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Design of Photovoltaic System Integrated with Distribution Network

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Abstract— The power consumption across the globe is increasing very rapidly resultantly the reservoirs of the conventional sources of energy are also depleting much speedily. In this scenario, the solar energy is the tangible solution being abundantly available and is environment friendly. Photovoltaic are the most popular form of harnessing solar energy into electricity where apart from stand-alone, the grid-connected PV systems are being installed at very large scale in most of the developed countries. However in the developing countries specifically where the utility grid and distribution networks do not meet the international power quality standards, RES producers face technical problems while integrating the PV systems with the utility grid. The poor quality issues of grid lead to loss of synchronization and disconnection of grid-interfaced PV inverter. This paper discusses the interconnection, synchronization and voltage mitigation techniques for interfacing of PV systems with utility grid. In this work an improved interconnection scheme of Grid-PV systems has been proposed to get reliable, cheaper and qualitative power supply at consumer end during normal as well as abnormal conditions of utility grid. The simulation has been carried out in MATLAB Simulink and results also verified from hardware of three phase 3 KVA mitigation unit; specially developed for the purpose to correct the voltage level in grid connected solar PV systems during abnormal condition of grid.

Index Terms— In-phase Power compensation, Microcontroller, Photovoltaic (PV), Phase-locked Loop (PLL), Pulse Width Modulation (PWM), 3 Phase bridge Inverter, Synchronization, Synchronous Grid-PV Interface Unit (SGPVI), Utility Grid.

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1 INTRODUCTION

Growing economies, increasing population, luxurious life style and broader use of technologies from large industries to the smaller factories let increase-in power demand as ever time phenomenon. The blind blistering of natural fuels for power production is not only causing scarcity of fossil fuels but it is also polluting our environment [1]. Thus finding and utilization of alternate energy resources on a broader spectrum is vital to fulfill the power thirst and decline the consumption ratio of the fossil fuels to culminate the climate change.

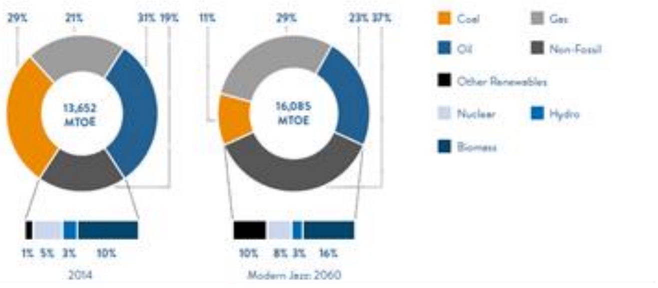

FIG.1 Primary Energy Mix (2014 – 2060) [2]

Among different renewable energy resources, the solar energy and wind systems keep high momentum of installation with an assessment that 30 % world energy need shall only be met by the wind & solar PV systems by 2040 [3]. However for small and medium power generation, the solar PV systems are preferred over the wind system due to technological advancement, economy, long-term return on investment, ease of installation and availability of solar energy in bulk. In this regard, the Grid connected PV systems have been installed at very large scale all over the world especially in the developed countries however the integration of solar PV systems with the weaker distribution network is difficult and complicated.

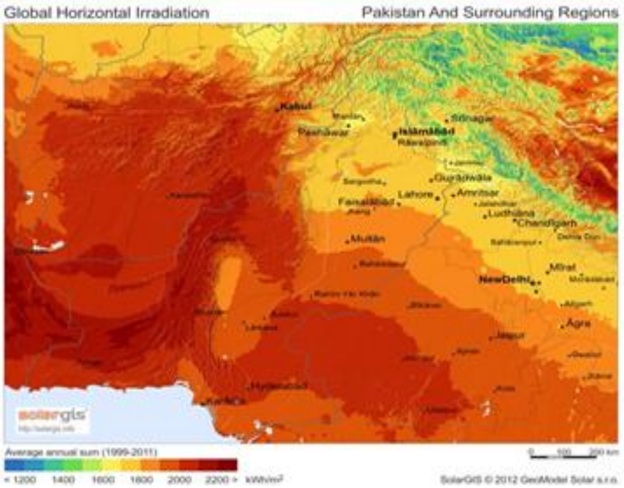

Fig.2 Global Horizontal Irradiance [4]

The similar situation has been seen in the rural areas of Pakistan where power utilities have overloaded systems, lengthy and degraded distribution network. In-spite of reserving great potential of solar energy estimated about 100,000 MW [5], Pakistan is found to be very far behind utilization of this cheaper source of energy. The people face low voltage

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problem, unscheduled power outages and frequent voltage disturbances. They are looking forward for alternatives but still the share of grid tied renewable energy (RE) system in generation portfolio is less than 1% [6]. The main reason behind this demotivation is the poor performance of the existing grid connected PV system due to grid derived abnormalities. Therefore it is the real challenge to address these technical problems while designing the Grid-PV interface system.

2 GRID CONNECTED PV INVERTER SCHEMES

The solar PV systems are mostly available in Stand-alone (with or without battery storage) and Grid tied mode which is also referred as virtual storage in the utility grid [7]. The charge controller, Inverter and the battery are the basic parts of hybrid PV system [8]. Charge controlling and dc-dc conversion is done through different converter like Push-Pull and Buck Converters [9] and dc-ac inversion is done through Inverter either current or voltage sourced. In grid tied systems, the generated PV supply is inverted into ac and coupled in parallel with the utility under contentment of the grid code and regulator's prescribed standards. For this purpose, the basic technical requirement and standards have been defined by the international bodies e.g. IEEE (Std. 1547-2003) & UL (Std. 1741) [10]. For grid interconnection, a number of inverter scheme (with or without using transformer) or based on two or three staged inversion techniques are in practice [11], [12], [13], [14]. The model of Conventional grid tied system [19] is shown in Fig. 3.

