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Simulation and Analysis of Power Sharing in Residential Hybrid Energy System

Premkumar S[1]*, Ramu.G[2], Gunasekaran.S[3], Baskar.D[4]

Assistant Professor, Dept. of EEE, Bharath University, Chennai, Tamil Nadu, India[1*,2,3,4,]

ABSTRACT: Electricity demand is increasing in almost all developing countries, including India, due to rapid growth of population. The availability of fossil fuels has diminished so that in most of the urban areas continuous power supply is not possible. For this an attempt has been made by investigating a cost effective micro inverter which can be operated as both off grid and grid tie inverter with change in load demand and available solar power.

In this paper the controller for the inverter is designed with the Phase-Locked-Loop technique in the feedback loop. The PLL can detect the phase and frequency of the grid voltage. The output of PLL is used to generate the SPWM signals to control the on and off states of IGBT switches in the inverter. So whenever load demand exceeds the available solar PV power, the grid will be switched on without disconnecting the solar PV system.

KEYWORDS: PLL, SPWM, IGBT

I. INTRODUCTION

Application of photovoltaic as electrical energy source shows increasing trend both in implementation on spread area over the world and in capacity of plant. This trend is triggered by many factors such as the increasing of fossil fuel cost and declination of production cost per kW electric from photovoltaic and also technology development that cause the photovoltaic power conversion more efficient [1].

Photovoltaic generation system can either be operated in isolated system or be connected to the grid to form integrated system, and with other electrical renewable energy source can form distributed renewable energy generation. In an integrated photovoltaic generation, one among aspects that take attention of researches is the power flow and load sharing problem between the grid and photovoltaic plant in order to supply electrical power for connected load, it is intended that power flow mechanism ensure that energy generated by the plant can be sent to the grid optimally. In such a system, load flow and load sharing mechanism are handled by the inverter as power interface between plant and grid, by using appropriate method, intended power flow and load sharing control can be achieved.

In PV generation system, PV inverter holds the role as interface between photovoltaic module and ac power grid. In this function, PV inverter and associated generation system equipment should have ability to maximize power extracting from the array, match DC voltage output from PV array, produce sinusoidal ac voltage with minimum distortion on output side, and control the power flow. If the PV inverter is from grid tie type, it must be completed with synchronizing mechanism and protection system from islanding condition or from others negative impact of grid phenomena.

From overall basic abilities listed above, PV inverter is hoped to operate in optimum conversion efficiency. Photovoltaic material exploration, converter topologies and its control mechanism have and being continuously developed. Development of effective conversion is can also be reached by optimizing configuration between PV module/array and associated PV inverter.

This paper describes model and simulation of Three Phase Voltage Source Inverter and its control unit work independently to supply three phase system. Model and simulation of load flow and load sharing control between PV generation and grid will be presented. The current of SPWM voltage source PV inverter is controlled by current control strategy using grid parameter as current reference. Simulation also shown that in synchronizing and connecting PV

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inverter to grid, application of grid voltage as PLL reference is advantageous when the grid voltage is uniform and operates with steady and linear loads.[2-4]

Further, effect of irradiance level and current control performance to load flow and load sharing will be analyzed. Model and simulation are implemented using Sim power System in MATLAB/Simulink.

II. CUK SWITCHING REGULATOR

Among all the topologies available, both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient.[5] On the other hand, the Cuk converter has low switching losses and the highest efficiency among non isolated dc–dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus, the Cuk configuration is a proper converter to be employed in designing the MPPT.

A Cuk converter and its operating modes is shown below, which is used as the power stage interface between the Solar PV Array and the inverter. The Cuk converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit.[6-7]

In this mode, the capacitor releases energy to the output. The equations for the switch conduction mode are as follows:

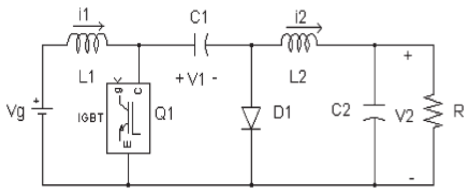

Fig.1 Electrical circuit of the Cuk converter used as the PV power-stage interface

