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PV Battery based Transformer Coupled Quasi-Z-Source Reconfigurable Inverter for Household Applications

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Abstract—*This paper proposed a Quasi-Z-source Reconfigurable inverter (qZSRI) for household applications which derived from the Z-source inverter (ZSI) topology provides a substitute for the conventional two stages (DC-to-DC/DC-to-AC) Photovoltaic (PV) inverter system with minimum number of component, overcomes some of the restrictions and problem related with the conventional inverter topology and simplest topology. This inverter possesses a single-stage single-phase topology and the key benefit of this inverter is that it can perform DC-to-AC, DC-to-DC and grid tie operation, therefore reduces size, cost, and loss of inverter. Household applications support to reduce the power loss by avoiding inessential double stages of power conversion and develop the harmonic profile by isolating DC type loads to DC supply side and remaining of AC side. One significant advantage of quasi-Z-source reconfigurable inverter is that it has a quasi-Z-network, which is comprised of inductors and capacitors, between input DC source and inverter. In the implementation of grid-connected Photovoltaic (PV) inverter system, power storage becomes a fundamental requirement as a backup to full fill the power demand. In this situation, the qZSRI topology has the advantage of easy connection with the storage element with a very minimal modification. This paper presents a study on the features of the qZSRI including improved reliability reduced passive components rating and distinctive regeneration ability. Initially, simulation is done in MATLAB/Simulink environment and furthermore some simulation results are provided to verify the effectiveness of the proposed schematic method. Such kind of PV solar powered house and inverter would be a key building block of energy efficient future Microgrid and Smart Grid.*

1. INTRODUCTION

The present century has observed the extraordinary development and progress of renewable energy globally [1]. There has been a significant rise in the production and capability of all renewable technologies and similarly progress in supporting policies. The world is progressively aware of the potential of renewable energy to decrease the dependence on conventional fossil fuels and to decrease the release of climate changing greenhouse gases and other pollutants; photovoltaic (PV) solar distributed generation system has become very important in the recent years. This is supported by the data shown in figure 1 from the International Energy Agency (IEA) which shows that at end of 2016 total accumulated capacity of installed PV solar reaches about 303 GW among 25 IEA PVPS countries represented 265 GW of cumulative PV solar installations together, mostly grid-connected, at the end of 2016 [2].

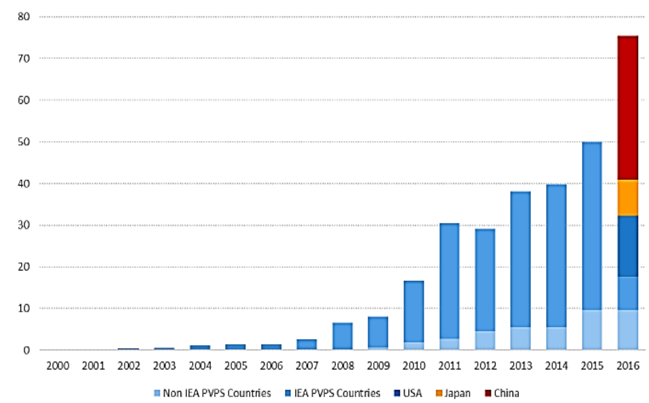

Figure 1: Evaluation of Annual PV Installations 2000-2016

Recently, Pakistan is facing severe electricity shortfall. Remarkable efforts are being made to provide reliable and continuous solutions by exploring renewable energy resources to overcome the crisis [3]. Pakistan has abundant type of renewable energy sources like solar, hydel, biomass, and wind [4-5]. The solar energy is the most important and plentiful type of renewable resource in Pakistan. There are two ways of harnessing solar energy to generate electricity: Photovoltaic (PV) and Concentrated Solar Power (CSP). The installation of solar power projects proves to be a fast and quick remedy for severe energy crisis. Solar applications could be pursued in near future to meet the electricity shortfalls. The future applications of solar energy consist of solar cooking [6], solar heating [7], drying [8] of the fruits in food industry, solar desalination [9], and integration of solar technology for thermal-electric purpose in smart homes. To reduce the uncertainty in PV solar production, storage options are presented such as battery system, Fuel cells etc.

