IPASJ International Journal of Electrical Engineering (IIJEE)
Web Site: http://www.ipasj.org/IIJEE/IIJEE.htm
A Publisher for Research Motivation........
Email: editoriijee@ipasj.org
Volume 3, Issue 9, September 2015
ISSN 2321-600X

Performance Analysis of an Islanded Microgrid for Non-Linear and Unbalanced Load

Pradeep kumar[1], Priyabrata Nayak[2], Kanhu Charan Patra[3]

Department of Electrical Engineering, NIT Calicut, Kerala, India

ABSTRACT

In a microgrid, voltage source inverters (VSI) are usually used for all kinds of distributed generation interfaces. VSIs play an important role in maintaining the voltage and frequency during islanded mode of operation which is being affected due to unbalanced and non-linear loads. This project report presents design, simulation and analysis of different non-linear loads such as SMPS, CFL etc. and the effect of unbalanced and non-linear loads and there harmonics is being calculated. Further to mitigate such power quality problems conventional proportional integral (PI) and proportional integral plus multi resonant controller based compensation strategy in a single fundamental positive-sequence synchronous reference frame is used. Harmonic contents due to different types of loads and sources has been calculated and compared for the different cases with both control strategies. THD is used as the harmonic index to study the effect of the non-linear loads at the utility. Both the control strategies are demonstrated in detail and validated with simulations.

Keywords: Microgrid, Voltage Source Inverter, Synchronous Reference Frame, Voltage Unbalance, Harmonics Compensation

1. INTRODUCTION

Nowadays modern solutions such as distributed generation(DG) which is mainly based on non-conventional energies, battery storage, flexible ac transmission systems(FACTS), load demand management (LDM), micro grids and smart control technique based on information and communication technologies (ICTs), leads to modify the conventional power system and make it more reliable and effective and also introducing new schemes. However, the power system is still not improved so much yet, so research work is still going on to make the system more advanced, reliable and cheaper in reality. To improve the older version of conventional centralized system, new advanced power electronics equipment and new technologies on distributed generation is being adopted. Different DG configurations are being employed but among them microgrid configuration is the most effective and flexible configuration and thus the micro grid is considered as the most effective DG system configuration.

In the three phase microgrid there will be different types of loads such as balanced, unbalanced and non-linear loads. When the system is isolated from the main utility grid, then it loss the control of voltage and frequency which is being supported by the grid due to which unbalanced and non-linear loads leads to degrade the power quality and produce harmonics. The distorted voltage due to unbalanced loads and harmonics cause severe problems on equipments such as, over-heat, over-voltage, vibration etc.

In [2], a new improved control strategy of microgrid is being presented in which battery storage system is used to control the unbalanced voltage and frequency and to make it constant voltage profile and proper frequency. And then also a proper control technique used which restore the disturbed voltage and frequency to the normal values.

In an islanded mode of operation of microgrid [5] the battery storage helps in improving the power quality and also fulfills the demand at the time of requirement and also it helps in maintaining the stability. But due to the fluctuation in the output of renewable source of energy leads to create problem for the battery storage because due to this the charging and discharging problem in the battery occurs and which leads to early damage of battery life. Also using and maintaining of different types of batteries according to use is very difficult. So battery storage leads to disadvantageous in use in microgrid.

In three phase microgrid it consists of different types of loads such as balance, unbalanced and non-linear loads. Due to such unbalanced and non-linear loads the voltage profile does not maintain constant and which leads to distortion in the output voltage and produce harmonics [3]. So the power quality of the islanded microgrid starts deteriorated due to such types of loads unbalanced and non-linear loads because when it is isolated from the utility grid the voltage and frequency support gets disconnected. Due to which severe problems such as over heat, vibration, voltage swag and swell occurs and leads to malfunctioning of instruments. Different types of filters are being utilised to compensate such problems. In comparing active and passive filter, active filter is mostly used to improve the power quality issues. Unbalanced voltage and harmonics are compensated by using series active filters by injecting negative sequence and harmonic voltage. But we cannot install active filters for each microgrid since it becomes uneconomical.