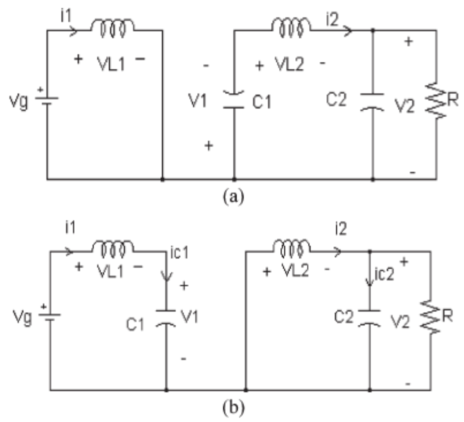

Fig.2 Cuk converter with (a) switch ON and (b) switch OFF

$vL1 = Vg$

$vL2 = -v1 - v2$

$ic1 = i2$

$ic2 = i2 - v2/R$

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On the second operating mode when the switch is open (OFF), the diode is forward-biased and conducting energy to the output. Capacitor C1 is charging from the input. The equations for this mode of operation are as follows:

vL1 = Vg –v1

vL2 = -v2

ic1 = i1

ic2 = i2 –v2/R

The principles of Cuk converter operating conditions state that the average values of the periodic inductor voltage and capacitor current waveforms are zero when the converter operates in steady state.

The relations between output and input currents and voltages are given in the following:

$$\frac{V_o}{V_{\text{in}}} = -\left(\frac{D}{1-D}\right) \frac{I_{\text{in}}}{I_o} = -\left(\frac{D}{1-D}\right)$$

The components for the Cuk converter used in simulation were selected as follows:

1. input inductor L1 =2.5mH
2. capacitor C1 (PV side) = 4.7 µF
3. filter inductor L2 =2.5mH
4. switch : IGBT
5. freewheeling diode
6. capacitor C2 (filter side) = 0.1µF
7. resistive load = 10Ω
8. switching frequency = 25000Hz

The power circuit of the proposed system consists of a Cuk converter and a gate drive, and the control of the switching is done using the control circuit.

III. INCREMENTAL CONDUCTANCE MPPT ALGORITHM

The P&O algorithm cannot compare the array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions.[8]

MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method. But the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience. A similar disadvantage of the neural network method comes with its reliance on the characteristics of the PV array that change with time, implying that the neural network has to be periodically trained to guarantee accurate MPPs. [9]

The Incremental Conductance method is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage. It is based on the incremental and instantaneous conductance of the PV module.

This is following the general rule used in the P&O method, in which the slope of the PV curve at the MPP is equal to zero.

$$\frac{dP}{dV} = 0.$$

$$\frac{dP}{dV} = I \cdot \frac{dV}{dV} + V \cdot \frac{dI}{dV}$$

$$\frac{dP}{dV} = I + V \cdot \frac{dI}{dV}$$

$$I + V \cdot \frac{dI}{dV} = 0$$

which is the basic idea of the IncCond algorithm.

The size of this permissible error (*e*) determines the sensitivity of the system.It is suggested to choose a small and positive digit such that it can be rewritten as

$$I + V \cdot \frac{dI}{dV} = e$$

In this paper, the value of "*e*" was chosen as 0.002 on the basis of the trial-and-error procedure. The flowchart of the IncCond algorithm within the direct control method is shown in Fig. 3. According to the MPPT algorithm, the duty cycle (*D*) is calculated. This is the desired duty cycle that the PV module must operate on the next step. Setting a new duty cycle in the system is repeated according to the sampling time.

