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INSIGHT SOLAR

Solar PV Grid Tied

Training System

Experiment **Manual**

includes 6 experiments with step by step procedure

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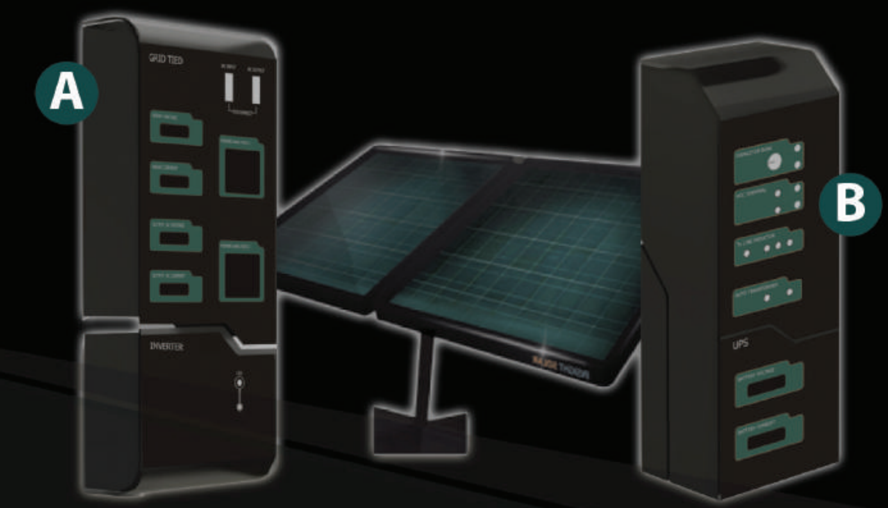
Develop an in-depth understanding of a Solar PV Grid-Tied System through a real-life hands on experience.

A Power Conditioning Unit

It has been designed keeping in view the user interactivity. It consists of all the digital panel meters for the easy and clear display of the readings of different parameters. It has in it both AC & DC MCBs to ensure protection to the user. It provides flexibility to operate the power analyzer while conducting different experiments.

B Virtual Grid

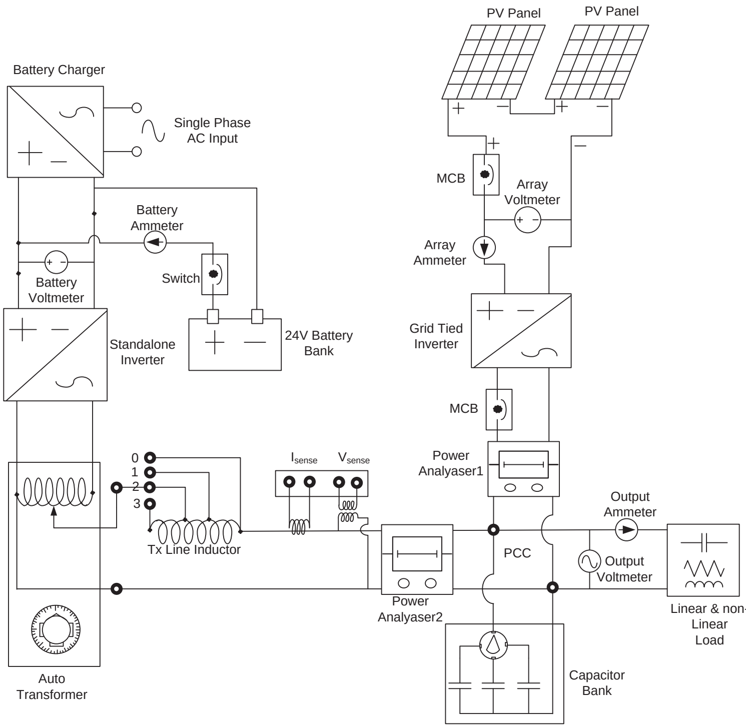
It consists of all the components as to use it as a Grid. Capacitor Bank is also provided to switch different capacitance values through a multiple switch. Inductance values can also be changed by using different line terminals. This Grid is compact enough and provide understanding of the actual grid. It also has load terminals retrofitted to it for connection to the external loads.



Insight Solar
Introduction

A Solar Grid-tied System is a grid connected PV system which links solar power generated by the PV modules to the mains. It acts as an interactive medium where the demand for electricity is fulfilled by the conglomeration of PV and mains. This product gives a deep insight into the dynamics of a Grid Tied system and its operation and maintenance.

The figure given below shows the line diagram of Solar PV Grid Tied Training and Research System. The grid tied system consists of a solar PV array connected to a grid tied inverter through a changeover switch. A voltmeter and an ammeter is connected to measure the panel output voltage and current respectively. The AC output of the grid tied inverter is connected to the



Line Diagram for Solar PV Grid Tied Training and Research System point of common coupling (PCC) through a power analyzer. The power analyzer measures the power delivered by the solar panel into the grid. A standalone inverter, connected to a battery bank through a voltmeter and ammeter, acts as a virtual grid for the system. The battery bank is charged through a battery charger using single phase AC as input. The output of the standalone inverter is connected to an auto transformer which is used to adjust the voltage level of the virtual grid. An inductor is connected in series in the system to depict the effect of transmission line inductance present in a real power system. A current sensor and voltage sensor are connected to observe the current and voltage waveform present in the grid. A power analyzer is then connected before the point of common coupling (PCC) to measure the flow of power to and from the grid. At PCC a capacitor bank is also connected through a multiple throw switch for power factor improvement. At the output the load is connected through an output ammeter and a voltmeter.

☺DOs

- Slowly increase the autotransformer terminal output voltage when capacitor bank is ON
- Make sure DC input MCB is OFF while changing over the panel output switch for external use
- Keep electrical connections tight and neat
- Make the connections as per given in the manual
- It is recommended to change the solar panel inclination angle seasonally

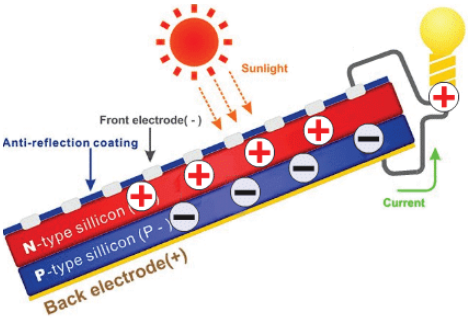
☹DON'Ts

- Don't touch live terminals
- Don't disconnect or change inductance while current is flowing through it
- Don't turn on or change the capacitor bank knob while line is live
- Don't load the output terminals above 300VA

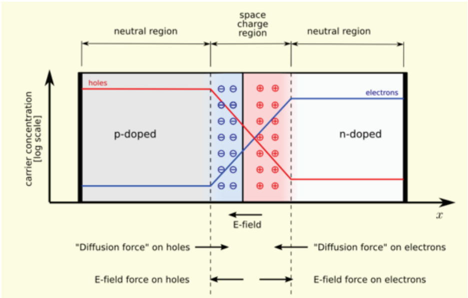
Insight Solar

Overview of Complete Solar PV System, Basics of PV Solar Technology & Corresponding Experimentation

A solar cell is a device that converts the energy of sunlight directly into electricity by the **photovoltaic effect.** Sometimes the term solar cell is reserved for devices intended specifically to capture energy from sunlight. The most commonly known solar cell is configured as a large-area p-n junction made from silicon. As a simplification, one can imagine bringing a layer of n-type silicon into direct contact with a layer of p-type silicon. In practice, p-n junctions of silicon solar cells are not made in this way, but rather by diffusing an n-type dopant into one side of a p-type wafer (or vice versa).



If a piece of p-type silicon is placed in intimate contact with a piece of n-type silicon, then a diffusion of electrons occurs from the region of high electron concentration (the n-type side of the junction) into the region of low electron concentration (p-type side of the junction). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. The diffusion of carriers does not happen indefinitely, however, because charges build up on either side of the junction and create an electric field which prevents the further diffusion of charge carriers. The region where electrons and holes have diffused across the junction is called the depletion region because it no longer contains any mobile charge carriers. It is also known as the space charge region. This phenomenon can be understood easily by following diagram.



Formation of P-N junction

When a photon hits a piece of silicon, one of three things can happen

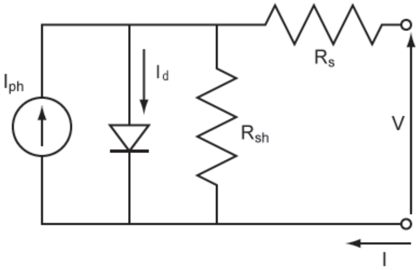
1. The photon can pass straight through the silicon — this (generally) happens for lower energy photons,
2. The photon can reflect off the surface,
3. The photon can be absorbed by the silicon, if the photon energy is higher than the silicon band gap value. This generates an electron-hole pair and sometimes heat, depending on the band structure.