In paper [4], controlling the VSI is being presented to compensate the unbalanced voltage and harmonics. With the help of voltage source inverter negative-sequence current is being injected into the microgrid to balance the voltage of the microgrid [13], but by doing so only unbalanced voltage is solved and the injecting current might be too large under severe conditions. Again using extra inverter for each microgrid is uneconomical so further research is being done. A new compensation strategy [6] is used in stationary reference frame to compensate the distorted voltage and which is economically good to use since it does not require any extra filter or inverter. It just works as a feedback loop to control the disturbances.

Some distributed generators is being used to operate in isolated condition recently but it occurs large imbalance condition due to the unbalanced and non-linear loads. When the system is connected with grid it is having surplus capacity. With a three-phase balancing method utilizing the surplus capacity. By the use of the proposed method, the voltage source inverter produces negative sequence current to eradicate any voltage disturbances.

During islanding mode of operation , the control of voltage and frequency is mainly depends on the inverter. Some practically research work has been done on 13.8 kV system but the outcome is not so satisfactorily correct and it is unable to compensate the unbalanced voltage and harmonics during the misbehaviour of unbalanced and non-linear loads present in the microgrid.

In another paper [7] it analyse different non-linear electric loads which is used for domestic purposes. After analysing the loads it got that due to this non-linear loads it produces harmonics which affects the other equipments connected to the grid. The harmonic behaviour of different non-linear loads is being presented which shows that non-linear loads produces high harmonics and leads to distort the voltage profile and disturb the frequency. To compensate the harmonics produce due to non-linear loads , filters is being used. So in this paper proper location of filters in the microgrid is also discussed.this paper also deals with the simulation and laboratory verification for the behaviour of the non-linear loads on the waveform of voltage and current. With the help of these models the effect of non-linear loads on the total harmonic disturbances is being observed and discussed.

In a three phase AC microgrid a large number different types of loads are present such as balanced, unbalanced and non-linear loads. These unbalanced and non-linear loads lead to distort the output voltage and produce harmonics. So the power quality of an islanded microgrid is also degraded under unbalanced and non-linear loads because it lacks the voltage and frequency support from the utility. Due to the unbalanced voltage and harmonics it will results in severe problems on other equipments which is parallel connected with the grid. To proper work of an islanded microgrid it requires some modification such as follows:

1) Voltage source converter should always maintain the voltage profile by giving feedback if there is any disturbance in the output voltage due to loads.

2) The disturbances produce due to unbalanced load and non-linear loads should be control and proper regulation of voltage should be done always.

3) VSCs should work regardless of any plant parameters..

The above mentioned requirements should be fulfilled in all balanced, unbalanced and non-linear load conditions but it is not possible without any voltage and current controller and compensator.

The challenges related to microgrid are very large and with the huge use of power electronics equipment it is increasing day by day. So to proper control and stable operation of microgrid we have to introduce a proper control strategy which will help in maintaining the unbalanced voltage to balance and make the system harmonic free.

To solve the problem and to compensate the unbalanced voltage and harmonics a proper modified PI controller is being introduced in the feedback control loop. By designing a proper and improved PI plus multi resonant controller we can reduce the harmonics which is produced due to non-linear loads and by improving the output impedance we can control the unbalanced voltage. So we first analyse the whole effect by introducing PI controller and then by proper modification in the designing of controller the effect of different types of loads is being nullified.

This paper is organised as follows: Section 2 provides the theory about grid connected and intentional islanding mode work. Section 3 shows the modelling of conventional PI controller. Section 4 deals with the modelling of the new proposed control strategy and Section 5 demonstrate the waveforms and results come from simulation. At last paper is concluded in section 6.

2. DG AND INTENTIONAL ISLANDING

Distributed generation (DG) is nothing but an interconnection of renewable source of energy with the grid which gives power to the utility grid or fulfils the demand of consumers during isolated condition. The issue with this is that many definitions have been used for DG and intentional islanding. A microgrid is always located nearby to the consumer side so that there are lots of benefits and the demand of consumer can be easily fulfilled.it is the combination of different types of alternating energy producer which is situated nearby consumer site to complete the load which is demanded by the consumer properly and easily. It is meant to make the electric system independent to the utility grid and if there is any fault in the utility side at that time also it will not disconnected the supply from the consumer side.