New technologies in houses and nonlinear modern household equipment are main source of generating harmonics current in distribution feeder and that adversely affecting the power quality, power losses along with creating a major challenge for electrical engineers. Modern household and loads present in earlier stage have different characteristics. On the other hand, harmonic reduction and/or its minimizations are great challenges in distribution system. Many literatures works have been described to address above-mentioned problems as follows.

Harmonic reduction in the distribution system using solar inverter by virtual harmonic damping impedance method is discussed in literature [10]. PV-Battery storage system is used to control the voltage stability in distribution system [11]. The control of solar powered grid connected inverter for electric vehicle charging is recommended in [12]. The DC microgrid and shown its benefits and challenges of making a complete DC home microgrid is proposed in [13]. Additional, this paper has examined by supposing all buildings in 2050, 80 % of buildings are already built. Therefore, emphasis is more on enhancing the efficiency of existing buildings than making a new complete DC home. The efficiency of residential building when it is converted into DC house over the conventional AC distribution house has been examined in [14]. They examined the data of 14 states in USA which used 380 V and 24 V voltages for DC distribution in home. There is a 33% savings when the AC equipment is changed with DC equipment. But changing all existing home appliances with its DC equivalent is not viable due to the high price and unavailability of the essential standards/flexibilities of equipment. A novel solution to REDUCE some of the harmonics related issues and efficiency problems by proposing a hybrid AC/DC Home grid system has been studied in [15]. A solar home is examined as a case study and a 12% improvement in efficiency and a 20% reduction in harmonics are attained 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 has been analyzed in [16]. For this specific purpose two stage conversions are needed to boost up the DC voltage and to convert it. On the other hand, this will increase the cost, size and loss of the system. Single phase single stage topologies of inverter are recommended to avoid above mentioned issues in [17-20]. In single phase inverter topology, transformer less inverter gained major research interest as proposed in [21]. Transformer less inverter has the benefit of low size and cost by avoiding the transformer but this will remove the galvanic isolation and inverter will become very sensitive to grid disturbances in the galvanic isolation and inverter will become very sensitive to disturbances in grid connected mode. Meanwhile, the PV solar is restricted by its essential intermittency features and, henceforward, battery storage (considered here) is needed to supply the power when there are not enough solar radiations. On the other hand having a distinct converter for battery's power management system will increase the cost and size of the converter as well. Therefore, a three phase topology of reconfigurable solar inverter is presented in [2] 2and [23] for utility PV solar system with battery storage. This reconfigurable system is appropriate to solar and wind farm applications. This topology is tested with a new algorithm and validated the results. Usually every PV solar powered household has a battery system to deliver a consistent supply system. Generally 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. However, [23] delivers very brief info but no details/outcomes are available about single phase single stage topology which can supply both AC and DC loads in literature. Also, [24] provides very brief info about single phase single stage topology of reconfigurable solar inverter.

The major contribution of this paper is to propose a single phase single-stage photovoltaic battery based inverter called quasi-z-source reconfigurable inverter (qZSRI) in the solar powered household application. The elementary idea of the qZSRI is to use a single power conversion system to implement different operational modes for example PV solar to grid (DC-to-AC, Inverter operation), battery to grid (DC-to-AC), PV solar to DC loads/battery (DC-to-DC operation), grid to battery (AC-to-DC) and battery/PV to grid (DC-to-AC) for PV solar systems with energy storage. In addition to the above-mentioned, other extra contributions are as follow. The variation in solar radiation is also supposed and PV sola-Battery operation is verified. The circulation current is mitigated due to operation of the switches in the topology for DC-to-DC operation. The electrical components are a little different from [24], and normal inductor only used for DC/DC operation. The variation in solar radiation is also assumed and PV solar -Battery operation is verified. The circulation current is reduced 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.

Section 2 presents the proposed inverter circuit, modes of operation and analysis. In Section 3, control of the proposed inverter is presented and necessary design considerations to upgrade into proposed inverter. Section 4 presented experimental outputs of the proposed topology. Section 5 & 6 summarizes results and concludes the outcomes.