When a photon is absorbed, its energy is given to an electron in the crystal lattice. Usually this electron is in the valence band, and is tightly bound in covalent bonds between neighboring atoms, and hence unable to move far. The energy given to it by the photon "excites" it into the conduction band, where it is free to move around within the semiconductor. The covalent bond that the electron was previously a part of now has one fewer electron — this is known as a hole. The presence of a missing covalent bond allows the bonded electrons of neighboring atoms to move into the "hole," leaving another hole behind, and in this way a hole can move through the lattice. Thus, it can be said that photons absorbed in the semiconductor create mobile electron-hole pairs. These mobile charge carriers are responsible for the current conduction across the junction.

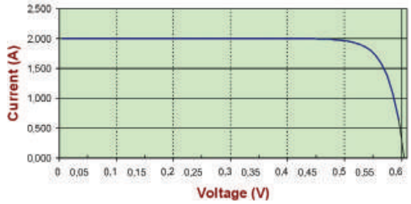
Theory

1. Characteristic Curves

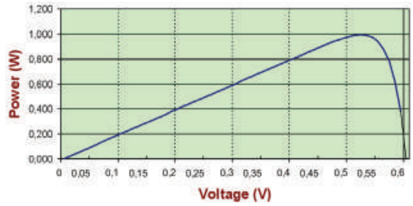
Solar cell can be represented by an equivalent circuit also. This circuit also includes the losses due to the solar cell manufacturing process. In this circuit Rs is the series resistance associated with the cell which is due to the grids above the solar cells and interconnection of solar cells. Rsh is the parallel resistance with cell which represents the leakage current through the cell. Equivalent circuit of cell is as follows:



Equivalent Circuit of Solar PV Cell



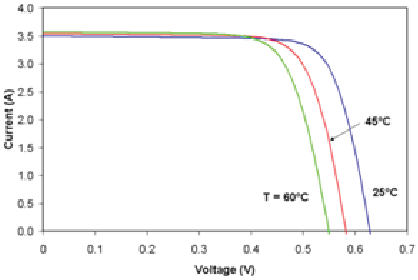
I-V Curve of Solar Cell



P-V curve of Solar Cell

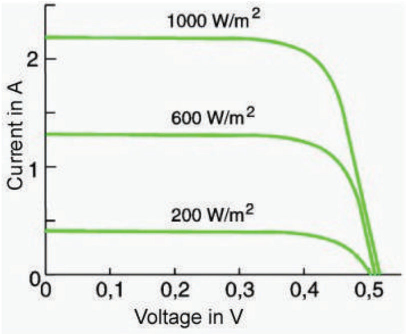
In these curves maximum current at the zero voltage is called short circuit current (I_{sc}) and the maximum voltage is known as open circuit voltage (V_{oc}). In P-V curve the maximum power is achieved only at a single point which is called MPP (maximum power point) and the voltage and current corresponding to this point are referred as V_{mp} and I_{mp}.

On increasing the temperature V_{oc} of module decreases while I_{sc} remains the same which in turn reduces the power.



Variation in Voc with change in temperature

On changing the solar insolation, I_{sc} of the module increases while the V_{oc} increases very slightly.

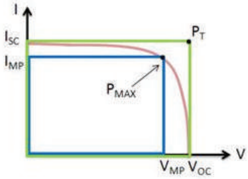


Variation in characteristic curve with Insolation

2. Fill Factor

The Fill Factor (FF) is essentially a measure of quality of the solar cell. It is calculated by comparing the maximum power to the theoretical power (P_T) that would be output at both the open circuit voltage and short circuit current together. FF can also be interpreted graphically as the ratio of the rectangular areas depicted in following Fig. Larger fill factor is desirable, and corresponds to an I-V sweep that is more square-like. Typical fill factors range from 0.5 to 0.82. Fill factor is also often represented as a percentage.

$$FF = \frac{P_{MAX}}{P_T} = \frac{I_{MP} \cdot V_{MP}}{I_{SC} \cdot V_{OC}}$$



3. Maximum power point

Every model of solar panel has unique performance characteristics which can be graphically represented in a chart. The graph is called an "I-V curve", and it refers to the module's output relationship between current (I) and voltage (V) under prevailing conditions of sunlight and temperature. Because of Ohm's Law (and the equation Power = Voltage x Current), the result of reduced voltage is reduced power output. The ideal position on any I-V curve—the sweet spot where we can collect the most power from the module—is at the "knee". That's the maximum power point (MPP), and can be observed that its position changes with temperature and irradiance

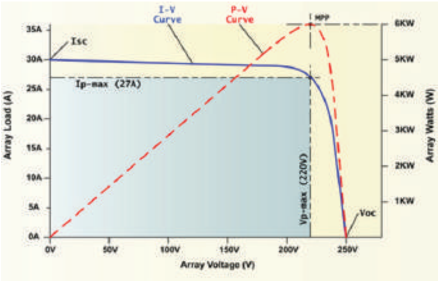


Fig-4 The I-V & P-V CURVES

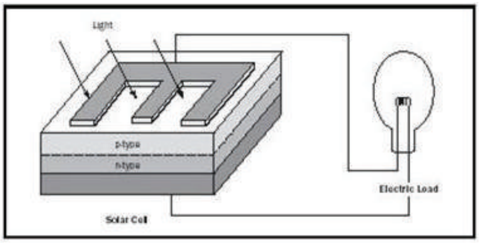
4. Efficiency of Solar PV Module

There are two main modes for charge carrier separation in a solar cell:

1. Drift of carriers, driven by an electrostatic field established across the device

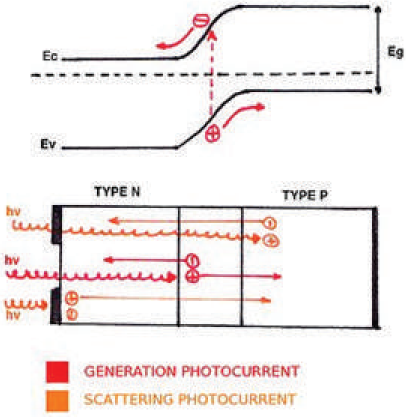
2. Diffusion of carriers from zones of high carrier concentration to zones of low carrier concentration (following a gradient of electrochemical potential).

In the widely used p-n junction solar cells, the dominant mode of charge carrier separation is by drift. However, in non-p-n-junction solar cells (typical of the third generation solar cell research such as dye and polymer solar cells), a general electrostatic field has been confirmed to be absent, and the dominant mode of separation is via charge carrier diffusion.



Block diagram of solar cell with external circuit

Generated hole goes in the direction of electric field while electron goes in the opposite direction of field and in this way all holes gets gathered on p-type surface and electron gets gathered on n-type surface. These charges at the surface make a potential which will cause the flow of current on connecting these by load through a wire.



Flow of charge carriers in solar cell

Following losses take place in solar cell

1. ***Reflection losses:*** Occurs at top surface of the cell were light is incident. Reflection of light results in low absorption of photons in the solar cell.

2. ***Recombination losses:*** Occurs everywhere in the volume of the solar cells. Carriers generated get recombine with each other in order to maintain equilibrium condition. Areas were these losses occur in large magnitude are Bulk region (base region), Top surface, Metal to semiconductor contact areas, Junction region.

3. ***Series resistance losses:*** Resistance, contributed by the Metal fingers, Metal to semiconductor contact resistance, Bus bar, Emitter region and Bulk region, is called as series resistance. Voltage drop and power loss results due to high value of series resistance and hence reduce efficiency.

4. ***Thermal losses:*** A very small quantity of light absorbed by the cell

is utilized in generation of power, remaining photon energy goes utilized in the form of heat which increases the temperature of the cell. Cell parameters such as open circuit voltage (V_{oc}), short circuit current (Isc) are functions of temperature. I_{sc} increases with temperature but this increment is negligible but there is a 0.5 % drop in V_{oc} with every degree rise above the 250C.

So it can be seen that only a part of solar radiation falling on PV cell is converted into useful energy. This efficiency is highest Mono crystalline type solar panels and is least for thin film type panels. Typical efficiency of Poly crystalline solar panel is between 12 to 15%.

Mathematically, efficiency of solar panel is given as

$$Efficiency(\eta,\%) = \frac{V_m * I_m}{Irradiance(W/m^2) * Area(m^2)} * 100$$

5. Impact of Partial Shading

If a part of module, a complete module or few modules of string are shadowed by neighboring building or tree, then it is called partial shading.

A shadow falling on a group of cells will reduce the total output by two mechanisms; 1) by reducing the energy input to the cell, and 2) by increasing energy losses in the shaded cells. Problems become more serious when shaded cells get reverse biased. As shown in equivalent circuit of the cell, there is a diode parallel to the current source which is function of radiation falling on the cell. If value of this radiation dependent current source is higher than output load current, then this diode is forward biased and there is no problem. But if radiation is not sufficient and current is smaller, then diode get reverse biased and offers high resistance, consumes power and significantly reduces the load current.

