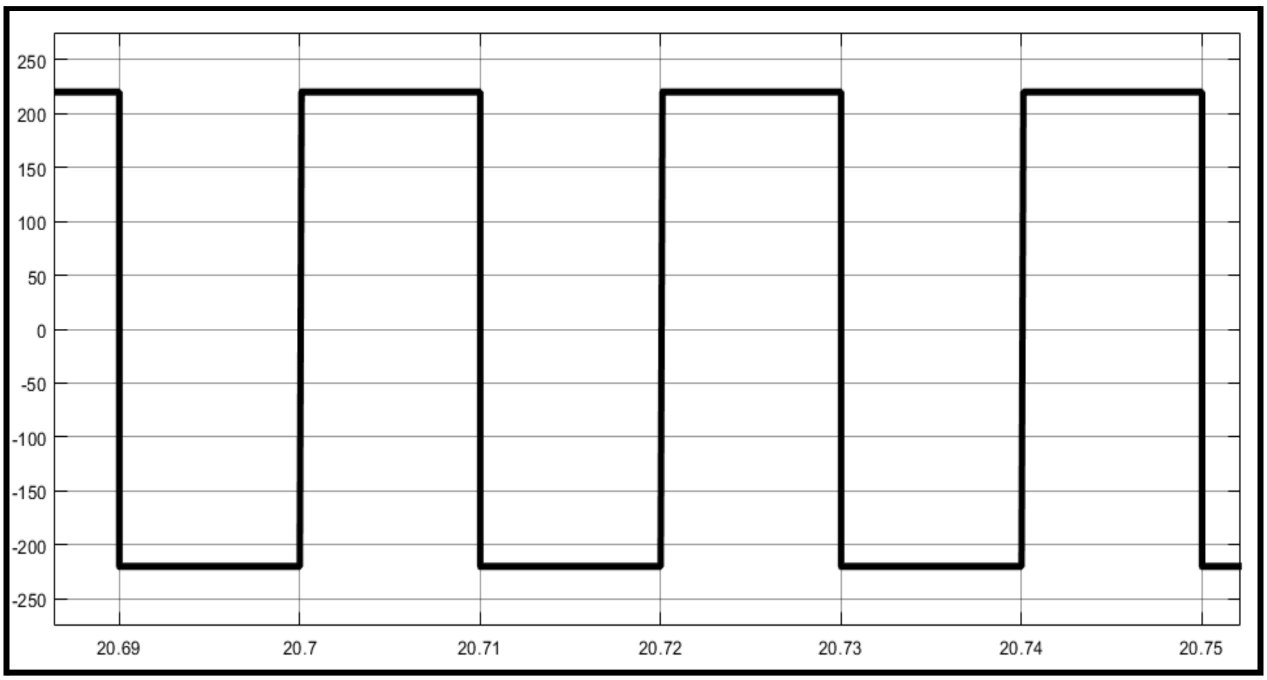


Figure: Output graph of inverter

To make the system automatic we have used switches. Whenever the AC supply is present the switches are designed in such a way that the load is supplied by the AC source and the battery charging circuit is on. When the main is off the battery charging circuit is switched off and the battery to boost converter's circuit is turned on. Thus the system is made automatic.

Finally designed version:
For simplicity of understanding the circuits are converted into sub-system.

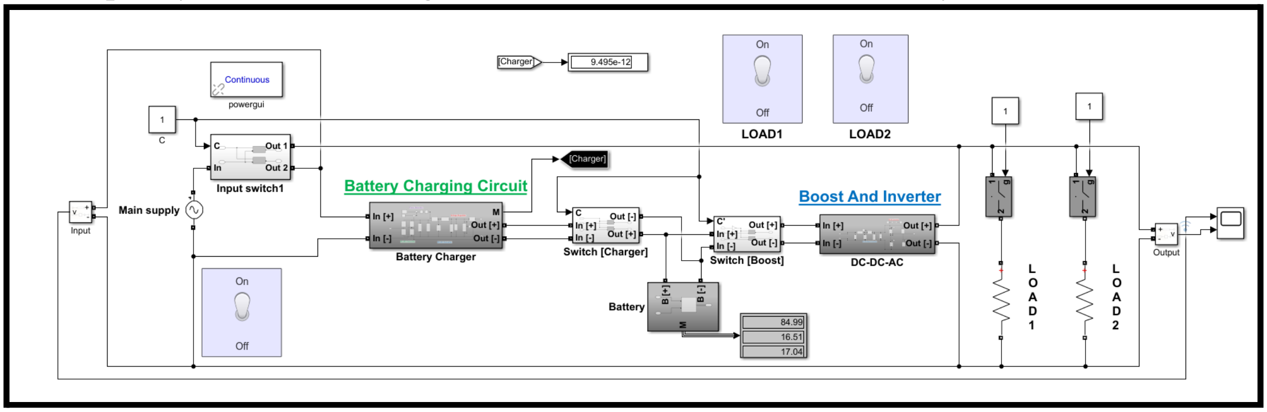


Figure: Finally designed circuit

Timing diagram:

The system's step by step output graphs are shown already in the design segment. So here we will observe only the input and output graph.