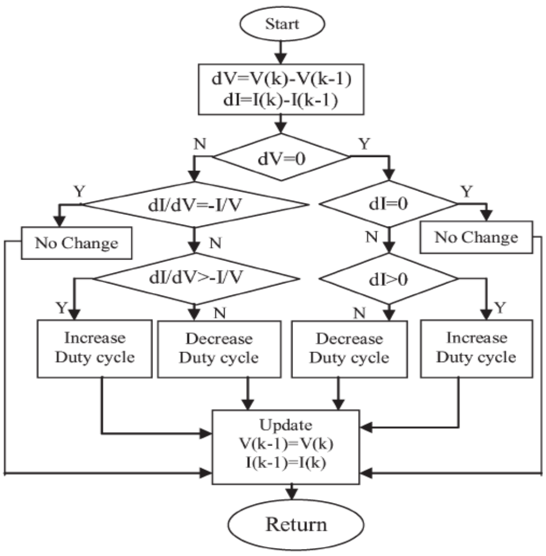

Fig.3 Flowchart of the IncCond method with direct control

The Proposed MPPT Controller is implemented to maintain the constant voltage at the inverter input terminals. The Solar PV Array voltage is widely varies and depends on irradiation for the specified latitude. The Cuk DC/DC converter will acts as the switching regulator which can convert the widely changing voltage to the constant voltage with less switching losses and high efficiency as compared to usual buck-boost or boost regulators.

The incremental conductance algorithm is implemented in simulink environment to provide the necessary duty cycle to Cuk regulator. The IGBT Switch is triggered with pulse width modulation generator driven by the duty cycle. The simulink implementation for the IncCond Conductance algorithm is shown in fig.4.

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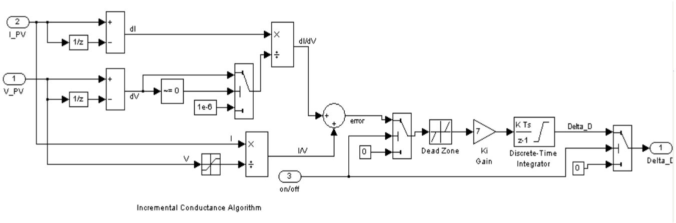

Fig 4 IncCond Algorithm Implemented in SIMULINK

The Cuk Regulator is combined with the developed solar PV array model. The Controller for the Cuk regulator is implemented with above mentioned algorithm to maintain the constant voltage at the inverter terminals. The Sim Power System Implementation of Cuk Regulator with the controller and Solar PV Array model is shown in fig 5.

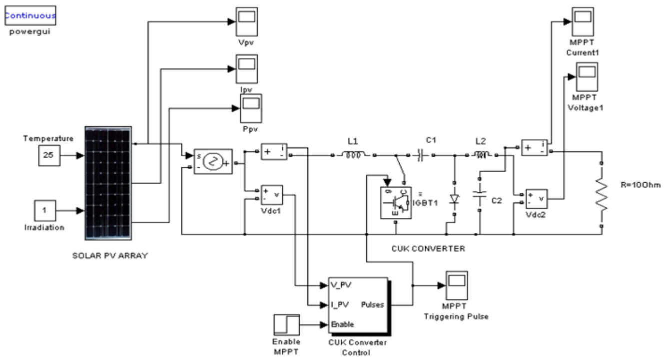

Fig.5 Cuk DC/ DC Converter or Switching Regulator with IncCond Algorithm

IV. POWER CONTROLLER

The control strategy for an integrated power system is a control algorithm for the interaction among various system components. The system controller determines the switching on of grid supply. Determining the best condition of operation is the key to achieve optimal operation the inputs of the controller are the parameters of control action. The inputs of the controller are the parameters such as unpredictable load power and renewable varying output solar energy.

A power control strategy is needed to control the flow of operational period continuously in the load. The fuzzy based technique/algorithm has been implemented in the control strategy to achieve optimal minimal operation to draw power from grid resulting in saving on cost of electricity due to less fuel consumption.

Power Control Algorithm:

The Concept of Fuzzy logic control has been used as an intelligent tool to integrate and manage energy sources to flow in the system in such a way that it meets the load power requirement in optimal way under varying condition. The system is comprised of PV Array, Inverter and grid supply. The procedure in making the control designs are setting the constraints, assigning the linguistic variables and setting the rules for the controller. Solar radiations and loads are the areas that affect the studied outputs and hence load demand are considered to be the input variables. The output variable of the controller is the duty cycle of operation i.e turn-on time (power sharing) period of the grid or generator at each sampling period of specified time depending on the solar pv array voltage as decided by fuzzy control action.