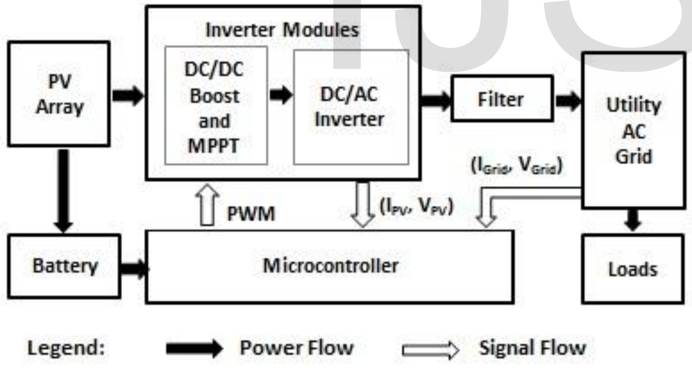


Fig. 3 Microcontroller based Grid tied Solar PV system

In grid tied solar system, the synchronization between both sources is the prime factor which can easily be done through zero crossing detection method. The replication of grid waveform while inversion of PV generation into AC output can be done through PWM (Pulse Width Modulation); which is the process of generation of pulses in square or rectangular form of variable duty ratios either through analog or digital signal generators. The microcontrollers has replaced the complex circuitry [16] and now these are widely used for controlling the conversion, inversion and synchronization activities including Maximum power point tracking (MPPT); a tool for maximum yield [15], [17], [18].

3 GRID INTEGRATED PROBLEMS AND SOLUTION

The main grid related problems include voltage fluctuations (under/over voltage), sag, swell, frequency deviations, transients and voltage interruptions. Sag and Swell are the respective phenomenon of decrease (0.1 to 0.9 per unit) and increase (1.1 to 1.9 per unit) in RMS values of current and voltage on the utility system frequency for durations from half cycles to 1 minute [20]. The conventional technique like zero-crossing method does not perform correctly under such severe grid abnormalities resulting failure of synchronization among both sources is occurred. In this regard, phase-locked loop (PLL) method of synchronization has better performance in which the output signals is generated whose phase is tracked with phase of an input "reference" signal and synchronization is done by comparison of both signals and output adjustment through feed-back control as shown in fig. 4 [21]. The PLL algorithm involves two transformations (i.e. Clark and Park transformations) for conversion of 3 phase grid voltage into two constant voltages of varying phase angles, however it is difficult to implement and required complex circuitry.

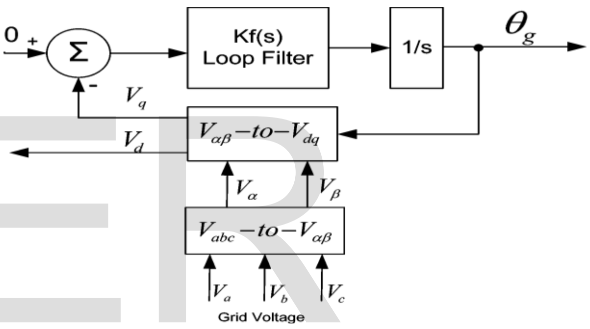


Fig. 4 Block diagram showing PLL-Model [20]

The voltage regulation is required at common point of coupling (PCC) to avoid voltage rise problem and tripping of inverter as outlined in [22]; an Australian utility experience. Normally pre-sag and in-phase compensation techniques are used in dynamic voltage restorer (DVR) for correction of grid voltage level at domestic level [23]; however its working in interconnection scheme is yet to be investigated. The vector diagram of in-phase compensation is shown as Fig. 5.

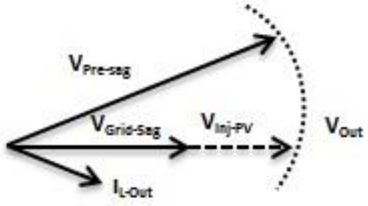


Fig. 5 In-phase Voltage Compensation

In order to get pure or near pure sine wave, very fast switching devices mainly IGBTs and MOSFETs are required for implementation of PWM technique, where MOSFETs are preferred for low and medium voltage application due to their fastest switching time (nanoseconds to the picoseconds), better efficiency and less switching loss [24].

4 DESIGN OF PROPOSED SCHEME

The proposed scheme consists upon following units to make a complete interface package:

A. PV Power Sharing Unit; comprised of PV Generator with Battery Storage and Microcontroller based PWM Inverter using PLL type of synchronization,
B. Voltage Mitigation Unit named Synchronous Grid-PV Interface (SGPVI) Unit

The block diagram of proposed scheme is shown below:

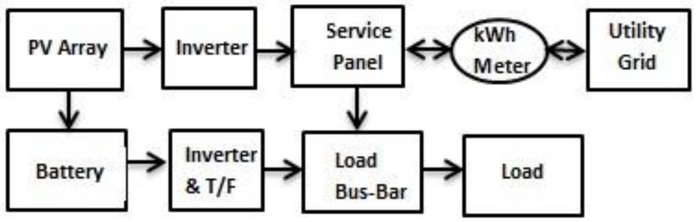


Fig. 6 Block Diagram of Proposed Scheme

The flow chart of proposed scheme is shown below:

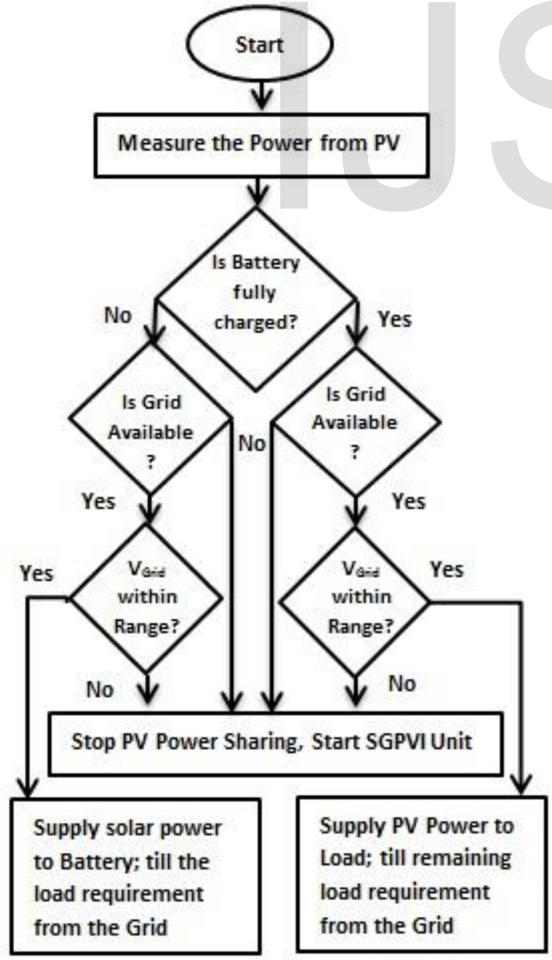


Fig. 7 Flow Chart of Proposed SGPVI Unit

Three switching modes are defined for operation of proposed scheme i.e. Mode-I: Normal state, Mode-II: Sag & Swell position and Mode-III: Voltage Interruption. In mode-I, only the power sharing unit will work. In this unit, PV generation shall be coupled with utility grid at PCC through typical interface model as shown in fig. 4. In addition it is proposed to implement the PWM technique based upon PLL algorithm for inversion of PV supply and synchronization with grid supply.

The second unit i.e. power compensation unit will work during grid disturbance i.e. Mode-II and III while PV source-1 will stop generation of power to avoid the islanding position. Power compensation unit is proposed between PCC and load bus-bar to mitigate the grid voltage as received at PCC during Mode-II. The generated PV supply as stored in the batteries shall be injected into the common line till achieve the output within specified standard limits.

The Block diagram of proposed SGPVI unit is given below:

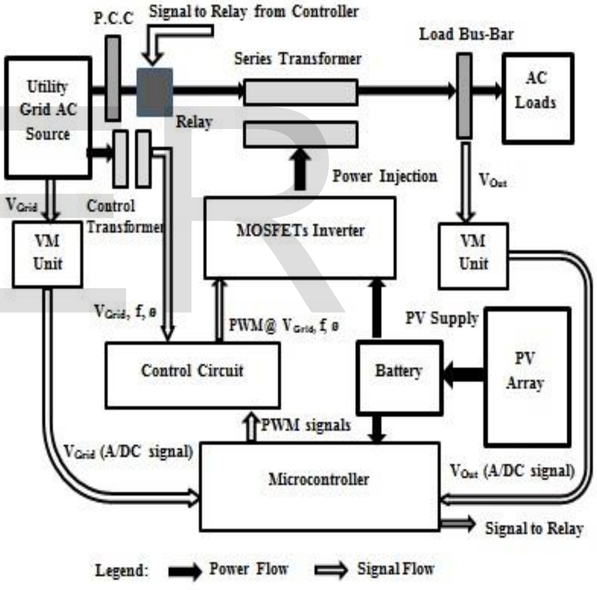


Fig. 8 Block diagram of Proposed SGPVI Unit

During Mode-III, the grid will be isolated from the interconnected system and PV source-2 shall operate in parallel to feed the load. Therefore after interfacing this unit between common point of coupling and load bus-bar, the voltage disturbances like fluctuation, sag, swell and interruptions shall be eliminated from the synchronized incoming source supplies at users' end point and qualitative or regulated supply shall be fed to the load.

The proposed SGPVI unit shall perform the following functions:

- Conversion of PV dc supply into usable Ac supply
- Synchronization between Grid and PV supplies

- Voltage mitigation between PCC and load bus-bar
- Operation of unit in 3 Switching Modes
- Measurement of voltage at both ends

The Flow chart of the proposed SGPVI unit is given below:

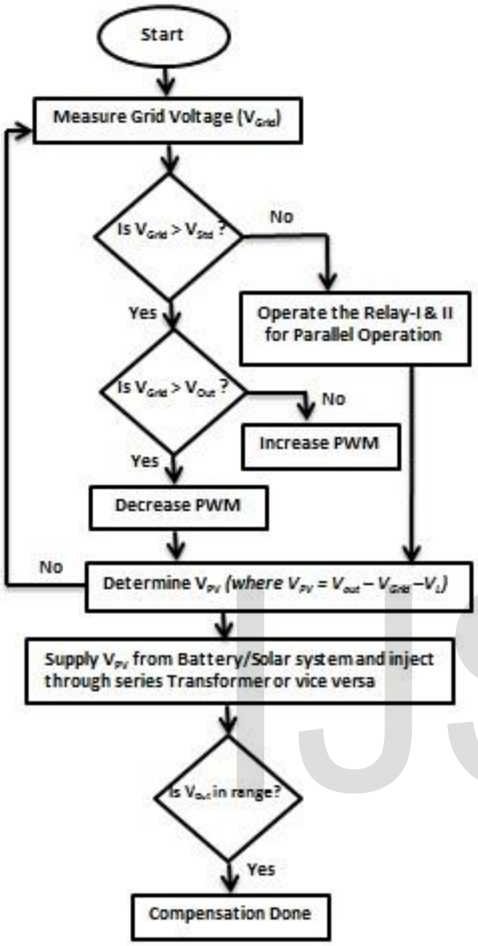


Fig. 9 Flow Chart of Proposed SGPVI Unit

5 SIMULATION

Simulation has been carried out in in MATLAB Simulink as shown in fig. 10. In the first part of power sharing unit, the utility source i.e. 3 phase LV grid source (400V AC) is coupled with PV source (through DC battery, 3 phase bridge inverter and step-up transformer) after measurement of power by 3 phase VI measurement block.

