A NOVEL SINGLE STAGE SINGLE PHASE RECONFIGURABLE INVERTER TOPOLOGY FOR A SOLAR POWERED HYBRID AC/DC HOME

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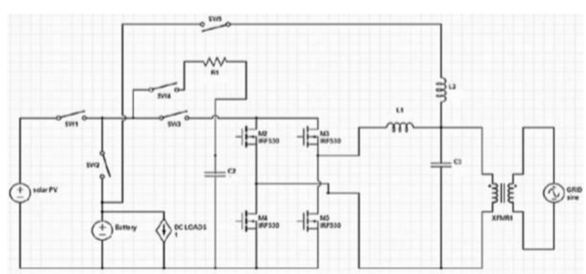
Abstract *This paper suggests a reconfigurable single phase inverter topology for a hybrid ac/dc solar powered home. This inverter possesses a single-phase single-stage topology and the main advantage of this converter is that it can perform dc/dc, dc/ac, and grid tie operation, thus reducing loss, cost, and size of the converter. This hybrid ac/dc home has both ac and dc appliances. This type of home helps to reduce the power loss by avoiding unnecessary double stages of power conversion and improves the harmonic profile by isolating dc loads to dc supply side and rest to ac side. Simulation is done in MATLAB/Simulink and the obtained results are validated through hardware implementation using Arduino Uno controller. Such type of solar powered home equipped with this novel inverter topology could become a basic building block for future energy efficient smart grid and micro grid.*

I INTRODUCTION

The current century has witnessed an unprecedented evolution and growth of renewable energy worldwide. There has been a substantial increase in the capacity and production of all renewable technologies and also growth in supporting policies. Between 2009 and 2013, solar photovoltaics (PVs) experienced the swiftest growth rate in added power capacity among all the renewables. In particular, rooftop solar PV are gaining more popularity in distribution system due to reduction in cost of solar panel, appropriate government policies such as feed in tariffs promoting renewable energy utilization, modularity, less maintenance, etc. However, the intermittent nature of the renewable causes the significant stability and reliability issues in the distribution system. The restructuring of the electric supply industry has prompted the situation, where customer is a critical business player. To mitigate the uncertainty in solar PV generation, storage options such as battery system and fuel cells, etc., are introduced.

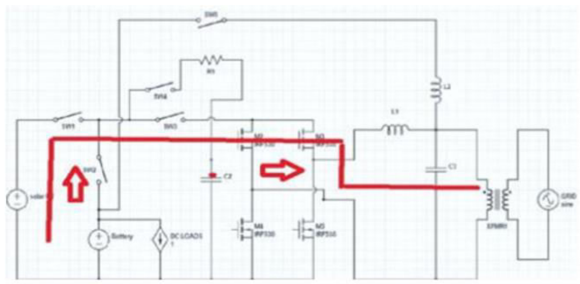
To improve the productivity and comfortability, the modern household adds more and more nonlinear equipment, which are also main source of generating harmonics current in distribution feeder. This further adversely affects power quality, power losses and creating a significant challenge for electrical engineers. Modern household loads have different characteristics compared to loads present in earlier stage. However, harmonic mitigation and/or its minimizations are big challenges in distribution system. Many literatures works have been reported to address aforementioned problems as follows



Schematic of the proposed RSC circuit

Modes of operation

Modes of operation	ON switches	Off switches
PV-GRID	SW1 SW3 SW 4	SW2 SW 5
PV-BATTERY-GRID	SW1 SW2 SW3 SW4	SW5
PV- BATTERY	SW1 SW3 SW5	SW2 SW4
BATTERY-GRID	SW2 SW3	SW1 SW4 SW5



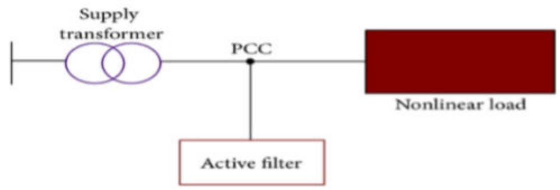
PV to grid

II ACTIVE HARMONIC MITIGATION TECHNIQUES

A growing number of harmonic mitigation techniques are now available including active and passive methods, and the selection of the best-suited technique for a particular case can be a complicated decision-making process. The performance of some of these techniques is largely dependent on system conditions, while others require extensive system analysis to prevent resonance problems and capacitor failure. A classification of the various available harmonic mitigation techniques is presented in this paper aimed at presenting a review of harmonic mitigation methods to researchers, designers, and engineers dealing with power distribution systems.