2. TOPOLOGY OF PROPOSED INVERTER

The block diagram of proposed system is shown in figure 2. Here we have a transformer coupled quasi-z-source reconfigurable inverter (qZSRI). Other two main components are PV solar with battery (energy storage device).

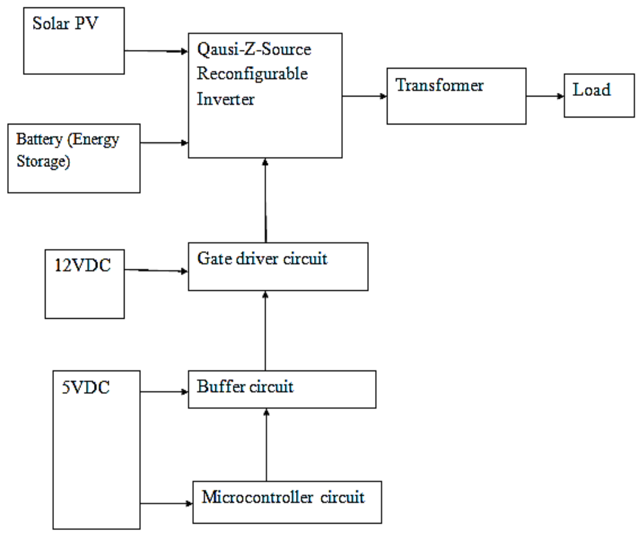

Figure 2: Block Diagram of Proposed System

The schematic of proposed quasi-z-source reconfigurable inverter (qZSRI) circuit is shown in figure 3.

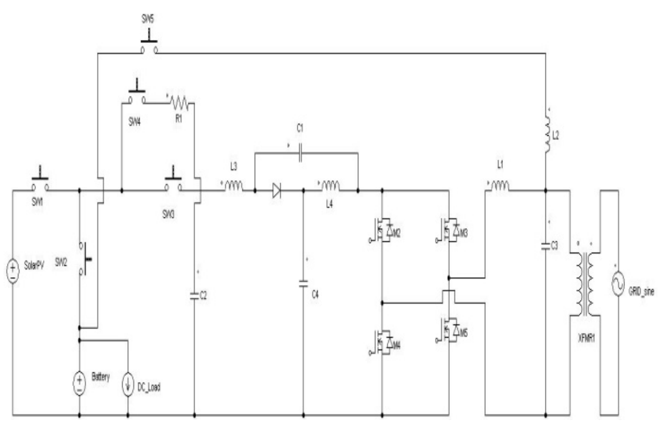

Figure 3: Schematic of Proposed Quasi-Z-Source Inverter

However it reduced current ripple in the input, increased current gain and reduced the no of power conversion stages. Also, quasi means half therefore the L and C values used reduced to half. The modes of operations of the proposed single phase single stage quasi-z-source reconfigurable inverter are given in table 1.

There are four modes of operation. These modes of operations depend upon the opening and closing of the switches.

2.1 PV Solar-Grid Mode

This mode directly connects PV solar to the Grid. The mode of operation is shown in figure 4. Maximum Power Point Tracking (MPPT) controller is used to extract maximum power from the solar panel. The inverter controller is used to coordinate with grid and transfer active power to the grid.

Table 1: Mode of Operations of Proposed Circuit Structure

Mode No.	Mode of Operation	Off Switches	On Switches
Mode 1	PV Solar-Grid	SW2, SW5	SW1, SW3, SW4
Mode 2	PV Solar-Battery-Grid	SW5	SW1, SW2, SW3, SW4
Mode 3	PV Solar-Battery	SW2, SW4	SW1, SW3, SW5
Mode 4	Battery-Grid	SW1, SW4, SW5	SW2, SW4