For function of microcontroller, two blocks (i.e. PLL and PWM) have been developed in simulation to show the inversion of DC in-to AC and the synchronization with the grid supply. The PLL block gets input grid voltage from VI unit and provides feedback of phase to the PWM block. The PWM block gets another input of grid current from VI unit and generates PWM signals to the 3 phase bridge inverter.

The MATLAB Simulink model of proposed scheme is shown below:

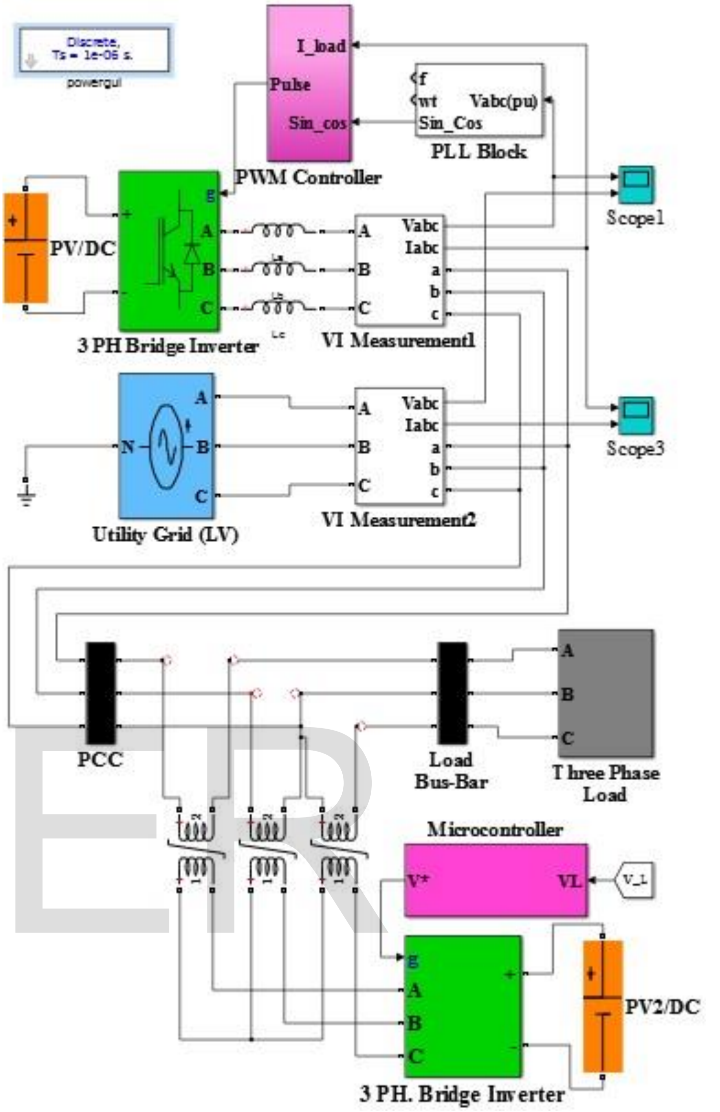


Fig. 10 MATLAB Simulink Model of Proposed Scheme

The PWM pulses as generated by the microcontroller are shown below:

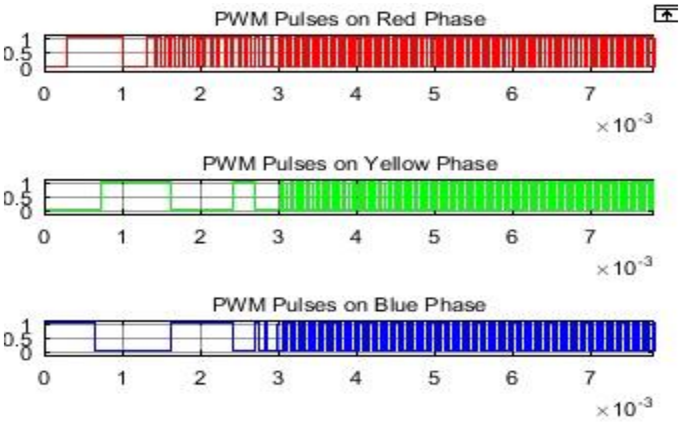


Fig. 11 PWM pulses for phase (a) Red (b) Yellow (c) Blue

During normal steady state or mode-I, power supplies of both sources shall be synchronized and coupled at common point of coupling (PCC) as shown below:

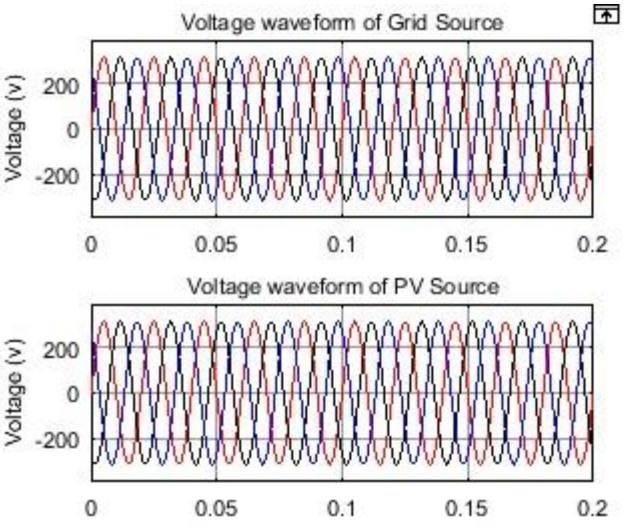


Fig. 12 Simulation result showing Synchronization b/w Grid and PV Source

During mode-II & III, the generation of PWM signals by controller of power sharing unit shall be stopped on occurring of grid abnormality to avoid islanding position. At this moment, Inverter 1 shall stop the feeding of power into the common line and the second unit of the proposed scheme i.e. SGPVI unit shall start its working for mitigation of grid voltage through in-phase injection or absorption of generated PV supply through series transformers and 3 phase PWM based bridge inverter and the regulated voltage within standard range shall be provided at load bus-bar. The simulation result during sag is shown below:

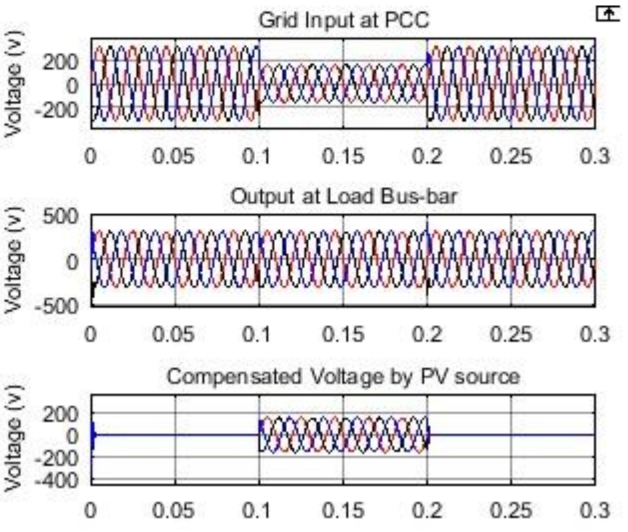


Fig. 13 Voltage waveforms (a) Input at PCC b) Output at Load bus-bar (c) Inject by PV Source

The abnormal conditions of sag, swell and interruption have been implemented by decrease of voltage amplitude of grid source by more than 5%, increase by more than 5% and decrease by more than 60% respectively. The voltage waveforms of grid received at PCC (in normal as well as abnormal states of sag and swell) and the output voltage provided at load bus-bar after regulated by SGPVI unit are shown by Fig. 14 below:

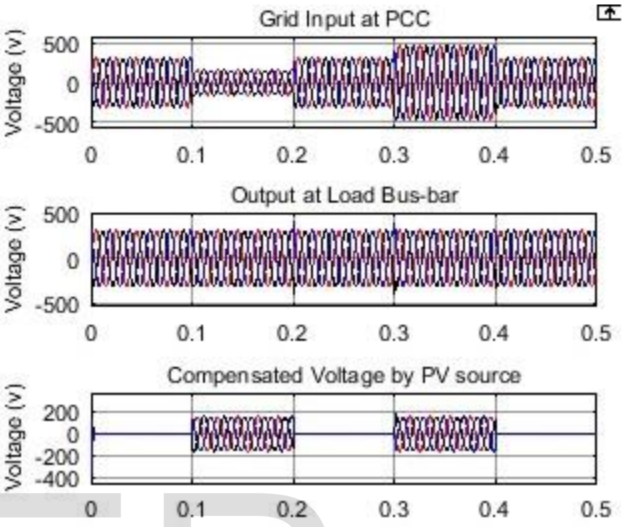


Fig.14 Voltage waveforms of (a) Grid input at PCC (b) Output at Load bus-bar (c) Injected by PV Source

6 CONFIGURATION OF 3 KWP PV GENERATOR

For low power production, solar PV modules are available in power capacities ranging from 100 W to 300 W in local market of Islamabad, Pakistan. Normally the selection of suitable PV module is made on the basis of nominal output, efficiency, mechanical structure, cell technology, cost and operating temperature [25]. Islamabad, Pakistan is located at 33.7294^{o} N and 73.0931^{o} E having annual average mean daily solar radiation of 4.675 kWh/m^2/d. The optimum tilt angles from horizon during winter, summer and fall/spring are 54^{o}, 60^{o} and 31^{o} respectively. The basic characteristic of the selected PV modules are shown in table 1.

For required nominal AC power, “$P_{Gen\text{-}ACn}$” of 3 kW and considering efficiency of inverter “η_{Inv}” 90 %, temperature correction factor, “k_{Temp}” 0.96, generator correction factor, “k_{Gen}” as 0.88, solar irradiance at standard condition, “G_{STC}” 1kW/m^2, the nominal DC output, “$P_{Gen\text{-}DC}$”, required number of modules “M”, and other useful parameters of PV generator [25] can be found using (1) to (11) as shown below:

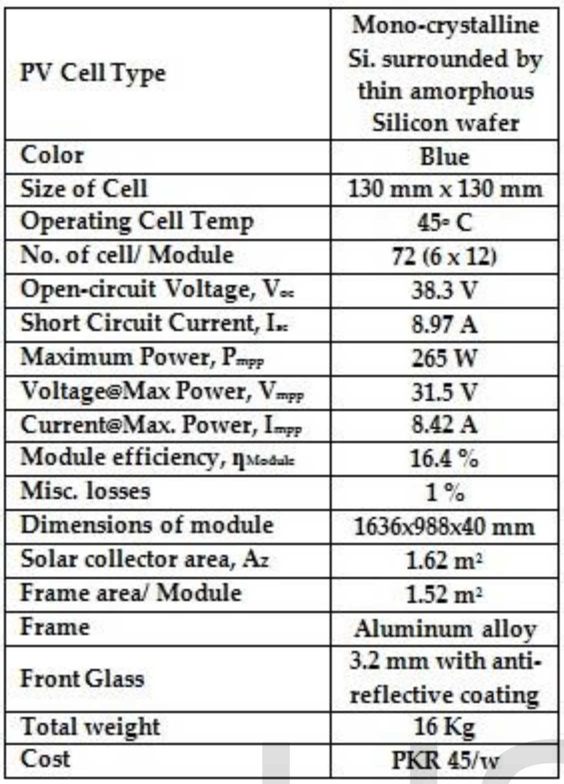
$$P_{Gen-DC} = P_{Gen-ACn}/\eta_{Inv}.k_{Gen}.k_{Temp} \quad (1)$$

