A FUZZY BASED SINGLE STAGE SINGLE PHASE RECONFIGURABLE INVERTER TOPOLOGY FOR SOLAR POWERED AC\DC HOME

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ABSTRACT: In this project, a reconfigurable single phase single stage inverter that is interfaced with Fuzzy Logic Control (FLC) is suggested for solar hybrid AC\DC home. The main advantage of this converter is that it can perform dc/dc, dc/ac, and grid tie operation and thus results in reducing loss, cost, and size of the converter. This hybrid ac/dc home has both ac and dc appliances. This type of configuration associated with the 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. In this project, the proposed FLC control of inverter connected in photovoltaic(PV) power plants is developed to address the flexiblility and fast computing of the system. MATLAB/Simulink software is used to illustrate the proposed FLC based reconfigurable inverter topology. The results presented illustrate the capability of the system in isolating dc loads to dc supply side and rest to ac side.

Index Terms—Harmonic mitigation, hybrid ac/dc home, single-phase single-stage inverter, solar photovoltaic (PV) Fuzzy Logic Controller.

INTRODUCTION

The current century has witnessed an unprecedented evolution and growth of renewable energy worldwide [1]. 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 photovoltaic's (PVs) experienced the swiftest growth rate in added power capacity among all the renewable. 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 pro-mpted 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 comfort ability, 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.

Harmonic mitigation in the distribution system using solar inverter by virtual harmonic damping impedance method is discussed in literature [2]. In [3], PV-battery storage system is used to control the voltage stability in distribution system. The control of solar powered grid connected inverter for electric vehicle charging is suggested in [4].

Patterson [5] has proposed the dc micro grid and shown its advantages and challenges of making a complete dc home micro grid. Further, this paper has analyzed by considering all buildings in 2050, 80% of buildings are already built. So, focus is more on improving the efficiency of existing buildings than making a new complete dc home. They analyzed the data of 14 states in the USA, which used 380- and 24-V voltages for dc distribution in homes. There is a 33% savings when the ac equipment is replaced with dc equipment. Propose a novel solution to mitigate some of the harmonics related problems and efficiency issues by proposing a hybrid ac/dc home grid system. A solar home is discussed as a case study and a 12% improvement in efficiency and a 20% reduction in harmonics are achieved by shifting dc loads to the dc supply side.

Conventional grid connected inverter uses high dc link voltage, which will be the peak magnitude of the line–line grid voltage [8]. For this particular purpose, two stage conversions are required to boost up the dc voltage and to invert it. However, this will increase the cost, size, and loss of the system.

In the single-phase inverter topology[9-12], transformer less inverter gained significant research interest. Transformer less inverter has the advantage of low size and cost by avoiding the transformer but this will eliminate the galvanic isolation and inverter will become very sensitive to grid disturbances. The solar PV is limited by its inherent intermittency aspects and, hence, battery storage (assumed here) is required to supply the power when there are not enough solar radiations.

But having a separate converter for battery's power management system will increase the cost and size of the converter as well. Hence, a three phase topology of reconfigurable solar inverter is suggested in [14] and [16] for PV system with battery storage. This reconfigurable system is suitable to solar and wind farm applications. This topology is tested with a new algorithm and validated the results. Normally, every solar powered household have a battery system to provide a reliable supply system. These batteries are charged when connected to ac system or they need a separate converter to manage the charging operations when it connected to dc supply side.

Therefore, the main contribution of this paper is to implement a single-phase single-stage solar converter called reconfigurable solar converter (RSC) in the solar powered hybrid ac/dc residential building with energy storage devices. The basic concept of the RSC is to use a single power conversion system to perform different operational modes such as solar PV to grid (Inverter operation, dc–ac), solar PV to battery/dc loads (dc–dc operation), battery to grid (dc–ac), battery/PV to grid (dc to ac) and Grid to battery (ac–dc) for solar PV systems with energy storage. This inverter is tested in a solar powered hybrid ac/dc home, which contains both ac and dc household loads. Individual appliances are selected according to the harmonic contributions they are injecting to the distribution grid from a typical modern house. Apart from the aforementioned, other additional contributions are as follows. The variation in solar radiation is also considered and solar PV-battery operation is verified. The circulation current is mitigated due to operation of the switches in the topology for dc/dc operation. Control logic and sampling of input quantities are also different in this paper.