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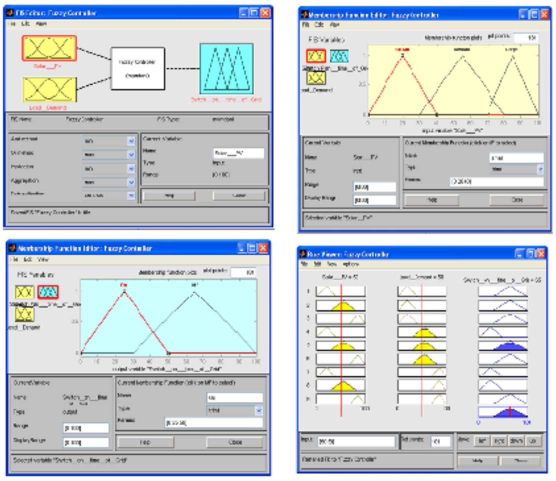

Fig.6 Power Controller Implementation in MATLAB using Fuzzy logic.

V. DESIGN OF INVERTER

The inverter is the heart of PV system and is the focus of all utility-interconnection. The PV inverters are classified into off-grid and grid tie inverters.

- Off grid inverters are operated with battery and charge controller in stand alone system.
- Grid tie inverters can feed the power generated by PV array to grid with or without battery bank.

It is not possible to connect the stand alone inverters to grid and grid inverters will not operate without taking reference signals from grid.

To achieve the optimized power sharing by integrating the solar pv system to the utility, it is very much necessary to design a new type of cost effective micro inverter suitable for low capacity residential loads.

This type of inverter should handle the residential load when the load demand is less than the designed maximum solar pv power. If the load demand is increased more than the available solar pv power, the micro inverter will connects to the grid so that it can allow the load to take remaining power from grid without disconnecting from solar pv system.

It is an attempt to introduce this kind of new feature to be implemented in the existing inverters such that two energy sources can co ordinate each other and share the load. With this it is possible to harvest optimized power from the cost effective solar pv system and the grid can be connected to the load when ever it is required.

Control Strategy for Optimized Power Sharing Characteristic of PV Inverter and Grid:

Fig.7 shows the simplified block diagram of hybrid energy system with proposed control strategy. Photovoltaic dc power is generated from PV array with variable input temperature and irradiance, PV inverter then converts dc to ac voltage to detected grid voltage using phase locked loop (PLL) scheme.

Power flow to the grid is controlled by power controller based on reference load set up. The simulation then run to show voltage and current of grid and PV inverter during grid is switch on and off. The current drawn by connected load is supplied from both grid and PV plant. It is different with paralleling two sources such as transformers or generators in supplying a connected load, where capacity and internal impedance are parameter that determine load sharing between both equipments, load current drawn by PV inverter in a grid is not depend on capacity of PV Plant.

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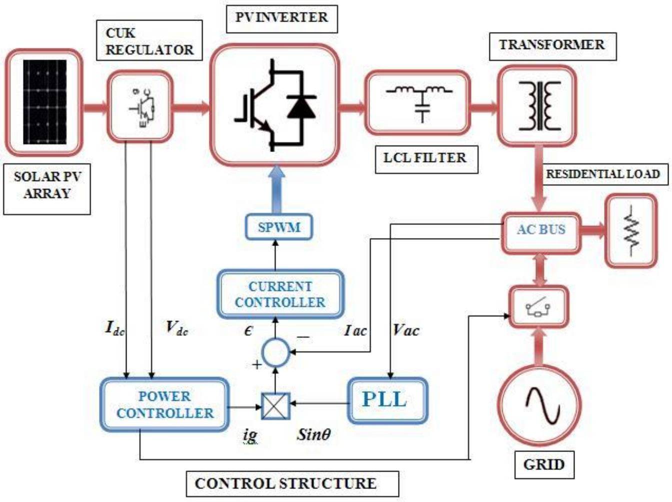

Fig.7 Block diagram of Hybrid Energy System with proposed control strategy.

Optimum power can be sent to the grid as long as there is sufficient power generated by PV plant. Fig.8 shows sim power system implementation of hybrid energy system. Initially PV Inverter is connected to the load and supplies the power up to its maximum generation. If the load demand is increased beyond the maximum available PV power then the PV inverter will connects to the grid, so that load can draw the power from grid.