The nonlinear characteristics of many industrial and commercial loads such as power converters, drives on the other hand are capable of generating significant levels of distortion at the point of common coupling (PCC), where other users are connected to the network.

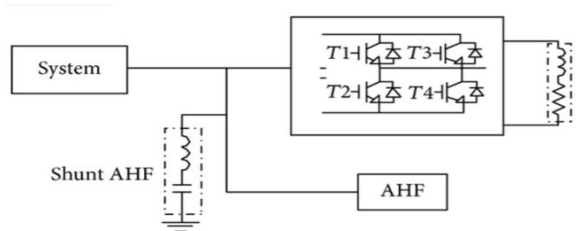
When using active harmonic reduction techniques, the improving in the power quality came from injecting equal-but-opposite current or voltage distortion into the network, thereby canceling the original distortion. Typically, these filters are sized based on how much harmonic current the filter can produce, normally in amperage increments of 50 Amps. The proper amperage of AHF can be chosen after determining the amount of harmonic cancellation current



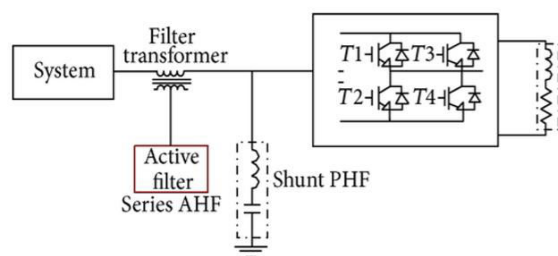
Parallel active filter

Hybrid harmonic mitigation technique

Hybrid connections of AHF and PHF are also employed to reduce harmonics distortion levels in the network. The PHF with fixed compensation characteristics is ineffective to filter the current harmonics



System with shunt AHF



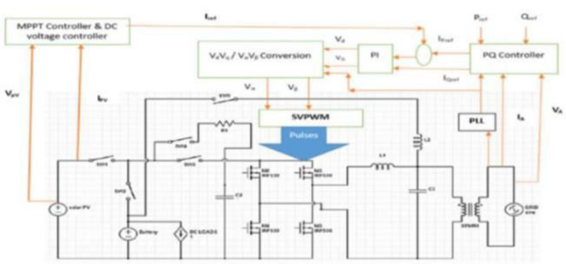
System with Shunt PHF and Active filter

Topology of RSC

The circuit diagram of reconfigurable solar inverter is given in the Fig. 1. Though it will reduce the no of power conversion stages but mechanical switches and cable requirement are more for this topology. The modes of operations of the proposed single-phase single-stage converter are given in Table I. In addition, different operations modes are given in Figs. 2–5. A

III CONTROL OF THE PROPOSED CONVERTER

For controlling this proposed single-phase inverter, PQ controller is used considering the advantage that it will control the active and reactive power according to the reference signal. Since the controlling elements for the ac system are very difficult due to their time-varying reference frame for effective control



DC/AC inverter operation

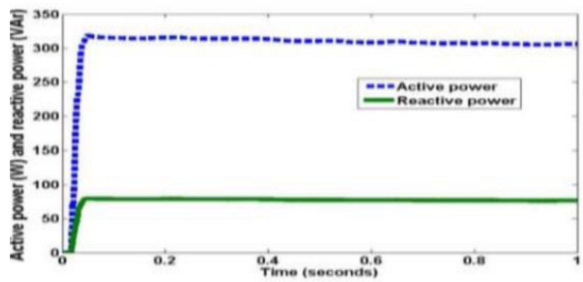
The control diagram for different modes of operations of the RSC is given in Figs. Above The inverter operation of the RSC is explained. From voltage and current measurement from the solar panel, voltage is set to extract maximum power from the panel using MPPT algorithm.