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. There are different operations modes which are given below in Figs. 2–5.

Mode-1

The mode of operation as shown in Fig. 2 is directly connects PV to the grid. Maximum power point tracking (MPPT) controller is used to extract maximum power from the solar panel. Inverter controller is used to synchronize with grid and transfer active power to the grid.

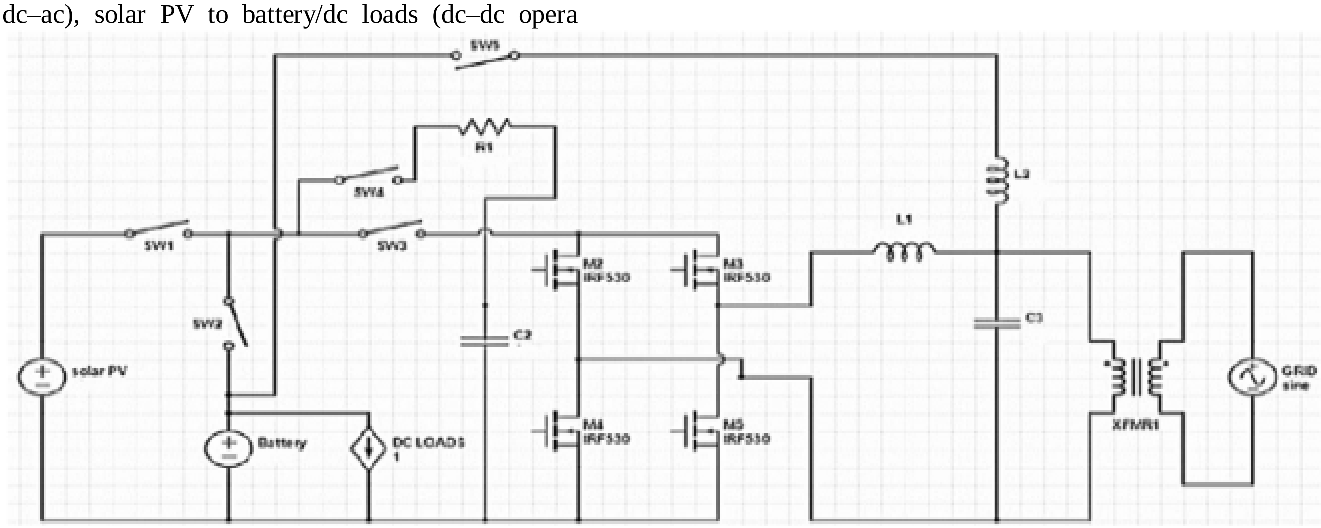

Fig. 1. Schematic of the proposed RSC circuit

Table I Modes Of Operation

Modes of operation	ON Switches	OFF Switches
PV-Grid	Sw1 Sw3 Sw4	Sw2 Sw5
PV-Battery-Grid	Sw1 Sw2 Sw3 Sw4	Sw5
PV-Battery	Sw1 Sw3	Sw2 Sw4
Battery-Grid	Sw2 Sw3	Sw1 Sw4 Sw5

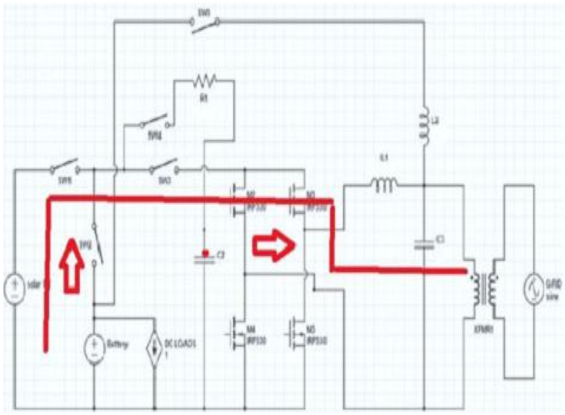

Fig. 2. PV To Grid.