Now suppose a string composed of series connected modules suffers partial shading i.e. a module is completelly shaded. Now this series connected module offers high resistance path to the current. Thus voltage is blocked across shaded module; consequently nearly zero current flow from the path. In order to prevent it, a bypass diode is used. Anode of diode is connected to negative terminal and cathode of diode is connected to positive terminal of each module. Now, if shaded module is reversed biased, load current continues to flow through bypass diode.

Impact of partial shading on P-V curve is that now multiple power peaks appear instead of single maximum power point.

Objective of this experiment is to develop basic understanding of PV panel characteristic curves and various terminologies.

Insight Solar
Experiment No. 1

Observation of Current Waveform for Linear & Nonlinear Loads and Calculations

Power electronics finds vivid applications in field of solar grid tied system. In order to learn the advance concepts related to power electronics applications in power control, one should have clear understanding of basic electrical concepts. Using the power electronics based apparatus, for example inverter in this case results in nonlinear current to flow in the electrical circuitry. One should be aware of mathematical definitions related to linear and non linear voltages and current. Hence the aim of this experiment is to recap those concepts by observing current waveforms in power scope and doing the mathematical calculations. In theory, basic definitions and formulas are given.

Theory

1. Displacement Factor

Mathematically, it is represented as cosine of angle between fundamental component of voltage and current. So if Ø is the angle between voltage and current's fundamental, Displacement Factor (DF) is given as

Displacement Factor = cos(Ø)

2. THD and Distortion Factor (DF)

It is measure of distortion present in the signal.

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \dots}}{V_{rms}}$$

Where, $V_{rms} = \sqrt{V_1^2 + V_2^2 + V_3^2 + V_4^2 + V_5^2 \dots\dots}$

$$DF = \frac{V_1}{V_{rms}} = \frac{V_1}{\sqrt{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \dots}} = \sqrt{1 - THD^2}$$

3. Power Factor

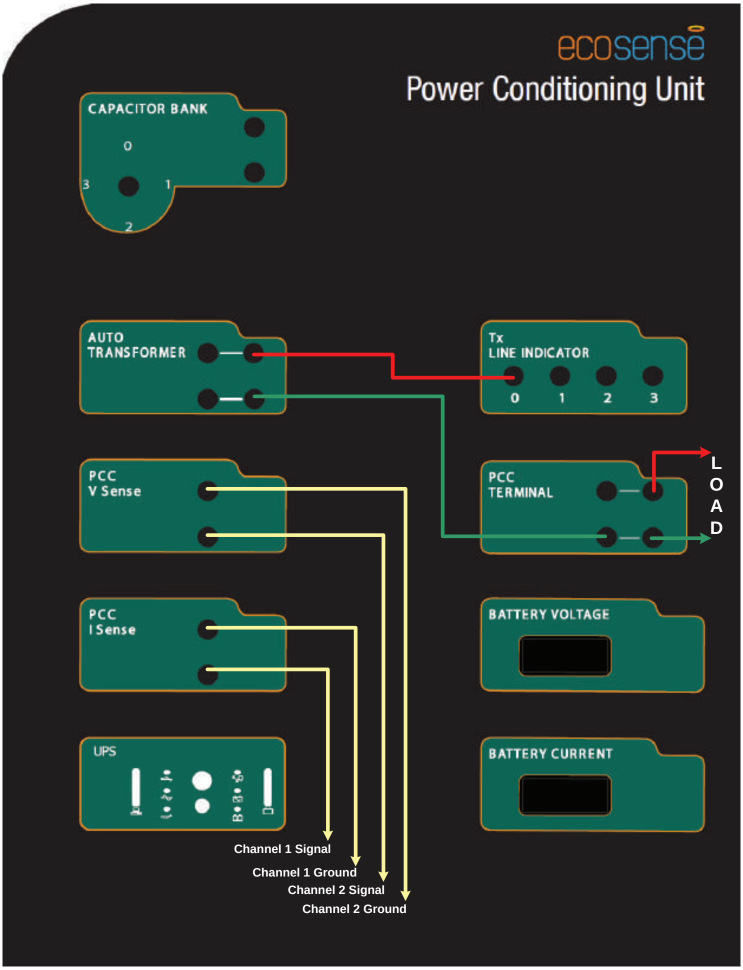
For purely sinusoidal loads, Displacement Factor and Power Factor are same as Distortion Factor is unity. However when the load connected is non linear, Power Factor is given as

Power Factor = (Displacement Factor)*(Distortion Factor)

$$PF = \frac{V_1}{\sqrt{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \dots}} \cos\phi$$

Experimental Setup

Connect the phase of autotransformer with 0 numbered terminal of Tx Line Inductor and connect the ground of autotransformer with ground of PCC (Point of Common Coupling) directly. By using this connection arrangement, we have connected the PCC terminals in parallel with autotransformer through Power Analyzer 2. Power Sockets are also connected in parallel with PCC terminals. Now rotate the knob of autotransformer so



as to adjust the voltage at PCC equals to 210V rms. Reading of PCC voltage can be taken from AC Output Voltmeter or from Power Analyzer 2. In order to observe the waveforms, we will require a power scope. Usually input voltage range of oscilloscope is limited so we can not directly connect the probe to AC voltage level. Secondly there is no isolation available in probes and grounds of channels of oscilloscope are internally connected. Oscilloscope with such limitations cannot be directly used to observe the power leveled voltage and current. One solution is to use separate isolated voltage and current probes which is not an economical solution. So isolated ports are provided through which voltage and current waveforms can be observed using a normal scope only. Now connect one channel of oscilloscope with VSENSE terminals and second with ISENSE terminals.

Demonstration and Calculations

Connect a linear load like 200W bulb (though it is not perfect linear) to the output terminals of sockets and turn on the switch. Take readings of Voltage (V in rms), Current (I in rms), Angle (Ø, phase difference between voltage & current), THD in voltage and current, Active power (P in Watt), Reactive Power (Q in VAr), total Apparent Power (S in VA).

Observe the waveforms in oscilloscope. From above readings, do the following calculations for

- $DF = \sqrt{1-THD^2}$ (Use THD in current)
- Displacement Factor = cos(Ø)
- Power Factor = DF*cos(Ø) and verify the result with measured Power Factor
- $S = \sqrt{P^2 + Q^2}$ and verify the result with measured apparent power
- $Fundamental Voltage = V_1 = V_{rms}\sqrt{1-THD^2}$ (use THD in voltage)
- $Fundamental Current = I_1 = I_{rms}\sqrt{1-THD^2}$ (use THD in current)

Repeat the same experiment by connecting a non linear load like laptop charger or diode bridge rectifier followed by filter capacitor and observer the waveform. It can be seen that current is highly distorted and THD is more than linear load case. Take the same reading as above and repeat the calculations. Calculated values should be nearly equal to measured values.

Result Table

Load Type	THD	Distortion Factor $DF = \sqrt{1-THD^2}$	DF = cos(Ø)	Power factor	Fundamental Voltage $V_1 = V_{rms}\sqrt{1-THD^2}$	Fundamental Current $I_1 = I_{rms}\sqrt{1-THD^2}$

Active Power(P)	Reactive Power (Q)	Apparent Power $S = \sqrt{P^2 + Q^2}$	Measured Apparent Power

Insight Solar
Experiment No. 2
Impact of Transmission Line Inductance on Voltage Quality at PCC

Transmission lines serve as interlinks between remote power generator and distribution network. Usually transmission lines run over several of hundreds of Km and have higher X/R ratio. Also presence of power transformers in the network results in significant inductance between generator and end users or PCC. There are several power quality issues associated with inductance like excessive reactive power requirement for charging of transmission lines, voltage sag and increased THD in voltage at PCC when a non-linear load is connected to the system.

In this experiment, role of transmission line inductance in voltage sag & poor THD at PCC voltage is demonstrated.