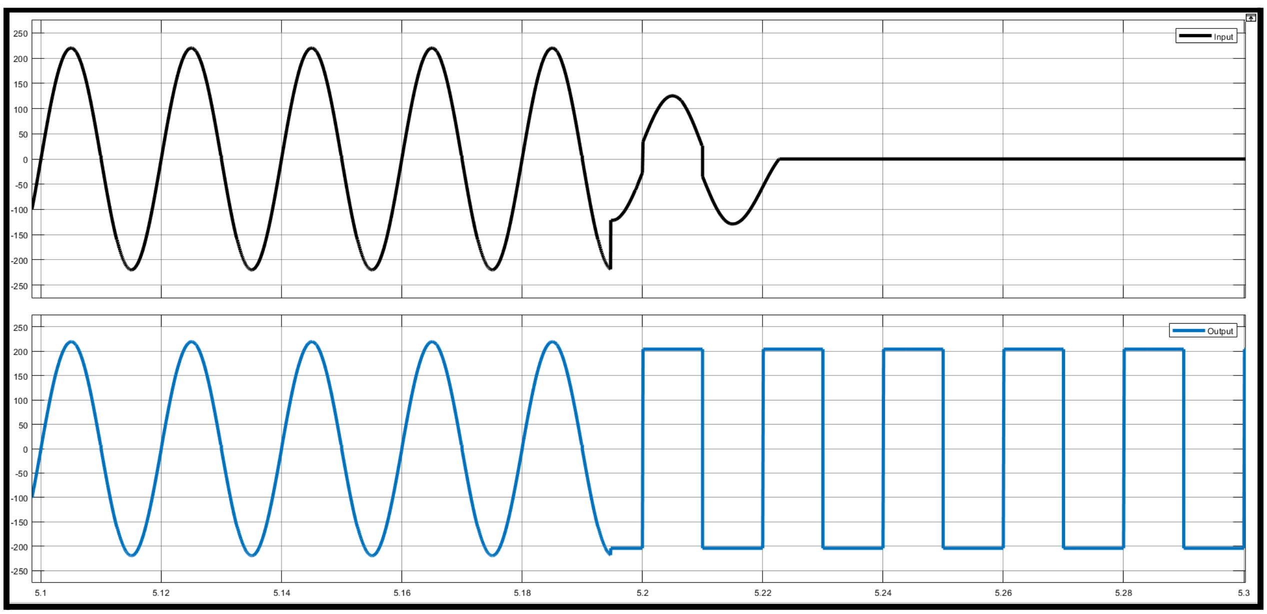


Figure:Input output graph

When the switch is turned on the AC main is supplying to the load, so the output is the same as input, sinusoidal. When the source is turned off the inverter and battery comes into action, thus the output is a 50Hz square wave. But the square wave initially is not 220V. But after some time the output becomes 220V 50Hz square wave.

