Your Project will involve:

- Understanding 3 - phase electrical power
- Understanding Load Balancing Techniques via case studies
- Understand Load Scheduling Techniques via case studies
- Analysing how these techniques can be applied to make the typical Rebel Kitchen more energy efficient
- Building an interactive calculator that takes inputs of equipment specifications and outputs load balancing and load scheduling schema.

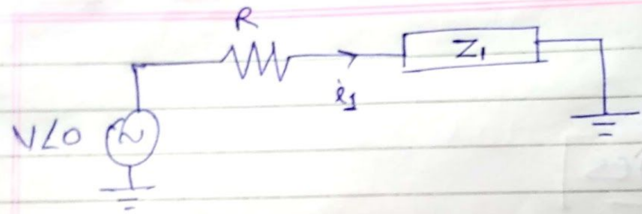
Understanding 3 - phase Power:

- Common method of AC power transmission
- Used for heavy loads and is more economical
- Constant power transfer to a balanced linear load.
- Single phase: Avg Power = P/2
- 3 phase: Avg Power = 1.5P (P = Peak Power of 1 phase)

Load Balancing:

- Questions to be answered:
  - How to include power factor of devices in Load balancing calculations?
  - What is the load behaviour of a line comprising resistive, inductive, and capacitive loads?
  - How are resistive(heating coils) and inductive loads(motors and compressors) balanced across lines?
- Answers to the above questions
  - Let us consider a mixed load(resistive+inductive+capacitive) and let Z be the total impedance on the line.
  - The line current is given by I=V/Z. Hence now the current will differ from the voltage phase angle decided by the power factor of the impedance(the type of load).
  - From the given power rating of the equipment, its power factor and operating voltage we can calculate the impedance(Z) of the device and we'll work with Z further.
  - For a balanced ideal condition, we aim to have Z1 = Z2 = Z3.

- But since in reality and practical problems, the above conditions won't be met always, we need to find a function which we'll minimize.
- Minimizing the difference in the magnitude of currents in the phases: (Trying to make the load voltage as equal as possible)



Let's say the power line in each phase has a small resistance R.

$\therefore$ Voltage across $Z_1 = V\angle 0 - i_1 R$

where $i_1 = \dfrac{V\angle 0}{R+Z_1} \approx \dfrac{V\angle 0}{Z_1}$ $\quad (Z_1 >> R)$

Let's try to make the magnitude of current through each phase equal.

$$\Rightarrow \frac{V}{|Z_1|} = \frac{V}{|Z_2|} = \frac{V}{|Z_3|}$$

$$\Rightarrow |Z_1| = |Z_2| = |Z_3|$$

This will give us the fastest algorithm of first finding $|Z|$ of each device and then arrange them in decreasing order and divide among three phases

Note this doesn't guarantee that the voltages across all phases at load-side is exactly the same. For that, we would also require the resistance value of the conductor (R).

- Another approach would be minimizing the current through the neutral conductor. As the neutral current leads to eddy current losses in the transformers, we might want to minimize it for load balancing. Following is the calculation:

Neutral current = $i_1 + i_2 + i_3$

$$= \frac{V\angle 0}{Z_1} + \frac{V\angle 120}{Z_2} + \frac{V\angle 240}{Z_3}$$

$$= V\left[\left(\frac{1}{Z_1} - \frac{1}{2Z_2} - \frac{1}{2Z_3}\right) + i\left(\frac{\sqrt{3}}{2Z_2} - \frac{\sqrt{3}}{2Z_3}\right)\right]$$

(We can observe that $Z_1 = Z_2 = Z_3$ makes neutral current $= 0$)

Hence with all the PnC of Z_1, Z_2 & Z_3 we can compute the above function and find Z_1, Z_2, Z_3 for which function is minimum.

Note this algorithm will require $\boxed{3^n}$ Computatio

- Another method can be a suitable combination of the above approaches. One combination can be:
  - Divide the impedances according to their magnitude in 3 phases.
  - Now further try all permutations of only the inductive/capacitive loads where we can find the combination for which neutral current is minimum.
- Making Z1 = Z2 = Z3 will take care of everything. The best approach would be **minimizing:**
  f(Z1, Z2, Z3) = |Z1-Z2| + |Z2-Z3| for all combinations of Z1, Z2, Z3.