Battery is charged from solar panel using dc/dc conversion mode of RSC, One of the MOSFET switch is used to obtain required voltage level for the battery. Here, constant voltage charging is used. MPPT controller will produce the required current which is given to a PI controller to produce the reference voltage.This voltage is compared with the battery voltage and duty cycle is generated. From this duty cycle, PWM pulses are generated,

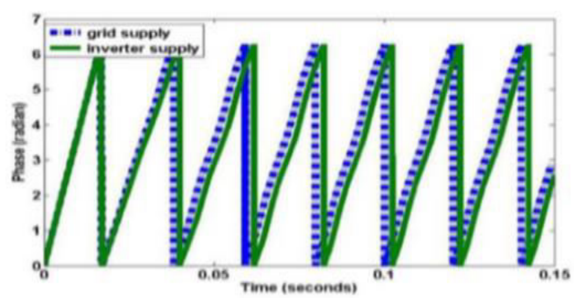
TABLE II Parameters considered for simulation

Components	Parameters
Battery	12 V, 9 Ah
Filter capacitor (C1)	47 μF
Filter inductor (L1)	2.3 mH
Switching frequency	4000 Hz
DC link capacitor (C2) 2 nos.	2200 μF, 16 V
Resistance (R1)	1 kΩ

Solar panel details	
No of cells per module	36
Open circuit voltage (V)	22.09
Short circuit current (A)	8.36
Voltage at maximum power (V)	17.7
Current at maximum power (A)	7.62
diode quality factor	1.25
number of series-connected module per module	1
number of modules per string	3
Series resistance (ohm)	0.165
Parallel resistance (ohm)	80

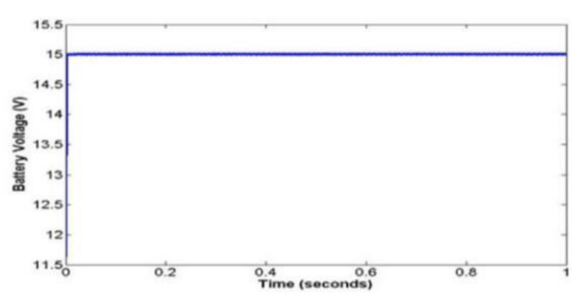


Active and reactive power generation



Phases in radians

Battery charged through the proposed topology. Here, constant voltage charging method is followed. Li-ion battery which is an inbuilt block of MATLAB/Simulink is used as battery storage



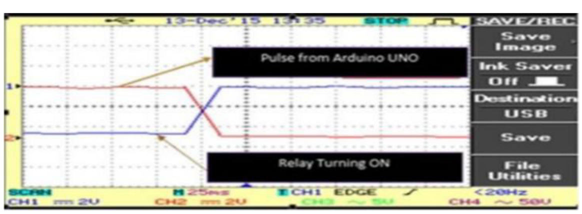
Battery voltage

Harmonic contributions by different appliances

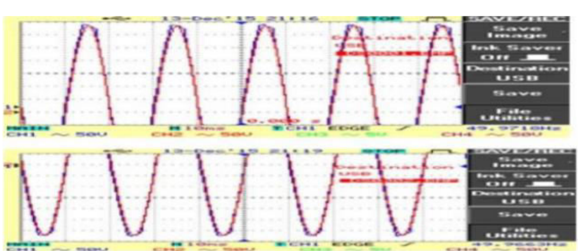
Appliances	THDV (%)	THDI (%)
Air conditioner	3.72	18
Bread toaster	2.3	2.7
CFL bulbs	3.6	99.9
Computer	2.7	99.6
Induction cook top	1.8	3.8
Fan	1.8	1.5
Incandescent bulb	1.7	2.2
Iron box	2.3	2.8
Laptop charger	2.3	39.1
Microwave oven	3.3	22
Mixer	2.9	13
Refrigerator	3	5.2
UPS	2.9	18
Battery charger	2.5	54
Cooler	2.4	1.7
Florescent lamp	2	99.8
Rice cooker	2.2	2.4
Tele vision	3	99.9
LED bulb	2.2	33.8

The output voltage during the charging is given in below Fig. Thus, all operations of the converter are tested in simulation and results are analyzed. The control algorithm works perfectly in the simulation in MATLABMATLAB/Simulink environment in order to implement the control logic of RSC. It has inbuilt PWM pulse generators and analog and digital input reader, which will be very useful in controlling the voltage and phase of the proposed converter. The dc