Intentional islanding is a condition in which the electric system is being isolated from the utility grid side and so it creates an island. These islands condition is created to support the consumer side and give continuous. In Figure1, shows the block diagram of AC microgrid, when disturbances are present on a distributed utility system, the grid is isolated itself, and the DERs supply the power which is demanded by to the load of the islands created until it will again reconnect with the main utility.

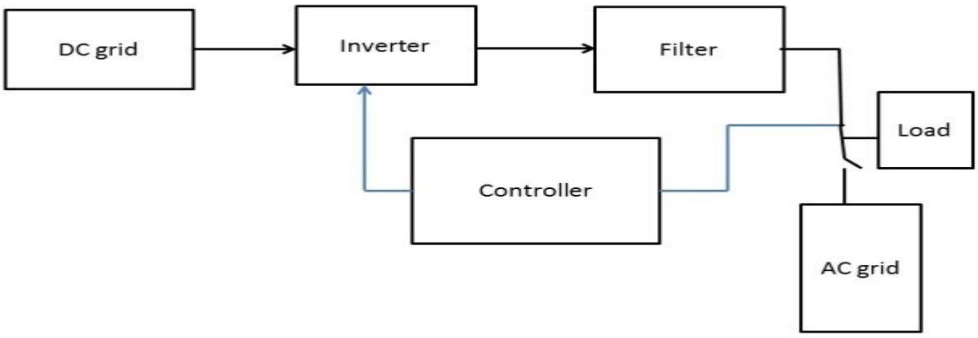

Figure 1 Block Diagram of a typical AC microgrid

For optimal use and location of the filters we have to study the behaviour and effect of different types of loads connected to the system. The main objective of the utility side is to supply undistorted voltage to the load side consumers with a pure sinusoidal voltage. The electric power which is generate is purely sinusoidal signal but due to the different types of loads which is having non-linear characteristics leads to the source voltage and currents get affected. Since nowadays more and more nonlinear loads are being introduced within the system so these waveforms get more distorted and harmonics will increase.

2.1 Switch mode power supply (SMPS)

It is one of the most widely used power electronic loads which is being commonly used by all consumers. It utilizes power electronics technology as shown in fig.2 which results in distorting linear currents and leads to produce distortion of output shape that contains large amount of third and higher order harmonics.

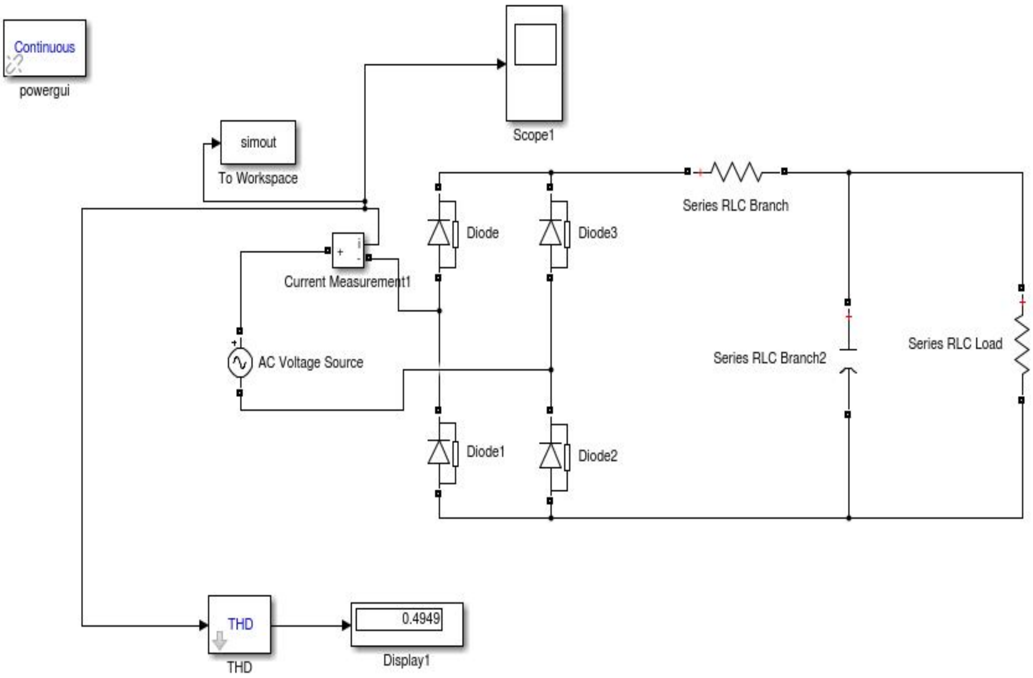

Figure 2 Simulation model of SMPS

The output current and THD analysis of SMPS is shown in fig.3 & 4 which shows that the current due to SMPS is highly distorted which will affect the power quality.