1. Voltage Sag

Theory

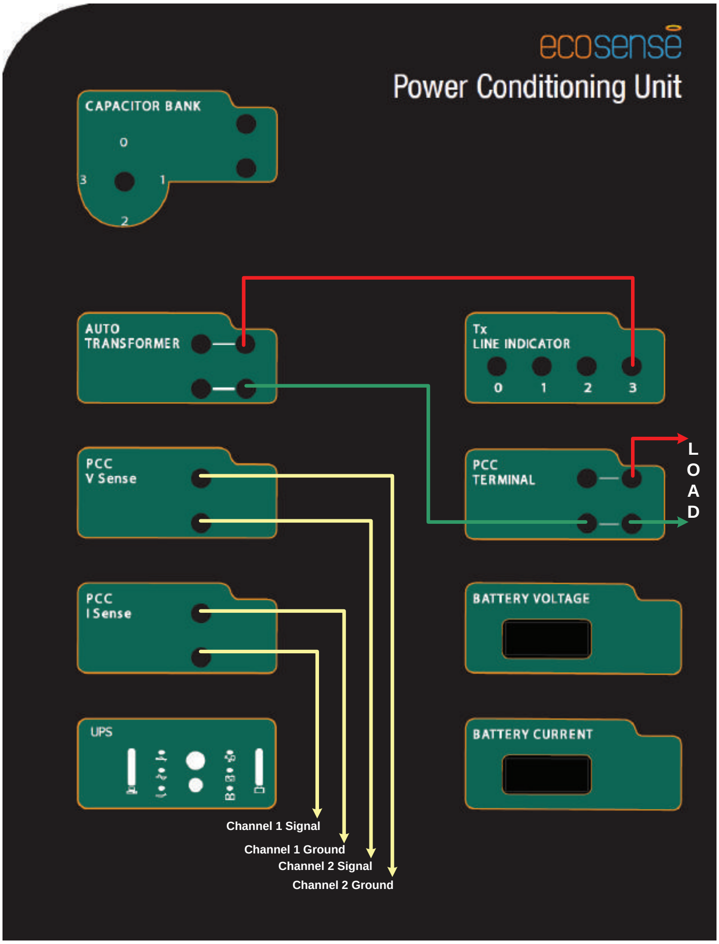
Since the transmission & distribution network has finite inductive reactance, there is always significant voltage drop when transmission lines are loaded. This voltage drop is depends on two things, inductive reactance & loading current. Again inductive reactance is function of length of transmission line. For a fixed voltage source (generator in this case), voltage varies throughout the length and different voltages appear at different nodes.

Secondly for the same node, voltage changes as load changes. In simple words, it is like more is the current flowing through the transmission line, more will be the drop across the transmission line reactance and more is voltage sag.

Experiment Setup

There are 4 connector port available for Tx Line inductance marked as 0, 1, 2,3. Inductance used in having 3 terminals and 1 common. Inductance values available are 1mH, 3mH and 6mH and are connected to terminal marked as 1, 2 and 3 respectively. Common point is connected to the terminal 0 and at the same time is connected to phase of PCC also. Usually the transmission line inductance is not that high, however higher inductance values are taken for sake of clear changes in two readings.

Connect the Auto transformer output to the PCC taking Tx Line inductance in series. First connect the phase of autotransformer (red connector) with 0 terminal of TX line inductance and connect the ground of auto transformer directly to the PCC ground. Common of TX line inductance is internally connected to the phase terminal of the PCC. Now change the knob of autotransformer to adjust the voltage at PCC equals to 210V rms. Use Power Analyzer 2 to take down all readings.



Demonstration

1. Connect a bulb of 100 Watt to the socket and turn on the switch. Socket is internally connected parallel to the PCC terminal. Take down the reading of voltage. There must be some dip in voltage. This dip occurs because of voltage drop across the inductance of autotransformer.

2. Now turn off the switch. Shift the connection from 0 numbered terminal to 1 numbered terminal of Transmission Line Inductance. This way we have included the 1mH transmission line inductance in addition to autotransformer inductance. Now turn on the switch and observe the voltage at PCC which will be lower than last reading.

3. Same way shift the connection for transmission line inductance from 1 to 2 numbered terminal and observe the voltage at PCC (Now additional inductance is 3mH).

4. Finally shift the connection from 2 to 3 numbered terminal and observe the voltage at PCC (Now additional inductance is 6mH).

Based on the reading taken from the last 4 steps, it can be concluded that with fixed voltage power source and with current, voltage changes as inductance of transmission line changes. Since inductance is function of length, voltage values are different at different lengths in transmission line. This is the reason why voltage dips more in remote areas.

Secondly repeat the above 4 steps firstly by changing the load from 100W to 200W and then to 300W. It can be observed the voltage sag is higher at PCC when load connected is higher. This phenomenon can be usually observed in industrial areas where bulb brightness fluctuates when an arc welding machine is operated.

Result Table

Voltage before loading	Inductance	Voltage at PCC	Voltage Sag

Notes

2. Change in THD with Change in Transmission Line Inductance

Theory

Increased usages of non-linear loads like mobile/battery chargers, power electronics converters/Inverters, diode bridge rectifier is polluting the electrical network as such loads draw current with higher order harmonics present in addition to fundamental current. Such loads affect the performance of nearby load also. For example, when a high rating charger is connected at the same terminals to which an induction motor is connected, motor torque oscillation takes place which consequent as difficultly in speed control of induction motor driven conveyer belts. This phenomenon can be explained in this way. We know that 3 phase synchronous generator is most commonly used for power generation, can be considered as stiff source and generates only fundamental voltage. As discussed above significant inductive reactance (say Z_{TX} = 2coswt) is present between generator and customer end point or say point of common coupling (PCC). Now when a nonlinear load is connected at PCC, it draws higher order harmonics current. Since generator is stiff source (say VS =210sinwt) and ideally generates fundamental voltage only, profile of voltage at PCC changes i.e. after loading with nonlinear load (let say IL = 10sinwt + 2 sin5wt + 0.8sin7wt), higher order components appear in PCC voltage ($V_{PCC} = V_S - Z_{TX} * I_L$). For a fixed nonlinear load current, THD in voltage increases with increase in inductance.

Source Voltage, V_S =210sinwt

Transmission Line Inductance, Z_{TX} = 2coswt

Nonlinear Load Current, IL = 10sinwt + 2 sin5wt + 0.8sin7wt

PCC Voltage = $V_{PCC} = V_S - Z_{TX} * I_L$ = 210sinwt – (2coswt)*(10sinwt + 2 sin5wt + 0.8sin7wt)

So we can conclude from above equations that with nonlinear loading, higher order harmonics appear in PCC voltage also and THD in PCC voltage increases with increase in transmission line inductance.

However effect of inductance on THD in current flowing is different. Inductor offers higher impedance to higher order frequencies. So higher is the inductance, higher will be the impedance seen by higher order harmonics, consequently THD in current decreases.

Demonstration

1. Do the same setup as done previously i.e. terminal numbered 0 connected to auto transformer, grounds of autotransformer &PCC connected externally and Voltage adjusted to 210V rms. Connect a significance nonlinear load or both linear and nonlinear load to the socket. For example, 100 Watt bulb can be connected with laptop or any another battery charger. Turn on the switch and note down the reading from Power Analyzer 2. Note down Voltage THD and Current THD. This time inductance present in circuit is only because of autotransformer.

2. Now turn off the switch and shift the connection from 0 to 1 numbered terminal of Tx Line Inductance. Take the same readings, i.e. THD in both voltage and current.

3. Repeat the step 2 firstly by shifting the connection from 1 to 2 numbered terminal and then from 2 to 3 numbered terminal. Take the readings from the both cases.

It can be observed that THD in voltage increases where as the THD in current decreases as inductance increases. This is exactly what is expected. Explanation is already given.

Result Table

Inductance	PCC Voltage THD	Current THD
0mH		
1mH		
3mH		
6mH		

Precautions

1. Do not shift the connections for Tx Line Inductor terminal while current is flowing through the circuit because breaking the current of highly inductive path results in sparking at breaking point.

2. Keep all connections properly tighten.

Insight Solar
Experiment No. 3

Power Factor Correction using Capacitor Bank and its Impact on Power Quality at PCC

In electrical network, Power Factor is notion for actual work done calculated with respect to efforts. Basic mathematical definitions say, it is ratio of actual power and apparent power or it is cosine of angle between voltage and current in power triangle. These definitions are valid only if voltage and current quantities are sinusoidal and then power factor is expressed as dimensionless number between -1 to 1. Watt (W) is unit for active power, where as for apparent power it is Volt-Ampere (VA).

When the current is passing through any inductive load like arc furnace, phase of current lags the phase of source voltage; while for a capacitive load like over excited synchronous motor, phase of current leads the phase of source voltage. Since the active power calculated is given as time integral of multiplication of voltage and current averaged over a cycle, so if voltage and current are phase shifted, power calculated is less than when both are in phase. Calculated active power is keeps on decreasing as phase angle keeps on increasing and becomes zero for quad phase difference. This reflects the attribute of inductor and capacitor to act as energy source; at various points through the AC cycle the reactive power is either storing energy, or it is returning to the system.

Above definition of power factor is limited to pure sinusoidal system only. However as we already have discussed, there are so many nonlinear loads connected to the power grid, so actual useful work with respect to total efforts cannot be evaluated as for sinusoidal system. For non linear systems, definition of power factor is already discussed. It is product of Distortion Factor and Displacement Factor.

Power supply utilities and generating bodies require their customers to present a load to the power grid that is as near to unity power factor as possible. The main, but not the only reason, is fiscal. The customer expects to pay for the "real" work done on his premises – in other words, the value of W, above. Main causes of low power factors are AC induction motors, arc lamp, electrical discharge lamp, industrial heating furnace etc.