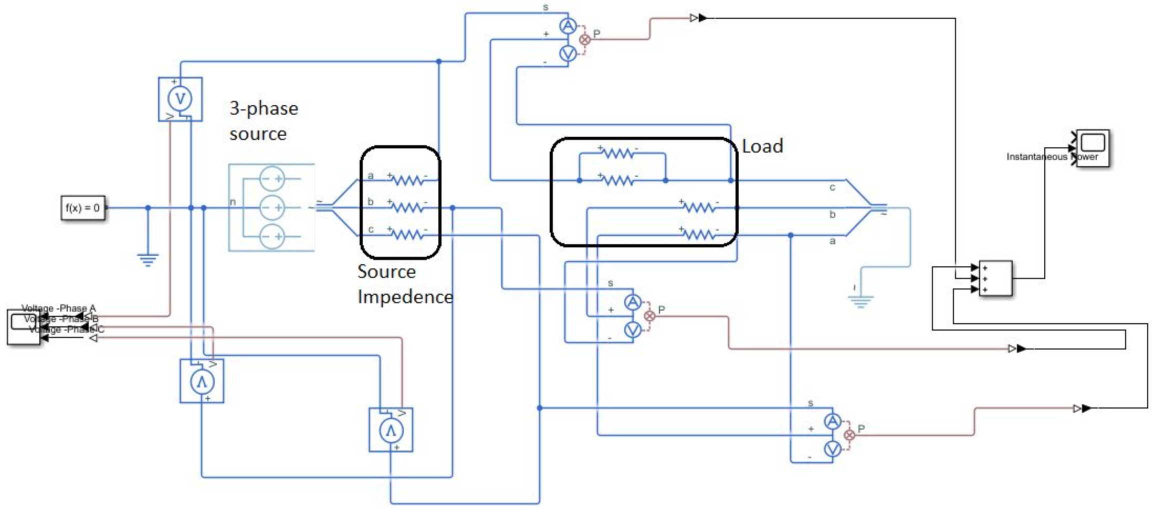
- https://www.ecmweb.com/power-quality-reliability/article/20892715/saving-energy-through-load-balancing-and-scheduling

- Need:

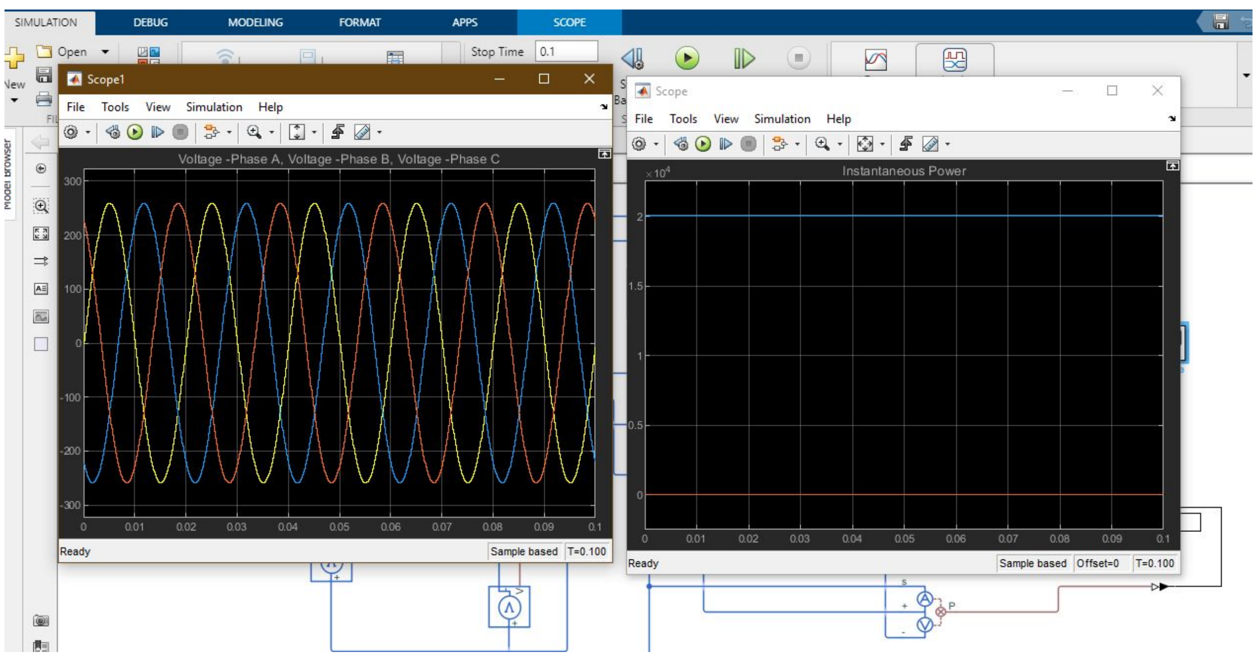
❖ Minimize energy loss
❖ Neural current = eddy current losses in the upstream transformer