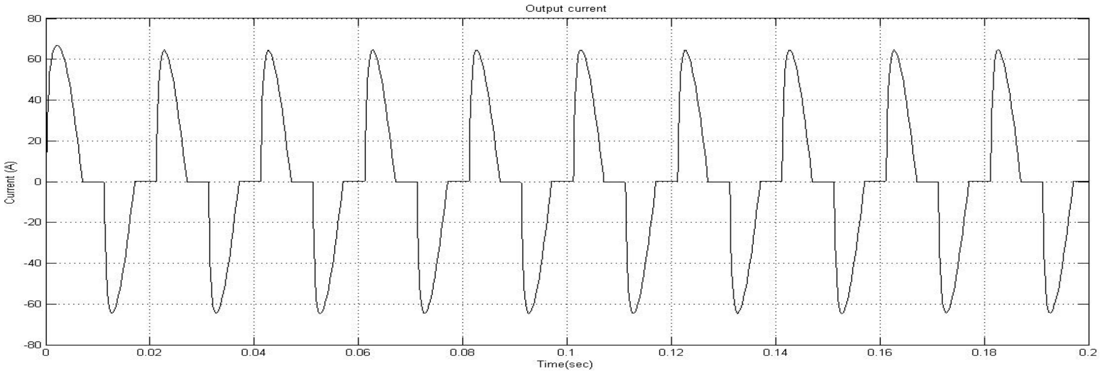

Figure 3 Waveform of Output Current for SMPS

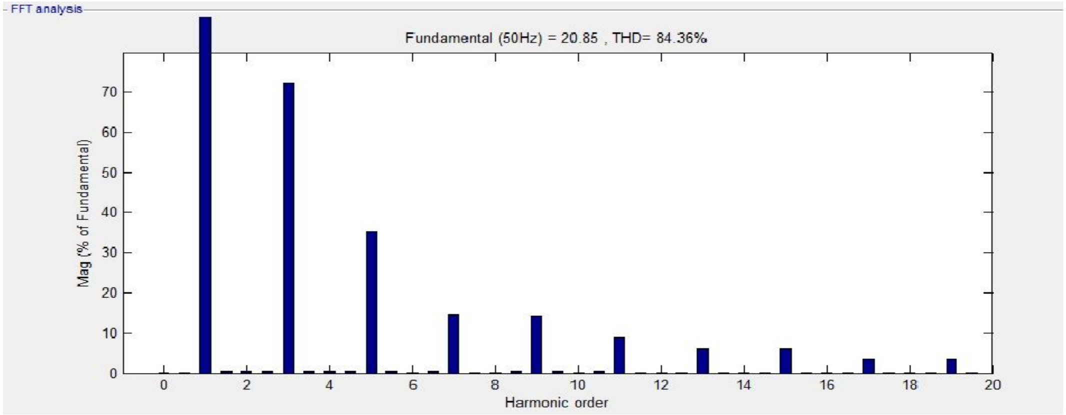

Figure 4 THD analysis of the current drawn by SMPS

2.2 Fluorescent Lamp

Fluorescent lamps are generally use of a ballast as shown in fig.5 to limit the current since it has a negative dynamic resistance behaviour [10]. Electronic ballasts employ transistors to change the supply frequency into high frequency AC while also regulating the current flow in the lamp. The electronic ballast comprises of half-bridge inverter and an LC filter which is used to acquire the nonlinear characteristics of the lamp. Electronic ballasts typically work in rapid start or instant start mode. Electronic ballasts are commonly supplied with AC power, which is internally converted to DC and then back to a variable frequency AC waveform. The current waveform and its harmonic analysis obtained for lamp load are shown in fig 6 and 7.