$$= 3 / (0.9 \times 0.88 \times 0.96) = 3.95\ kW$$

$$M = P_{Gen} / P_{module} \quad (2)$$

$$= 3.95 / 0.265 \approx 15 \text{ Nos. modules}$$

Table. 1



PV Cell Type	Mono-crystalline Si. surrounded by thin amorphous Silicon wafer
Color	Blue
Size of Cell	130 mm x 130 mm
Operating Cell Temp	45◦ C
No. of cell/ Module	72 (6 x 12)
Open-circuit Voltage, V_{oc}	38.3 V
Short Circuit Current, I_{sc}	8.97 A
Maximum Power, P_{mpp}	265 W
Voltage@Max Power, V_{mpp}	31.5 V
Current@Max. Power, I_{mpp}	8.42 A
Module efficiency, η_{Module}	16.4 %
Misc. losses	1 %
Dimensions of module	1636x988x40 mm
Solar collector area, A_Z	1.62 m²
Frame area/ Module	1.52 m²
Frame	Aluminum alloy
Front Glass	3.2 mm with anti-reflective coating
Total weight	16 Kg
Cost	PKR 45/w

Three parallel strings are proposed in which each string will consist of 5 modules in series. Therefore, Open-circuit voltage "Voc", Short circuit current "I_{SC}", Voltage at maximum power "Vmpp" and Current at maximum power "Impp" of the PV generators are calculated below:

$$V_{OC\text{-}Array} = \text{No. of module in series} \times V_{OC\text{-}Module} \quad (3)$$
$$= 5 \times 38.3 = 191.5 \text{ V}$$

$$I_{SC\text{-}Array} = \text{No. of parallel string} \times I_{SC\text{-}Module} \quad (4)$$
$$= 3 \times 8.97 = 26.91 \text{ A}$$

$$V_{mpp\text{-}Array} = \text{No. of module in series} \times V_{mpp\text{-}Module} \quad (5)$$
$$= 5 \times 31.5 = 157.5 \text{ V}$$

$$I_{mpp\text{-}Array} = \text{No. of parallel string} \times I_{mpp\text{-}Module} \quad (6)$$
$$= 3 \times 8.42 = 25.26 \text{ A}$$

Required area for PV Generator; "A_{Gen}":

$$A_{Gen} = \text{No. of module} \times A_{Module} \quad (7)$$
$$= 15 \times 1.62 = 24.3 \text{ m}^2$$

Total space required for solar generator "A_T", when Land Factor "LF" = 2;

$$A_T = LF \times A_{Gen} \quad (8)$$
$$= 2 \times 24.3 = 49 \text{ m}^2$$

Annual energy yield "Y_F":

$$Y_{F-AC} = \eta_{Inv} . k_{Gen} . k_{Temp} . H_G / G_{STC} \quad (9)$$
$$= 0.9 \times 0.88 \times 0.96 \times 4.675 = 3.555 \text{ kWh/kWp/day}$$

The Annual and monthly Energy yield "E_{AC}":

$$E_{AC} = P_{Gen-STC} . \eta_d . Y_{F-AC} \quad (10)$$
$$= 3 \times 365 \times 3.555 = 3893 \text{ kWh/annum}$$

OR 324 kWh/month

The full load AC hours "t_v":

$$t_v = E_{AC} / P_{Gen-ACn} \quad (11)$$
$$= 3893 / 3 = 1298 \text{ h/annum}$$

Saving @ PKR 6/ kWh per annum = 3893 x 6 = PKR 23358

7 HARDWARE IMPLEMENTATION

The proposed scheme of SGPVI unit is implemented practically using UPFC techniques [23], [26] as shown in the circuits diagram and the major components used are explained below:

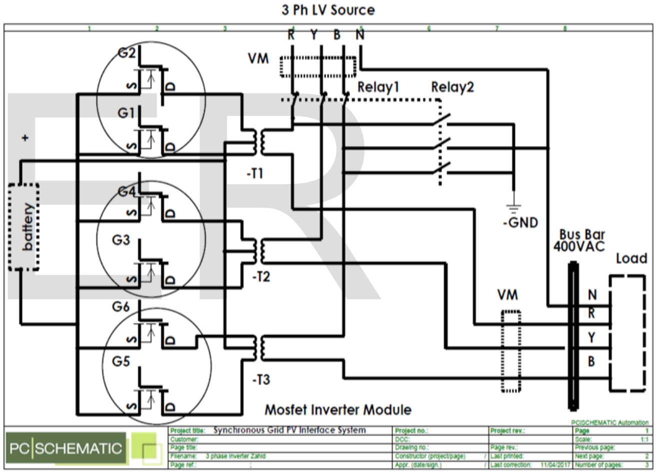


Fig. 15 Circuit Diagram of Inverter and Mitigation Unit

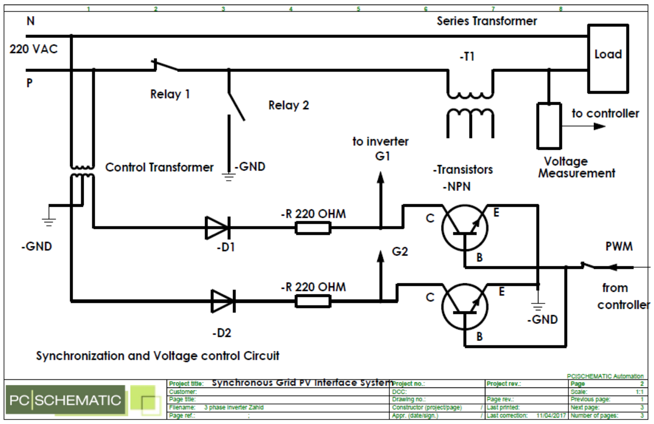


Fig. 16. Circuit Diagram of Controlling Unit

7.1 VM Unit

First of all, voltage measurement is carried out at PCC and load bus-bar. The RMS AC power values are converted into DC by VM Unit [27] and continuous analogue values are provided at input pins of arduino board.