- ## Simulations:

  I carried out the following simulations in Matlab with 3-phase source and resistive load on each phase connected in star format.



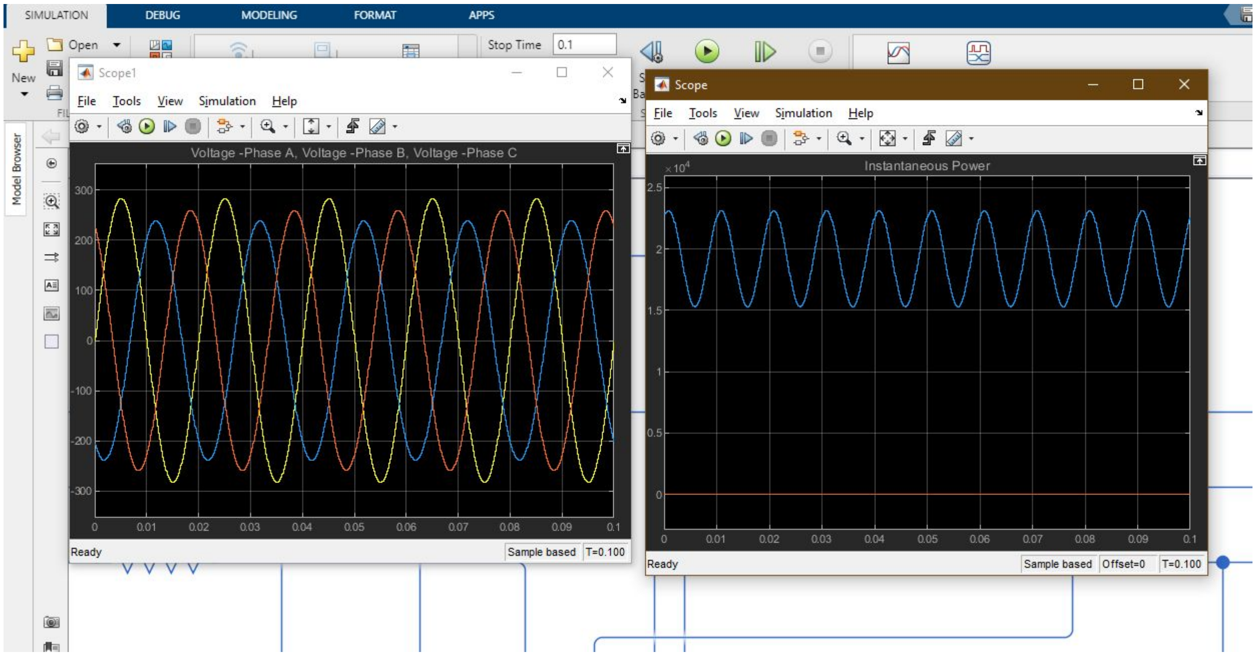
❖ Balanced Load:



We can see that all the phase voltages(Left) are equal in magnitude and separated by 120 degrees.

The total instantaneous power (right) is a constant value.