Mode-2

According to the Fig. 3, the mode of operation is to supply power to the grid from both solar PV and battery. This mode operates when there is a shortage of power from the solar PV due to external conditions, e.g., weather, etc. One of the drawbacks of this connection is that the battery voltage and PV voltage should always be matching each other. Since battery voltage is stiff, MPPT controller cannot be used for this configuration.

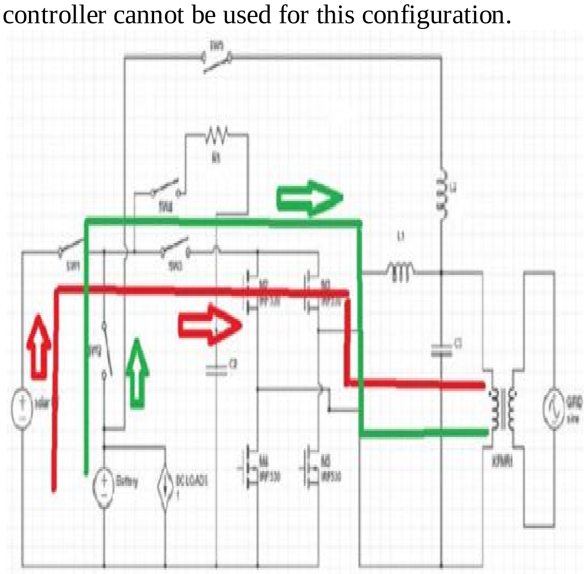

Fig. 3. PV-Battery To Grid

Mode-3

From the Fig. 4 which shows dc/dc operation of the proposed topology, where battery is charged by a chopper action of the converter. The extra inductor is optional to reduce ripple in the charging current further. When there is an excess energy available, the battery is charged for the night time usage.

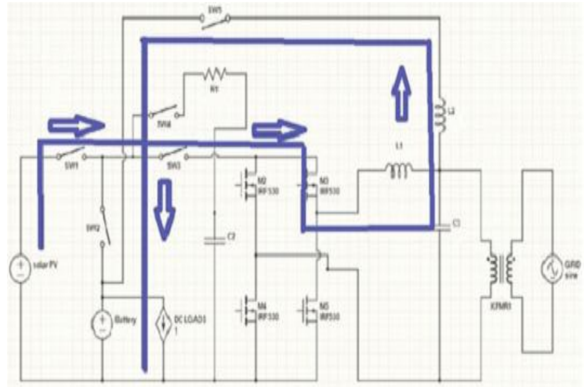

Fig. 4. PV To Battery Charging.

Mode-4

According to the Fig. 5, there are energy stored in battery can be released to the appliances or grid during the night hours or when there is no solar radiation due to clouds or rainy conditions. Battery can supply stable power to the inverter. Thus, it can be very helpful in power quality improvement and ancillary services provision.

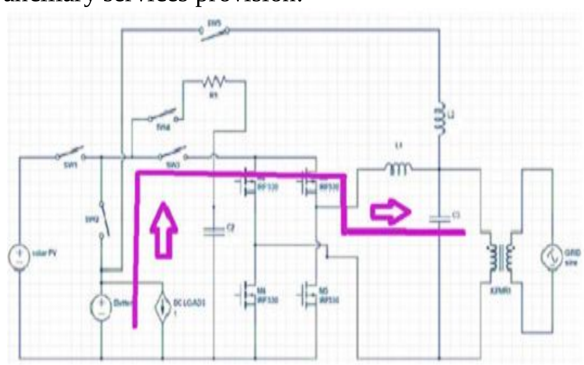

Fig. 5. Battery to Grid.