A power factor of less than one is effectively an increase in utility's costs, and one that they pass back to customers by imposing an increased tariff for customers with low power factor loads. There are lot of technical issues associated with operating at poor power factor like now a part of transmission line capacity is utilized in transporting reactive power which in unnecessary. Losses in transmission lines and transformers increase. Low power factor also tends to be associated with other negative attributes for a well-behaved electrical load. Highly-distorted current waveforms drawn from the mains can inject high-order harmonics back into the supply grid (just what we demonstrated in previous example).

If we just consider about sinusoidal lagging current, problem of poor Power Factor (or displacement factor) can be improved by many ways. Few of them are by using fixed and variable capacitor bank, over excited synchronous motor and using active filters like STATCOMs.

Theory

Now we know that we need the power factor improvement. Most common practice of improving the power factor (word power factor is used here for Displacement Factor) is using variable capacitor. Usually a zero crossing detection circuit is used for sensing the phase difference between the voltage and current. A controller keeps on switching the capacitor till both phase difference is zero or minimum possible. However there are some negative impacts associated with power factor correction using capacitor bank. Objective of this experiment is to demonstrate the change in THD in voltage when a capacitor bank is switched on to improve the power factor.

Suppose a lagging load is connected in parallel with nonlinear load. There is always a finite amount of inductive reactance present in network and as we demonstrated in previous experiment that if a non linear load is present, harmonics appears at PCC voltage. As capacitor bank is switched on to improve the power factor, though the Displacement Factor (cosØ) improves but the THD in both voltage and current increases. This leads to degrading distortion factor. Reason behind increased THD in voltage and current is low impedance path offered by capacitor to the higher order currents. Since the impedance offered by capacitor is inversely proportional to frequency so small impedance path is seen by PCC voltage harmonics appeared because of grid inductance & nonlinear load. Now capacitor is sinking high frequency currents which ultimately worsen the THD in voltage and line current.

Experimental Setup

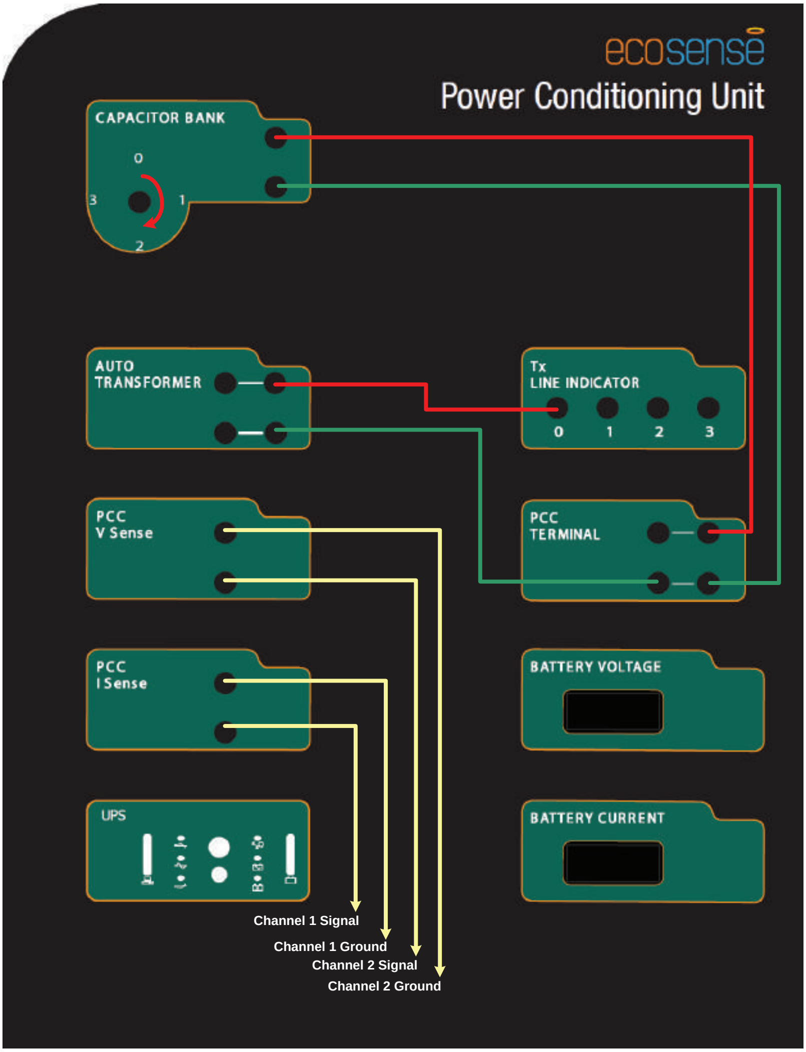
For this experiment, first connect the phase of autotransformer to 3 numbered terminal of Tx Line Impedance and autotransformer ground directly to the ground of PCC. This way 6mH inductance is connected in series. Do the parallel connections of capacitor bank to the PCC terminals. Capacitor knob can move for four positions including off. Other three positions connect 0.75μF, 1.5μF and 3μFcapacitors to PCC.

Demonstration

1. Connect a lagging load like single phase induction motor operating at poor power factor and a nonlinear load like laptop charger to PCC through socket. Keep the capacitor bank knob and the load socket switch off. For waveform observation, connect the oscilloscope channels to the VSENSE & ISENSE. Now rotate the autotransformer knob to adjust the PCC voltage at 210V rms. Use Power Analyzer 2 for taking the reading.

Note down THD in voltage & current, phase angle and calculate cosØ. Also observe the waveform of voltage and current in oscilloscope. It can be seen that the current is lagging and at the same time is distorted.

2. Now rotate the autotransformer knob to make voltage zero again. Change the capacitor bank knob to first position. Now capacitor connected is 1.5μF and adjust the voltage slowly to 210V rms. Turn on the load. Take all those readings again. Observe waveforms.



3. Repeat the Step no 2 by changing the capacitor from 1.5μF to 3.0μF and then from 3.0μF to 6.0μF.

It can be seen that though the angle between voltage and current is decreasing or now current is becoming from lagging to leading (based on load rating), the THD in voltage and current is increasing at the same time. Using capacitor solves one part and contributes to other problem.

Result Table

Capacitance	Voltage THD	Current THD	Displacement factor	Power Factor
0μF				
1.5μF				
3μF				
6μF				

Precautions

1. Never change the position of capacitor bank knob online i.e. while voltage is available at autotransformer terminal. Because capacitor is discharged initially. If suddenly it is connected across voltage source, it acts as short circuit and results in capacitor or power source damage.

2. Tighten all connections properly.

Notes

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Insight Solar
Experiment No. 4

Grid Synchronization of Solar PV Inverter and it Performance Analysis

A single generator cannot serve the need of even a small town so multiple power source/ generators have to work together to cater the electricity needs. In order to make multiple power sources work together, these need to have nearly same instantaneous voltage at terminals and exactly the same instantaneous phase. The process used to ensure the same is called grid synchronization. Synchronous generators are commonly used as prime power source. There are several methods available for grid synchronization like dark lamp method, synchro-scope, using synchronizing relays etc.

Currently major part of electrical network is centralized i.e. the generators are centralized at some place quite far from the place where it is consumed. Centralized system suffers from many problems as compared to distributed power generation. Congestion and losses in transmission lines, stability issues etc are main highlights of problems. Now trend is shifting from centralized to distributed power generation and usage of renewable energy sources as distributed power generation seems a viable solution. Renewable power is scattered over wide land not focused, it is clean so such plants can we installed in populated areas. For solar PV system, there are two categories – Standalone and Grid Tied based. Unlike standalone solar PV system, Grid Tied Solar PV inverter needs to be electrically connected to a voltage source or grid. Advantage with grid tied topology is that if the local power requirement is less than what PV is generating, extra power can serve the loads connect at any another node of grid.

Theory

Zero Crossing Detection (ZCD) is simplest way to obtain the frequency information. Zero crossing of voltage is sensed and ideally duration between two consecutive zero crossing equals to reciprocal of double of voltage frequency. However as it has been discussed that there are always harmonics present in the utility voltage and which can ultimately result in detection of zero crossing at the rate different than fundamental frequency. Also it is not possible to get instantaneous phase information.

Phased-Looked-Loop (PLL) based technique for grid synchronization is fast, efficient and most commonly adopted. With slight modifications, three phase PLL can be used for single phase system also. Operation for the same can be explained as below. For a three phase system, three voltage components V_a, V_b and V_c are converted to two components system (d-q frame) by applying below mentioned mathematical operation

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

We can write this in complex notation as

$$V_{dq} = V_d + j * V_q$$

V_d and V_q are two sinusoidal quantities in which V_q lags the V_d by 90°.