❖ Unbalanced Load:



We can see that the phase voltages are not equal (Left) (due the different currents drawn, drops across source impedance is different)

Also now, the total power drawn is also not a constant value but oscillates. (Right)

- ## Details:

❖ Greater load lesser current.

❖ Balance loads during installation.

❖ Calculate the loads in VA instead of Watt.

❖ Try to divide this VAs between 3 phases.

❖ In the practical world, the 3-phase system is rarely “perfectly” balanced.

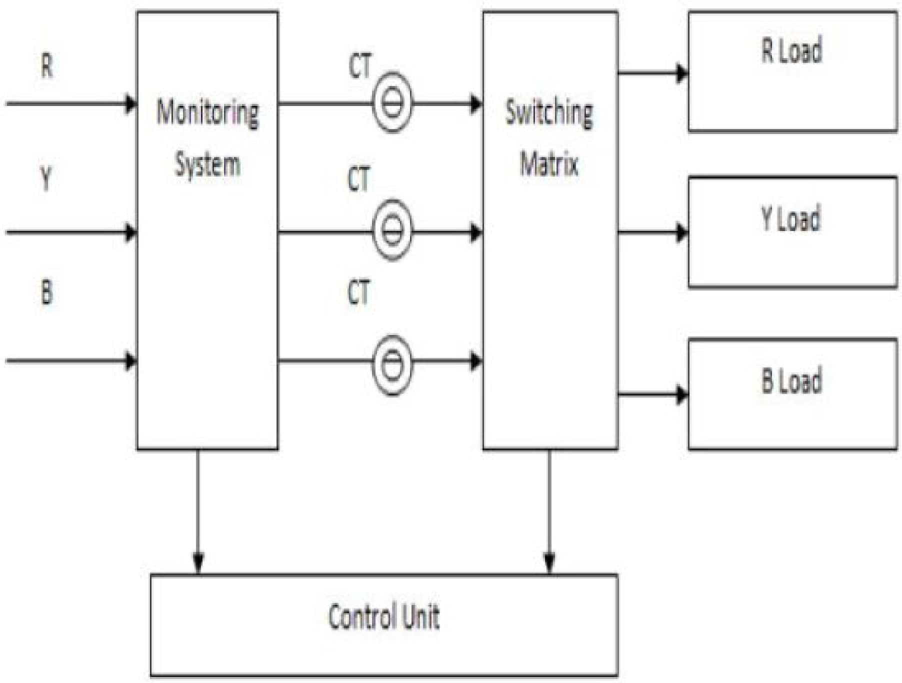
❖ Must monitor and record both voltage and current to determine the extent of the load imbalance in a system.

❖ Measuring the imbalance(IEEE/NEMA method and Method of Symmetrical Components) and some standards:
https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8316140
This paper proposes the idea to charge consumers for unbalanced loads.

