Do It yourself, Smart Energy Monitor.

Eng.: Mohamed Maher Ibrahim

Experienced Founder with a demonstrated history of working in the electrical and electronic manufacturing industry. Skilled in Matlab, Simulink, Smart Grid, Home Automation, Engineering, and Control Systems Design. Strong entrepreneurship professional graduated from Faculty of engineering Mansoura University.

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- **Acknowledgement**

With my sincere love and appreciation, dedicate my first engineering books to my father and mother, who have often struggled for our sake.

I wish them full health and happiness.

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1.1 Introduction

Smart metering essentially involves an electronic power meter supplemented by full remote control, diagnostics, power peak and consumption analysis, anti-tampering mechanisms, fault alert, time-variable tariffs, and many more possibilities. Using power-line communication (PLC) or other wired and wireless technologies to connect the meter to the service provider enables all of the above features to be feasible and compatible with future smart-grid protocols.

Smart meters, a common form of smart grid technology, are digital meters that replace the old analog meters used in homes to record electrical usage. Digital meters can transmit energy consumption information back to the utility on a much more frequent schedule than analog meters, which require a meter reader to transmit information.

Electric energy use will be recorded every hour or less at your home. Smart meters will enable you to monitor your consumption more precisely so you can make more informed energy choices. Depending on the feature set, the meter may also notify the utility of a power outage or allow the utility to remotely switch electricity service on or off.

1.2Historical Review:

A home energy monitor provides feedback on electrical energy use. Devices may also display cost of energy used, and estimates of greenhouse gas emissions. Various studies have shown a reduction in home energy use of 4-15% through use of home energy display.

Electricity use may be measured with an inductive clamp placed around the electric main, via the electric meter (either through an optical port, or by sensing the meters actions), by communicating with a smart meter, or by direct connection to the electrical system. The display portion may be remote from the measurement, communicating with the sensor using a cable, network, power line communications, or using radio. Online displays are also available which allow the user to use an internet connected display to show near real-time consumption.

A means to reduce household energy consumption is to provide real-time feedback to homeowners so they can change their energy use. In 2010, UK based Current Cost announced a partnership with Google Power Meter, a former online tool that connected to Current Cost devices, enabling users to receive real-time energy information on their customized Google homepage, wherever they were. Real-time data on how much energy is being consumed in the home was sent directly to the Google Power Meter. The free software tool then visualized the information for users to view on their own I Google homepage, a personal web portal which enabled individuals to create and access a wide range of customizable information, web feeds and Google Gadgets. Note Google Power Meter is now defunct.

A study using the Power Cost Monitor deployed in 500 Ontario homes by Hydro One showed an average 6.5% drop in total electricity use when compared with a similarly sized control group. Hydro One subsequently offered free power monitors to 30,000 customers based on the success of the pilot.

1.3 Understanding AC Power:

Power in an electric circuit is the rate of flow of energy past a given point of the circuit. In alternating current circuits, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow.

The portion of power that, averaged over a complete cycle of the AC waveform, results in net transfer of energy in one direction is known as active power (sometimes also called real power). The portion of power due to stored energy, which returns to the source in each cycle, is known as *reactive power*.

1.4 Types of Loads:

A whole house energy monitor measures the energy used by appliances connected to the house mains. To understand how it does this, it is useful to know something about how appliances interact with the electrical system.

Not all appliances interact with the electricity system in the same way. This article will first discuss resistive loads and how the power they use is calculated. It then goes on to discuss reactive loads and a bit about non-linear loads. Finally, it will show how we measure the direction of power flow, which is important if energy is generated as well as consumed.

1.4.1 Resistive loads

Incandescent light bulbs, kettles, irons, electric water heaters, electric cookers are all quite straightforward. They use all the energy given to them. They are resistive loads which mean their current draw is equal to the voltage divided by their resistance (Ohm's Law). A purely resistive load gives a voltage and current waveform output similar to the following:

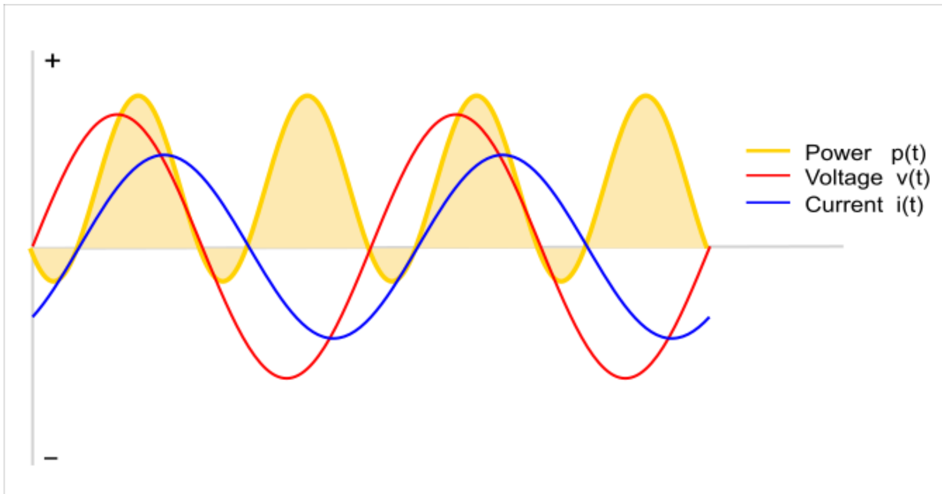


Fig 1 – *Voltage and current phase relationships in a resistive load.*

The yellow line is power at a given time (at any given instant it's called instantaneous power) which is equal to the product of the voltage and current at a given time. Notice the power is always positive. In this case, the positive direction is energy flowing to the load.

1.4.2 Partially Reactive Loads:

However things like fridges, washing machines, pillar drills and arc welders are not as straightforward as these appliances take in a certain amount of energy, then release some energy back into the mains supply. These have inductive (e.g. motors) or capacitive (e.g. arc welders) components in addition to the resistive component. A partially inductive load gives a voltage and current waveform output similar to the following:

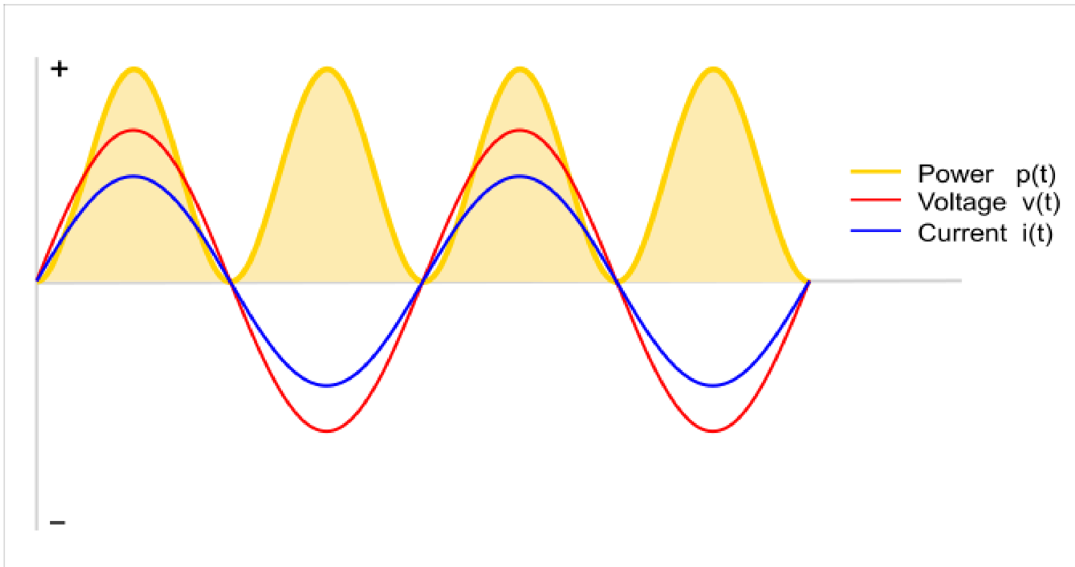


Fig 2 – *Voltage and current phase relationships in a partially reactive load*

Notice the yellow line now goes negative for a period of time, the positive bit is energy flowing to the load and the negative bit is energy flowing back from the load.

The other thing to consider is that the voltage and current waveforms have been shifted apart. Imagine charging a fairly large capacitor with a resistor in series (so that it can't charge instantly): To start with, the capacitor is discharged. The supply voltage rises, and is higher than the voltage on the capacitor, so current flows into the capacitor (the positive direction on the graph), which causes the capacitor voltage to rise. The supply voltage falls. Now, the voltage across the charged capacitor is higher than the supply voltage. Current starts to flow back in the direction of the supply (the negative direction on the graph). This causes the current waveform to appear as if it is shifted, as depicted in the graph. (This is referred to as phase shift).