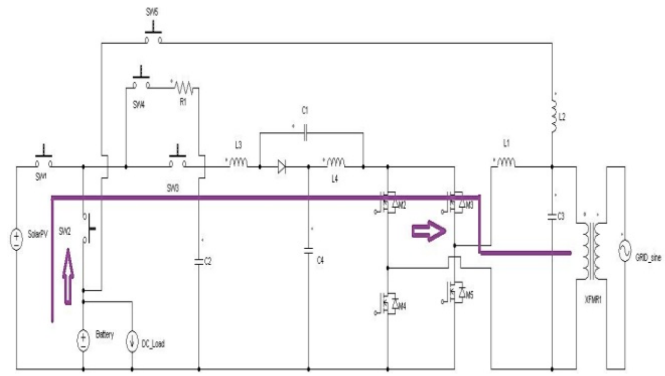

Figure 4: Mode 1 (PV Solar to Grid)

2.2 PV Solar-Battery-Grid Mode

This mode is to providing power to the grid from both PV solar and battery. The mode of operation is shown in figure 5. This PV Solar-Battery-Grid mode operates when there is a lack of power from the PV solar because of external conditions, e.g., weather etc. One of the disadvantages of this mode connection is that the PV solar voltage and battery voltage should always be matching each other. Since battery voltage is stiff, MPPT controller cannot be used for this configuration.

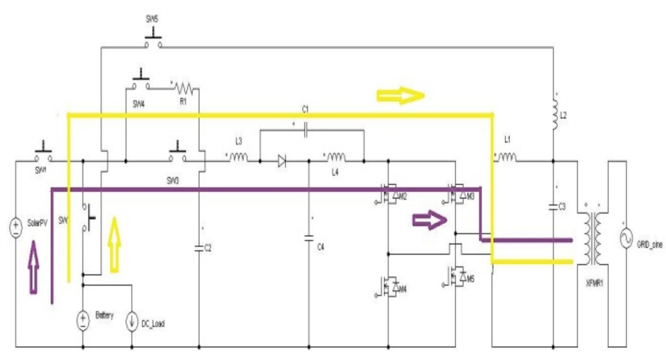

Figure 5: Mode 2 (PV Solar-Battery to Grid)

2.3 PV Solar-Battery Mode

This mode displays DC-to-DC operation of the proposed model topology where a chopper action of the inverter is used to charge battery. The mode of operation is shown in figure 6.

Additional the extra inductor is optional to decrease ripple in the charging current. When there is a surplus energy accessible at day time, the battery is charged for the night time usage.

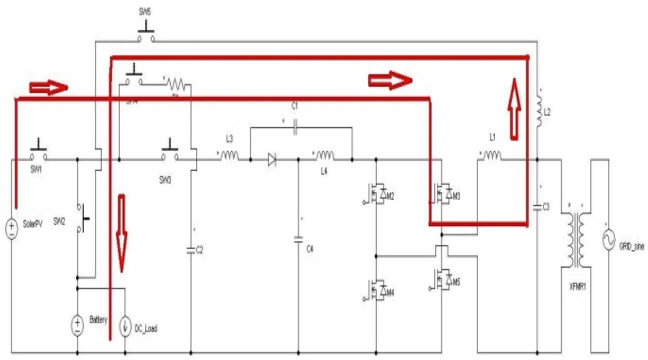

Figure 6: Mode 3 (PV Solar to Battery Charge)

2.4 Battery-Grid Mode

In this mode the energy stored in battery can be transmitted to the grid or appliances when there are rainy conditions or no solar radiation due to clouds or during the night hours. The mode of operation is shown in figure 7. Battery can release steady power to the inverter. Therefore, it can be very cooperative in power quality improvement.

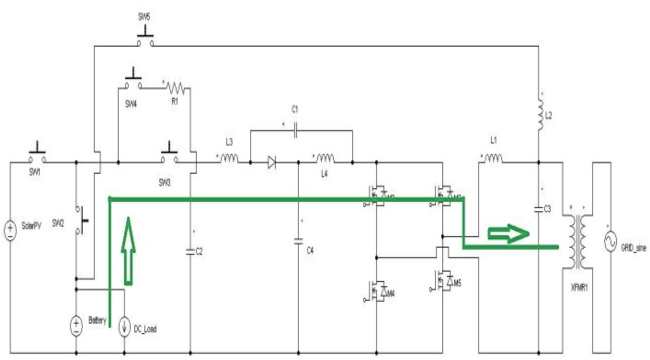

Figure 7: Mode 4 (Battery to Grid)

3. CONTROL OF PROPOSED INVERTER

For controlling this proposed single phase single stage qZSR inverter, PQ controller is used bearing in mind the benefit that it will control the reactive and active power according to the reference signal. In the meantime the controlling components for the AC system are very difficult because of their time varying nature, for effective control the AC control variables are changed to a stationary reference frame from a rotating reference frame [26].