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 nature, the ac control variables are converted to a stationary reference frame from a rotating reference frame for effective control.

Let $F\alpha$ and $F\beta$ be the rotating reference frame variables, which can be voltage or current, whereas Fd and Fq be the stationary variables. In rotatory reference frame, the active and reactive powers can be calculated by using

$$P = \frac{1}{2}\left[v_d * i_d + v_q * i_q\right] \quad (1)$$

$$Q = \frac{1}{2}\left[v_d * i_q - v_q * i_d\right] \quad (2)$$

where v and i are the instantaneous values of voltage and current, respectively.

When the inverter is synchronized to the grid, the value of vq becomes 0, and (1) and (2) becomes

$$P = \frac{1}{2}[v_d * i_d] \quad (3)$$

$$Q = \frac{1}{2}[v_d * i_q] \quad (4)$$

The active and reactive reference currents are given in (5) and (6) as

$$\hat{\imath}_d = \frac{2*\hat{P}}{v_d} \quad (5)$$

$$\hat{\imath}_q = \frac{2*\hat{Q}}{v_d} \quad (6)$$

where Pˆ and Qˆ are the reference power signals of active and reactive power, respectively.

Calculated values of id and iq are converted into stationary reference frame and given as signal to PQ controller to produce reference signals for the sinusoidal pulse width modulation controller. Synchronizing the solar inverter with grid requires the knowledge of the magnitude and phase of the grid supply voltage. Phase lock loop (PLL) will track the phase of the grid and help to synchronize with the grid. To obtain maximum power from the solar panel, according to maximum power transfer theorem, the panel resistance should be equal to the load resistance, which is connected to this panel. To achieve this, a hill climbing MPPT algorithm is used. This technique will equalize the resistances and extract maximum power from the solar panel.

The control diagram for different modes of operations of the RSC is given in Figs. 6 and 7. In Fig. 6, 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. This voltage is compared with the set dc-link voltage and error is given to a PI controller for DC link voltage regulation. This PI controller will produce reference current, which is compared with reference current produced using PQ controller, which is given in (5) and (6). This error is given to a PI controller, which will generate reference voltage for active power control. Reactive power is separately controlled using another PI controller. These reference voltages are converted to rotating reference frame voltages and given to space vector pulse width modulation (PWM) to drive the inverter.

Battery is charged from solar panel using dc/dc conversion mode of RSC, which is given in Fig. 7. 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, which is given to the MOSFET switch. Thus, both ac and dc loads are given supply using a single reconfigurable inverter.