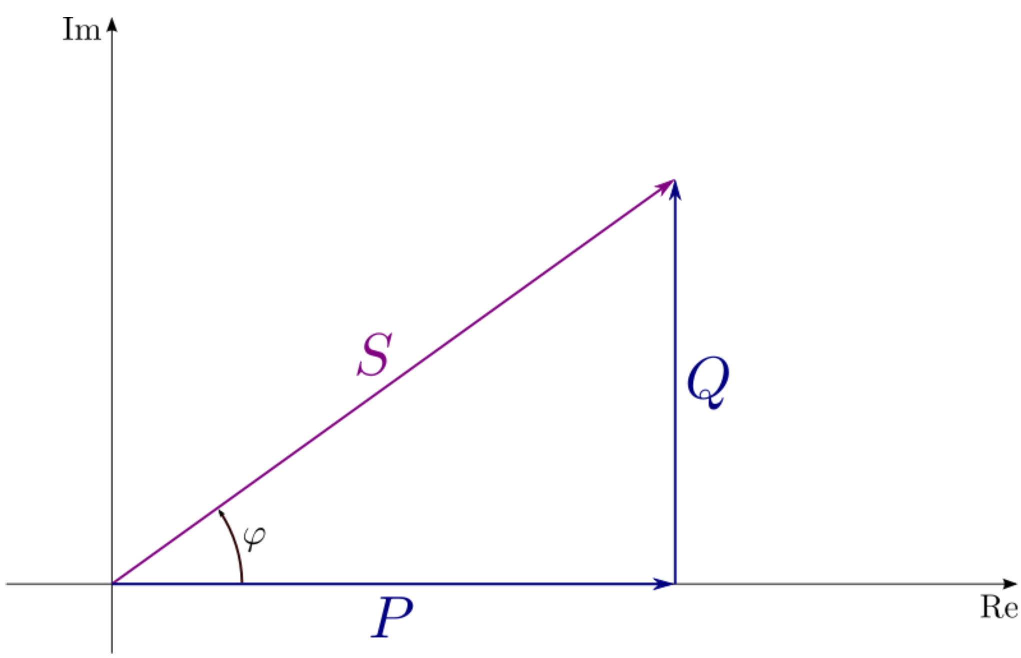
1.5 Active, Reactive and Apparent Power:

In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive or zero, the result being that the direction of energy flow does not reverse. In this case, only active power is transferred.

If the load is purely *reactive*, then the voltage and current are 90 degrees out of phase. For two quarters of each cycle, the product of voltage and current is positive, but for the other two quarters, the product is negative, indicating that on average, exactly as much energy flows into the load as flows back out. There is no net energy flow over each half cycle. In this case, only reactive power flows: There is no net transfer of energy to the load, however, electrical power does flow along the wires and returns by flowing in reverse along the same wires. During its travels both from the power source to the reactive load and back to the power source, this purely reactive power flow loses energy to the line resistance. Practical loads have resistance as well as inductance, and/or capacitance, so both active and reactive power will flow to normal loads. Power engineers analyses the apparent power as being the magnitude of the vector sum of active and reactive power. Apparent power is the product of the rms values of voltage and current. Electrical engineers take apparent power into account when designing and operating power systems, because although the current associated with reactive power does no work at the load, (it heats the conductors and wastes energy) it still must be supplied by the power source. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work. Failure to provide for the supply of sufficient reactive power in electrical grids can lead to lowered voltage levels and under certain operating conditions to the complete collapse of the network or blackout. Another consequence is that adding the apparent power for two loads will not accurately give the total power unless they have the same phase difference between current and voltage (the same power factor).

Conventionally, capacitors are treated as if they generate reactive power and inductors as if they consume it. If a capacitor and an inductor are placed in parallel, then the currents flowing through the capacitor and the inductor tend to cancel rather than add. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially compensate for reactive power 'consumed' by the load. Purely capacitive circuits supply reactive power with the current waveform leading the voltage waveform by 90 degrees, while purely inductive circuits absorb reactive power with the current waveform lagging the voltage waveform by 90 degrees. The result of this is that capacitive and inductive circuit elements tend to cancel each other out.

Engineers use the following terms to describe energy flow in a system (and assign each of them a different unit to differentiate between them):



Active power, *P*, or real power: watt (W)

Reactive power, *Q*: volt-ampere reactive (var)

Complex power, *S*: volt-ampere (VA)

Apparent power, |*S*|: the magnitude of complex power *S*: volt-ampere (VA)

Phase of voltage relative to current, φ: the angle of difference (in degrees) between current

$$\Phi = \arg(V) - \arg(I)$$

These are all denoted in the diagram to the right (called a Power Triangle).

In the diagram, *P* is the active power, *Q* is the reactive power (in this case positive), *S* is the complex power and the length of *S* is the apparent power. Reactive power does not do any work, so it is represented as the imaginary axis of the vector diagram. Active power does do work, so it is the real axis.

The unit for all forms of power is the watt (symbol: W), but this unit is generally reserved for active power. Apparent power is conventionally expressed in volt-amperes (VA) since it is the product of rms voltage and rms current. The unit for reactive power is expressed as var, which stands for volt-ampere reactive. Since reactive power transfers no net energy to the load, it is sometimes called "wattles" power. It does, however, serve an important function in electrical grids and its lack has been cited as a significant factor in the Northeast Blackout of 2003. Understanding the relationship among these three quantities lies at the heart of understanding power engineering. The mathematical relationship among them can be represented by vectors or expressed using complex numbers, $S = P + j\,Q$ (where *j* is the imaginary unit).

1.6 Calculations and Equations:

The formula for Complex Power (units: VA) in phasor form is:

$$S = |I|^2 Z = \frac{|V|^2}{Z^*}$$

Where *V* denotes Voltage in phasor form, with the amplitude as rms, and *I* denotes current in phasor form, with the amplitude as rms. Also by convention, the complex conjugate of *I*is used. This is done such that a leading current (capacitive load, negative reactance), results in negative reactive power.

Other forms of complex power (units in Volt-Amps, VA) are derived from *Z*, the load impedance (units in ohms, Ω).

$$S = |I|^2 Z = \frac{|V|^2}{Z^*}$$

Consequentially, with reference to the power triangle, real power (units in watts, W) is derived as:

$$P = |S|\cos\varphi = |I|^2 R = \frac{|V|^2}{|Z|^2} \times R$$

For a purely resistive load, real power can be simplified to:

$$P = \frac{|V|^2}{R}$$

R denotes resistance (units in ohms, Ω) of the load.

Reactive Power (units in Volts-Amps-Reactive, var) is derived as:

$$Q = |S|\sin\varphi = |I|^2 X = \frac{|V|^2}{|Z|^2} \times X$$

X denotes reactance (units in ohms, Ω) of the load.

Combining, the Complex Power (units in Volt-Amps, VA) is back-derived as:

$S = P + jQ$ and the Apparent Power (units in Volt-Amps, VA) as

$$|S| = \sqrt{P^2 + Q^2}$$

These are simplified diagrammatically by the power triangle.

1.7 Power Factor:

The ratio of active power to apparent power in a circuit is called the power factor. For two systems transmitting the same amount of active power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from energy storage in the load. These higher currents produce higher losses and reduce overall transmission efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of active power. The power factor is 1.0 when the voltage and current are in phase. It is zero when the current leads or lags the voltage by 90 degrees. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle of current with respect to voltage. Voltage is designated as the base to which current angle is compared, meaning that we think of current as either "leading" or "lagging" voltage. Where the waveforms are purely sinusoidal, the power factor is the cosine of the phase angle (ϕ) between the current and voltage sinusoid waveforms. Equipment data sheets and nameplates will often abbreviate power factor as "cos ϕ" for this reason.

Example: The active power is 700 W and the phase angle between voltage and current is 45.6°. The power factor is cos (45.6°) = 0.700. The apparent power is then: 700 W / cos (45.6°) = 1000 VA.

So, the Relationship between real, reactive and apparent power for

1.8 IDEAL sinusoidal loads:

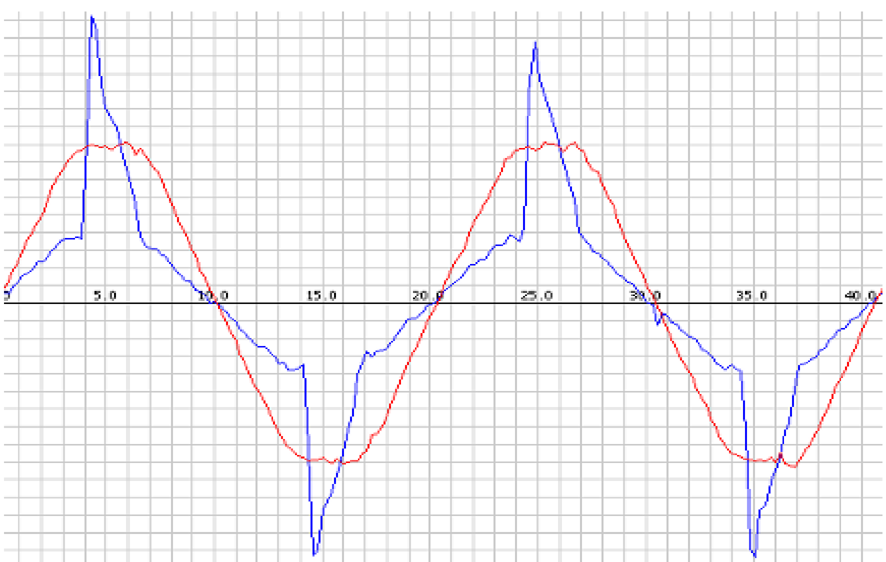
Real Power = Apparent Power x cosΦ

Reactive Power = Apparent Power x sinΦ

cosΦ is also known as power factor.

However, a note about non-linear loads:

This power factor relationship is valid only for *linear* sinusoidal loads. Most power supplies for DC devices like Laptop computers, present a non-linear load to the mains. Their current draw often looks like this:



We can still calculate power factor from the following equation:

Power Factor = Real Power / Apparent Power

But the relationship

(Apparent Power) ^{2} *= (Real Power)* ^{2} *+ (Reactive Power)* ^{2}

Which is true for pure sine waves, is no longer correct? Neither is *power factor = cosΦ*, since the effects of higher order harmonics in both voltage and current waveforms must be considered.