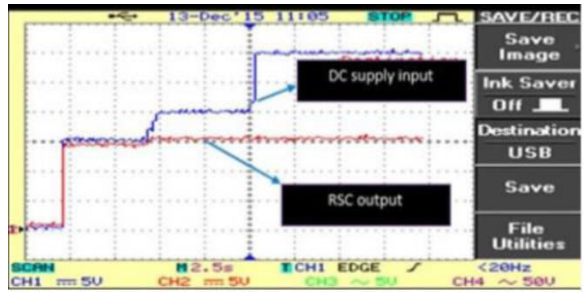
The relay used in this experiment is SONGLE 4 relay module each with a rating of 250-V ac, 10 A or 30-V dc, 10 A. The operation time of this relay is 10 ms.



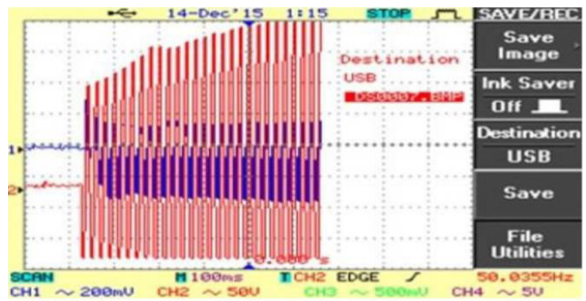
Relay turn ON



Since the peak voltage of DSO in the lab is 300 V maximum and so, two waveforms are given in Fig. 12 (upper and lower) to show the synchronization with the grid without any



DC/DC operation of the RSC



Mode-0 to Mode-1

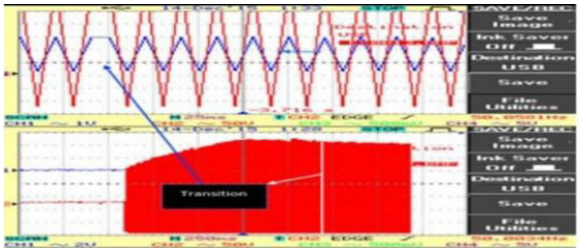
Different types of modes

Mode-0 to Mode1

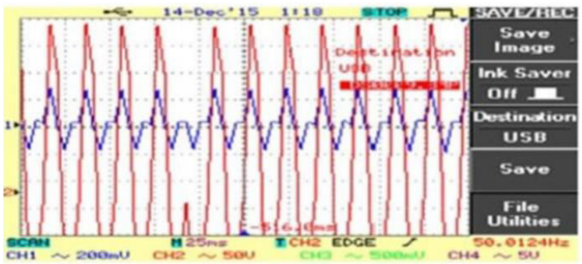
For example, off state of the converter is labeled as Mode-0 stage. Similarly, Mode-1 is solar panel to grid, Mode-2 is solar panel/battery to grid, Mode-3 is battery to grid, and Mode-4 is solar panel to battery charging. A resistor of 1 kΩ is put in series to the dc-link capacitor to avoid high inrush current during the mode change.

Mode-1 to Mode-2

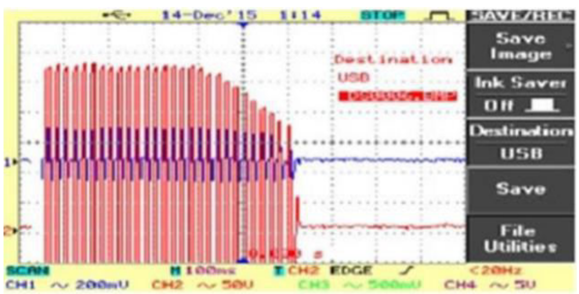
In this mode, the battery is connected with solar panel to share the load. The output waveforms are shown in fig After the relay switched ON, there is momentarily delay to track the voltage which is shown in Fig. 16 as transition. The voltage is



Mode-1 to Mode-2



Mode-2 to Mode-3



Mode-3 to Mode-4

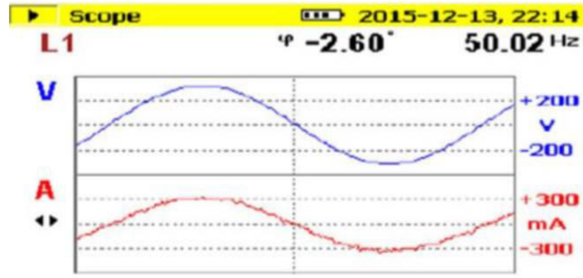
220 V and current is 2-A peaks. The delay in one cycle is the time required for the controller and MPPT controller cannot be used in this mode.