Phase Locked Loop (PLL):

A *phase lock loop* (PLL) produces an output signal which synchronizes in phase and frequency with the input signal, using a negative feedback loop. The basic idea of the PLL system is a feedback system with a PI-regulator tracking the phase angle. Input is the three phases of the grid voltage and output from the PLL is the phase angle of one of the three phases.

There are two alternatives, either assuming the grid voltages are in balance and track only one of the phases and then shift with 120 degrees for each of the other two phases or having three PLL systems, one for each phase. There are mainly three types of PLL systems for phase tracking: zero crossing, stationary reference frame and synchronous rotating reference frame (SRF) based PLL.

The SRF PLL is the one among the above mentioned with the best performance under distorted and non-ideal grid conditions. The control strategy is developed by a feed back loop consists of a PLL to synchronize the inverter with grid. The inverter is operated with SPWM technique which is generated by the feed back loop by taking the reference from grid.

Sim Power System Implementation of Main controller:

The control unit for the inverter is implemented with the three phase PLL by measuring the grid voltage and grid current. The output of PLL is phase and dq transformation of measured voltage and current of grid. They are given to the current controller to generate the SPWM signals.Fig.9 shows the simulink implementation of Main controller for inverter.

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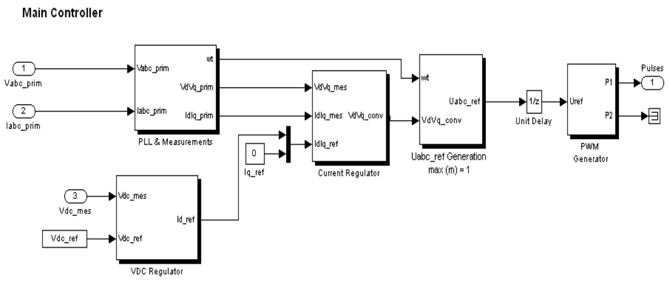

Fig. 9 The control unit of inverter with PLL and SPWM generator

VI. RESULTS AND DISCUSSION

Power Controller implemented with the sampled PV power at regular intervals and the predefined load curve for a typical residence. The inputs for the controller are shown below.

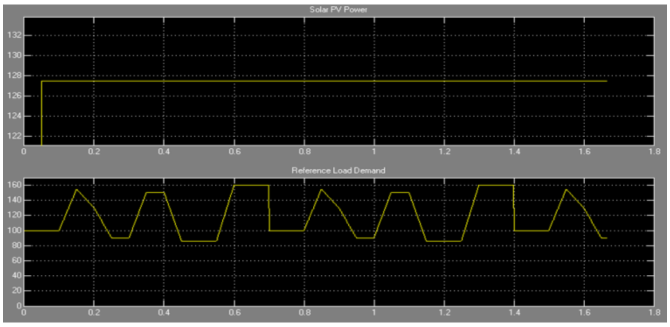

Fig.10. Sampled PV Power and Variable Load demand at regular intervals

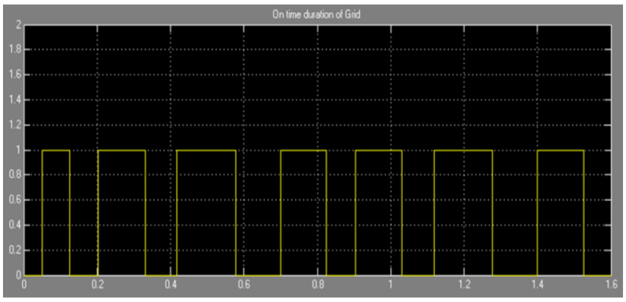

Fig 11 on time duration of External Supply from the Grid

Simulation results of PV Inverter and Main Controller:

The PV Inverter is controlled by a main controller which is implemented with the proposed control strategy. It consists of Phase locked loop, current controller and SPWM generator. The PLL is used to detect the phase and frequency of the grid voltage. In this the park transformation technique is used to extract the fundamental value of the voltage and current wave form from the grid. Six SPWM signals are generated to trigger the IGBT switches in the inverter. For simplicity only two signals are shown in fig.12. The generated three phase voltages from the Output LCL filter is shown in fig.13 This will follows the variation in the grid voltage and maintains the same phase and frequency as compared with grid voltage.