The power factor value measures how much the mains efficiency is affected by BOTH phase lag ϕ AND harmonic content of the input current.

1.9 Starting with Arduino:

MM-93 is based on Arduino UNO, so we need deep understanding of Arduino Processing and how it’s Functions and Module working.

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike.

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for It applications, wearable, 3D printing, and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide.

1.9.1 Why Arduino?

Thanks to its simple and accessible user experience, Arduino has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. Teachers and students use it to build low cost scientific instruments, to prove chemistry and physics principles, or to get started with programming and robotics. Designers and architects build interactive prototypes, musicians and artists use it for installations and to experiment with new musical instruments. Makers, of course, use it to build many of the projects exhibited at the Maker Faire, for example. Arduino is a key tool to learn new things. Anyone - children, hobbyists, artists, programmers - can start tinkering just following the step by step instructions of a kit, or sharing ideas online with other members of the Arduino community.

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Net media's BX-24, Phi gets, MIT's Handy board, and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

Inexpensive - Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than $50

Cross-platform - The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.

Simple, clear programming environment - The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with how the Arduino IDE works.

Open source and extensible software - The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, you can add AVR-C code directly into your Arduino programs if you want to.

Open source and extensible hardware - The plans of the Arduino boards are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

1.10 About Our Model (MM-93):

Our version (MM-93) had been built for researcher and analysis needs more than normal customers' needs, here some of our meter abilities:

- **Multi-inputs:**

You can measure all electrical parameters for Utility input and do the same for Renewable Source like solar or wind turbine at the same time

- **Multi- Outputs:**

We built our source code to handle up to 5 inputs measuring and 5 out measuring you just need to add more CTs and PTs for each additional input / outputs as we will discuss that in Hardware section.

- **Measures all load parameters (V, I, PF, P, Q).**
- **USB Communications:**

So easily to interface our (MM-93) to Computer and establish stable and safe communication between your PC and (MM-93).

- **Support Terminal Commands:**

After connecting (MM-93) to your PC, you can ask it to send you any input/ output measurements through the Serial monitor.

For example:

Command “U”: (MM-93) will send you all the measurements of the Utility Input.

- **KWh Meter:**

Counts KWh consumed by each load and for each Source.

- **Data Logger:**

Saving all readings with time line from the moment when (MM-93) starting until you shut it down.

- **Data Plotting using Mat lab:**

You can plot and analyze all the measurements using Mat lab / Simulink with a quiet simple modification, just install Mat lab / Simulink Arduino supporting package.

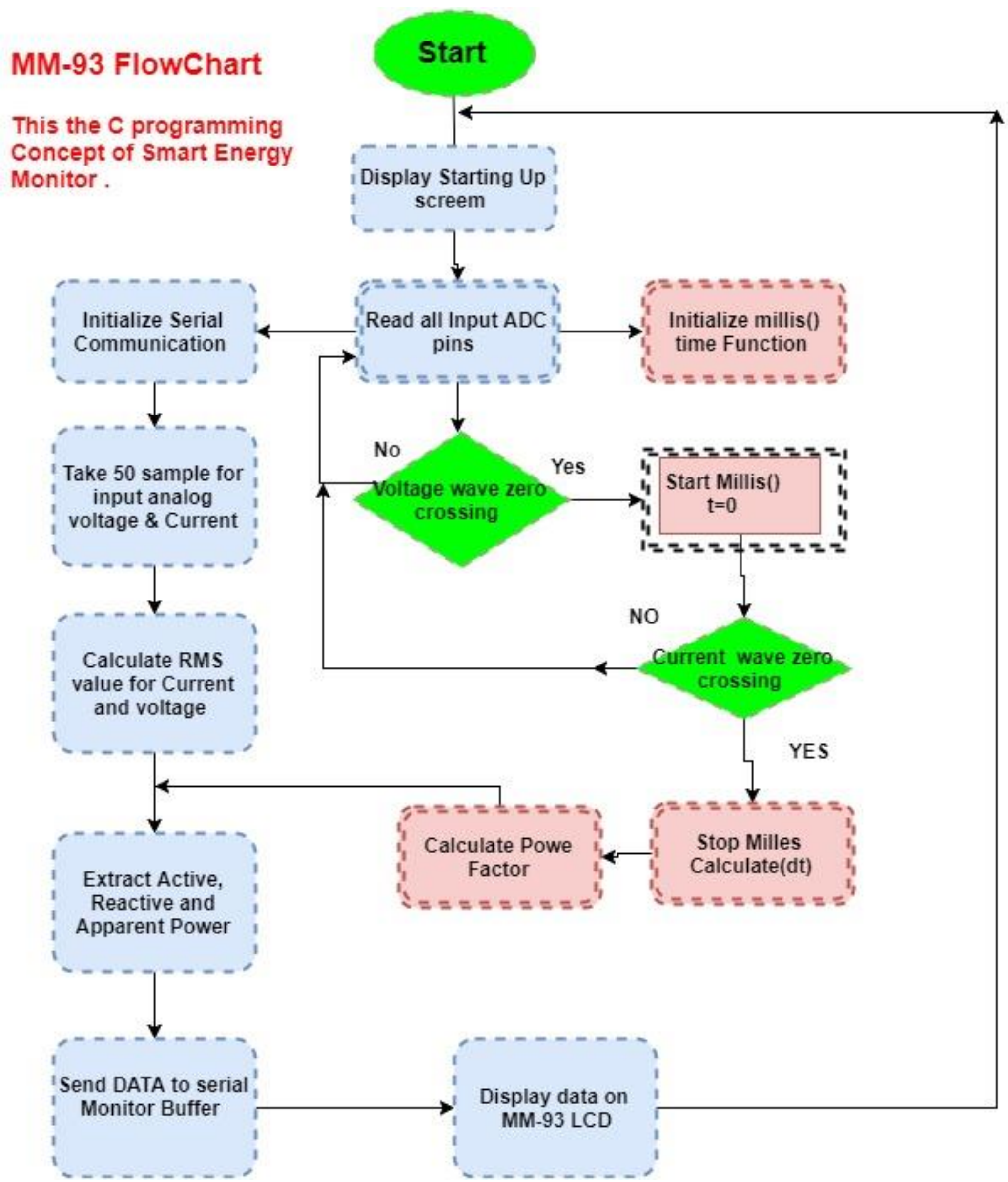
1.10.1 Building (MM-93) Using Arduino:

Every Processing Unit has its merits and limitations, Arduino Uno is not fast enough for this kind of complex data extraction and processing, but we did our best to make it suitable enough.

To extract all the electrical parameter of each input or output, you just need to measure voltage, Current

And power factor. In following steps, we going to study and analysis mathematical equations for voltage and current and choose the suitable ones for our missions.

The following **flowchart** shows in brief, the C programming concept of project algorithm.



1.10.2 Measuring Current – CT Sensor :

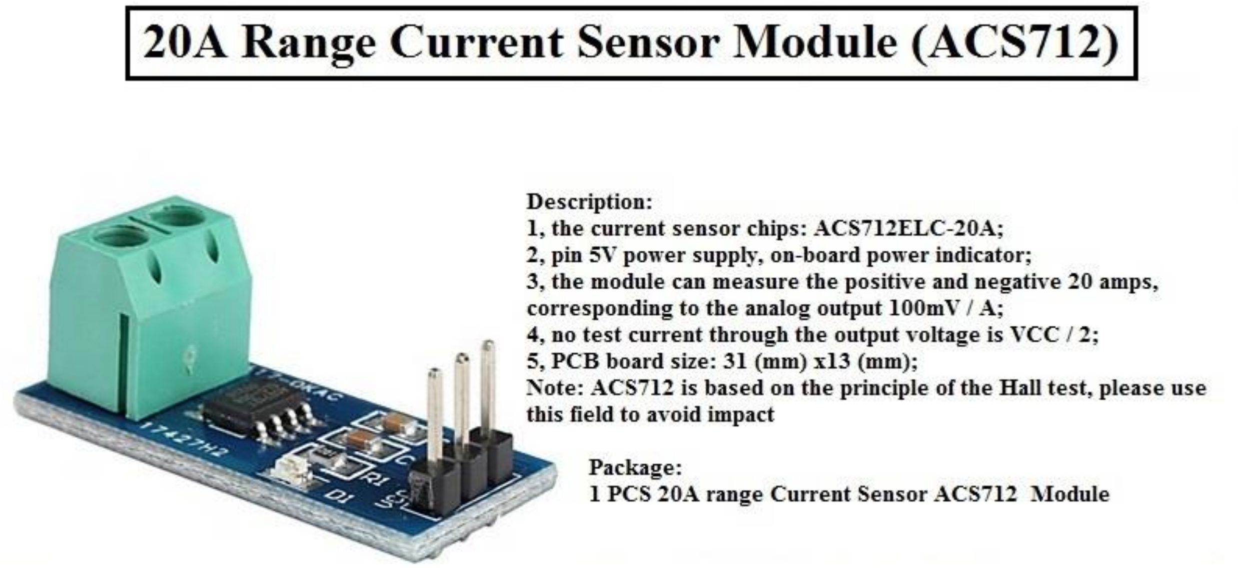
There are many types of CTs in the market, we collected some types below:

Pictured below, is an example of a **split-core** HYDC CT:

Here's an example of a Magnelabe **split-core** CT:

In addition to the split-core type, **solid-core**, (aka **ring-core**) CTs are available. Here's an example of a Magnelab **solid-core** CT.