C. Mode-2 to Mode-3

The transition from Mode-2 to Mode-3 is shown in Fig. The solar panel is removed and battery is powering to the grid. The delay in changes is due to mode transition and controller is set to new stiff voltage by battery.

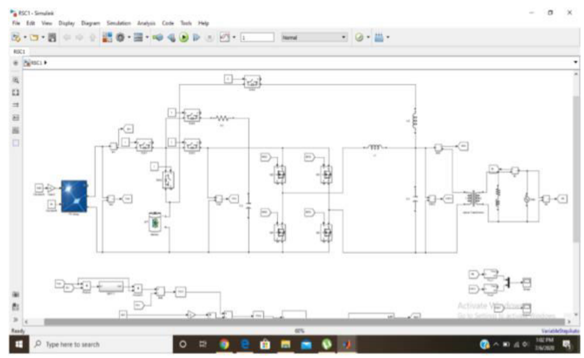
D. Mode-3 to Mode-4

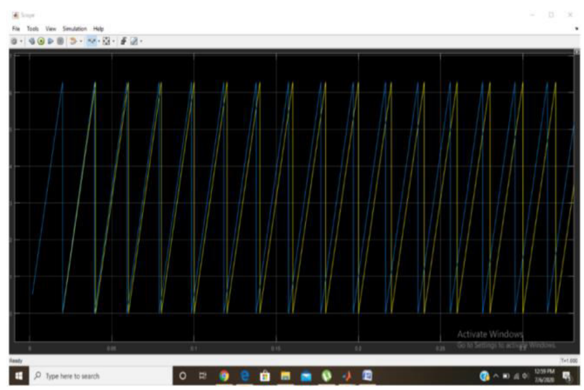
In transition to Mode-4 operation from Mode-3, the inverter operation is shut down, which is shown in Fig.

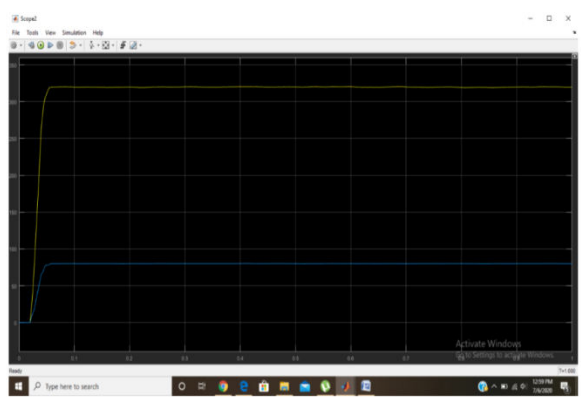


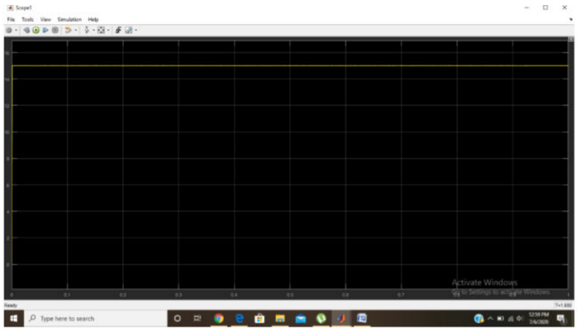
Voltage and current waveform

IV SIMULATION RESULTS









V CONCLUSION

This paper suggested a more suitable converter topology for a solar powered hybrid ac/dc home. The main idea of this topology is to utilize single conversion of ac power to dc and vice versa, which improves the efficiency, reduces volume, and enhances the reliability.

The hardware implementation validates that the suggested converter topologies would be helpful to reduce significant amount of harmonics in the residential feeders of the future smart grid. Though, here only solar PV is considered as source of power, this topology could be equally applicable to wind, fuel cells, etc.

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