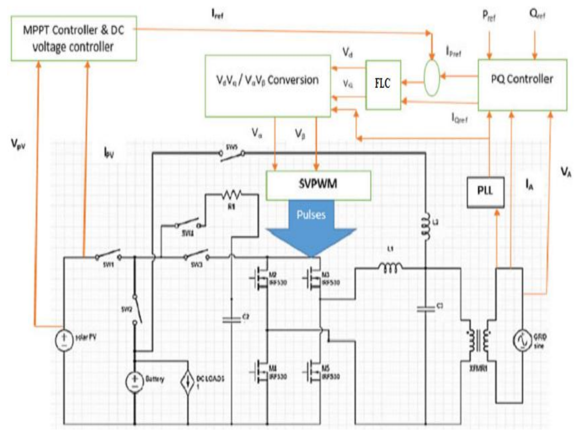

Fig. 6. DC/AC inverter operation

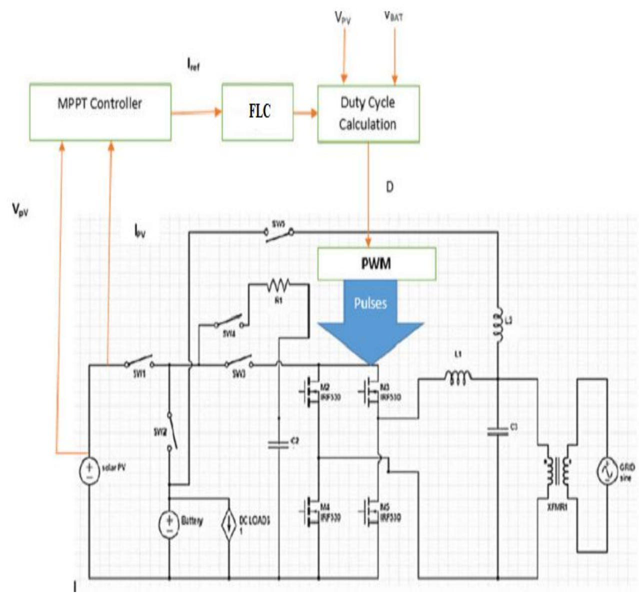

Fig. 7. DC/DC chopper operation.

FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

The FLC comprises of three parts: i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

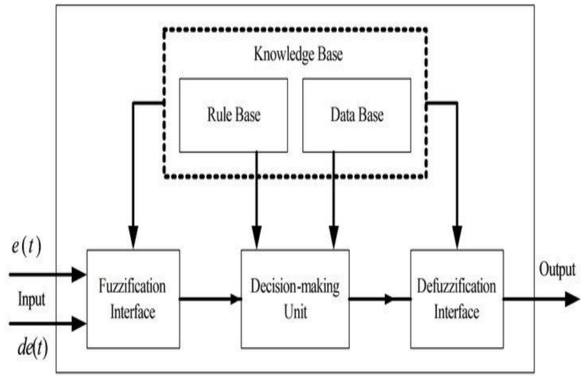

Fig.8.Fuzzy logic controller

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

TABLE II: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (7)$$

$$CE(k) = E(k) - E(k-1) \quad (8)$$

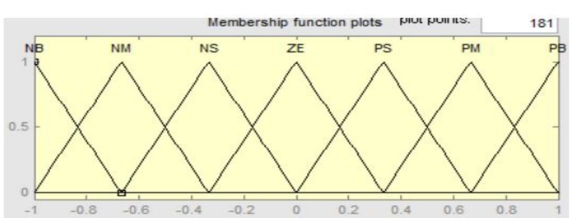

Fig 9 Input Errors As Membership Functions

Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

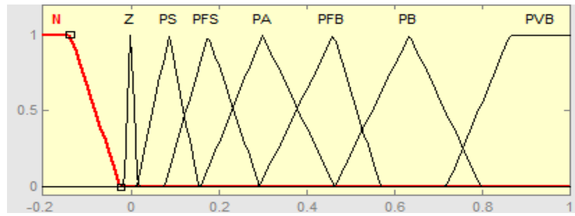

Fig 10 Change As Error Membership Functions

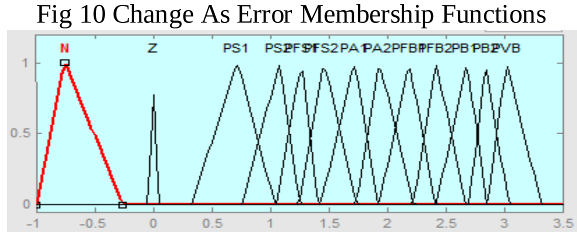

Fig.11 output variable Membership functions

Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha E + (1-\alpha) * C] \quad (9)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

EXECUTED RESULTS

Simulation of the proposed converter is done in MATLAB/Simulink. The parameters used for the simulation are given in Table II. The radiation is kept at maximum at 1000 W/m2. Inbuilt PLL and PWM pulse generator blocks in MATLAB/Simulink are used for controlling the inverter. . The design is done for 500-W inverter topology. The active and reactive power output for a load of 320 W and 80 VAr is simulated and shown in Fig. 12.