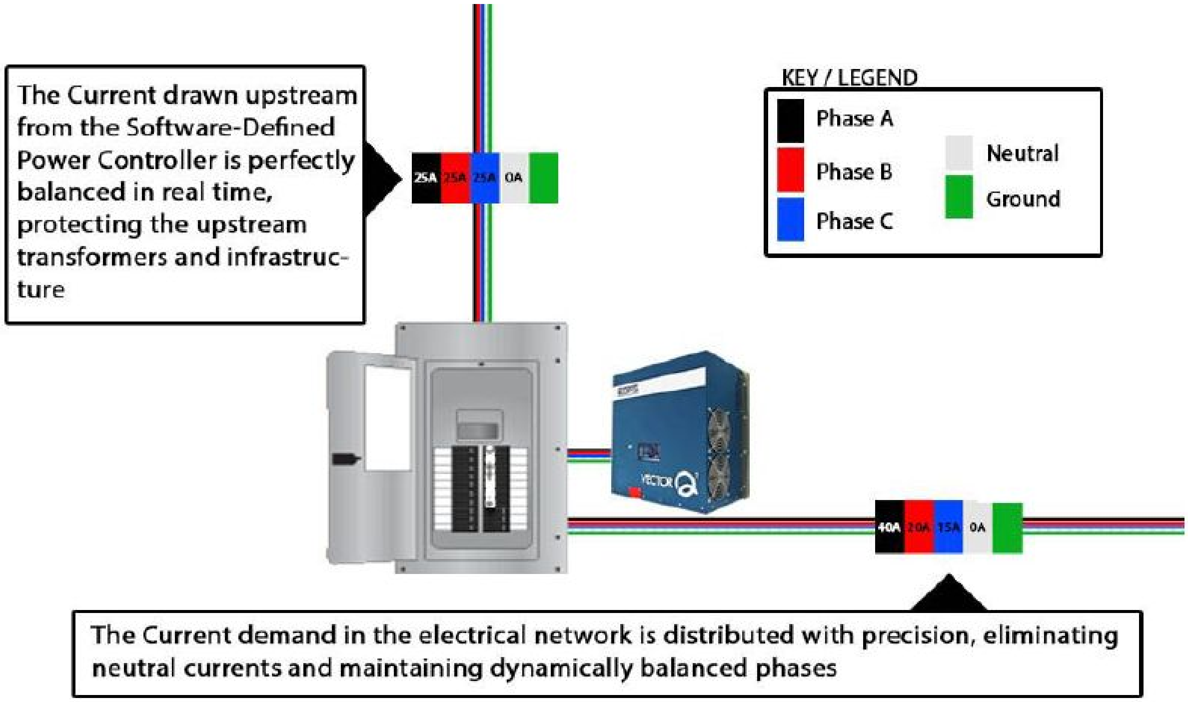
- ## Load Balancing Techniques:

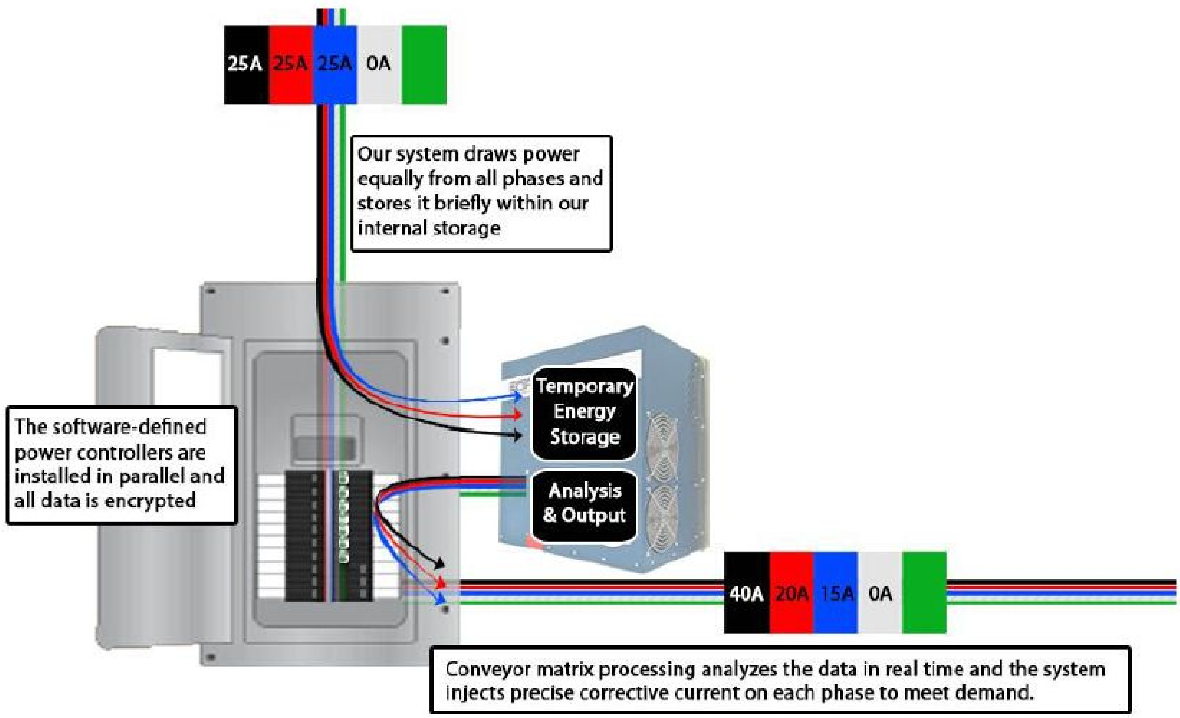
❖ Calculate all the single-phase load and balance it between 3 phases to the possible extent.