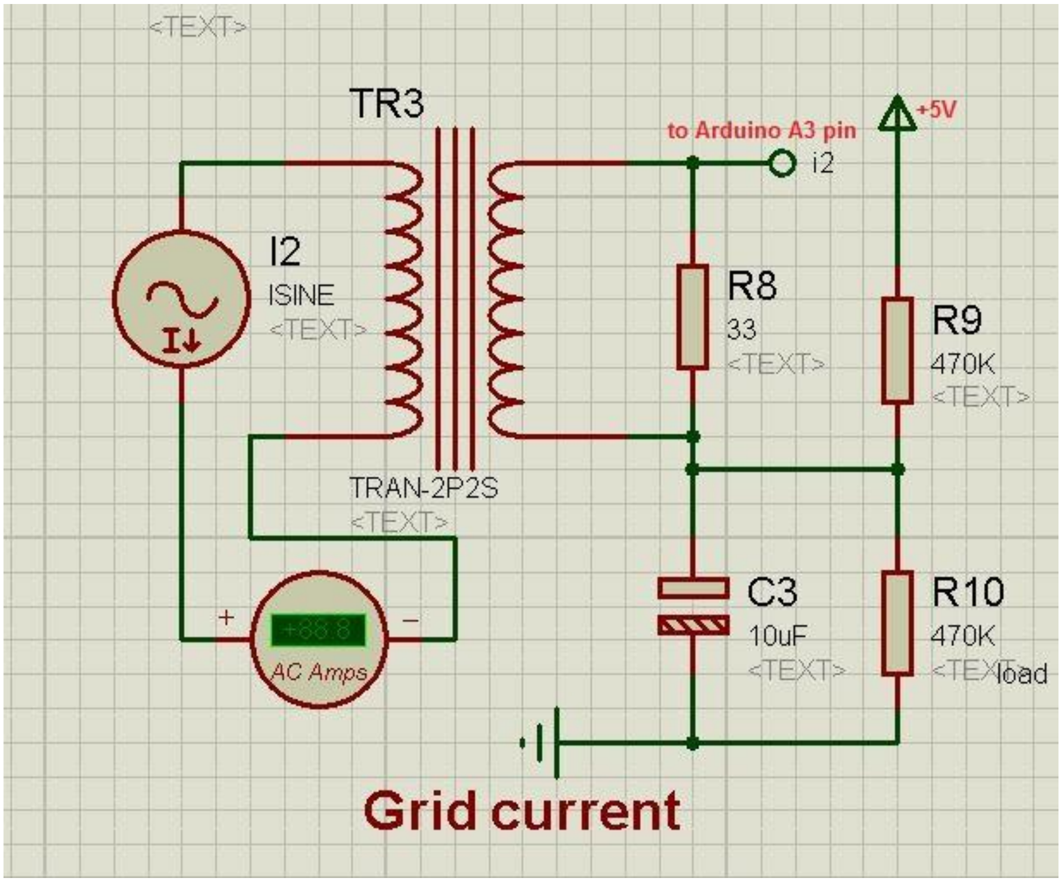
But in our project, we used CT module for educational purpose its current range is suitable for Arduino analog read sensitivity but , it's harmonics and noise source.



CT modeling in Protues:

The following circuit consists of current transformer, R8=33 Ohm as Z burden to convert secondary current of CT to voltage because Arduino analog input is sensitive to voltage only.

Capacitor C3 is used for wave form smoothing, R9, R10 with +5volt DC source is used as DC offset removal.



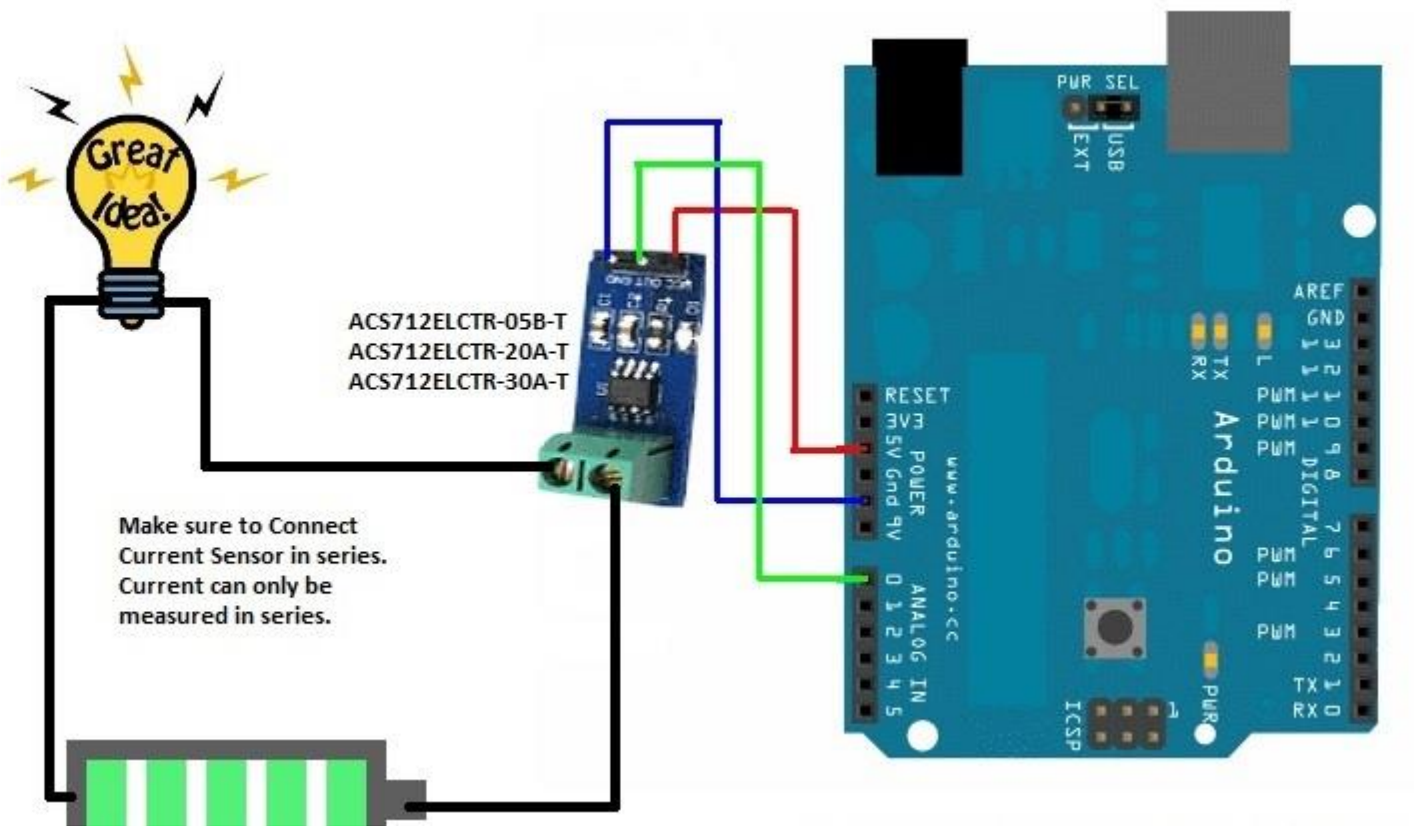
1.10.3 ACS712 CT interfacing with Arduino:

As we mentioned before, this CT is for educational purpose. It's cheap, low accuracy, harmonic source cannot handle more than 10 A load current although its data sheet says its current capacity is **20 A**. But we found that not true by experiments, it goes crazy with load capacity less than 10 A.

So for an industrial version of our (MM-93) we have to use one of CT types which we mentioned before.

To connect a CT sensor to an Arduino, the output signal from the CT sensor needs to be conditioned it meets the input requirements of the Arduino analog inputs, i.e. a positive voltage between 0V and the ADC reference voltage

Now, the next figure shows us **ACS712** configuration between the load and Arduino Board.