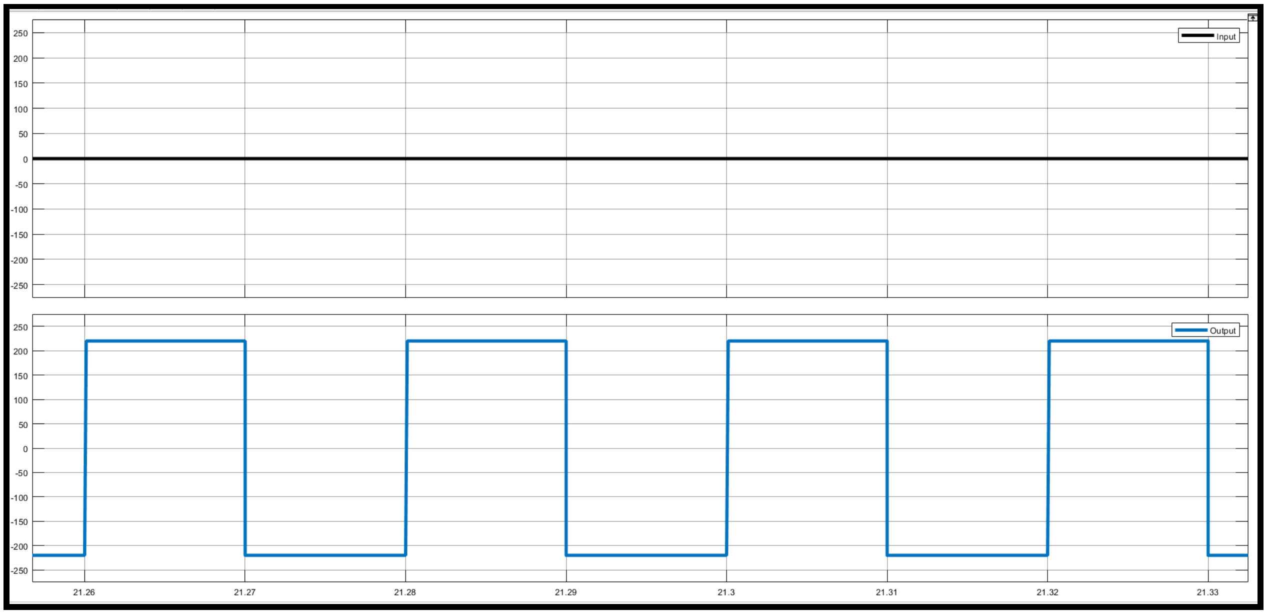
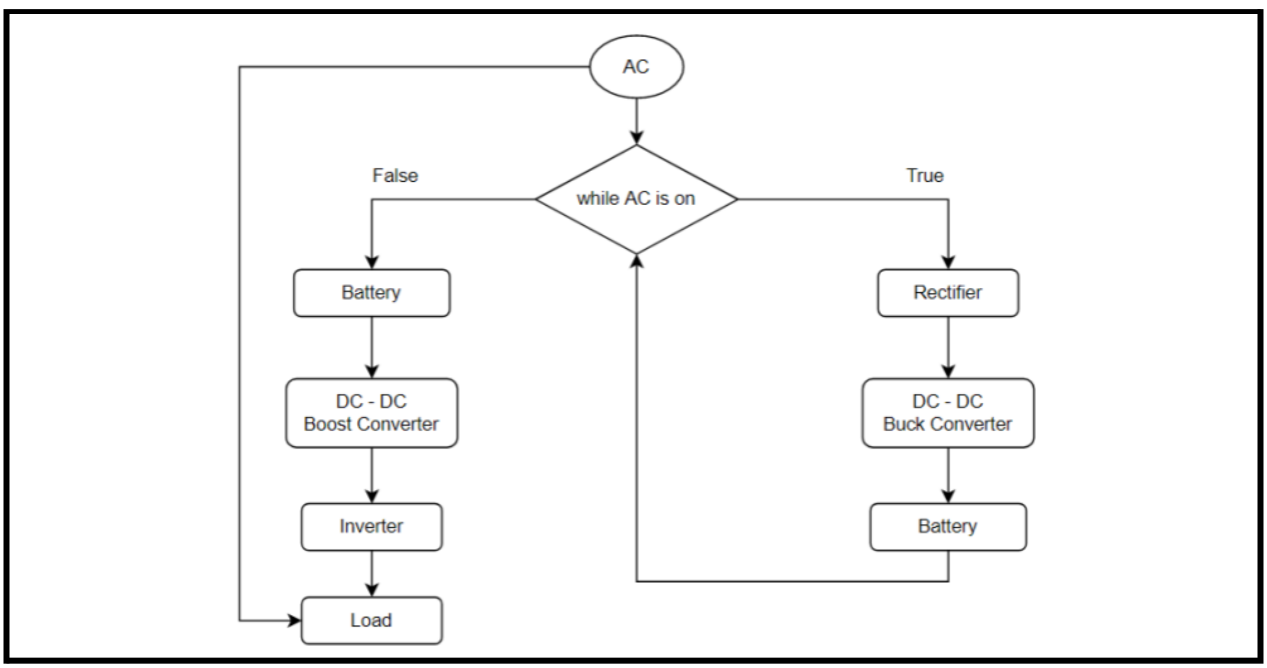


Figure:Input output graph

Here we can see after sometime when the input is off the square wave is of around 220V and the system becomes stable.

Result and observation:



From the flow chart we can see the operation principle of the system.

Working procedure:

Switching mechanism: In the circuit the input was 220V 50Hz AC. As long as there is main available, the switch is in such a position that the input AC and the load is connected. During this time the main is also connected to the battery charging circuit and the output of the battery charging circuit is also connected to the battery . Whenever the main is off the load is disconnected from the main and the battery is also disconnected from the battery charging circuit. During this time the battery to boost converter switch is on.