❖ Automatic Load Balancing and Switching Circuitry:
Found two papers on this:
https://ieeexplore.ieee.org/document/8384514 (Couldn't access)
https://www.irjet.net/archives/V4/i3/IRJET-V4I3247.pdf



❖ Connect the device in parallel. (3DFS Technology) Software Controlled power network.



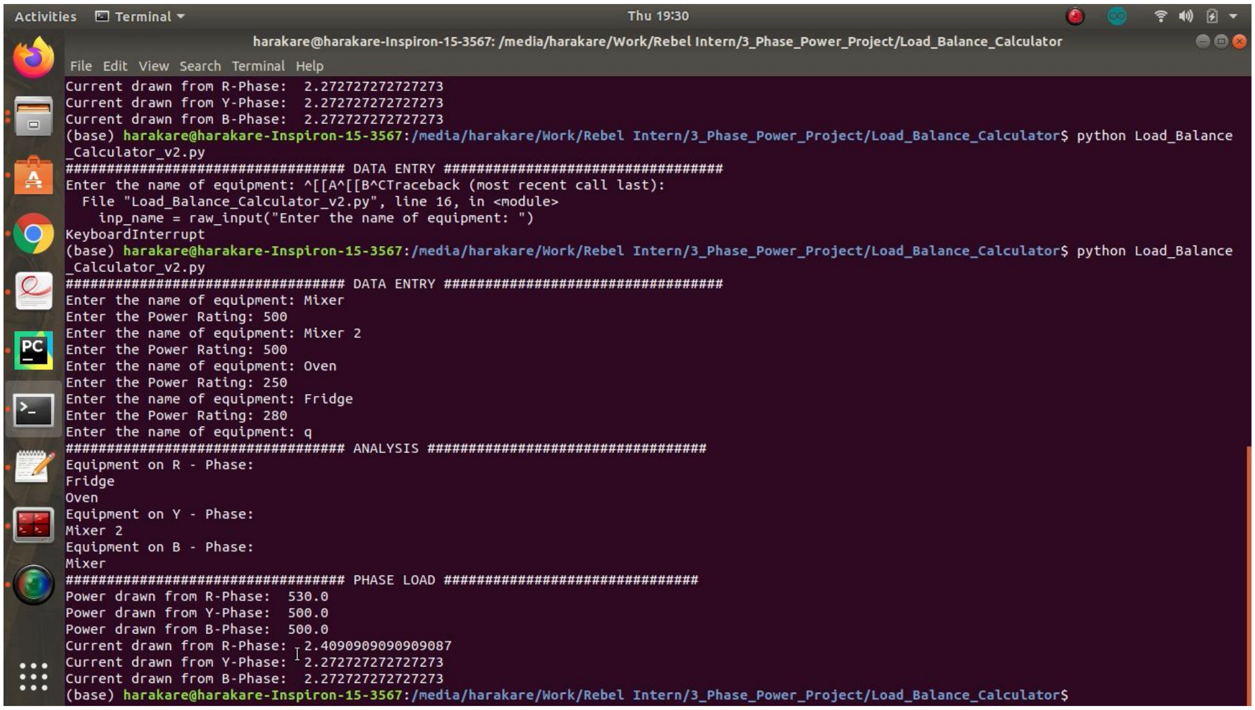


❖

- Load Balancing Software:

❖ I have developed a basic software which takes the power ratings of appliances as input and outputs the load balancing schema as shown below.

❖ The appliances are considered to be a purely resistive load.

❖ 

Load Scheduling:

❖ Higher costs at peak demand.

❖ Log the power usage and use appliances smartly.

❖ Identify which appliances can be used at non-peak hours.

Actionables:

❖ Add 3 phase loads to the code. (DONE)

❖ Formatting/Commenting in the code. (DONE)

❖ Read from Excel file. (DONE)