CSE211s:Introduction to Embedded Systems

Lect. #9: Switched-mode power supply

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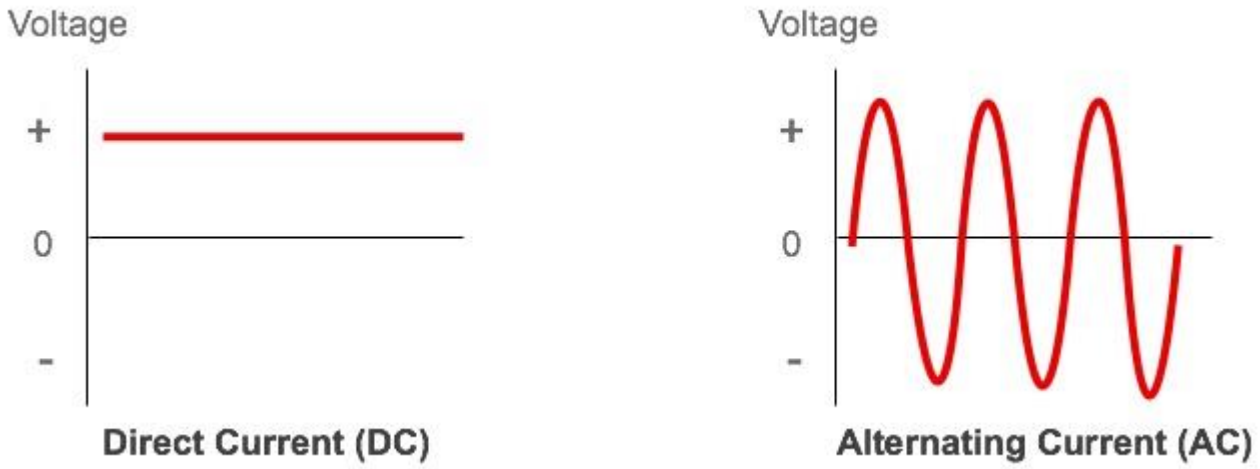
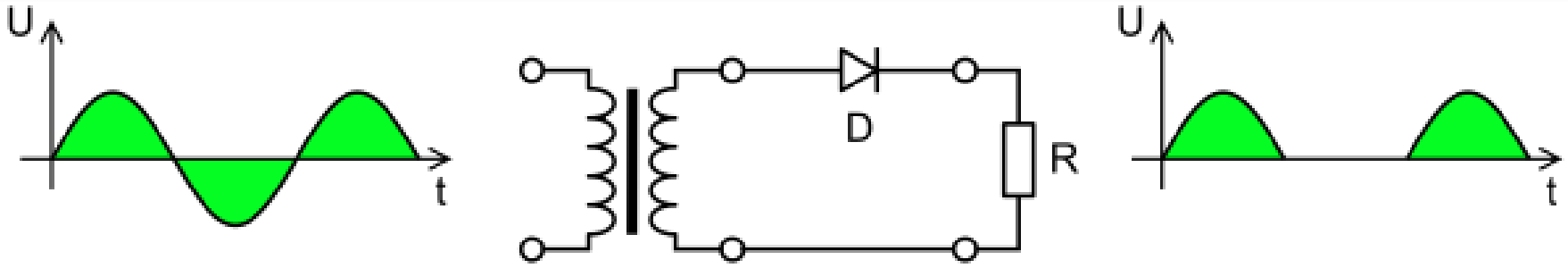
Rectifier

- A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction.



Rectifier

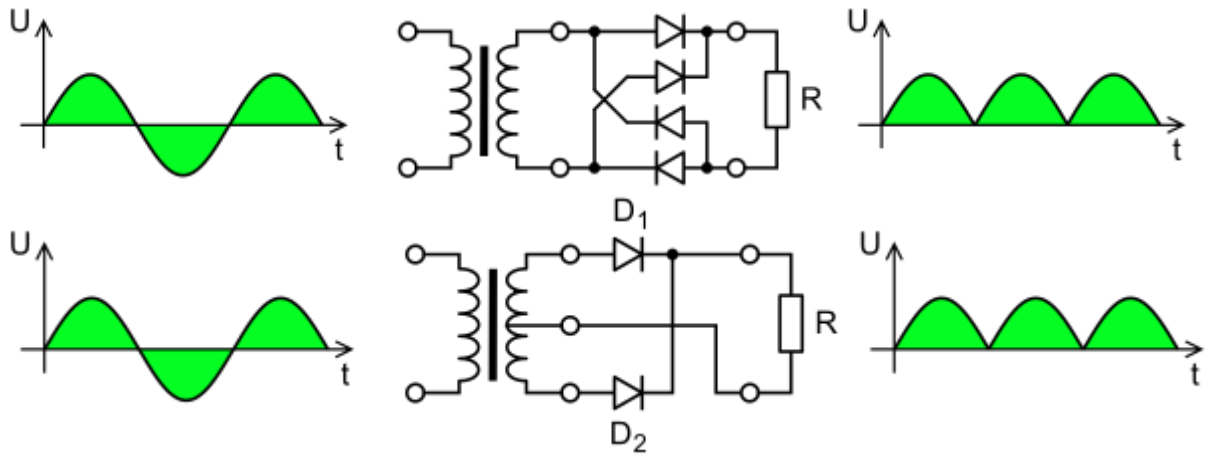
Single-phase rectifiers (Half-wave rectification)



- In half-wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply

Rectifier

Single-phase rectifiers (Full-wave rectification)