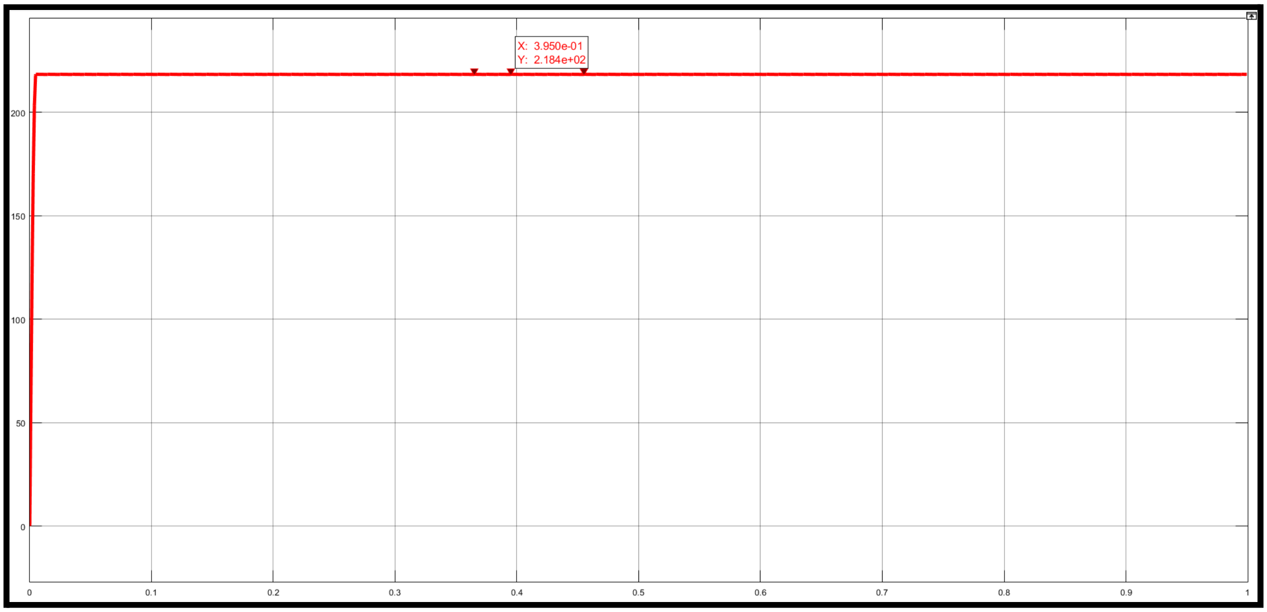
Battery charging circuit: The rectifier converts the AC input to DC and a filter capacitor is connected in parallel to the load, so we get smooth DC. This DC is then stepped-down using a buck converter to around 17V.

DC to AC converter: The 17V is then boosted to 220V DC using a boost converter and the boosted output of the DC-DC boost converter is then fed to the inverter. The inverter is then used to convert the DC to AC 50Hz square wave.

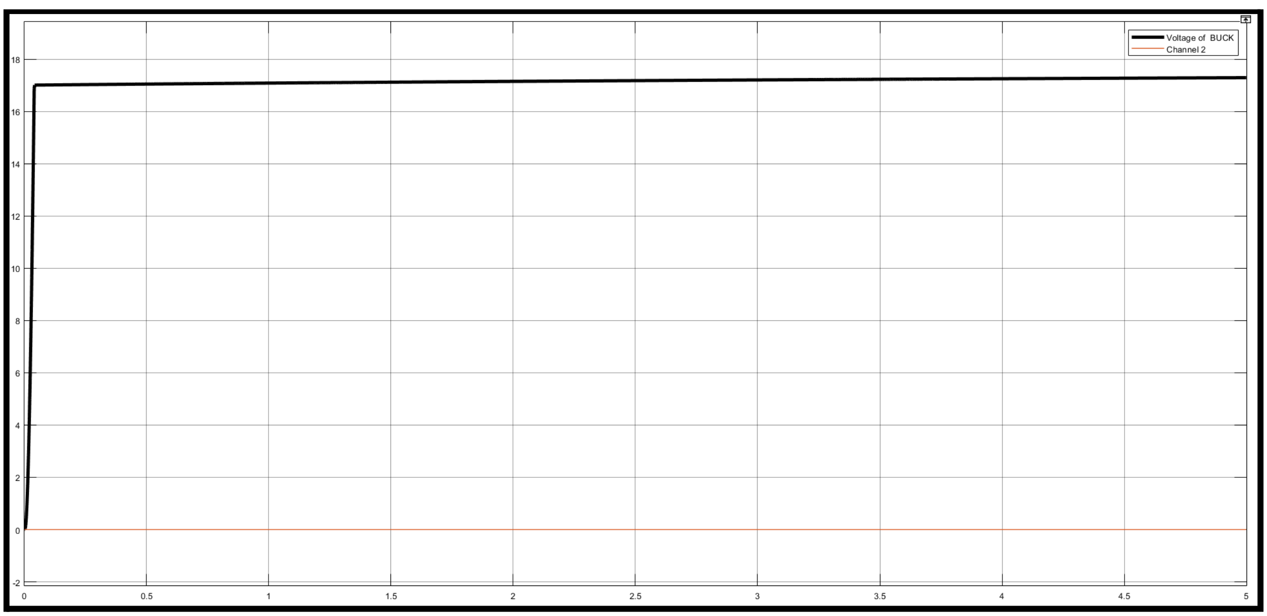
Voltage regulators: In the circuit to cap the output to our desired value we have used a zener diode. The zener diode caps the voltage to our desired voltage resulting in voltage regulation.

Feedback network: There is a feedback loop in buck converter, which compares the output with a certain value and based on that generates an error signal which DC offsets the output of sawtooth and regulated pulse is generated. Thus the feedback keeps the output of the buck converter stable.