1.10.4 Measuring Voltage – PT Sensor :

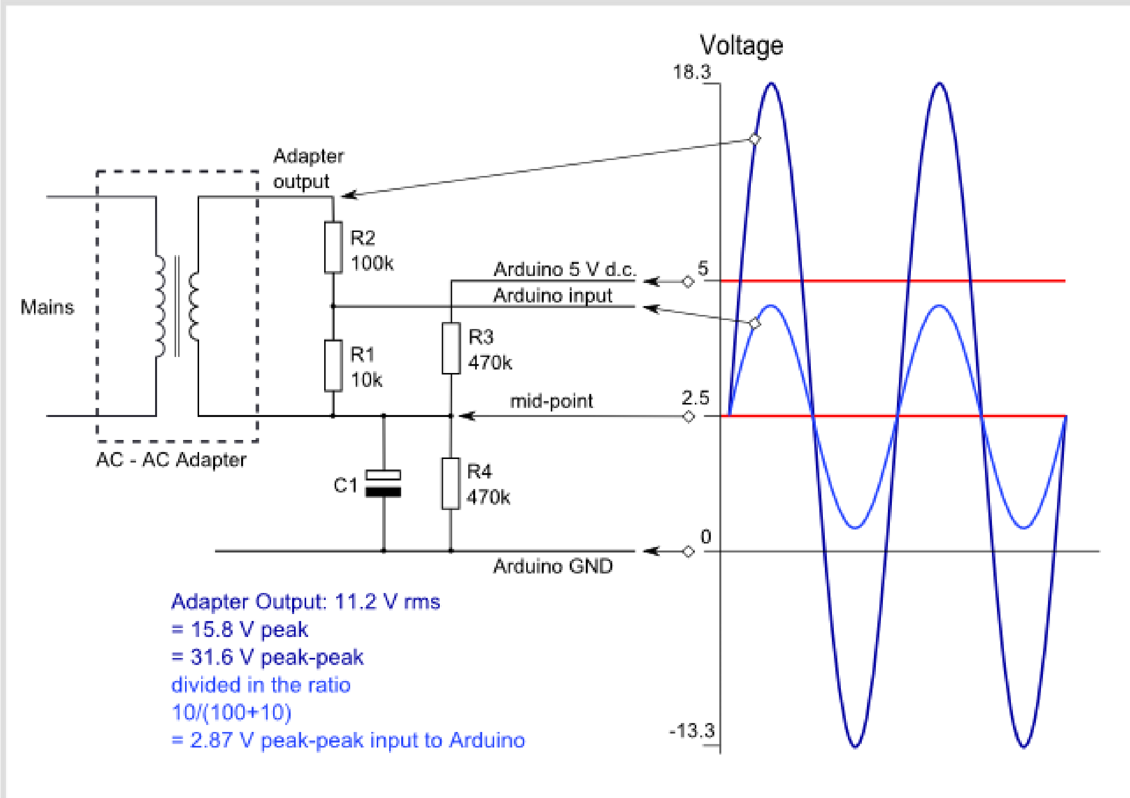
AC voltage measurement is needed to calculate real power, apparent power and power factor. This measurement can be made safely (requiring no high voltage work) by using an AC to AC power adaptor. The transformer in the adapter provides isolation from the high voltage mains.

To measure AC voltage using Arduino analog input we need to:

- **scale down** the waveform and
- **add an offset** so there is no negative component.

The waveform can be scaled down using a voltage divider connected across the adapter's terminals, and the offset (bias) can be added using a voltage source created by another voltage divider connected across the Arduino's power supply

The following circuit shows how we going to do that .



Resistors **R1** and **R2** form a voltage divider that scales down the AC voltage. Resistors **R3** and **R4** provide the voltage bias for DC Offset. Capacitor **C1** provides a low impedance path to ground for the AC signal. The value is not critical, between 1 µF and 10 µF will be good enough.

For our (MM-93), we used **ZMPT101B** Voltage sensor module for educational purpose

- **The ZMPT101B voltage sensor:**

ZMPT101B voltage sensor module is a voltage sensor made from the ZMPT101B voltage transformer. It has high accuracy, good consistency for voltage and power measurement and it can measure up to 250V AC. It is simple to use and comes with a multi turn trim potentiometer for adjusting the ADC output. The analysis in this paper tends to find more accurate relationship between the input voltage and the ADC output by regression analysis. The ADC output is adjusted using the trim pot to an appropriate value against a reference input.

There are many methods for voltage measuring and calibration using Microprocessors, we used

The Instantaneous voltage calculation method, the nature of the voltage and current in DC power system is characterized by having a constant value unless the voltage level or loads current are changed. But when it comes to an AC supply the voltage and currents are sinusoidal in nature, hence a sinusoidal varying voltage is connected to the sensor which means it can only read the value of the voltage at a particular time. The instantaneous calculation is used in the case of AC supply in which an algorithm uses the samples of the voltage to calculate the rms value of the voltage. It is also useful in the calculation of the rms current and real power consumption of the system. As the voltage is sampled at regular intervals the Arduino programming calculates the rms voltage as illustrated in following Equation:

$$V_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} V_i^2}$$

For this equation we take about 50(n=50) voltage samples every 20 milliseconds,

Then calculate the RMS value.

1.10.5 Measuring Power factor

Two different types of powers are associated with electric power system. Active power is consumed by load while Reactive power energizes capacitive as well as magnetic circuits. Reactive flows in system but it is not utilized. The utility companies restrict the flow of reactive power to a certain value. To determine the amount of reactive power, a quantity called power factor was introduced.

Power factor is defined in two different ways. One is related to the flow of power in the system.

It is the ratio of the active power to the total power of the system.

$$p.f = \frac{Active\ power}{Total\ Power} = \frac{KW}{KVAR}$$

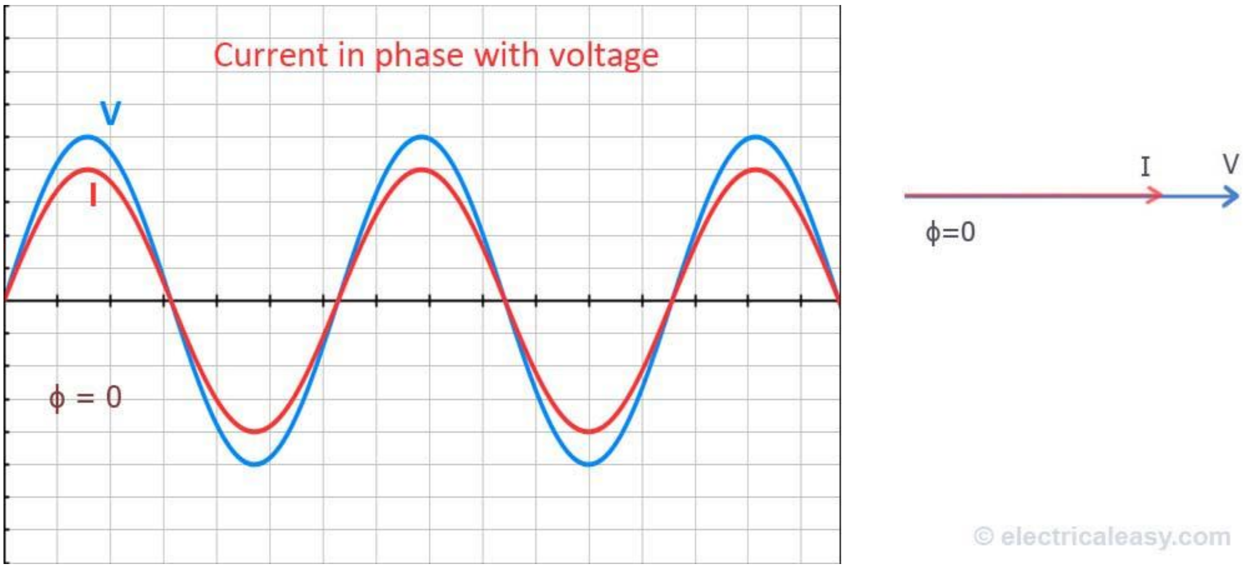
Where Φ is the angle between voltage and current of the system.

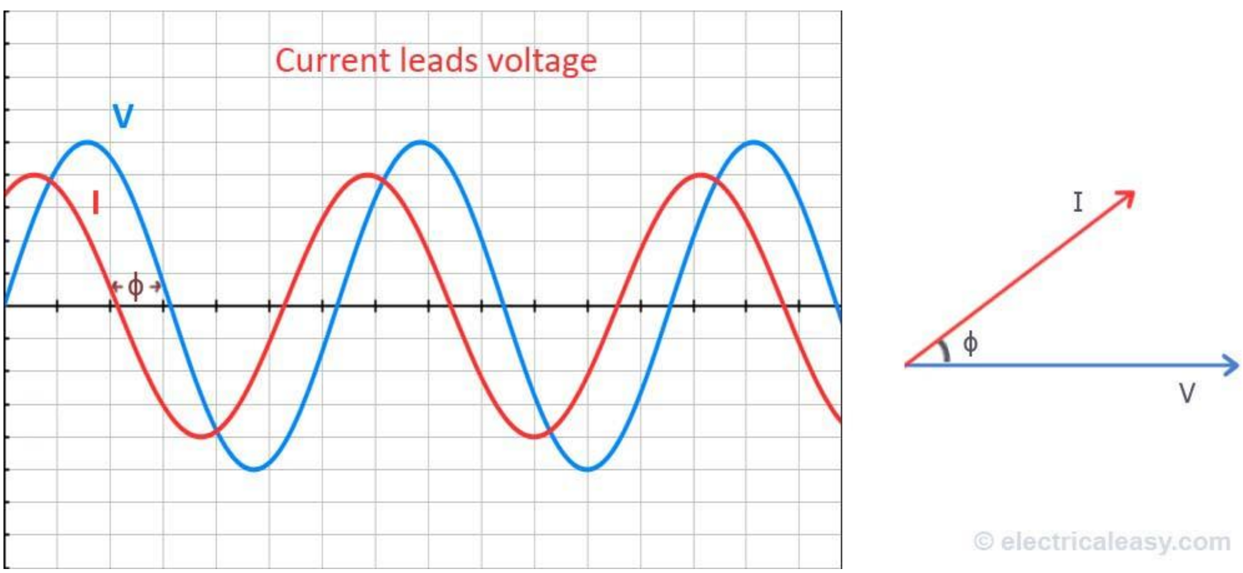
But, As we know active and reactive power are still unknown to us , so we cannot use the first way.

We have to measure the P.F Using Zero crossing for each Voltage and Current wave forms.

To that we don't need more extra hardware installation; we built a functions using C programming language to measure the time in seconds from the **MM-93** is on. When the fundamental voltage wave form arrives Processor take a **time mark** and do the same when the Current waveform arrives too.

By calculating the difference time between both wave forms we can calculate the angle between them.





1.10.6 Arduino Math for analog measuring:

All our processes depend on the analog readings from ADC module of Arduino, so let's talk a bit about Arduino ADC Module.