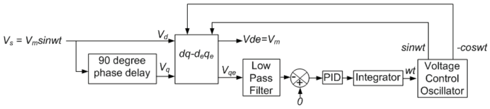
Since there is only one voltage component available for single phase unlike three for three phase system, so instead of using the abc - dq transformation matrix, single phase voltage (say Vs = Vm*sin(wt+Ø)) component itself is assume to be direct axis component (i.e. $V_q = V_s = V_m$*sin(wt+Ø)). Then 90° phase delayed component of single phase voltage is calculated and is assumed to be quadrature axis component (i.e. Vq = Vm*sin(wt+Ø -90) =- Vm*cos(wt+Ø)). If we draw V_{dq} phasor on d-q axis we will see a vector with magnitude equals to V_m rotating at speed equals to synchronous speed (w) or instantaneous phase equal to(wt+Ø).

Now suppose if this vector is observed from the frame rotating at the synchronous speed, it appears to be a stationary vector with a magnitude equal to Vm and a constant phase Ø.

Mathematically we can realize such observation by following transformation matrix (dq –deqe). Let us assume that this frame rotates at angular speed W_0.

$$\begin{bmatrix} V_{de} \\ V_{qe} \end{bmatrix} = \begin{bmatrix} \sin w_0 t & -\cos w_0 t \\ \cos w_0 t & \sin w_0 t \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix}$$

Both the vector will appear stationary with respect to each other only when speed of this frame equals to synchronous frame speed (i.e. w = w_0) and even if phase is also matched the q –axis component becomes zero. Figure below shows the block diagram of PLL.



Performance of PLL is evaluated in terms of its ability to get synchronized to poor quality voltage, time elapsed to synchronize, response to rapidly changing frequency and up to what poor quality voltage it can stay synchronized.

Objective of this experiment is a lab setup so as to make solar inverter synchronized to grid. Secondly, performance of inverter is evaluated in terms of time taken to synchronize the grid, how closely it is operating to MPPT, efficiency and finally its output power quality.

Experimental Setup

For this experiment, first connect the phase of autotransformer to 0 numbered terminal of Tx Line Impedance and autotransformer ground directly to the ground of PCC. This way inductance is by passed and there is a power analyzer 2 in the current path. Adjust the voltage of autotransformer at 210V. PV panels can be connected to the DC input of inverter by turning on the PV input MCB. Voltage of PV panel should be more than 45V for solar inverter to operate and inverter can generate rated output only if PV voltage is equal or more than 65V. In order to connect the grid to output of the inverter, turn on the AC output MCB. As soon inverter is supplied with DC voltage, it tries to synchronize. Now connect one channel of oscilloscope with VSENSE terminals and second with ISENSE terminals.

Data related to PV output (DC Voltage, DC Current and DC Power) can be monitor and stored on an intuitive GUI installed on computer. Just connect the USB cable from data logger and plotter box. Connect (CTRL+C) to the virtual port created by Serial to USB data converter cable and click on run button (F5). Time V/s Voltage, Current & Power curves can be monitored in real time.

Demonstration

1. Turn on the 'PV Panel MCB'. By doing so PV panels are now connected to the DC terminal of the solar grid tied inverter. Take the voltage reading of DC voltmeter. It is showing the reading of PV panel voltage. Now move the change over switch position towards the top. This way PV panel output is connected to DC input of grid tied inverter. Turn on the AC output MCB. Some current starts flowing from grid to inverter. As soon inverter gets synchronized, current starts flowing from inverter to grid. Note down the time taken for synchronization.

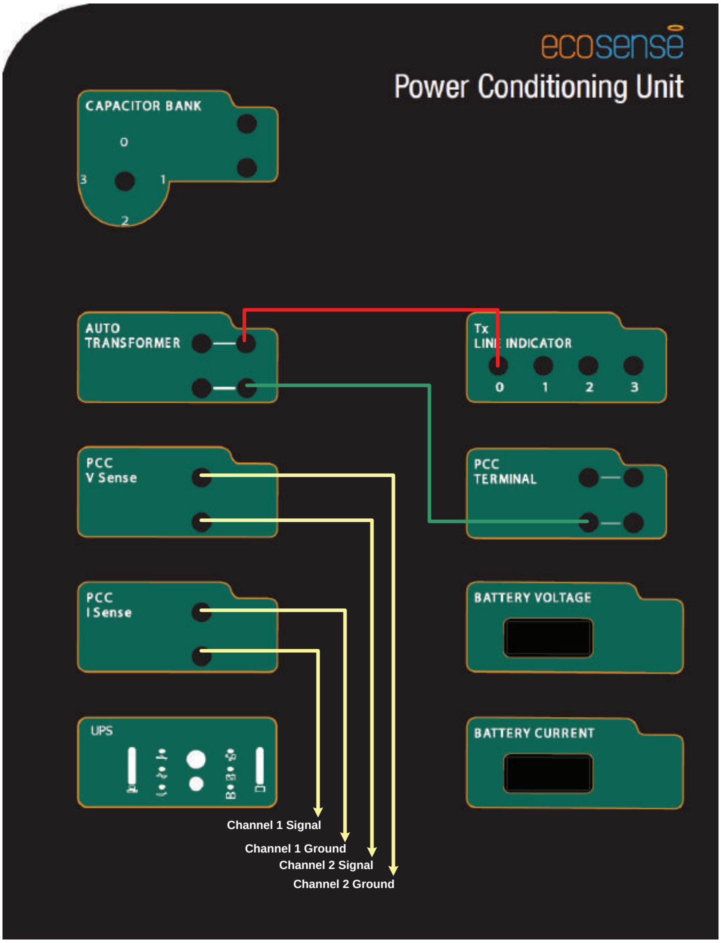
2. In order to judge the performance of inverter MPPT algorithm, take the reading of PV panel voltage and current from DC voltmeter and DC ammeter when inverter is synchronized. Multiply measured voltage and current to calculate the supplied power by PV panels. This experiment requires a rough estimation of maximum power that PV panels can produce with current solar insolation. Six panels are rated for net 450W at 1000W/m^2. Usually at noon time, panels produce 60-70% of power for which it is rated i.e. from 350-300W. In this way we can judge the performance of solar inverter. For more precise results, PV panels can be connected to a variable resistance and PV curve can be drawn by varying the resistance. From the curve, maximum power can be calculated for current solar insolation.

3. In this part, efficiency of solar grid tied inverter is calculated. Take down the reading of active power from power analyzer 1 and also calculate the power supplied by PV panels by multiplying the DC voltmeter and Ammeter reading. Efficiency can be calculated as below

$$Efficiency(\eta) = \frac{P_{inverter}}{V_{DC} * I_{DC}} \times 100$$

4. Next, output power quality analysis is done. For this take the reading of inverter voltage THD, supplied current THD and also for the operating power factor. One thing that is worth watching is that THD in current supplied by inverter is higher for low current (i.e. when PV panels are supplying low power) and vice versa.

Readings for above 4 steps can give the idea of performance of grid tied solar inverter solar inverter. Ideally an inverter should have low grid synchronization time, should operate close to Maximum Power Point, higher efficiency, low current THD and unity power factor. Observe the voltage and current waveform on oscilloscope. This gives the clear idea about distortion in current supplied by the solar PV inverter.



Result Table

Time taken for synchronization	
Manually calculated maximum power of PV Panel	
Maximum power by MPPT algorithm	
Inverter operating efficiency	
Inverter operating Power Factor	
Inverter supplied current THD	

Precautions

1. Manually finding the maximum power of PV panel should be done carefully and under the guidance of experienced one.
2. Keep all the connections properly tightened.

Notes

Insight Solar
Experiment No. 5

Evaluation of Active, Reactive Power & Apparent Energy Flow between Grid-Tied Inverter, Grid & Load and Net Metering concept

Just imagine of a house with roof top solar power plant. For the day times when solar irradiations are enough, electricity generated is usually more than the local load requirement of the house. If the solar plant is standalone type, the maximum power harnessed is limited to the load connected to the system (assuming batteries are fully charged). So this extra capacity of plant remains unutilized. However grid tied plant are beneficial in terms the excessive power can be sold to utility. Likewise for night time, loads can be supplied power by the utility grid as what usually happens. This scheme promotes more and more roof top grid tied solar plant installation as it provides opportunities for extra income or cutting in electricity bills, at the same time overcomes electricity shortage problem. However there should be a mechanism to govern the net amount to be received / paid by user with roof top installation. Net Metering Systems keep track of power drawn by user from grid and power fed to grid.

1. Instantaneous Power Balance

Theory

As per Kirchoff's Law, net current at any electrical node is zero i.e. sum of currents entering in a node is equal to current leaving the node. Same way, active & reactive powers are individually balanced at any load. In this experimental system, Point of Common Coupling is any electrical node/junction of three lines. One line is connected to main or artificial grid; second one to grid tied solar PV inverter and third one to the local load. At any instant of time, there should be individually net balance between active power, reactive power and apparent power. In terms of mathematical quantities it can be shown as below.