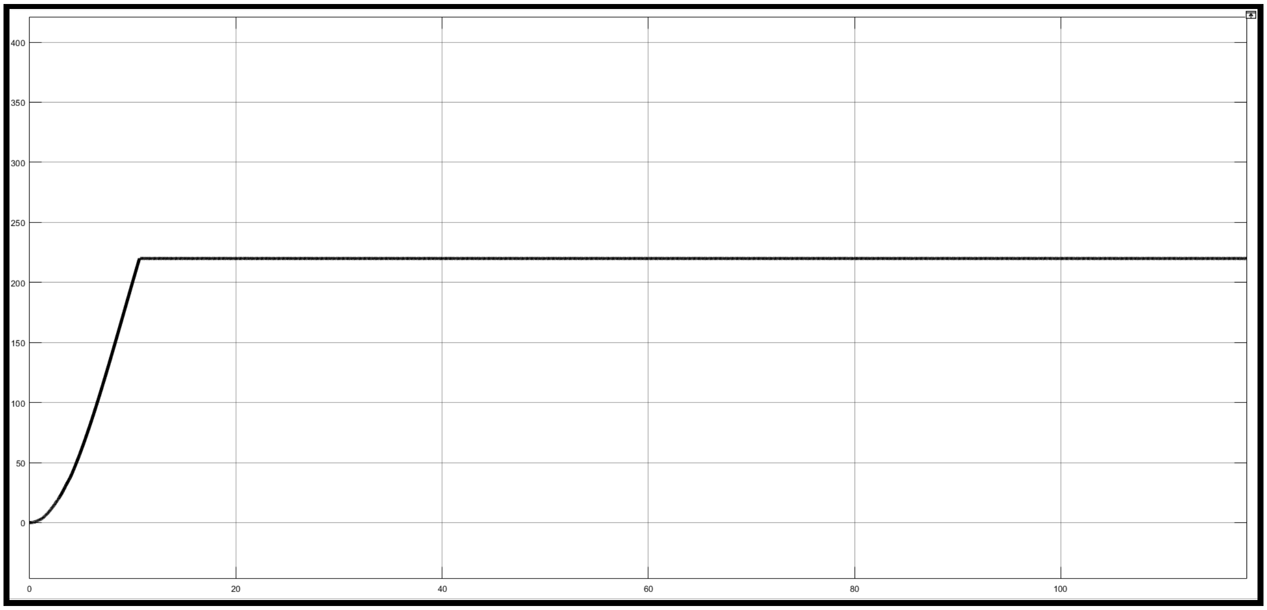
Result and observation:



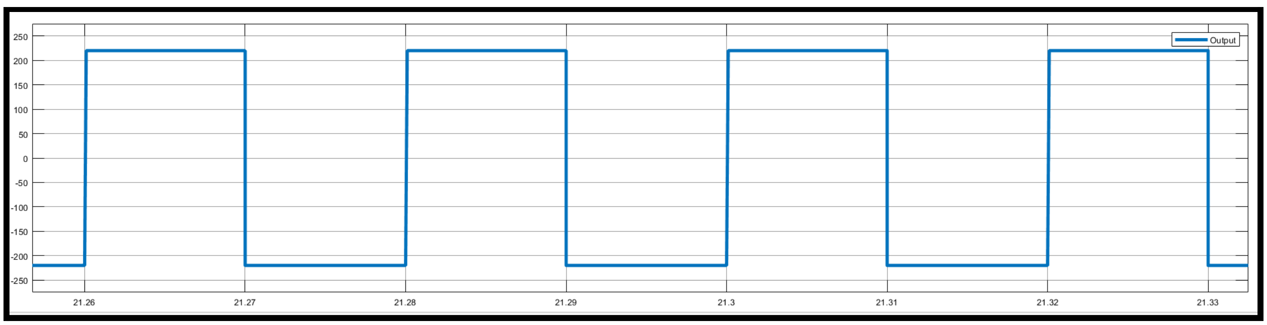
This is the output graph of the AC-DC converter. The resultant graph is stable and smooth DC.



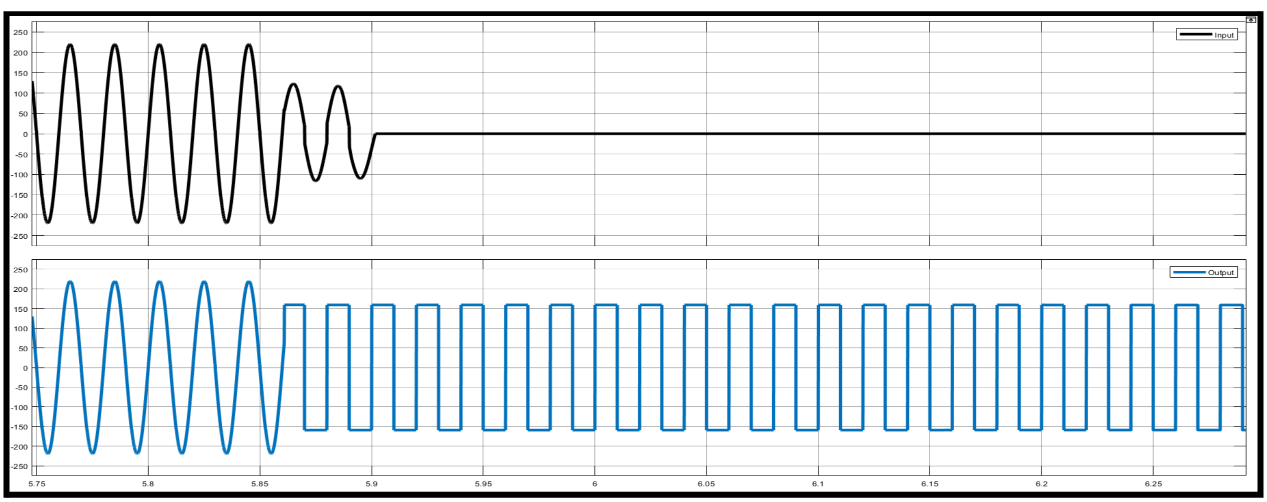
This is the output of a buck converter with voltage regulated output. The output is stable. This is the input for the battery to charge the battery.