The concept of ADC (Analog to Digital Conversion) in ARDUINO UNO. Arduino board has **six** ADC channels, as show in figure below. Among those any one or all of them can be used as inputs for analog voltage. The **Arduino Uno ADC** is of 10 bit resolution (so the integer values from (0-(2^10) 1023)). This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023. So for every (5/1024= 4.9mV) per unit.

For handling ADC readings, we have some built in C functions:

```
analog Read(pin);
analog Reference();
analogead Resolution(bits);
```

1.10.7 Voltage and Current Calibration:

There are many methods for voltage and current measuring and calibration.

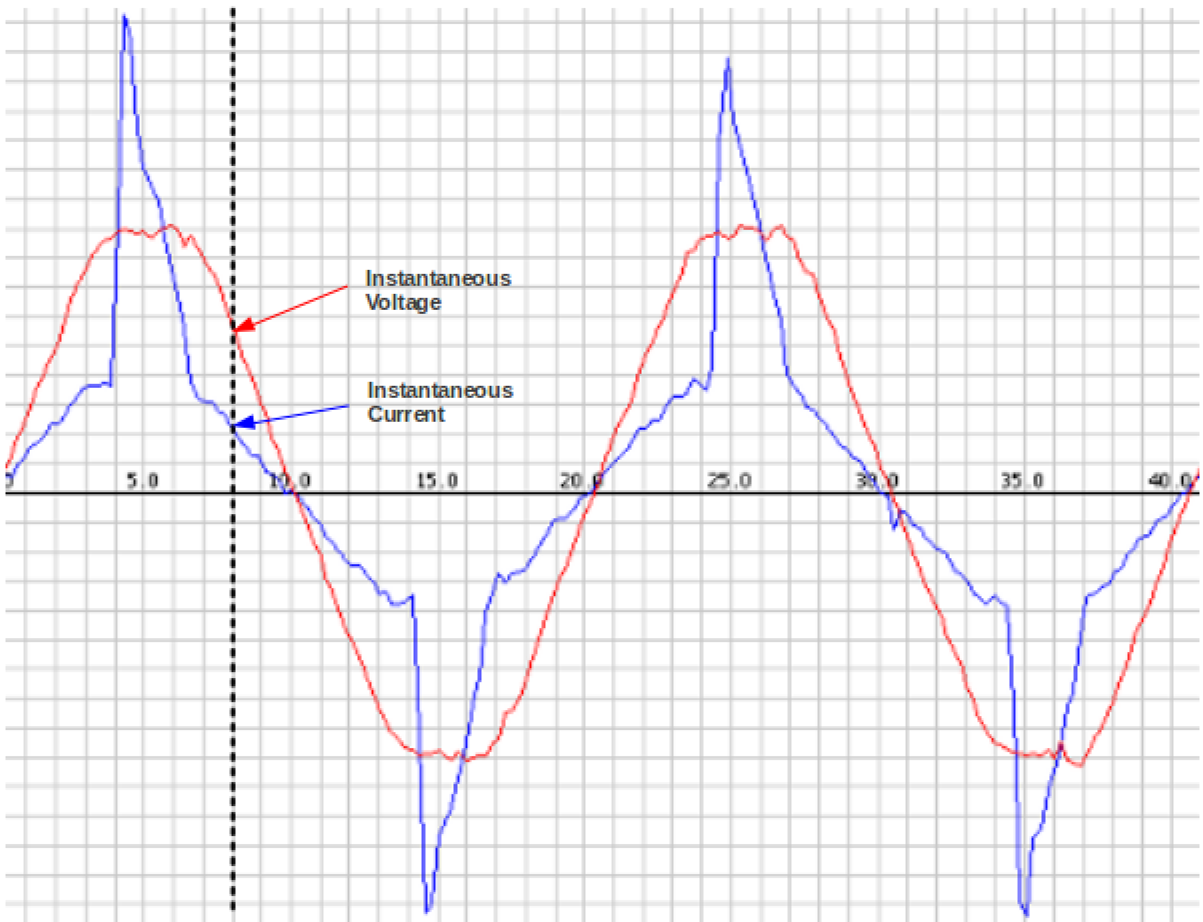
When we tested the ADC readings we found it **measures the peak value and** we need to measure the **RMS value.**

So we have to change our methodology of reading to read RMS values.

As the name suggests, AC Voltage and current continually alternate. If we draw a picture of the voltage and current waveform over time, it will look something like the image below. Depending on the type of load consuming power, the current waveform - blue in the diagram below - is what you get if you look at a typical laptop computer power supply. (There's an incandescent light bulb present, as well).

The image was made by sampling the mains voltage and current at high frequency, which is exactly what we do on the Arduino. We make between 50 and 100 measurements every 20 milliseconds. 100 if sampling only current. 50, if sampling voltage *and* current. We're limited by the Arduino analog read command and calculation speed.

Each individual sample is an instantaneous voltage or current reading.



1.10.8 Calculate Root-Mean-Square Voltage:

The root-mean-square is calculated in the way the name suggests. First we square the quantity, then we calculate the mean and finally, the square-root of the mean of the squares, this is how it's done:

```
For (n=0; n// inst_voltage calculation from raw ADC input goes here.

  squared_voltage = inst_voltage * inst_voltage;

  sum_squared_voltage += squared_voltage;}

mean_square_voltage = sum_squared_voltage / number_of_samples;
root_mean_square_voltage = sqrt(mean_square_voltage);
```

1.10.9 Calculate Root-Mean-Square Current:

Same as the RMS voltage calculation:

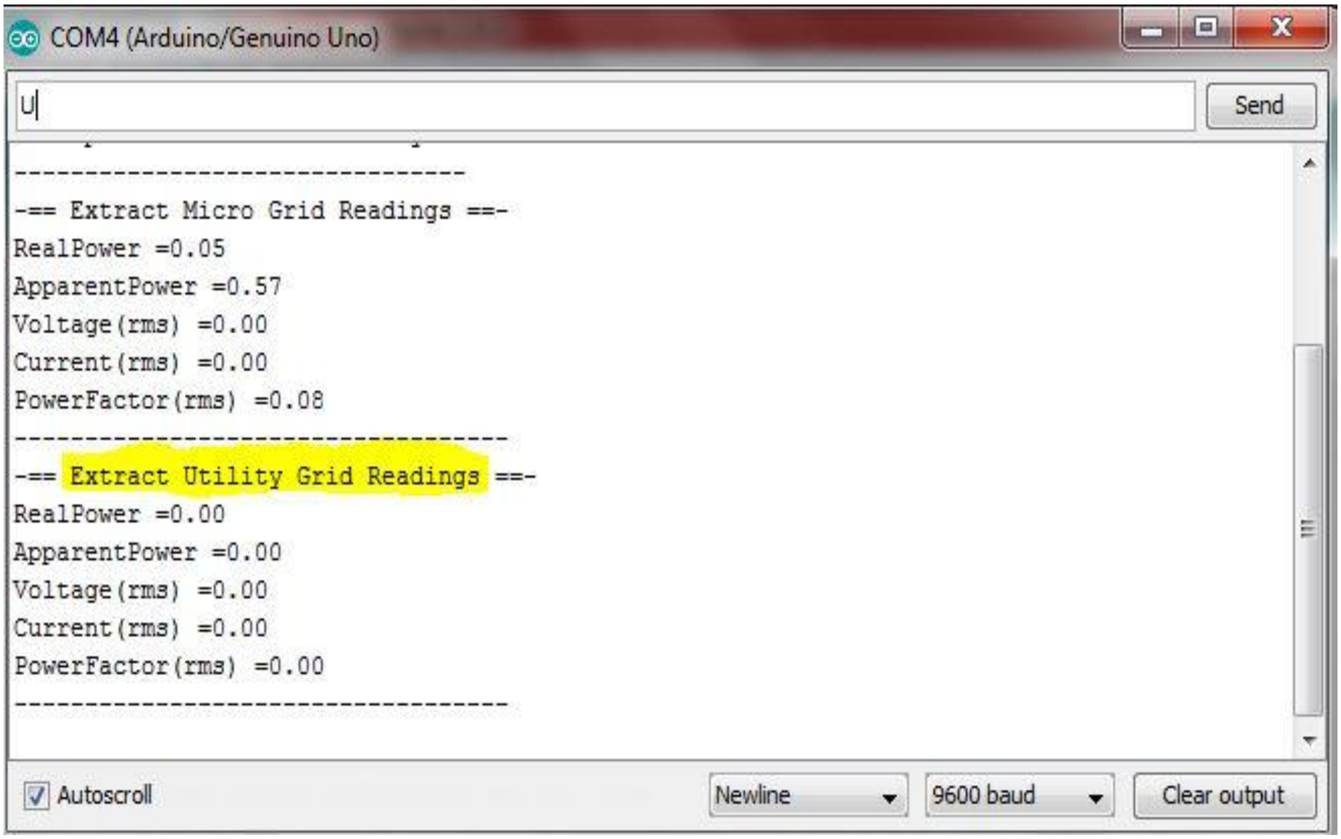
```
For (n=0; n// inst_current calculation from raw ADC input goes here.

  squared_current = inst_current * inst_current;

  sum_squared_current += squared_current;
}

mean_square_current = sum_squared_current / number_of_samples;
root_mean_square_current = sqrt(mean_square_current);
```