$S_{PV} = P_{PV} + jQ_{PV}$ = Apparent Power supplied by PV inverter

$S_{GRID} = P_{GRID} + jQ_{GRID}$ = Apparent Power supplied by Grid

$S_{LOAD} = P_{LOAD} + jQ_{LOAD}$ = Apparent power drawn by Load

Then

$$S_{GRID} + S_{PV} = S_{LOAD}$$

$$P_{GRID} + P_{PV} = P_{LOAD}$$

$$Q_{GRID} + Q_{PV} = Q_{LOAD}$$

For example, if grid tied solar inverter is supplying 200W of active power (P_{PV}), 10VAr of reactive power (Q_{PV}) and load is drawing 300W active power (P_{LOAD}), 50VAr of reactive power (Q_{LOAD}); then active power (P_{GRID}) supplied by grid is 100W and reactive power (Q_{GRID}) is 40VAr. Obviously there is balance is apparent power also known as the PCC.

Objective of this part of experiment is to calculate the power requirement of load. Also it tried to simulate the two real world scenarios, one represents the day time in which, power supplied by grid tied inverter is more than load connected. Hence extra power is fed to the grid. Second scenario represents night scenario, in which local load consumption is more than power generated & required extra power is now supplied by grid.

Experimental Setup

Experimentation setup is same as previous experiment. Power analyzer 2 is connected between main grid and PCC while power analyzer 1 connected between solar grid-tied inverter and PCC. Only a RMS ammeter ('Output AC Current') is connected between load and PCC & a RMS voltmeter across the load ('Output AC Voltage').

Demonstration

1. Synchronize the grid tied inverter as done previously
2. For simulating scenario 1, Connect small load, say 100W bulb with some lagging load. Take the reading of active power, reactive power and apparent power for the power analyzer 1 & 2. Note down the output AC voltage and current
3. Calculate P_{LOAD}, Q_{LOAD} and S_{LOAD} using measured values of P_{GRID}, Q_{GRID} and S_{GRID} and P_{PV}, Q_{PV} and S_{LOAD}
4. Also calculate apparent power of load by using $S_{LOAD} = V_{RMS} * I_{RMS}$. This should be equal to apparent power calculated in step 3.
5. Similarly scenario 2 can be simulated by connecting a large load and same calculation can be done.

Result Table

P_{PV}		Q_{PV}		S_{PV}		V_{LOAD}	
P_{GRID}		Q_{GRID}		S_{GRID}		I_{LOAD}	
P_{LOAD}		QL_{OAD}		S_{LOAD}		S_{LOAD}	
P_{PV}		Q_{PV}		S_{PV}		V_{LOAD}	
P_{GRID}		Q_{GRID}		SG_{RID}		I_{LOAD}	
P_{LOAD}		Q_{LOAD}		S_{LOAD}		S_{LOAD}	

2. Net Metering

Theory

As discussed above, Net Metering is mechanism to govern the tariff to be paid or earned by the electricity consumer with grid tied solar plant. One way to calculate the net power consumed and fed to grid is having two separate connections with two unidirectional energy meters, one for load and another for plant. Both energy meters records units of electricity and electricity bill is prepared based on these readings. Another way is to use bidirectional meters which can record both imported and exported power to grid.

Objective of this part of experiment is to demonstrate the Net Metering Feature. Both power analyzers can record imported active, reactive & apparent energies and exported active, reactive & apparent energies with 8 decimal accuracy.

Experimental Setup

Exactly the same lab setup is used. Since the power analyzer 2 is connected between grid and the PCC so all the readings corresponding to net metering are taken from this meter.

Demonstration

1. Note the reading of imported active (I-E), reactive (I-rE) and apparent energies (A-E). Also note down exported active (E-E), reactive (E-rE) and apparent energies (A-E).
2. Synchronize the grid tied inverter to main grid.
3. Connect the load to socket after 15 minutes.
4. Again take the same readings after 30 minutes.
5. Calculate the net energies.

Result Table

<table>
<tr><th colspan="2">Readings at time __ __:__ __</th><th colspan="2">Readings at time __ __:__ __</th><th colspan="2">Net Energies</th></tr>
<tr><td>Imported Active Energy</td><td></td><td>Imported Active Energy</td><td></td><td rowspan="2">Net Active Energy</td><td rowspan="2"></td></tr>
<tr><td>Imported reactive Energy</td><td></td><td>Imported reactive Energy</td><td></td></tr>
<tr><td>Exported Active Energy</td><td></td><td>Exported Active Energy</td><td></td><td rowspan="2">Net Reactive Energy</td><td rowspan="2"></td></tr>
<tr><td>Exported Reactive Energy</td><td></td><td>Exported Reactive Energy</td><td></td></tr>
<tr><td>Apparent Energy</td><td></td><td>Apparent Energy</td><td></td><td>Net Apparent Energy</td><td></td></tr>
</table>

Insight Solar
Experiment No. 6

Demonstration of Anti-Islanding protection of Grid-Tied Inverter for Sudden Grid Failure and running the system using virtual grid

Islanding is defined as a state in which a portion of electrical utility grid, containing load and generation, continues to operate isolated from rest of the grid. Generation and loads may be any combination of customer-owned and utility owned. By using islanding technique, part of grid keeps running irrespective of severe fault, thus critical loads can be served.

Traditionally, the grid is an interconnection of large generators operated by utilities, which had plenty of engineers, operations, and maintenance personnel. With expansion of electrical network, it has become hard to give an engineer, review to all the generators connected to grid against any kind of fault. With electrical network moving towards decentralized generation, it may even be hard to monitor the running status of all small, medium and large power generators, especially with root top installed PV and wind based grid tied generator. Real problem appears when an electrical network is taken down for some maintenance by either shutting down the large and medium capacity generator or by opening the circuit breakers of feeds/transmission lines connected. Even then small capacity distributed power generators may keep on supplying the power the grid. It may result hazardous for maintenance crew unaware of such generator being online.

Thus it can be understood from above discussion that precautionary measures and improvement in design of such small capacity generators (inverters as in particular) needs to be incorporated.

1. Anti Islanding Protection

Theory

The inverters for grid-parallel operation (grid-interactive inverters) work as current sources which feed power into the utility grid. This kind of inverter is typically unable to supply the utility grid because doesn't work as voltage source. The grid-tied inverters feed power into the grid as AC current with the same frequency of the grid voltage. Island is a condition in which a portion of an area electric power system (EPS) is energized solely by one or more local EPSs through the associated points of common coupling (PCCs) while that portion of the area EPS is electrically separated from the rest of the area EPS.

The “island” condition is present when, due to a fault condition in the grid or due to a particular load condition on the grid, the grid shows a resonant-load behavior. In such conditions even if the voltage from the network is no longer present, the resonance between the L-C component still maintain the voltage at the inverter’s output terminal and so the inverter could not be able to detect the grid voltage absence. In this case if the resistive load matches the power produced by the inverter, the parallel operation is still possible and creates the “island condition”.

Island condition can be dangerous primarily because four reason:

1. Safety concerns: if an island condition is present the utility workers may be faced with unexpected live wires while expect no voltage is present on the line.
2. Equipment damage: customer equipment could theoretically be damaged if operating parameters differ greatly from the norm. In this case, the utility is liable for the damage.
3. Ending the failure: reclosing the circuit onto an active island may cause problems with the utility's equipment, or cause automatic reclosing systems to fail to notice the problem.
4. Inverter damaging: reclosing onto an active island may cause damaging of the inverters.

Due to the above main reasons the inverter shall be equipped with anti-islanding detection and protection mechanism to avoid the island condition.

The applicable rules about the detection and interruption of island condition are various from country to country.

Different standards typically introduce different requirements in terms of island condition detection time and disconnection time as soon as the island condition is detected, as well can define different test set-up and testing procedure. About the test set-up differences, these are represented by the different Q-factor of LC resonant load, while the grid-frequency resonant load usage for testing is common among the standards.

Most inverters detect the islanding condition by looking for some combination of the following:

1. A sudden change in system frequency.
2. A sudden change in voltage magnitude.
3. A sudden change in the rate of change of frequency.
4. A sudden increase in active output power well beyond the expected 'normal' level.
5. A sudden change in reactive output power well beyond an expected 'normal' level.

Depending on their internal control programming, one or any of these events could indicate that the small generator and some amount of load have become disconnected from the grid. (For example, it could be just your home with its PV system, or it could be your whole neighborhood disconnected as a block from the larger grid.)

When this island condition is detected, the small generation sources trip offline.

There are specific performance requirements for distributed generation defined in IEEE Standard 1547, which covers the time in which anti-islanding protection should operate, and what levels of parameters define abnormal conditions.

As for the internals of anti-islanding protection in inverters, they specifically use a phase locked loop (PLL) with a small amount of positive feedback in its control loop to quickly and continuously check the grid connectivity.