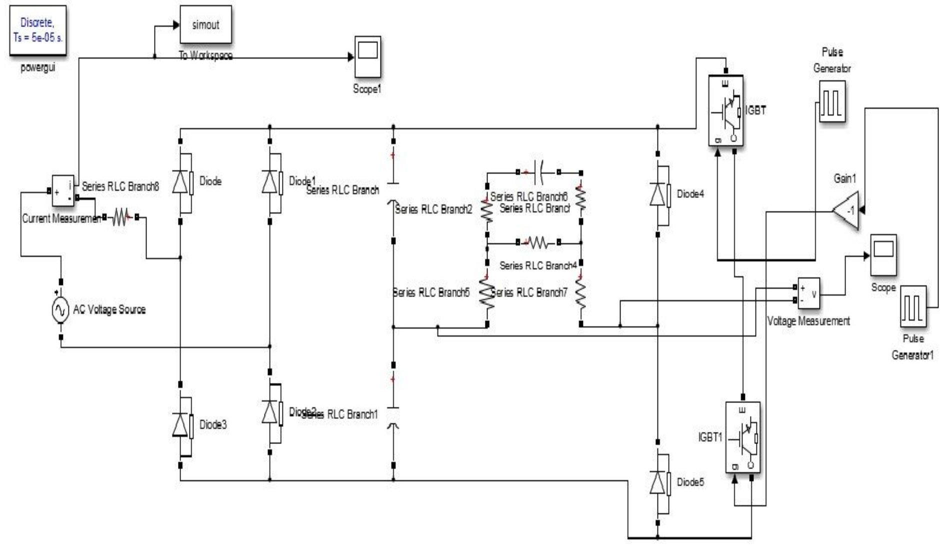

Figure 5 Simulation model of CFL

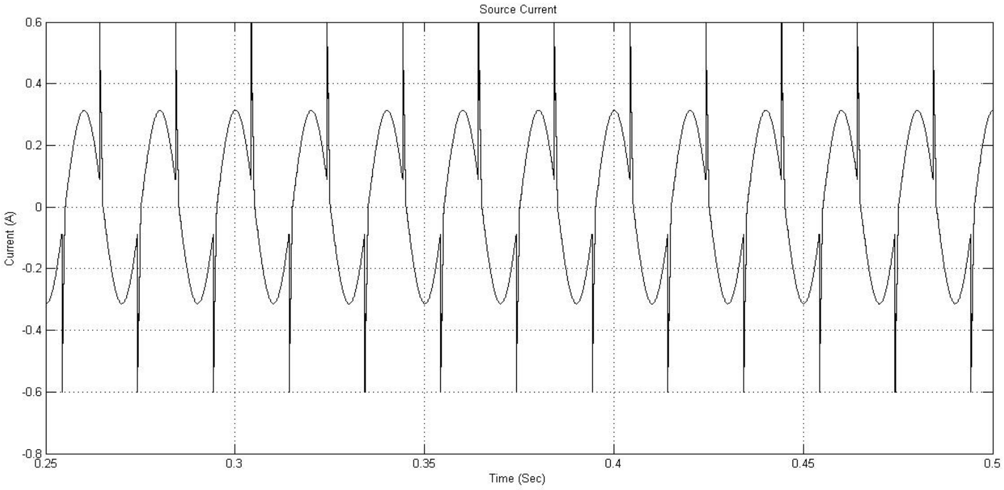

Figure 6 Waveform of source current drawn by CFL

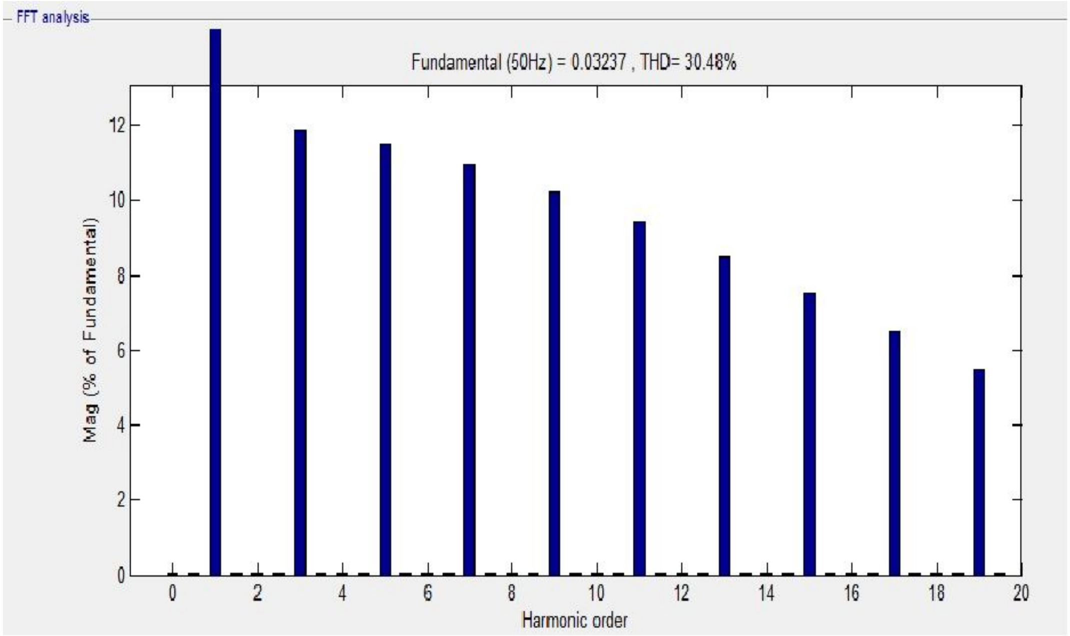

Figure 7 THD analysis of the current drawn by CFL

Fig.7 shows that the current has 30.48% of total harmonic disturbance. Harmonic distortions lead to the flickering of the lamp and decrease or increase the light intensity due to which the device reduces its life and damaged soon. Due to the harmonics production the nearby equipments also gets highly affected.

3. Modeling of PI controller

The inner current and voltage loops are implemented with PI controllers. The actual model of the voltage source inverter, the voltage and current control loops in synchronous reference frame (SRF) are shown in fig.3.20 and 3.21 where u^*_{sdq}, i^*_{Ldq} and d_{dq} are the voltage reference calculated from the power droop loop, the current reference which comes from the voltage loop and the duty ratio of the PWM modulator from the current loop respectively.