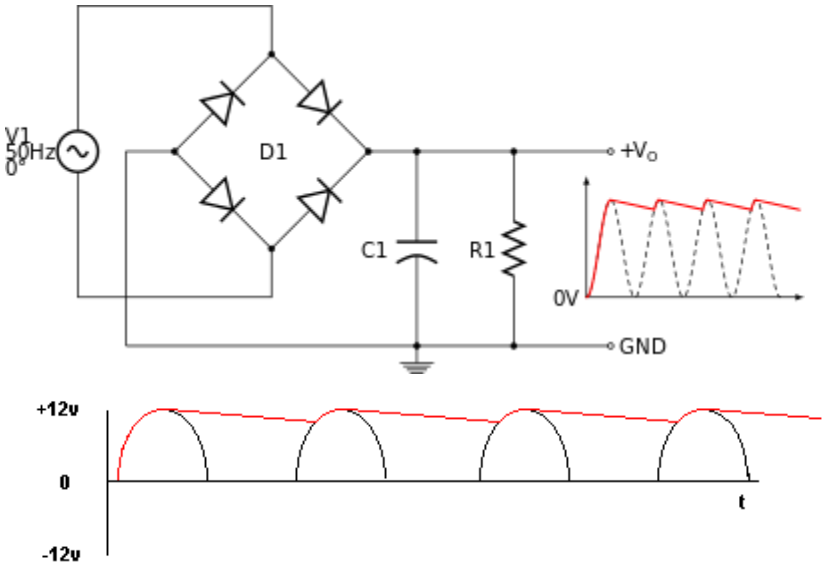


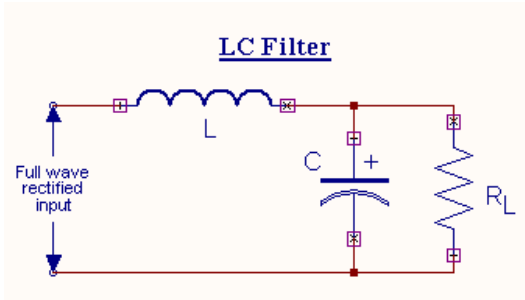
- A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Mathematically, this corresponds to the absolute value function.
- Full-wave rectification converts both polarities of the input waveform to pulsating DC (direct current), and yields a higher average output voltage.

Rectifier

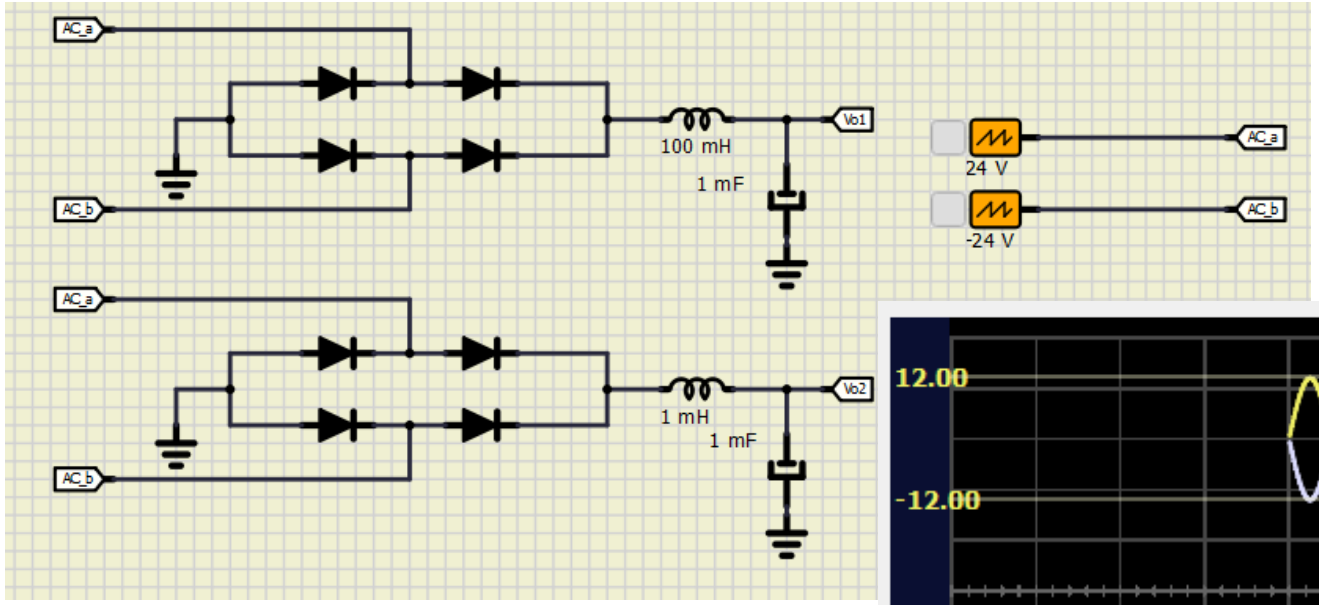
Output smoothing

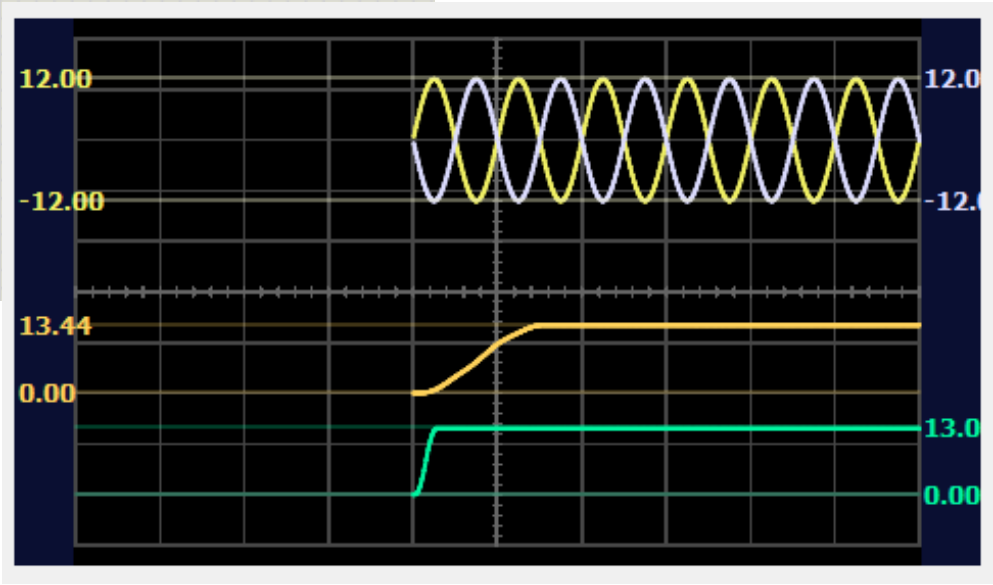
- While half-wave and full-wave rectification deliver unidirectional current, neither produces a constant voltage.
- There is a large AC ripple voltage component at the source frequency for a half-wave rectifier, and twice the source frequency for a full-wave rectifier.
- Ripple voltage is usually specified peak-to-peak.
- Producing steady DC from a rectified AC supply requires a smoothing circuit or filter. In its simplest form this can be just a capacitor (also called a **filter**, reservoir, or **smoothing capacitor**)