7.2 Atmega 2560 with Arduino Board

On the basis of VM values, the output PWM signals are generated through microcontroller Arduino Atmega 2560; which is a user interactive board and provides open-source support for physical interfacing in IDE environment with 54 digital and 16 analogue input pins and number of interfacing and communication ports [28].

7.3 Series Transformer

The compensated power of PV supply is injected into the common line between PCC and Load bus-bar through step-up center-tapped (12/110+110 V) transformer. 3 Nos. series transformer of 1 KVA ratings are installed on each phase in star configuration in which tap-I is used for positive half cycle and tap-II for negative half cycle.

7.4 Inverter

3 phase bridge inverter is made by 3 No. modules (i.e. one module per phase). 20 No. MOSFETs (160 W each) are connected in each module in half bridge configuration i.e. 10 Nos. for positive half cycle and 10 Nos. for negative half cycle.

7.5 Relay Board

For operation of SGPVI unit into 3 different modes, 2-Channel interlocked Relay interface board is used. Relay-I in close and Relay-II will be in Open condition during Mode-I & II whereas both relays will be reversed in Mode-III.

7.6 Control Circuit

The inverter will need the control signals for tracking grid frequency and phase and switching by PWM signals generated by microcontroller. All this will be achieved through control transformers, rectifier and control circuit. The primary of center-tapped stepped down (220/12+12 V) control transformers are connected parallel on each phase of utility LV panel while secondary side with the rectifier of control circuit.

8 FUNCTIONING OF THE SCHEME

During the day time as soon as the solar energy will be available, Power sharing unit of PV source shall work. If the load requirement is more than generated PV power, it shall be fulfilled by the grid source and in inverse case the excess PV supply shall be stored in the batteries or injected into distribution network. The microcontroller on the basis of input values from power measurement units of utility grid and PV sources will generate the PWM signals following PLL algorithm for synchronization and coupling of both sources at common point of coupling (PCC). During Mode-II, in happening of sag or swell condition, the microcontroller will stop the PWM signals to the inverter 1 and power sharing unit will be isolated from the interconnected system, however the utility grid will continue to feed power at PCC. The SGPVI unit will start functioning for mitigation of incoming grid supply. The VM units on PCC and Load bus-bar will provide voltage measurement to microcontroller and the microcontroller will generate the PWM signals for NPN transistor. The duty ratio of PWM signals will cause the ON and OFF switching of NPN Transistor thus the stepped down voltage by control transformer and further rectified by the rectifier circuit will travel through rectifier to the gates of MOSFETs Inverter-2. After inversion of DC supply into AC, the synchronization will be carried out by the microcontroller and series transformers will inject the power into the common line. In Mode-III when grid voltage falls below 60% of standard voltage level, the interlocked relays will operate and the primary side of series transformers will be disconnected from the PCC and grounded. Now the PV source will operate in parallel to feed the loads.

Fig. 17. Testing of Developed hardware in Lab

This system can be used for balanced and unbalanced voltage variation. The hardware was tested in the laboratory where the sag, swell and voltage interruption conditions were applied though LV 400V AC variable source bench set and both the voltages of input and output were checked by power analyzer. The result as taken by oscilloscope is shown by fig. 18.

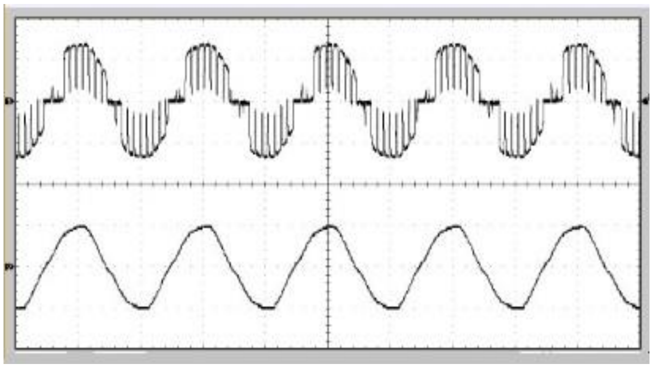


Fig. 18 Voltage waveforms of (a) output injected by PV source supply (b) Input grid supply

9 CONCLUSION

This research strives to resolve the issue of failure of grid connected PV system in weak grid conditions. The hardware of 3 kVA Grid-PV interface system for home based solar PV system is developed. The results show that the PV system is fully synchronized with the grid and developed unit has the capability to deal with the abnormal conditions of grid like voltage fluctuations, sag, swells and interruptions.

FUTURE WORK

For future work it is suggested to investigate the harmonics in the output of grid connected PV system and bring viable solution to reduce them.

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REFERENCES

[1] “Energy, Climate change and Environment, 2016 In-sights”, [online] Available: https://www.iea.org/publications, accessed Feb. 22, 2017.

[2] “World Energy Scenarios 2016”, [online], Available: https://www.iea.org/publications, accessed Feb. 22, 2017

[3] “World Energy Outlook”, [online], Available: https://www.iea.org/publications/, accessed Jan. 25, 2017.

[4] [Online] Available: https://en.wikipedia.org/wiki/Solar_power_in_Pakistan

[5] Munawar A Sheikh, “Renewable energy resources potential in Pakistan” in proc of Renewable and Sustainable Energy Reviews 14 (2010), Vol. 13, pp. 354-363.