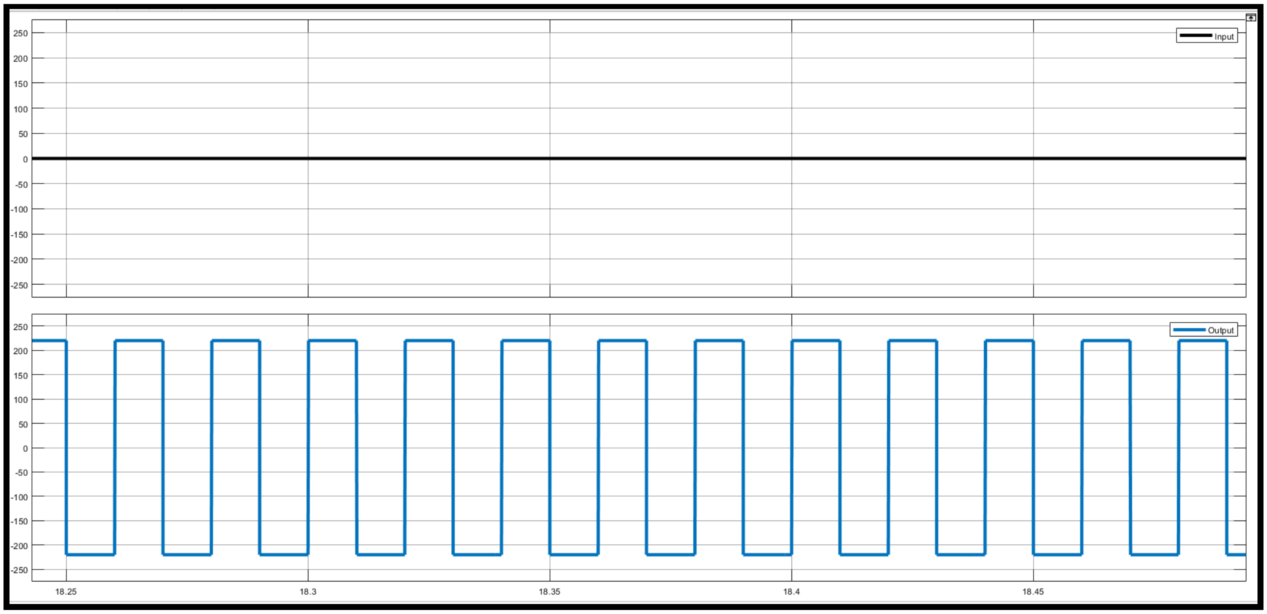
This is the output of the boost converter and the output is capped at 220V and smooth DC.



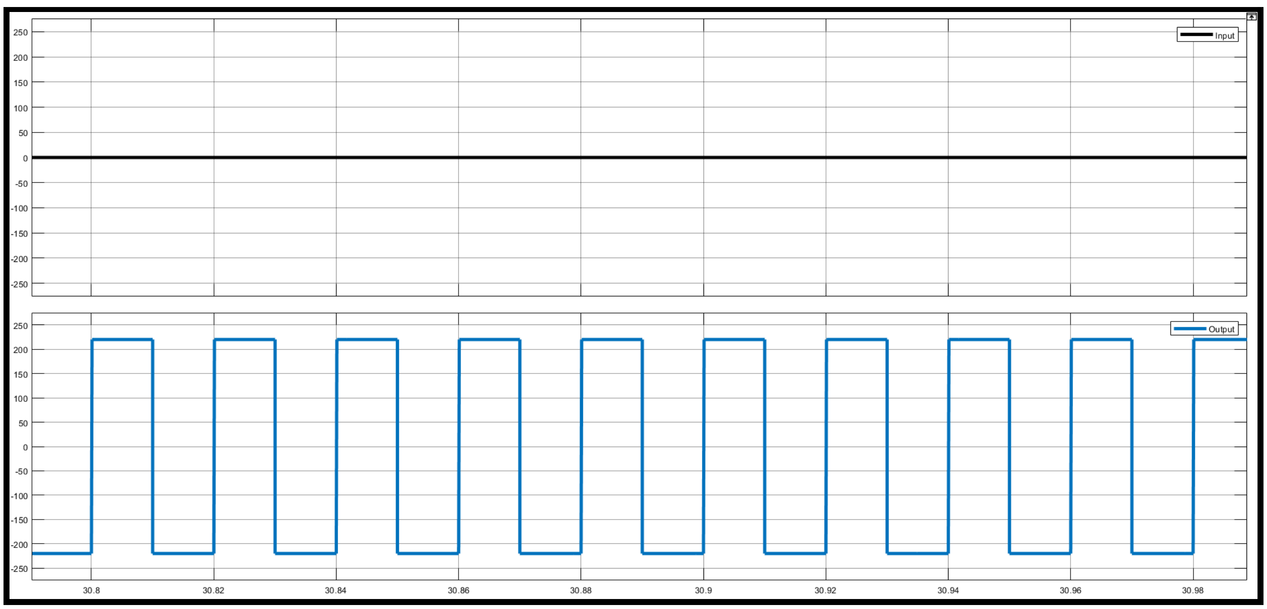
This is the output of the inverter and the output is having 220V 50Hz AC output.