This converted reference frame given as signal to PQ controller to generate reference signals for the Sinusoidal Pulse Width Modulation (SPWM) controller. The knowledge of the phase and magnitude of the grid supply voltage needs for synchronizing the solar inverter with grid. The phase of the grid will be track by Phase Lock Loop (PLL) and help to synchronize with the grid. To gain maximum power from the PV solar panel, according to maximum power transfer theorem, the solar panel resistance must be equal to the load resistance which is connected to this panel. To obtain this, a MATLAB/Simulink built-in block of Maximum Power Point Tracking (MPPT) is used. This built-in block will equalize the resistances and fetch maximum power from the PV solar panel. The control diagram of qZSRI for different modes of operations is shown in figure 8 & 9. The inverter operation of the qZSRI is described in figure 8. From current and voltage measurement from the PV solar panel, voltage is set to fetch maximum power from the panel using built-in block of MPPT. For DC link voltage regulation this voltage is matched with the set DC link voltage and error is given to a PI controller. This PI controller will generate reference current which is compared with reference current generated using PQ controller. This error is given to a PI controller which will produce reference voltage for active power control. Reactive power is distinctly controlled using an additional PI controller. These reference voltages are transformed to rotating reference frame voltages and given to space vector PWM to drive the inverter. To obtain this, a MATLAB/Simulink built-in block of space vector PWM is used.

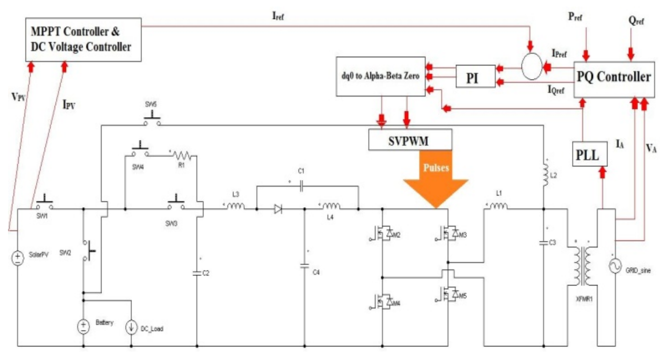

Figure 8: DC-to-AC Inverter Operation

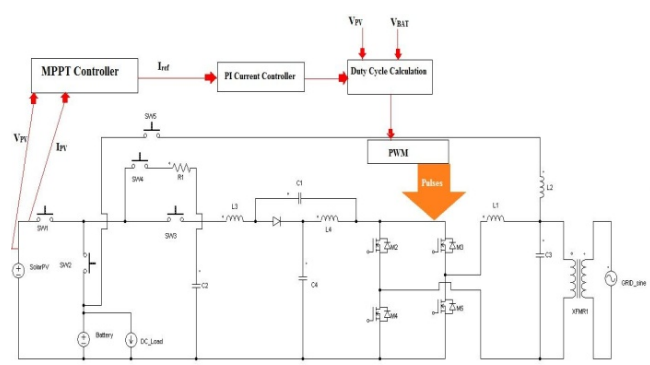

Figure 9: DC-to-DC Chopper Operation

DC-to-DC conversion mode of qZSRI charged battery from solar panel using which is given in figure 9. One of the MOSFET switch is used to gain essential voltage level for the battery. At this time constant voltage charging is used. MPPT controller will generate the necessary current which is given to a PI controller to generate the reference voltage. The battery voltage is compared with this voltage and duty cycle is produced. From this duty cycle pulse width modulation pulses are produced which is given to the MOSFET switch. Therefore, both AC and DC loads are given supply using a single quasi-z-source reconfigurable inverter.