1.10.10 Command line Terminal :

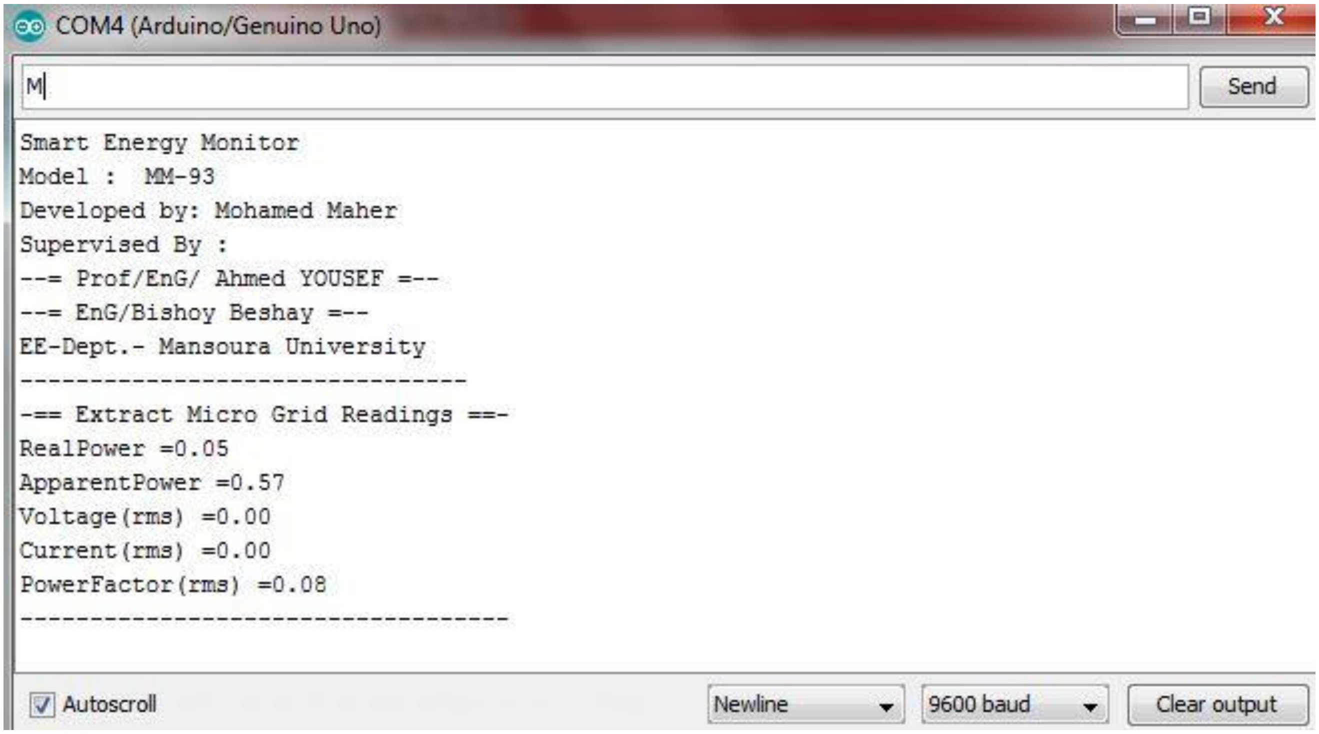
After connecting (MM-93) to your PC , you can ask it to send you any input/ output measurements through the Serial monitor .

For example

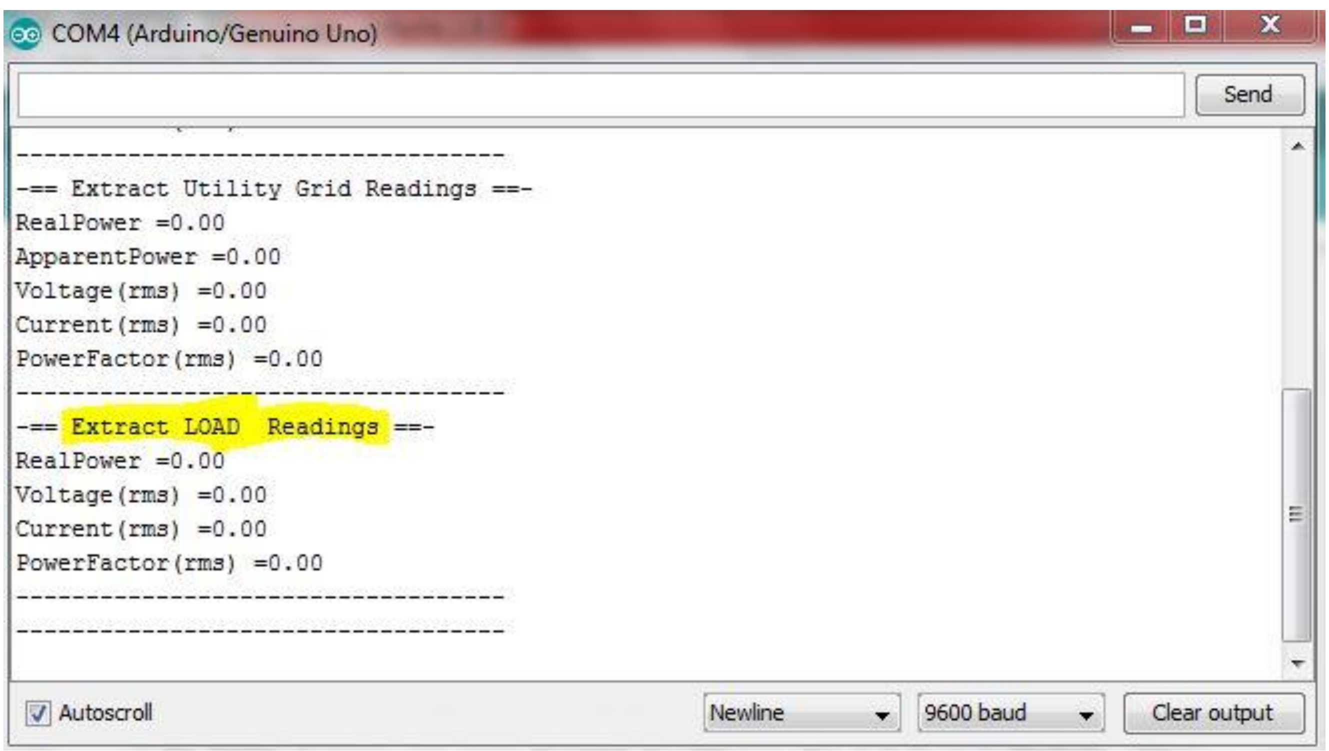
Command **"U":** (MM-93) will send you all the measurements of the Utility Input.



Command "**M**": (MM-93) will send you all the measurements of the MicroGrid Input.

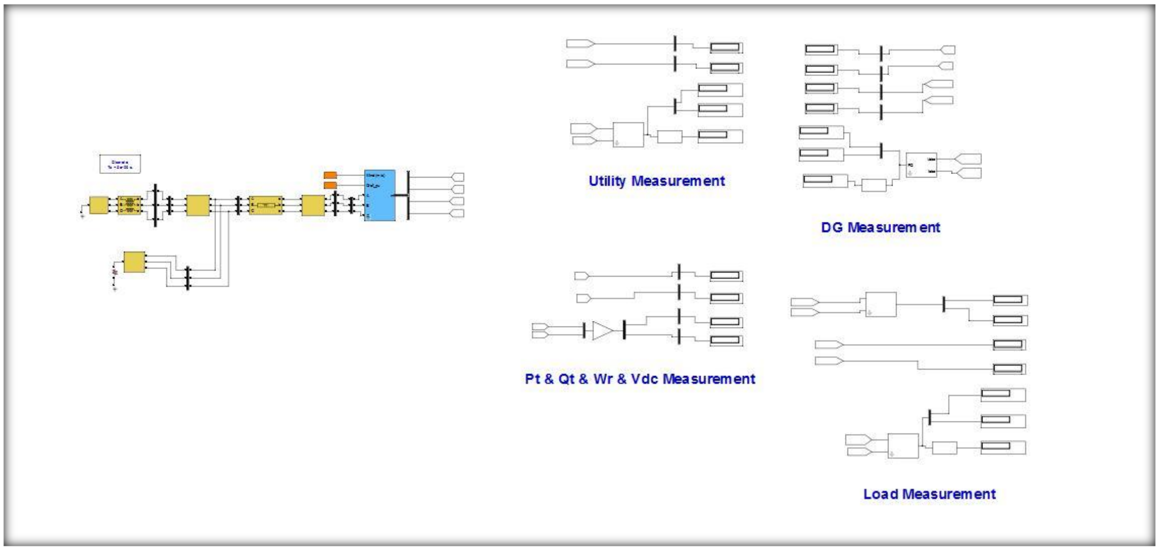


Command “**L**”: (MM-93) will send you all the measurements of the Load Input.



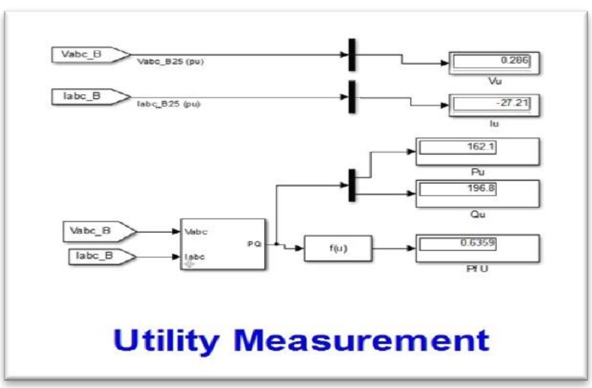
The importance of that feature is that we easily can interface MM-93 data to Mat lab for analysis, Data logging or send a report through mail with some bit software communications.