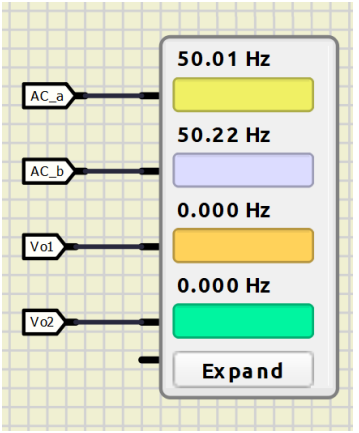




Effect of small/large cutoff frequency

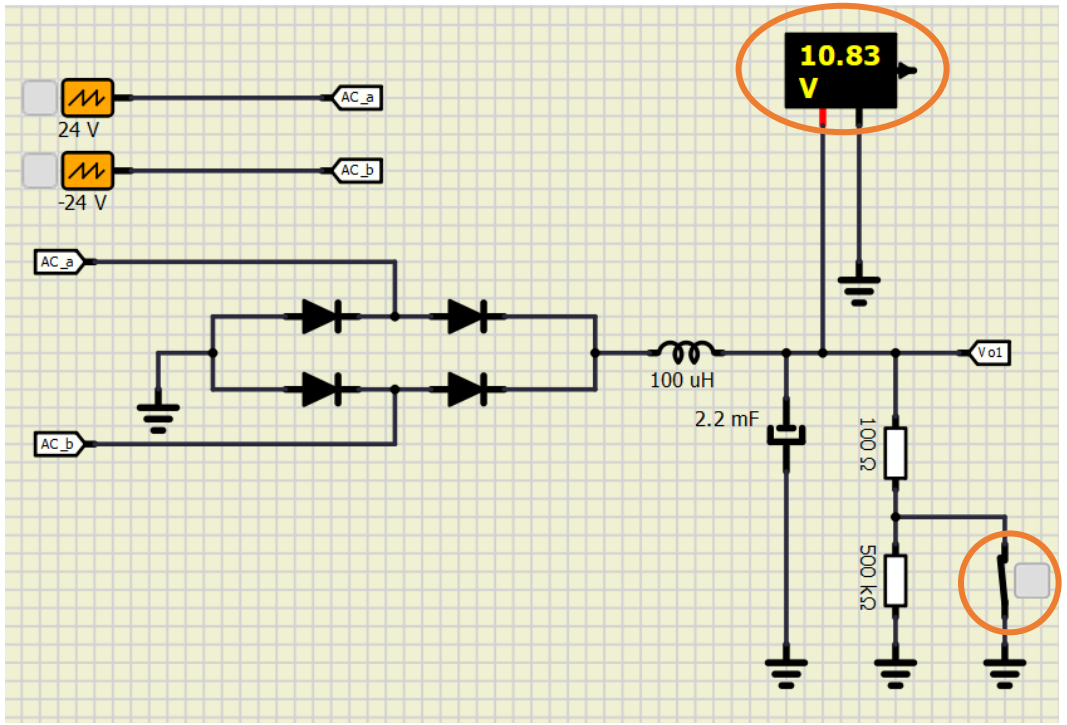


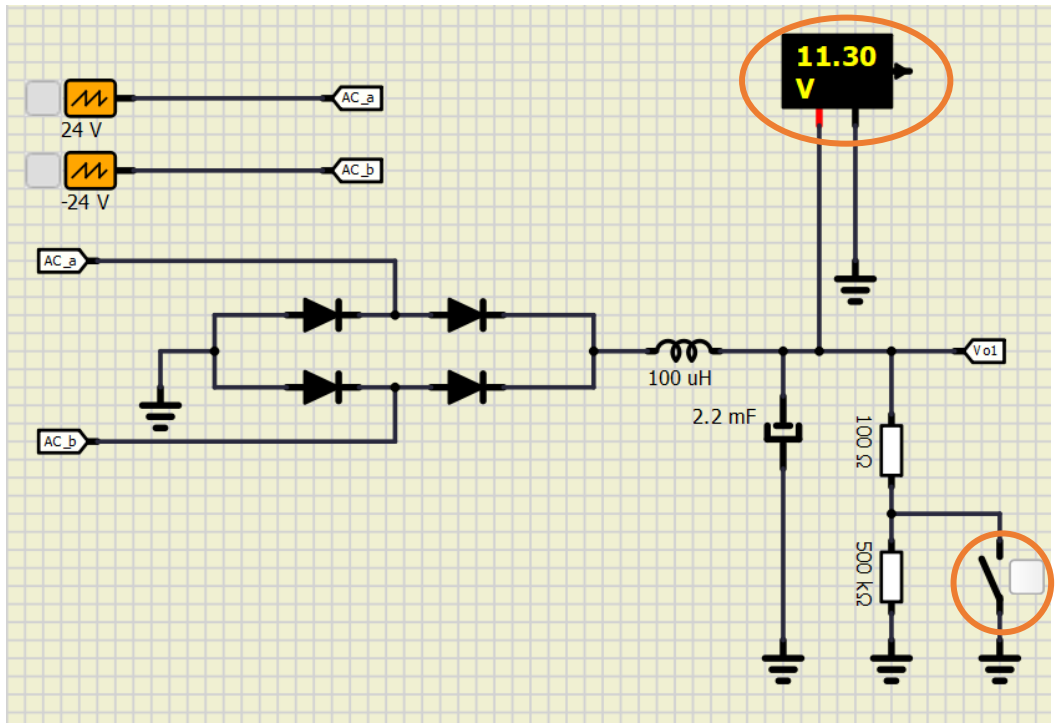




- Small R-L-C (large cutoff frequency)
  - Less smoothing with fast response (green curve)
- Large R-L-C (Small cutoff frequency)
  - More smoothing with slow response (yellow curve)