Inbuilt dq0 to Alpha-Beta Zero, PLL and PQ controller blocks in MATLAB/Simulink are used for controlling the inverter. The magnitude and phase of the grid supply voltage must be known in order to synchronize the PV solar inverter with grid. Phase locked loop (PLL) is system which will track a signal with other signal system. Phase locked loop (PLL) is in fact a servo mechanism which will decrease the difference between frequency and phase of incoming signal to a reference signal. If there is a difference between the phase of the inverter and the grid supply system then active power transfer to the grid is possible. PLL will capture the phase of the grid supply and needed phase shift is produced using inverter controller for power transfer.

Battery charged through the proposed inverter topology. At this point constant voltage charging method is followed. MATLAB/Simulink inbuilt Li-ion battery block is used as battery storage. Therefore all operations of the inverter are tested in simulation and results are analyzed. The control works perfectly in the simulation in MATLAB.

4. SPECIFICATIONS

The parameters used for the simulation is given in Table 2.

Table 2: Simulation Parameters

Components	Parameters
Solar Panel Details	
Short Circuit Current ISC	4.75A
Open Circuit Voltage	10V
Irradiance Used For Measurement	1000 W/m^2
Series Resistance	5.1 e^-3 Ohm
First Order Temperature Co-Efficient For I_{PHASE}	0.65 e^-3
Energy Gap EG	1.12
Measurement Temperature	25Deg C
Solar Panel	24V
Battery	1V, 12V, 25V, 9Ah
Load Resistance	500 Ω
Resistance (R1)	1000 Ω
DC Link Capacitor (C3)	2200µH
Filter Inductor (L1)	2.3mH

5. SIMULATION RESULTS AND DISCUSSION

The Proposed system is modeled in MATLAB/Simulink. Comprehensive simulation studies are carried out on MATLAB/Simulink platform and the results obtained for various operating conditions are presented in this section. The parameters used in simulation already given in above section. Battery charged through the proposed inverter topology. At this point constant voltage charging method is followed. MATLAB/Simulink inbuilt Li-ion battery block is used as battery storage. Therefore all operations of the inverter are tested in simulation and results are analyzed. The control works perfectly in the simulation in MATLAB.