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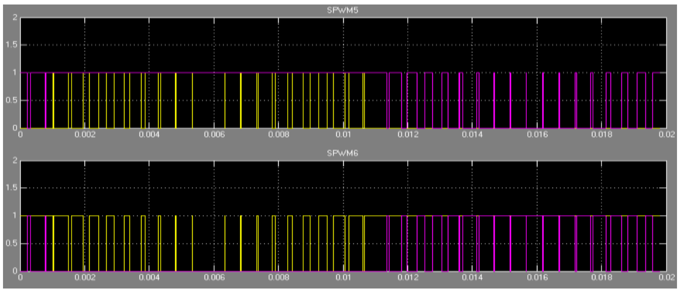

Fig 12 SPWM signals from the main controller to trigger the IGBT switches of Inverter

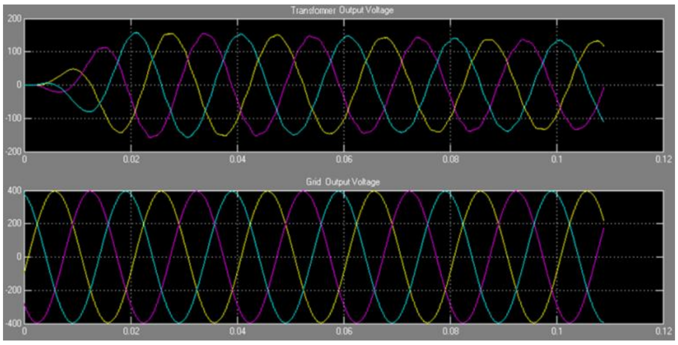

Fig 13 Three phase Sinusoidal Voltage waveforms of Inverter with output LCL filter synchronized with grid voltage.

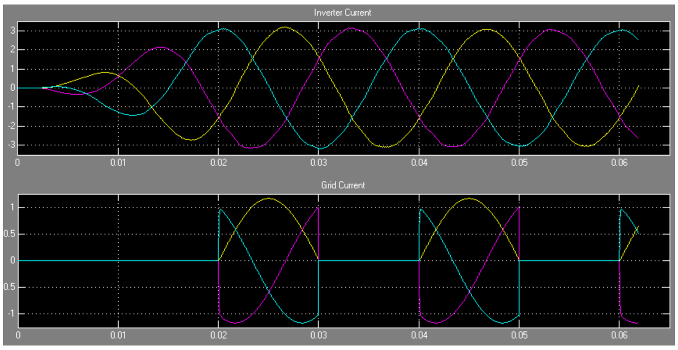

Fig.14 Output waveforms of both the energy systems for varying load demand

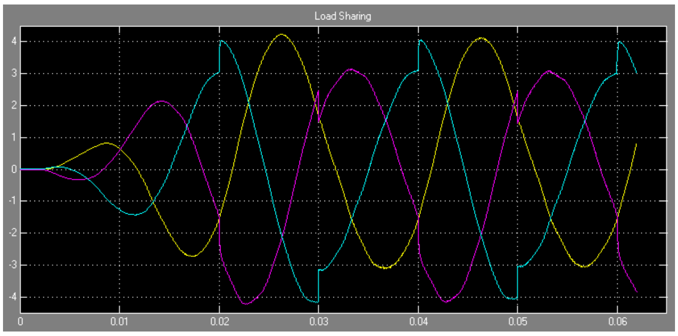

Fig 15 Load sharing of solar PV system with grid

When the Load demand is increased more than the designed solar pv capacity, the load sharing characteristics are shown in fig 14. and fig 15.

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VII. CONCLUSION

The Hybrid Energy system is designed especially for Residential applications with a cost effective micro inverter which will have the capability to act as both off grid and grid tie inverter. Simulation analysis shows that as the load demand is increased more than the solar pv power, the inverter is connecting to the grid and allows the load to share the power with external energy source. The power sharing is optimized with the proposed controllers and it is possible to implement the controllers after designing the inverter suitable for the local grid conditions.

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