Objective of this part is to show the anti-islanding protection when grid voltage reaches below a certain value.

Experimental Setup

First connect the phase of autotransformer to 0 numbered terminal of "Tx" Line Inductance and autotransformer ground directly to the ground of PCC. This way inductance is by passed and there is a power analyzer 2 in the current path. Adjust the voltage of autotransformer at 220V. Turn the position of change over switch towards top. PV panels can be connected to the DC input of inverter by turning on the PV input MCB.

Demonstration

1. Turn on the AC MCB so as to synchronize the grid tied inverter to main grid.
2. Suddenly rotate the transformer knob so that voltage reaches below 200V.
3. Observe the grid tied inverter is now off.

2. Running the Grid Tied PV System Using Virtual Grid

Theory

Above discussion clears the need of Anti-Islanding Protection. Though this protection is essential but when grid power goes off, solar PV grid tied inverter does not operates. It results in loss of power that can be harnessed from the PV panels & even local load cannot be served. Lack of grid reference causes inverter to stop. Suppose if somehow grid tied inverter is provided with a reference voltage that is isolated from main grid, we can utilize the PV panel power.

Arrangement for this system is such that a standalone pure sine-wave inverter provides the reference voltage for grid tied solar PV inverter. When Grid power is not available, a smart change-over switch automatically connects the solar inverter to this standalone inverter. This way solar inverter is isolated to main grid. Even small capacity standalone inverter is enough for such arrangement as its role is mainly to provide the voltage reference to solar inverter. Most of part of local load is served by grid tied inverter. If PV power is less than local load then standalone inverter can serve it till its rating. Similarly if local load is less than PV power available, extra power can charge the batteries of standalone inverter as standalone inverter is bidirectional. One thing worth observing is that grid tied solar inverter operates as first priority power source. Irrespective of rating of standalone inverter, solar inverter tries to serve the local load to maximum available PV power.

Objective of this part of experiment is to run the grid tied inverter using a standalone inverter when main grid voltage goes off.

Experimental Setup

Experimental setup is same for above part. Keep the voltage at nearly 220V and synchronize the grid tied inverter.

Demonstration

1. Connect a 100W bulb load across the socket.

2. Turn off the main grid and observe that grid tied inverter also turns off.

3. Observe that smart change over switch automatically changes the connection from main grid to standalone inverter. Grid tied inverter automatically synchronizes to new virtual grid provided by standalone inverter.

4. Take the power reading to trace the power flow. If PV power is higher than load, then extra power charges the batteries. Battery voltage and current can be noted down. If battery is charging, the reading in dc ammeter is negative.

5. Increase the load such that it exceeds the PV panel power. So a part of load is shared by standalone inverter. Also observe that still grid tied inverter is still trying to harness the maximum possible power. Only the remaining power is supplied by standalone inverter. This shows that renewable energy based operates at higher priority than conventional energy resources.

Notes

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Appendix

Grid Tied Solar inverter (300W)

DC input side (PV-generator)	
Maximum start voltage	100 V
Maximum input voltage	135 V
Minimum input voltage	45 V
Minimum input voltage for rated output	64 V
MPP voltage	45 V ... 100 V
Maximum input current	5 A
Maximum input power	320 W
Maximum recommended PV Power	375 Wp
De-rating /Limiting	automatic when - input power is higher - the device is not cooled sufficiently - input currents > 5 A (higher currents are limited by the equipment and therefore will not damage the inverter)
AC output side (Grid connection)	
Grid voltage	207 V … 253 V [other values are possible]
Rated grid voltage	230 V
Maximum output current	1.5 A
Maximum output power	300 W
Rated power	300 W
Rated frequency	50 Hz
Frequency	48 Hz … 52 Hz [other values are possible]
Night-time power loss	< 0.1 W
Feeding phases	single-phase
Characterization of the operating performance	
Maximum efficiency	94.8 %
European efficiency	93.4 %
MPP efficiency	99 %
Power de-rating at full power	from 40 °C
Switch-on power	2 W
Standby power	0 W

Solar PV modules (450WP):

There are **TWO** modules of rating **250W$_p$** connected in series

S.No.	Parameter	Rating
1	Power rating	250Wp
2	Maximum power voltage	35.0V
3	Maximum power current	7.14A
4	Open circuit voltage	43.2V
5	Short circuit current	7.5A
6	Module dimension	980*1745mm
7	Panel Type	Poly Crystalline Type

Standalone Inverter & Battery Charger Specifications

S.No.	Parameter	Rating
1	Output Power	750VA / 500W
2	Nominal Output Voltage	230V AC
3	Waveform Type	Pure Sine
4	Input Voltage Range for Battery Charging	160 – 286V
5	2 Batteries	12V, 7.5Ah (each)
6	Intelligent Battery Management	YES

Power Analyzer

S.No.	Features	
1	R.M.S. AC Voltage &Current	Yes
2	Max-Min Voltage & Current	Yes
3	% THD in Voltage & Current	Yes
4	Power Factor	Yes
5	Angle	Yes
6	Active, Reactive and Apparent Power	Yes
7	Exported Active Energy	Yes
8	Imported Active Energy	Yes
9	Exported Reactive Energy	Yes
10	Imported Reactive Energy	Yes
11	Apparent Energy	Yes

Charge Controller

S.No.	Parameter	Rating
1	Maximum Input Voltage	150V
2	Maximum Output Battery Charging Current	10A
3	Modes of Operation	Auto and Manual Mode
4	Output Voltage in Automatic Mode	78V
5	Gate Voltage for Manual Mode	5V peak

Capacitor Bank Specifications

Capacitance at Position 1 = 1.5uF, 415V

Capacitance at Position 2 = 3.0uF, 415V

Capacitance at Position 3 = 6.0uF, 415V

Transmission Line Inductance = 1mH, 3mH, 6mH, 5A, 50Hz

Autotransformer Specification = 5-270V AC, 5A

Isolated Voltage Sensing 500V AC (peak to peak) = 5V AC (peak to Peak)

Isolated Current Sensing 5A AC (peak to peak) = 5V AC (Peak to Peak)

Isolated PV Panel Voltage Sensor Ratio 150V (Panel Voltage) = 5V isolated

Isolated PV Panel Current Sensor Ratio 5A (Panel Current) = 5V isolated

Notes

Notes

ecosense

Delivering environmental friendly mechanisms

Ecosense Training Systems

• Solar Thermal Training Systems

Solar Thermal
Training System

Solar Concentrator
Training System

Thermal Energy Storage
Training System

• Solar PV Training Systems

Solar PV
Training & Research System

Solar PV Grid Tied
Training System

Solar PV Emulator

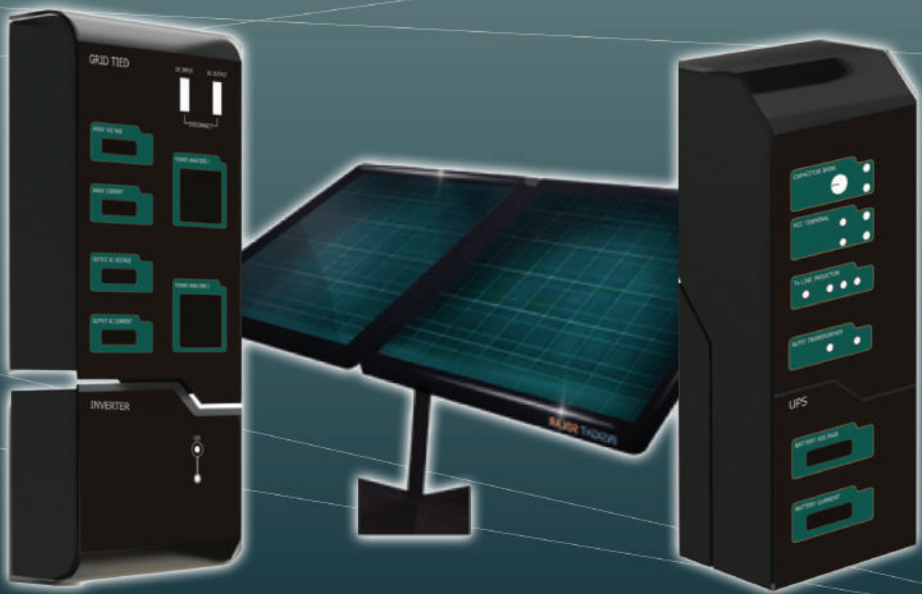
• Wind Energy Training Systems

Wind Energy
Training System

Wind Energy Emulator

About Ecosense

Ecosense provides world class training solutions in renewable energy and clean environment. As a group of engineers, researchers and designers, Ecosense has developed cutting edge products to create skilled human resource for renewable energy sector. Founded by group of IIT graduates, Ecosense is dedicated towards building mechanisms that will develop highly skilled workforce that enables the development of clean environment for human race.



ecosense

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