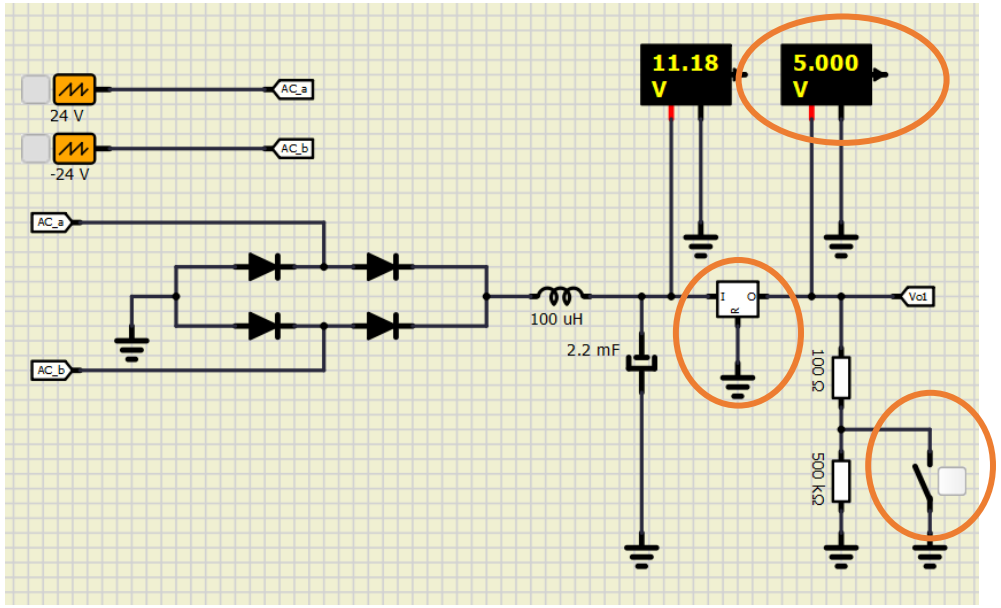
Effect of load change

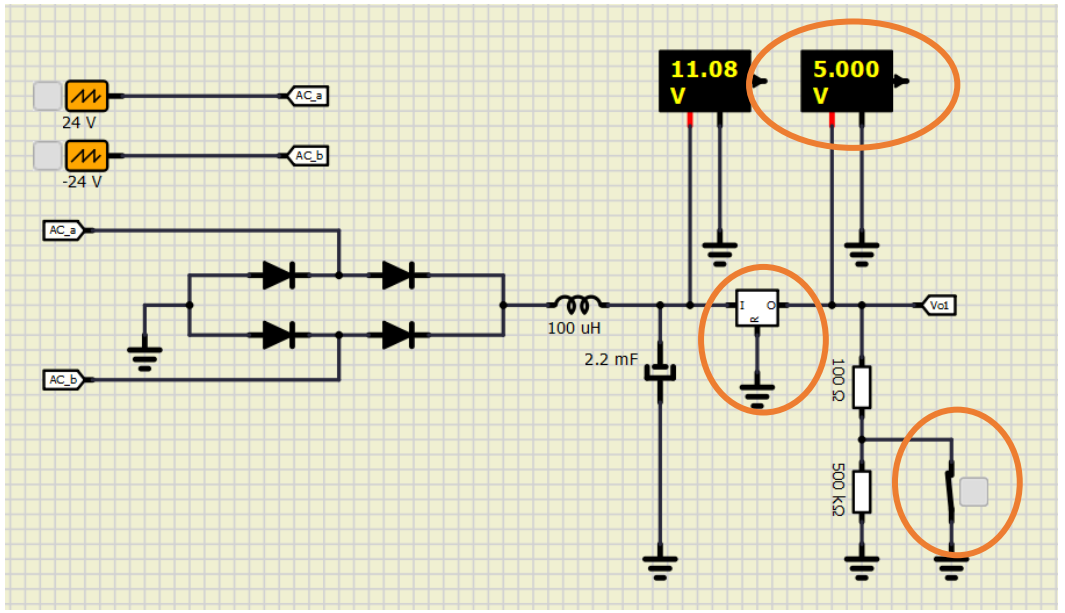




- A change on the output voltage with load change

Linear regulator

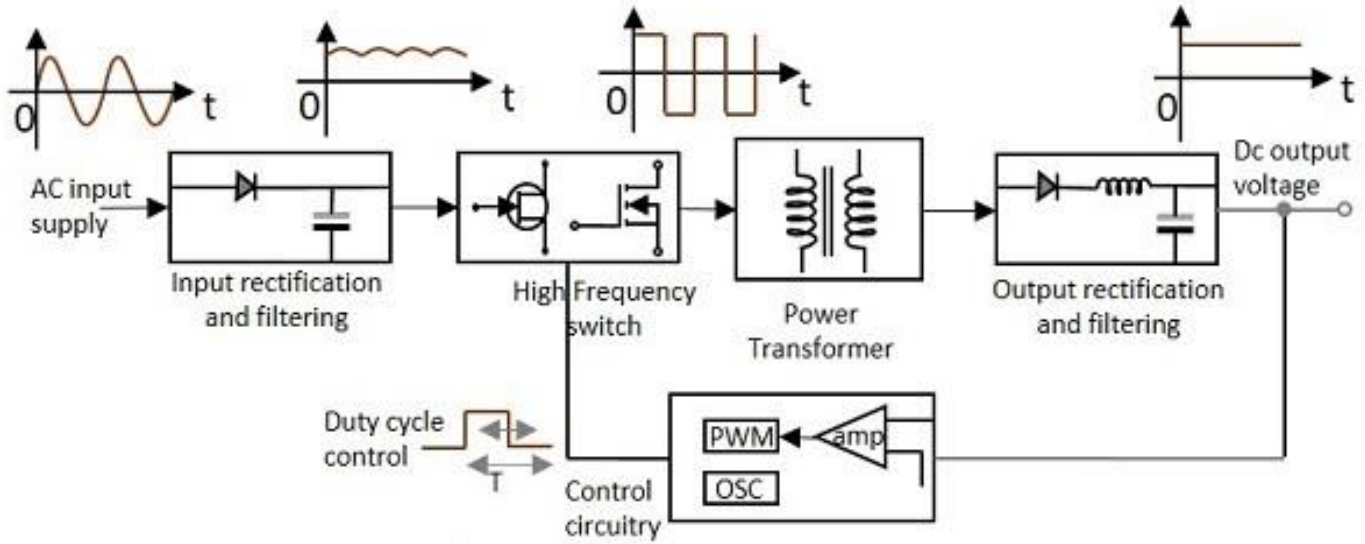




7805 VOLTAGE REGULATOR

Switched-mode power supply

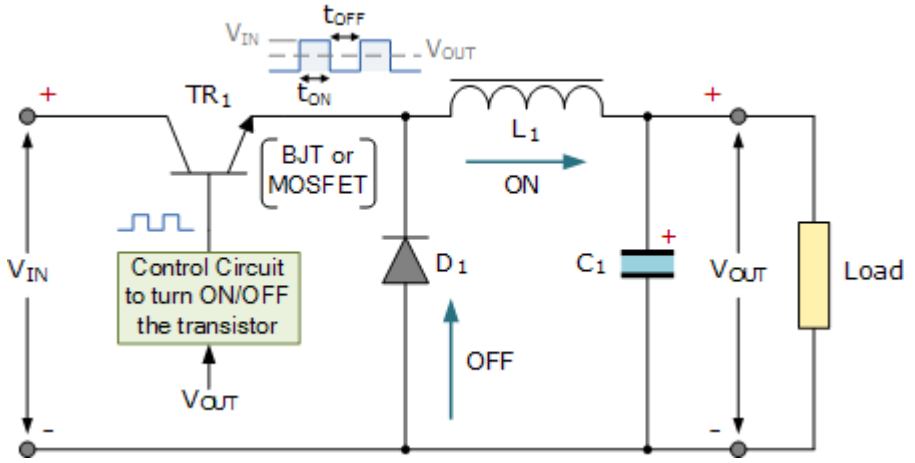
A switched-mode power (SMPS) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently.



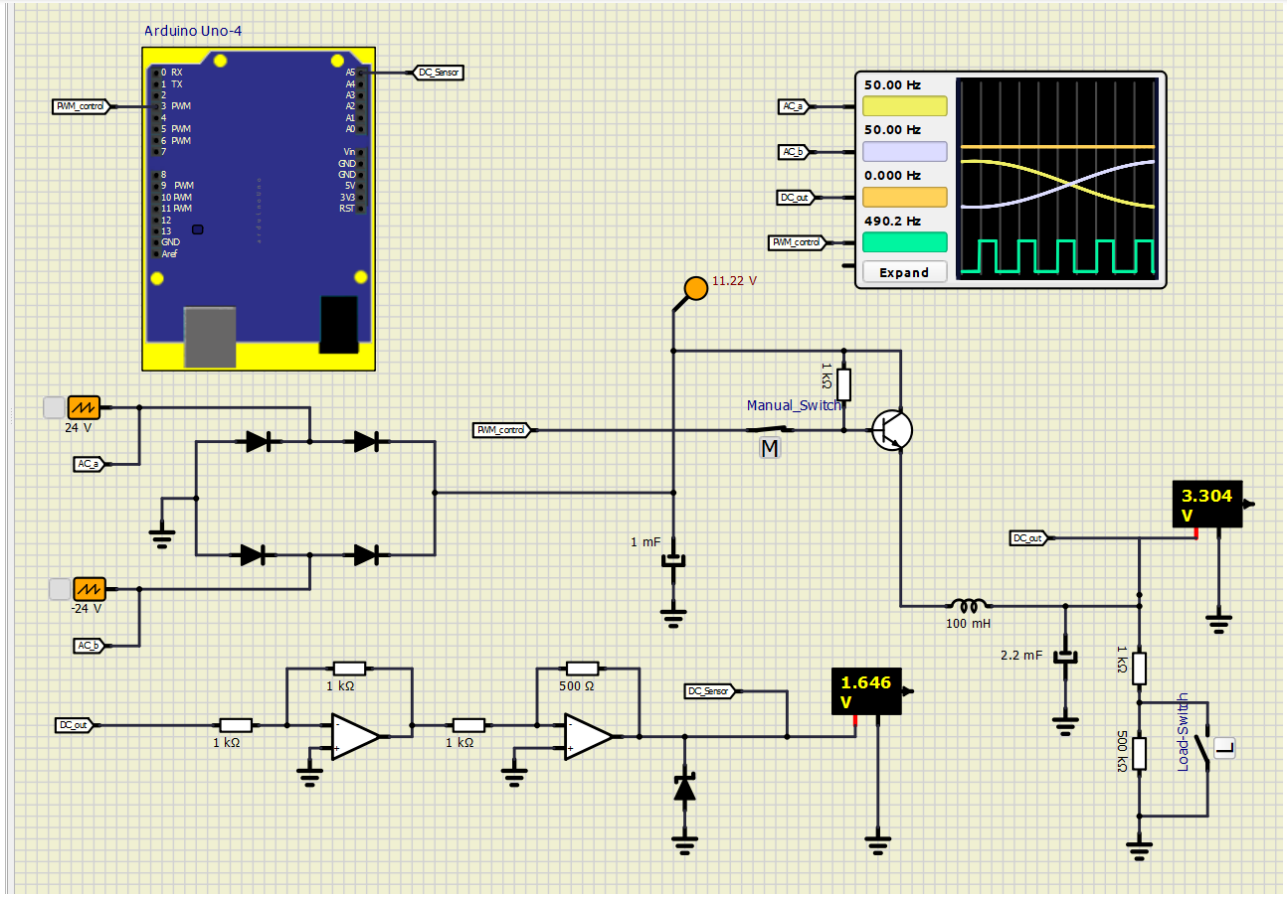
Functional block diagram of SMPS

Switched-mode power supply
Buck converter

The Buck switching regulator is a type of switch mode power supply circuit that is designed to efficiently reduce DC voltage from a higher voltage to a lower one, that is it subtracts or “Bucks” the supply voltage, thereby reducing the voltage available at the output terminals without changing the polarity. In other words, the buck switching regulator is a step-down regulator circuit, so for example a buck converter can convert say, +12 volts to +5 volts.