When both the loads are on, the output is initially a little less than the expected output.

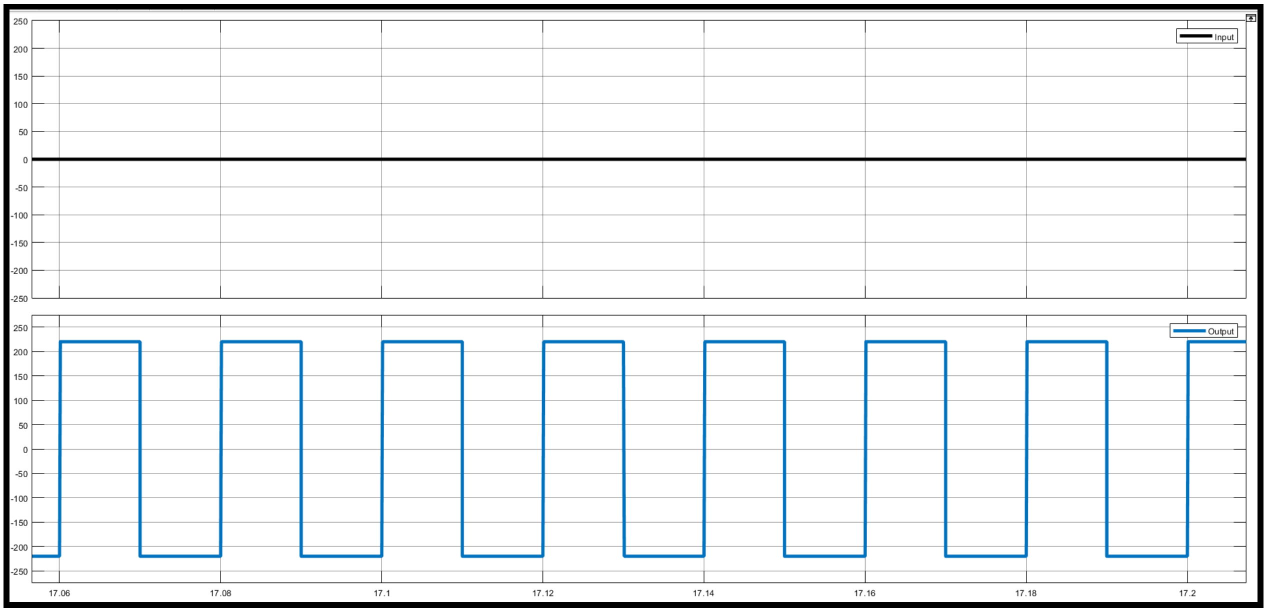


After some time the output has become stable and we are getting 220V square wave. This time both the loads are on.