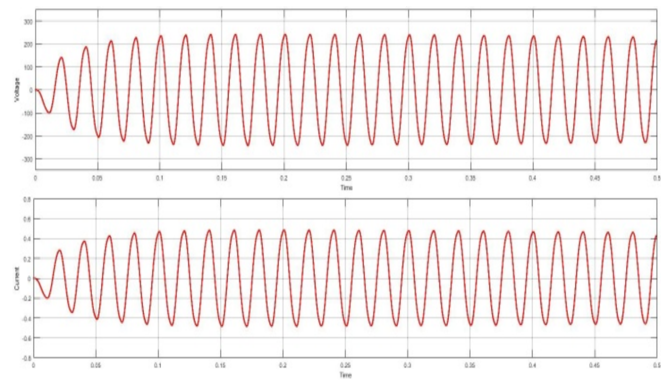

Figure 10. Output Voltage and Current of Proposed System

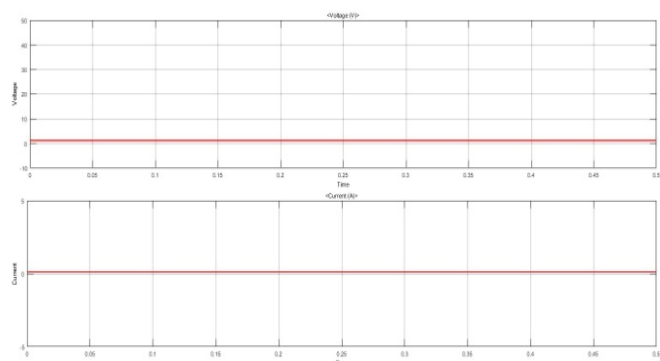

Figure 12. Battery for Mode 1

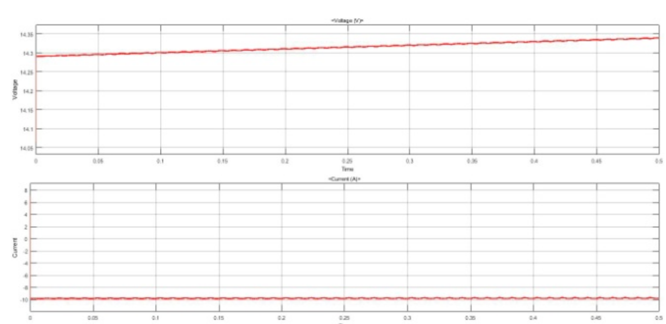

Figure 13. Battery for Mode 2

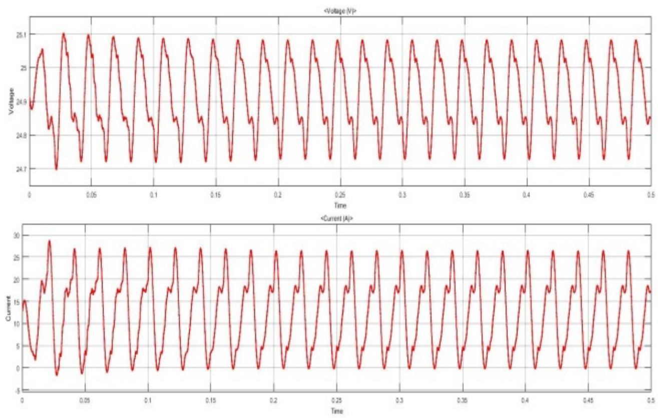

Figure 14. Battery for Mode 3

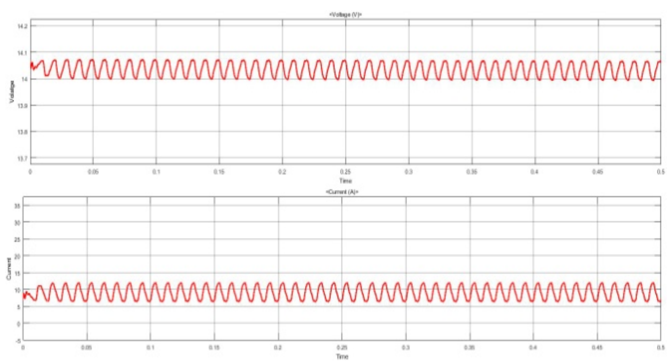

Figure 15. Battery for Mode 4

6. CONCLUSION

This paper recommended a more appropriate inverter topology for a PV-Battery based household application. The main concepts of this topology is that a single phase single conversion of AC power to DC and vice versa is applied, which enhanced the efficiency, decreases volume and improves the reliability. The simulations authenticates that the suggested inverter topology would be helpful to decrease major amount of harmonics in the residential feeders of the future Smart Grid. However, here only solar PV is supposed as source of power, this topology could be equally applicable to other renewable energy sources like wind, fuel cells etc.