Switched-mode power supply using Arduino (Concept Ct.) (Target 3.3 Volt)



Switched-mode power supply using Arduino (Concept Ct.) (Target 3.3 Volt)

(cont.)

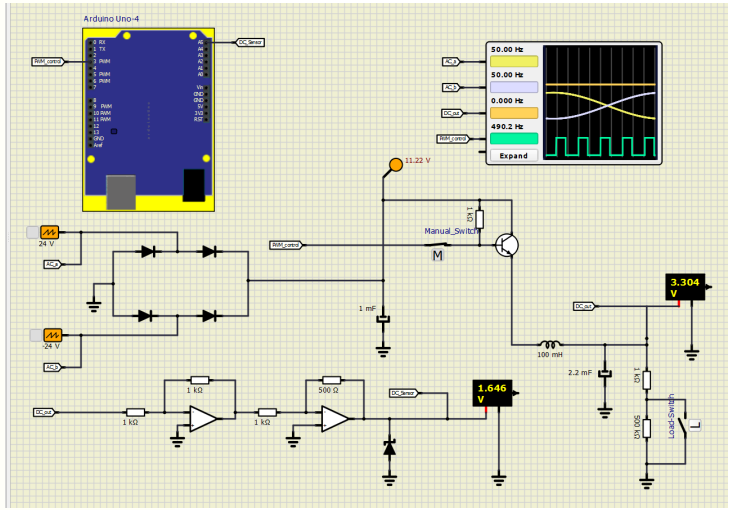
```
#define ANALOG_IN_PIN 5
#define ANALOG_OUT_PIN 3
#define MAX_VAL 1000
#define MAX_U MAX_VAL
#define MIN_U 0
#define MAX_IN_V 10.0

void setup() {   Serial.begin(9600);}
float read_val(void){
   int val = analogRead(ANALOG_IN_PIN);
   float ret=MAX_VAL*(val/1023.0);
   return (ret);
}
void set_val(float f_v){
   int i_v=(long int)((f_v/MAX_VAL)*254);
   i_v=(i_v<=0)?1:i_v;
   i_v=(i_v>254)?254:i_v;
   analogWrite(ANALOG_OUT_PIN,i_v);
}

float r=3.3*MAX_VAL/MAX_IN_V;
float ui,up,ud,e,u;
float e_old,ui_old;

//float Kp=0.005; float Ki=0.01; float Kd=0 ;
float Kp=0.01; float Ki=0.1; float Kd=0 ; // Fast

void loop(void) {
   float v=read_val();
   e=r-v;
   up=Kp*e;
   ui=ui+Ki*e;
   ud=Kd*(e-e_old);
   u=up+ui+ud;
   if ( (u>MAX_U) || (u<MIN_U) ) {
      ui=ui_old;
      u=up+ui+ud;
   }
   e_old=e;
   ui_old=ui;
   Serial.print("r= ");   Serial.print(r);
   Serial.print(", v= "); Serial.print(v);
   Serial.print(", u= "); Serial.print(u);
   Serial.print(", e= "); Serial.println(e);
   set_val(u);
}
```