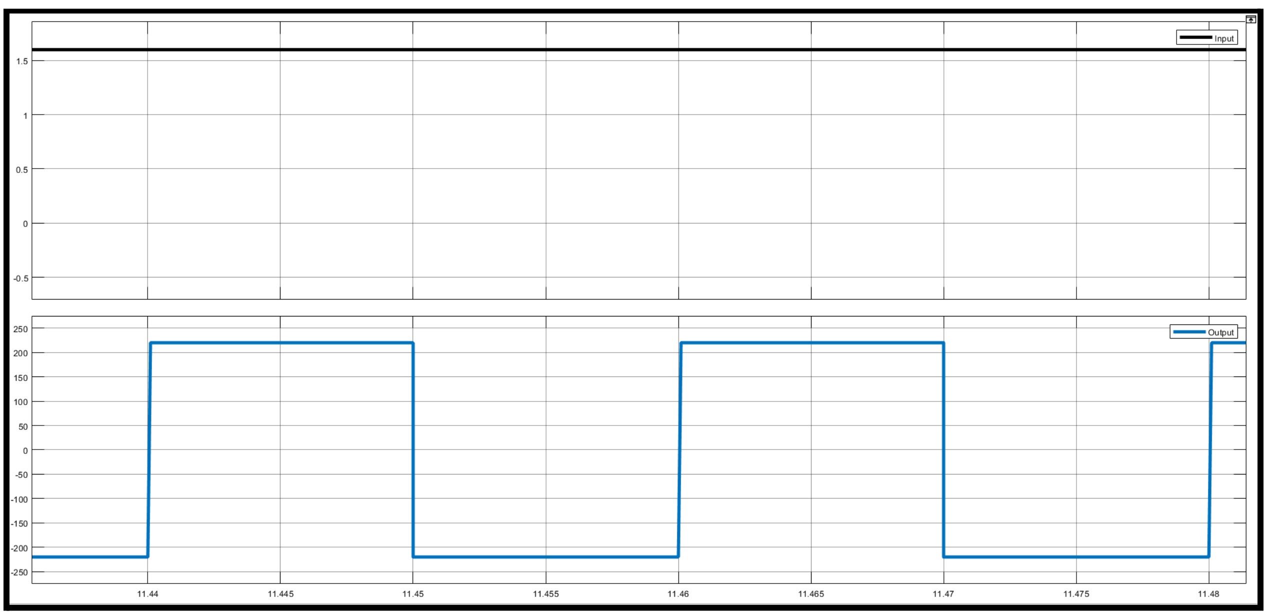


During this time only one load is on and we are still getting 220V square wave as expected.

As the specification states, the input AC may vary. So the output of the system is varied. Initially the input is set as 200V.



Here though the input is changed to 200V, the output is still stable at 220V.

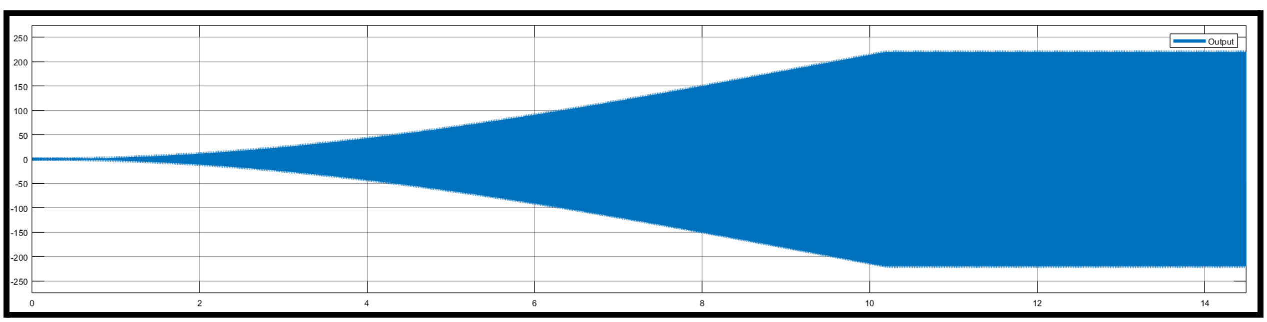


Here though the input is changed to 250V, the output is still stable at 220V.

Though the input of the system is varying from 200-250V the implemented system is outputting a stable 220V 50Hz square wave. So the implemented design is accurate. Whenever the main AC gets disconnected the IPS system gets turned on automatically, thus proving the automatic switching of the IPS during load shedding.

Discussion:

In this project we were asked to design a hypothetical IPS. From our implemented design in matlab simulink we have found out that the implemented system gives us output as expected. Though the design was successful, we still faced some issues during the implementation process. As the input will vary so to correct the output and make the buck converter's output stable 17V we had to implement a feedback system. The feedback system is designed in such a way that the output is sampled and subtracted from a constant, resulting in an error signal. This error signal is used as a DC offset. By using this DC offset, the sawtooth circuit is DC offsetted and finally using a zero-crossing detector we generated the required gate pulse for the system. While generating the pulse rather than using a pulse generator, we used some other blocks and simulated the same system. While implementing the voltage regulator, we couldn't find any zener diode, so we modelled it using a normal diode and changed the forward biasing voltage so that it acts as a zener diode. While implementing the design, we required intensive knowledge of various AC-DC, DC-DC and DC-AC converters. For voltage regulation of the boost converter, when the circuit was implemented with feedback, it worked for a small range, but when we wanted the output of 220V the feedback network didn't work properly. Though we couldn't implement it, using a zener diode as a voltage regulator we overcame the problem of unstable output.



From the graph we can see that initially it took around 10 seconds to make the output stable 220V. The design was done according to the given equations, so this delay is due to the time taken for the boost converter to reach the saturation. Except this small error, the designed system is completely stable and gives proper output, resulting in a successful design of a hypothetical inverter.

Reference:

- https://www.electrical4u.com/boost-converter-step-up-chopper/
- https://www.sciencedirect.com/topics/engineering/buck-converter

Simulation file links:

https://drive.google.com/file/d/1EVg8ENEduRrU5Z0bVWlt45nj6KAcExn2/view?usp=sharing