REFERENCES

[1] GSR (2017) - Renewables 2014 Global Status Report.
[2] PVPS, IEA (2016). A Snapshot of Global PV Report.
[3] M. Irfan, J. Iqbal, A. Iqbal, Z. Iqbal, R. A. Riaz, and A. Mehmood, "Opportunities and challenges in control of smart grids–Pakistani perspective," Renewable and Sustainable Energy Reviews, vol. 71, pp. 652–674, 2017.
[4] Ahmed A and Zahedi G. Sustainable energy systems : role of optimization modeling techniques in power generation and supply—a review. Renew Sustain Energy Rev 2011; 15: 3480–3500.
[5] Zafar T, Zafar K, Zafar J, et al. Integration of 750 MW renewable solar power to national grid of Pakistan: an economic and technical perspective. Renew Sustain Energy Rev 2016; 59: 1209–1219.
[6] Cabrera FJ, Ferna´ndez-Garcı´a A, Silva RMP, et al. Use of parabolic trough solar collectors for solar refrigeration and air-conditioning applications. Renew Sustain Energy Rev 2013; 20: 103–118
[7] Kabir E, Kumar P, Kumar S, et al. Solar energy: potential and future prospects. Renew Sustain Energy Rev 2018; 82: 894–900.
[8] Abbas T, Ahmed Bazmi A, Waheed Bhutto A, et al. Greener energy: issues and challenges for Pakistan-geothermal energy prospective. Renew Sustain Energy Rev 2014; 31: 258–269.
[9] Sampaio PGV and Gonza´lez MOA. Photovoltaic solar energy: conceptual framework. Renew Sustain Energy Rev 2017; 74: 590–601
[10] S. Munir, Li Yun Wei, "Residential Distribution System Harmonic Compensation Using PV Interfacing Inverter," IEEE Trans. Smart Grid, Vol. 4, No. 2, pp.816-827, June 2013.
[11] J. Von Appen, T. Stetz, M. Braun, A. Schmiegel, "Local Voltage Control Strategies for PV Storage Systems in Distribution Grids," IEEE Trans. Smart Grid, Vol. 5, No. 2, pp.1002-1009, March 2014.
[12] A. Arancibia, K. Strunz, F. Mancilla-David, "A Unified Single- and Three-Phase Control for Grid Connected Electric Vehicles," IEEE Trans. Smart Grid, Vol. 4, No. 4, pp.1780-1790, Dec. 2013.
[13] B. T. Patterson, "DC, Come Home: DC Microgrids and the Birth of the Enernet," IEEE Power and Energy Magazine, Vol. 10, No. 6, pp.60-69, Nov.-Dec. 2012.
[14] Vagelis Vossos, Karina Garbesi, Hongxia Shen, "Energy savings from direct-DC in U.S. residential buildings," Energy and Buildings, Vol. 68, Part A, January 2014.
[15] Nikhil Sasidharan, Nimal Madhu M., Jai Govind Singh, Weerakorn Ongsakul, "An approach for an efficient hybrid AC/DC solar powered Homegrid system based on the load characteristics of home appliances," Energy and Buildings, Vol. 108, 1 December 2015.
[16] B. Mariappan, B. G. Fernandes, M. Ramamoorty, "A novel single-stage solar inverter using hybrid active filter with power quality improvement," 40th Annual Conference of the IEEE in Industrial Electronics Society, pp. 5443-5449, Oct. 29 2014-Nov. 1 2014.
[17] Chien-Ming Wang; Chia-Hao Yang, "A novel high input power factor soft-switching single-stage single-phase AC/DC/AC converter," 2005 IEEE Conference in Vehicle Power and Propulsion, 7-9 Sept. 2005.
[18] K. M. Shafeeque, P. R. Subadhra, "A Novel Single-Phase Single-Stage Inverter for Solar Applications," 2013 Third International Conference on Advances in Computing and Communications (ICACC), pp. 343-346, 29-31 Aug. 2013.
[19] S. Z. Mohammad Noor, A. M. Omar, N. N. Mahzan, I. R. Ibrahim, "A review of single-phase single stage inverter topologies for photovoltaic system," 2013 IEEE 4th Control and System Graduate Research Colloquium (ICSGRC), pp. 69-74, 19-20 Aug. 2013.
[20] E. S. Sreeraj, K. Chatterjee, S. Bandyopadhyay, "One-Cycle-Controlled Single-Stage Single-Phase Voltage-Sensorless Grid-Connected PV System," IEEE Trans. Ind. Electron., Vol. 60, No. 3, pp. 1216-1224, March 2013.

[21] H. Patel, V. Agarwal, "A Single-Stage Single-Phase Transformer-Less Doubly Grounded Grid-Connected PV Interface," IEEE Trans. Energy Conversion, Vol. 24, No. 1, pp.93-101, March 2009.
[22] Hongrae Kim; Parkhideh, B.; Bongers, T.D.; Heng Gao, "Reconfigurable Solar Converter: A Single-Stage Power Conversion PV-Battery System," IEEE Trans. Power Electron., Vol. 28, No. 8, pp.3788-3797, Aug. 2013.
[23] B. Parkhideh, Hongrae Kim, “Reconfigurable Power Systems and Converters,” US Patent Application Publication No. 2012/0261999 A1, 18th October, 2012.
[24] Sasidharan, Nikhil, and Jai Govind Singh. "A Novel Single-Stage Single-Phase Reconfigurable Inverter Topology for a Solar Powered Hybrid AC/DC Home." IEEE Transactions on Industrial Electronics 64.4 (2017): 2820-2828.