Linear Regulated vs. Switch Mode Power Supply

Linear Regulator

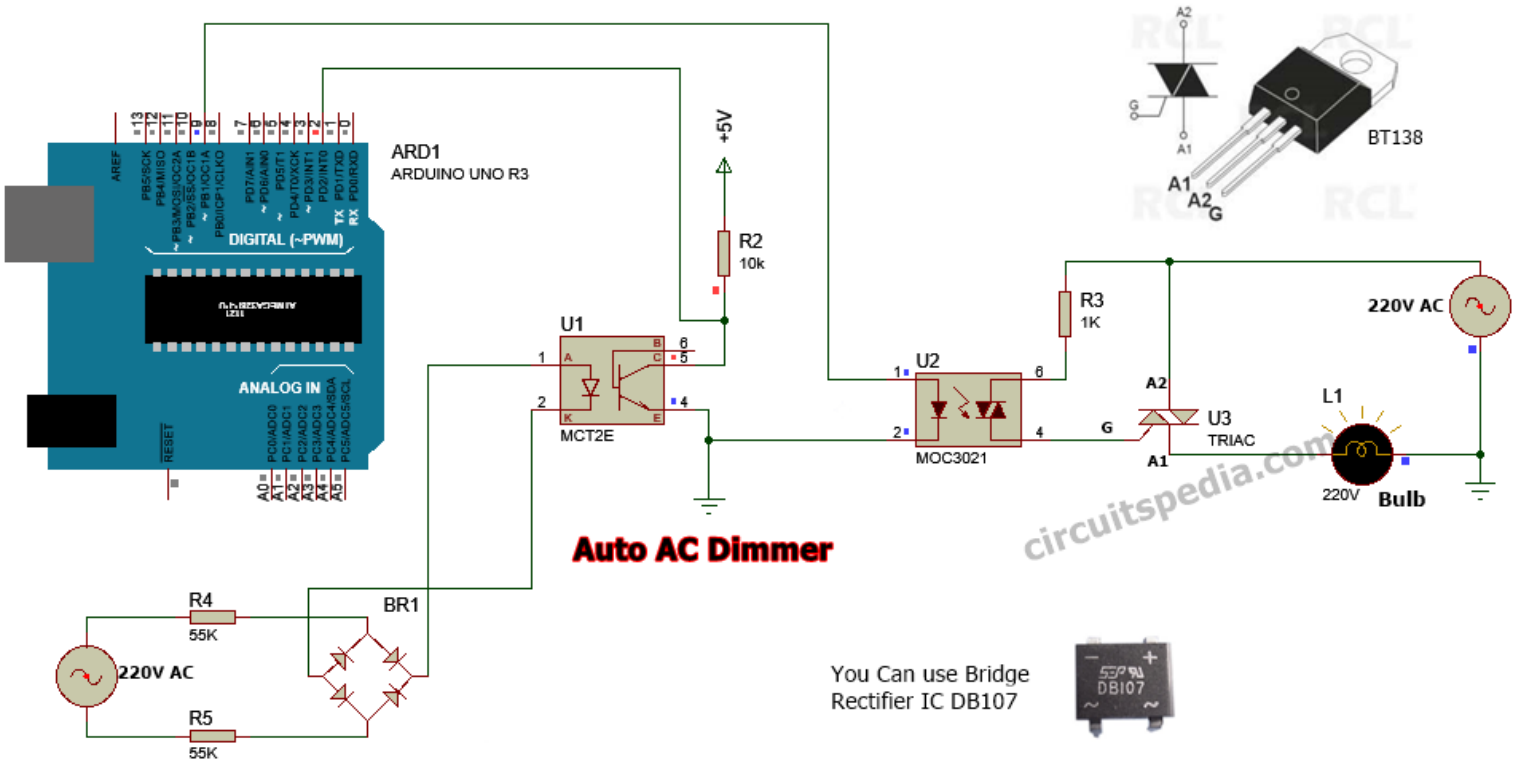
- **Advantages**
  - **Simple application:** Linear regulators can be implemented as an entire package and added to a circuit with only two additional filter capacitors.
  - **Low cost:** If your device requires a power output of less than 10W, then the component and manufacturing costs are much lower when compared to switching power supplies.
  - **Low noise/ripple:** Linear regulators have a very low output voltage ripple and high bandwidth. This makes them ideal for any noise-sensitive applications including communication and radio devices.
- **Disadvantages**
  - **Limited flexibility:** Linear regulators can only be used to step down voltage. For an AC-DC power supply, a transformer with rectification and filtering will need to be placed before the linear power supply which will add to overall costs and effort.
  - **Limited outputs:** Linear regulated power supplies only provide **one output voltage**. If you need more, then you'll need to add a separate linear voltage regulator per required output.
  - **Poor efficiency:** The average linear regulated device achieves an efficiency between **30%-60%** due to heat dissipation. It also requires the addition of a heat sink which adds to the size and weight of the device.

Linear Regulated vs. Switch Mode Power Supply

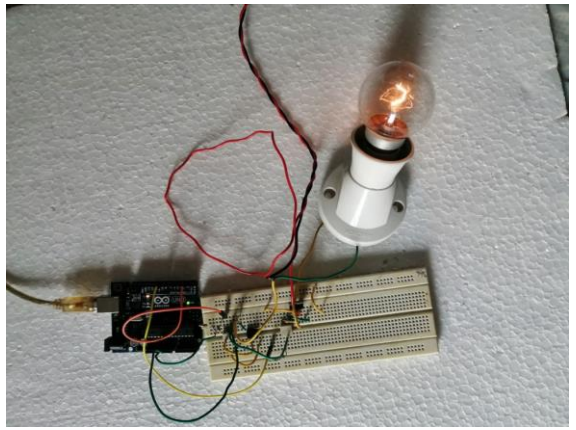
Switch Mode Power Supply

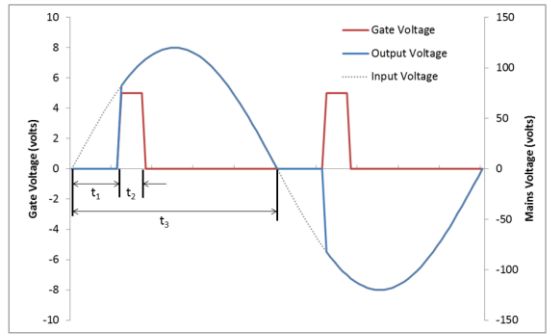
- **Advantages**
  - **Small form factor**. The step-down transformer in an SMPS operates at a high frequency which in turn reduces its volume and weight. This allows a switching power supply to enjoy a much smaller form factor than linear regulators.
  - **High efficiency**. Voltage regulation in a switching power supply is made without dissipating excessive amounts of heat. SMPS efficiency can be as high as 85%-90%.
  - **Flexible applications**. Additional windings can be added to a switching power supply to provide more than one output voltage. A transformer-isolated SMPS can also provide output voltages that are independent of input voltages.
- **Disadvantages**
  - **Complicated design**. Compared to linear regulators, planning and designing a switching power supply is typically reserved for power specialists. This is not the best power supply to choose if you plan to design your own without careful study or experience.
  - **High-frequency noise**. The switching operation of the MOSFET within a switching power supply provides high-frequency noise in the output voltage. This often requires the use of RF shielding and EMI filters in noise-sensitive devices.
  - **Higher cost**. For lower power outputs of 10W or less, it's cheaper to use a linear regulated power supply.