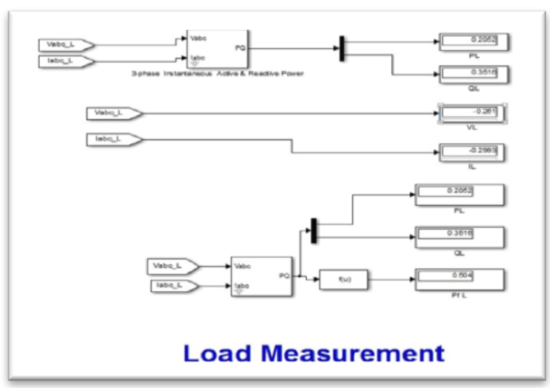
1.11 Smart Meter Modeling in Simulink.

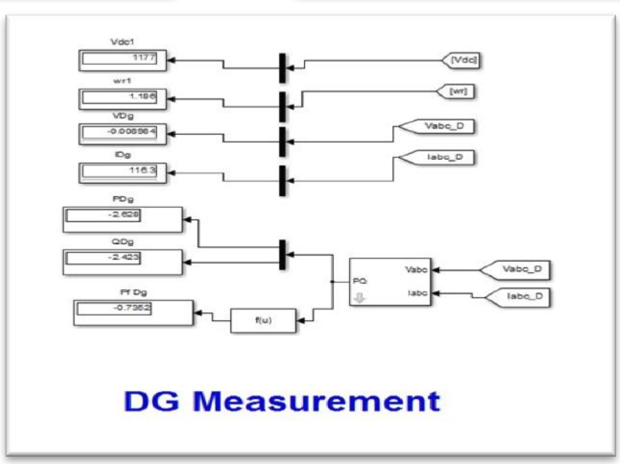


Using wind model in test measuring, at load side, DG side and Utility and compare reads

To make the perfect load control gives the most efficiency.







1.12 Testing (MM-93)

Our Testing Version of hardware had been built for measuring 2 AC inputs (Utility and Solar Inverter) and feeding one load .

For testing we have to notice some **TIPS:**

- **Utility terminals interfacing with Inverter output :**

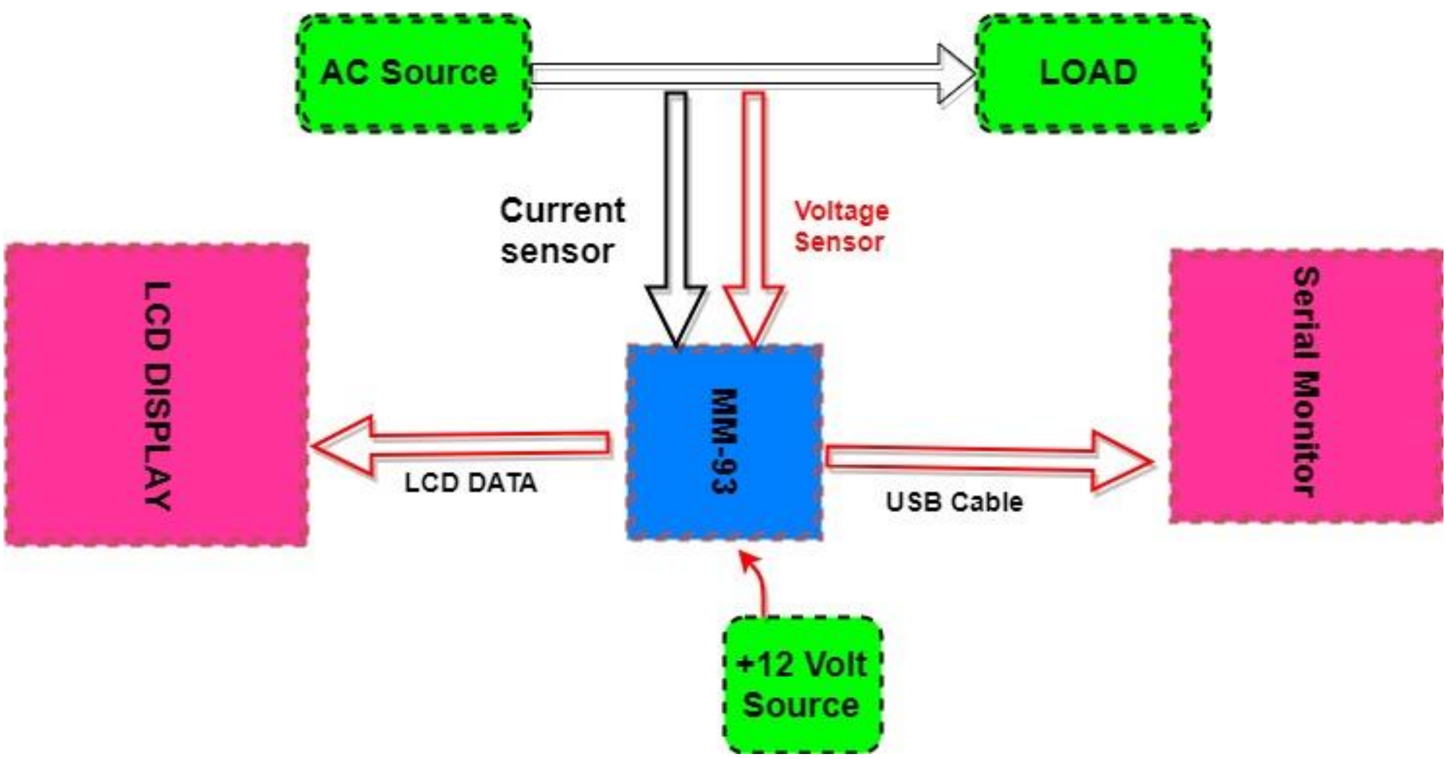
  The inverter must be ON GRID to insures that the voltage and frequency is common.

- **The ZMPT101B voltage sensor interfacing**
  it's important to connect the Line of source to line input pin of ZMPT101B and the Neutral to neutral input pin, Reversed connection may cause serious Module damage.

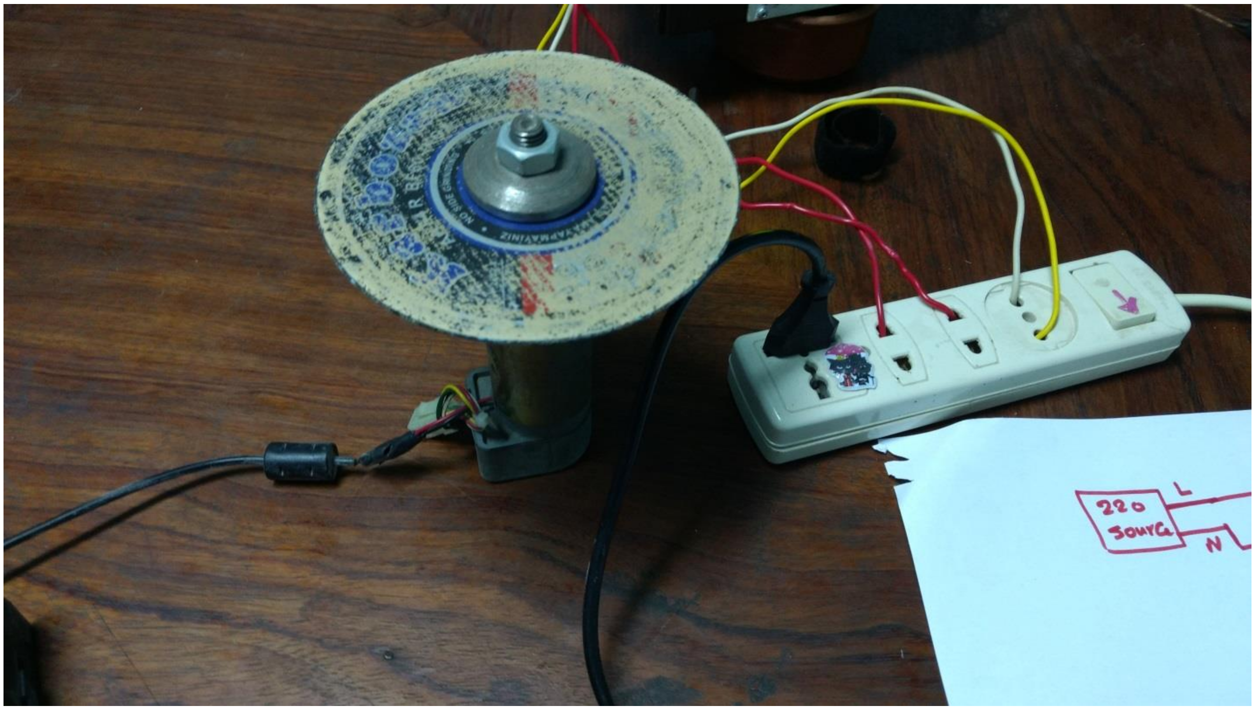
- **Arduino Boards is very sensitive to harmonics** , the source must be as less harmonics as we can, or externally Removed.

- **Current sensor is connect in series between source and load.**

WE going to test each input reading alone .Starting with MicroGrid input.



Our load in Experiment is Motor with rated current 2 A.



We testing the measuring of power consumed by load form solar source and the results :

And the net readings :

Then doing the same for the other input, the Utility Input .

And the results of measuring and extracting all the factor is :

And the net Readings is :

You can watch testing video for connections and results from the link below:

https://www.youtube.com/watch?v=y-EdhLCSwds&list=PLydpWS-jHL_y8hfee6pWXURRY3gGgDE0D

References

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