[6] “Annual Report of NTDCL, Power system statistics 41 Ed.”, [online] Available: https://www.ntdc.com.pk, accessed Jan. 31, 2017.

[7] M. R. Narayan, D. V. Gupta, R. C. Gupta, R. S. Gupta, “Design, Development and Installations of 100KW Utility and Grid Connected Solar PV Power Plants For Rural Applications – An Indian Experience”, Proc. 1994 IEEE Conf., Photovoltaic Energy Conversion, vol., no. 1, pp. 1073-76, Dec 1994.

[8] I. Takahashi, T. Sakurai, I. Andoh, “Development of a Simple Photovoltaic System for Interconnection of Utility Power System”, Proc., 1996 IEEE Conference Publications, vol., no. I, pp. 88-93.

[9] D. C. Martins (Member IEEE) and Rogers D., “Inter-connection of a Photovoltaic Panels Array to a Single Phase Utility Line From a Static Conversion System”, Proc. 2000 IEEE Conf. Power Electronics Specialist, vol., no. 3, pp. 1207-1211.

[10] “IEEE Standard 1547-2003 for Interconnecting Dis-tributed Resources with Electric Power System”, Proc., 2003 IEEE Standards Coordinating Committee 21, June 2003.

[11] M. F. Rahman, L. Zhong, “A new Transformer-less Photovoltaic Array to Utility Grid Interconnection”, IEEE Conference Publications”, in proc. Of Power Electronics and Drive System, vol., no.1, pp. 139-143, 1997.

[12] W. Wongssaichua, W. J. Lee, S. Oraintara, Chiman Kwan, and F. Zhang, “Integrated High-Speed Intelli-gent Utility Tie Unit for Disbursed/Renewable Generation Facilities”, Proc. 2004 IEEE Conf., Industry application Records, vol., no. 1, pp. 2051-2056.

[13] V. John, Eric Benedict and S. M. Danial, “A Universal Interconnection System to Connect Distributed Gen-eration to the Grid”, International Conference on Power Electronics, Drives and Energy Systems, DOI, pp. 1-7, 2006.

[14] P. Sritakaew and A. Sangswang, “Reliability Im-provement of a Distribution System Using PV Grid Connected System with Tie Switch”, Proc., 2006 Asia Pacific Conference Publications, Circuits and Systems, vol., no., DOI:10.1109/APCCAC, pp. 1354-1357.

[15] K. Neupane, T. M. Undeland and A. Rouniyar, “Smart Controller Design for Solar-Grid Hybrid System”, Intelligent Green Building and Smart Grid, in proc. Of IEEE International Conference, DOI: 10.1109/IGBSG.2014.6835155, pp. 1-4, 2014.

[16] Bandana Bhutial, Dr. S.M. Ali, Narayan Tiadi, “Design of Three Phase PWM Voltage Source Inverter For Photovoltaic Application”, Proc., International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol., no. 2,ISSN 2321, Issue 4, April 2014.

[17] P. Mohanty, G. Bhuvaneswari and R. Balasubramanian, “On-field Performance Assessment of Power Converters of Solar PV Systems under Different Operating Conditions”, Proc., 2011 India Conference INICON, IEEE Conference Publications, vol., no., DOI: 10.1109, pp. no. 1-7.

[18] Muhammad Waqas Khan, Muhammad Saleem, Ashfaq Ahmad and Ahmad Ayaz, “Synchronization of Photo-voltaic System with a Grid”, IOSR Journal of Electrical and Electronics Engineering (IOSR-IEEE), vol. 7, issue 4, September 2013, pp. no. 01-05.

[19] “An Engineer’s Guide to Power Inverter for Solar Energy Harvesting” by Steve Taranovich, Courtesy Microchip Semiconductor, [online] Available: https://www.digi-key.com, accessed, Jan. 15, 2017.

[20] “A Draft Standard Glossary of Power Quality Terminology”, Prepared by the Working Group of Power Quality Definitions of SCC22 – Power Quality.

[21] Yilmaz Sozer and David A. Torrey, “Modeling and Control of Utility Interactive Inverters”, IEEE Transactions on Power Electronics, vol. 24, issue 11, Nov. 2009.

[22] Donald McPhail, “Voltage Regulation of Distribution Network using Inverter Reactive Power Functionality – Australian Utility Experience”, Proc., 2015 IEEE APPEEC Conference, vol., no. DOI: 10.1109/APPEE.2015.7381077, pp. 1-6.

[23] S.F. Torabi, D Nazarpur and Y Shaestehfard, “Compensation of Sag and Swell Voltage using Dynamic Voltage Restorer (DVR) During Single-Line to Ground and Three-Phase Faults”, International Journal of Technical Physical Problems in Engineering, issue Sep. 2012, vol.no. 4, issue. 3, pp. 126-132.

[24] F.Z.Peng, L.Chen, F.Ahang, “Simple Topologies of PWM AC-AC Converters”, Proc., 2003 IEEE Trans. Power Electron. Letters, vol., no. 1, pp.10-13.

[25] Heinrich Haberlin, “Photovoltaics, System Design and Practice”, 1st Ed. 2012, John Wiley & Sons.

[26] Shahezad Shaikh, M Oza, S. Pathiar and D. Makwana, “Unified Power Quality Conditioner For Power Quality Improvement using Fuzzy Logic and Neural Networ”, International Journal for Technical Research in Engineering, vol. 3, issue Feb. 2016.

[27] “RMS to DC Conversion”, [online], Available: https://www.radanpro.com/Radan2400/ Napajanje/home2.pdf, accessed Feb. 01, 2017.

[28] “Specification of microcontroller arduino atmega 2560” [online], Available: https://www.arduino.cc/, accessed Dec, 3, 2016.