AC Dimmer

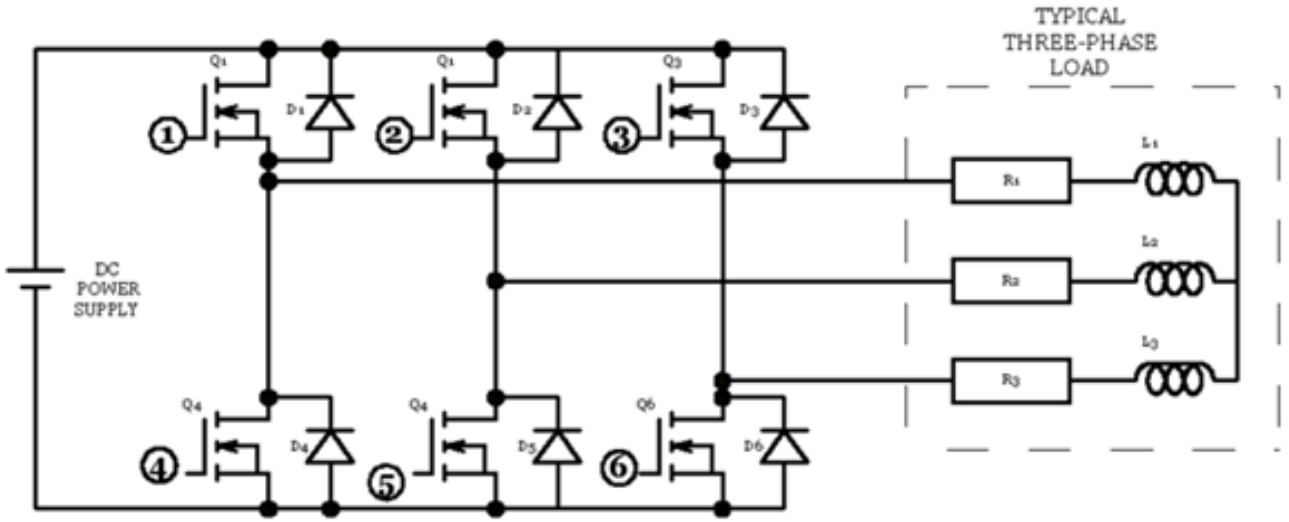


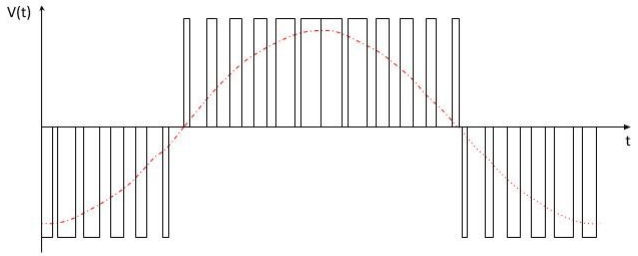
You Can use Bridge Rectifier IC DB107

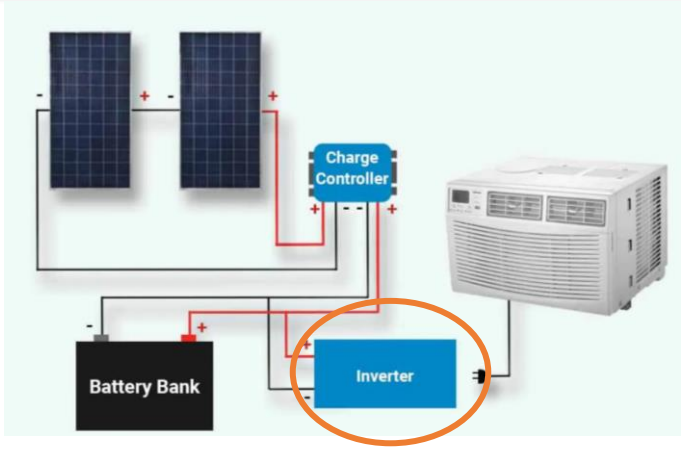




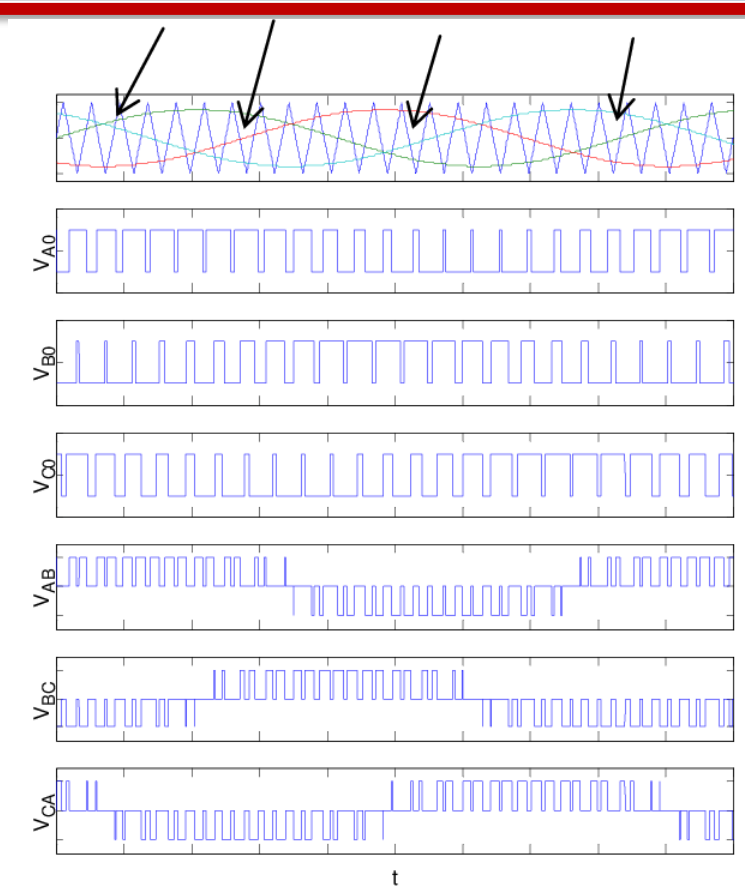
Variable-frequency drive VFD
(AC Inverter)







Variable-frequency drive VFD
(AC Inverter) (Cont.)



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12) https://www.google.com/url?sa=i&url=https%3A%2F%2Fmyelectrical.com%2Fnotes%2Fentryid%2F250%2Fhow-d-c-to-a-c-inverters-work&psig=AOvVaw2ACkpp5ervViPYQbbt0m2R&ust=1652554789763000&source=images&cd=vfe&ved=0CAwQjRxqFwoTCJCssL-U3fcCFQAAAAAdAAAAABAD
13) https://www.researchgate.net/figure/Waveforms-of-Three-Phase-Sine-PWM-Inverter_fig3_238072325
14) https://en.wikipedia.org/wiki/Variable-frequency_drive
15) https://www.autodesk.com/products/eagle/blog/linear-regulated-vs-switch-mode-power-supply/