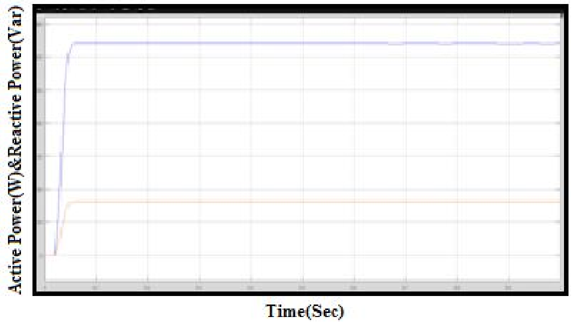

Fig. 12. Active and Reactive Power Generation.

PLL is actually a servo mechanism which will reduce the difference between phase and frequency of incoming signal to a reference signal. Active power transfer to the grid is possible if there is a difference between the phase of the inverter and the grid supply system. PLL will capture the phase of the grid supply and required phase shift is generated using an inverter controller for power transfer. The phasor diagram of inverter and grid supply during the power transfer is shown in Fig. 13.

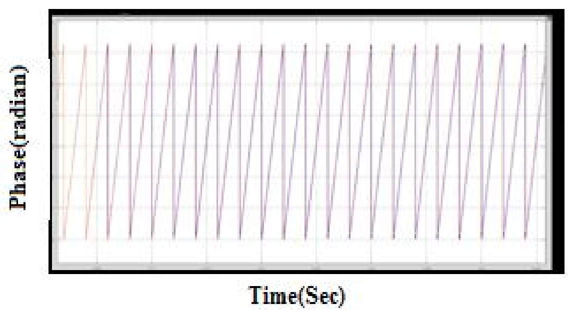

Fig.13. Phases in radians

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.

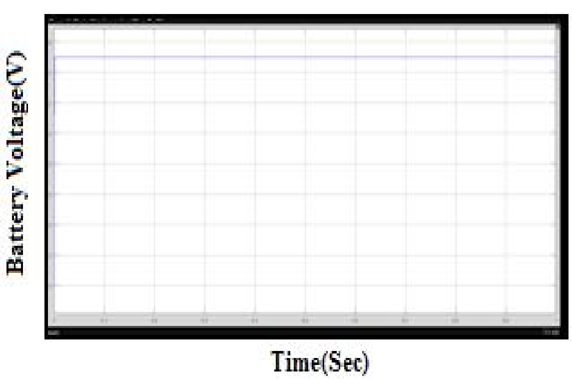

Fig. 14. Battery voltage.

The output voltage during the charging is given in Fig. 14. Thus, all operations of the converter are tested in simulation and results are analyzed. The control algorithm works perfectly in the simulation in MATLAB

TABLE II Simulation Parameters

Components	Parameters
Battery	12V,9Ah
Filter Capacitor(C1)	47 µh
Filter Inductor(L1)	2.3 Mh
Switching Frequency	4000Hz
DC link Capacitor(C2) 2nos	2200 µF,16 V
Resistor(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

CONCLUSION

In this project a more suitable converter topology for a solar powered hybrid ac/dc home is suggested. 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 synchronization of the inverter and phase of the load is achieved by using PLL which will track a signal with other signal. PLL will capture the phase of the grid supply and required phase shift is generated using an inverter controller for power transfer. The proposed state of the system from transient state to steady state is controlled using fuzzy logic control. Fuzzy logic control results in the quick operation of the system. It is concluded that this fuzzy based reconfigurable inverter is helpful to reduce significant amount of harmonics in the residential feeders of the future smart grid and also reduce the distortion power. All the operations of the converter are tested in simulation and results are analyzed. The control algorithm works perfectly in the simulation in MATLAB.

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