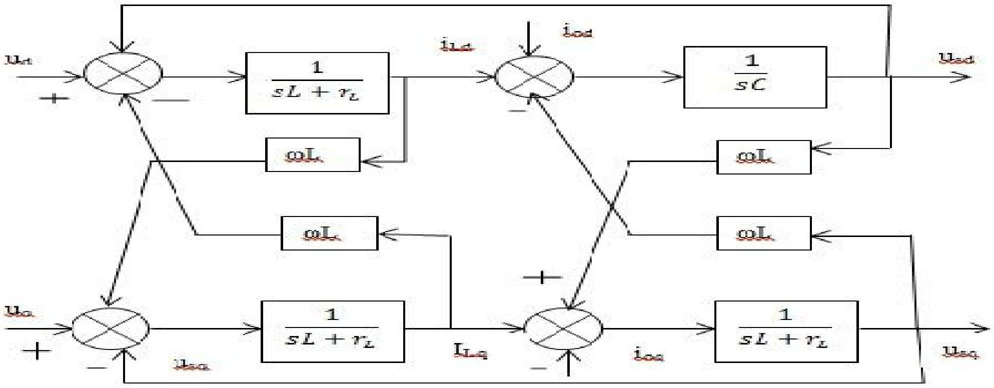

Figure8 VSI model

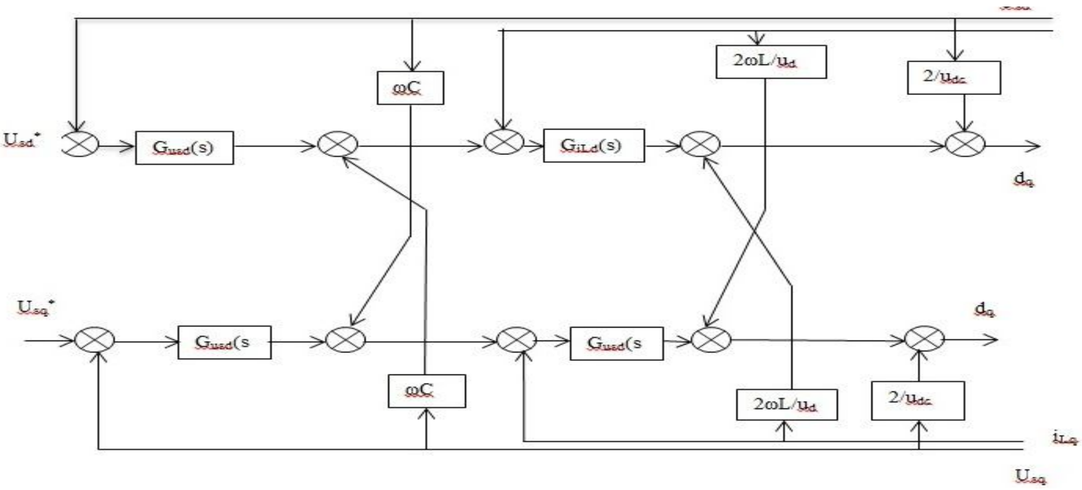

Figure 9 Voltage and Current loops

The closed loop transfer function of the voltage and the current loop can be derived as:-

$$Gi(s)=\frac{i_{Ldq}(s)}{i^*_{Ldq}(s)}=\frac{G_{iL}(s).\frac{1}{sL+r_L}}{1+G_{iL}(s).\frac{1}{sL+r_L}} \qquad (1)$$

$$u_{sdq}(s)=\frac{G_{us}(s).G_i(s).\frac{1}{sC}}{1+G_{us}(s).G_{is}(s).\frac{1}{sC}}.u^*_{sdq(s)}-\frac{\frac{1}{sC}}{1+G_{us}(s).G_{i(s)}.\frac{1}{sC}}.i_{odq}(s) \qquad (2)$$

where,

$$G_{iL}(s)=k_{ip}(s)+k_{ii}/s$$

$$G_{us}(s)=k_{vp}(s)+k_{vi}/s$$

$Gi(s)$ is the transfer function for the closed current loop.

$k_{ip}(s)$ & $k_{ii}(s)$ are the PI controller's parameters for the current loop

$k_{vp}(s)$ & $k_{vi}(s)$ are the PI controller's parameters for the voltage loop

Traditionally, the inner voltage and current loops are implemented with PI controllers. The model of the VSI, the volage and current control loops in synchronous reference frame are presented.

4. Design of PI plus multi resonant controller

Conventional PI controller can only provide zero-error tracking capability on dc components which is having 0Hz frequency and thus it can be utilised to regulate DC component only. So to get zero error tracking capability at different frequencies i.e., $2f_0$, $6f_0$, 12 f_0 and so on a new control strategy is being applied known as PI plus multi resonant controller as shown in fig.10. It can be used as a selective harmonic compensation. With the use of this controller, basically the gain at a selected resonant frequency is being improved for eliminating the steady state error at those particular frequencies.

The basic equations with the use of PI plus multi resonant controller which is being used are given as:

$$G_{PIR}(s) = K_{vp} + \frac{K_{vi}}{s} + \frac{K_2 s}{s^2+2\omega_2\, s+(2\omega_0)^2} + \frac{K_6 s}{s^2+2\omega_6\, s+(6\omega_0)^2} + \cdots \qquad (3)$$

$$u_{sdq}(s) = G_{ur}(s)\,.\,u^*_{sdq}(s) - (G_{ur}(s).\,Z_{ordq}(s))\,.\,i_{odq}(s) \qquad (4)$$

$$G_{ur}(s) = \frac{G_{PIR}(s)\,.\,G_i(s)\,.\,(1/sC)}{1+G_{PIR}(s)\,.\,G_i(s)\,.\,(1/sC)} \qquad (5)$$

$$Z_{ordq}(s) = \frac{(1/sC)}{1+G_{PIR}(s)\,.\,G_i(s)\,.\,(1/sC)} \qquad (6)$$

where $G_{ur}(s)$ is the closed loop voltage transfer function, $Z_{ordq}(s)$ is the output impedance, K_{vp} & K_{vi} are the voltage loop PI controller's parameters and K_2 & K_6 are the multi resonant controller's parameters.

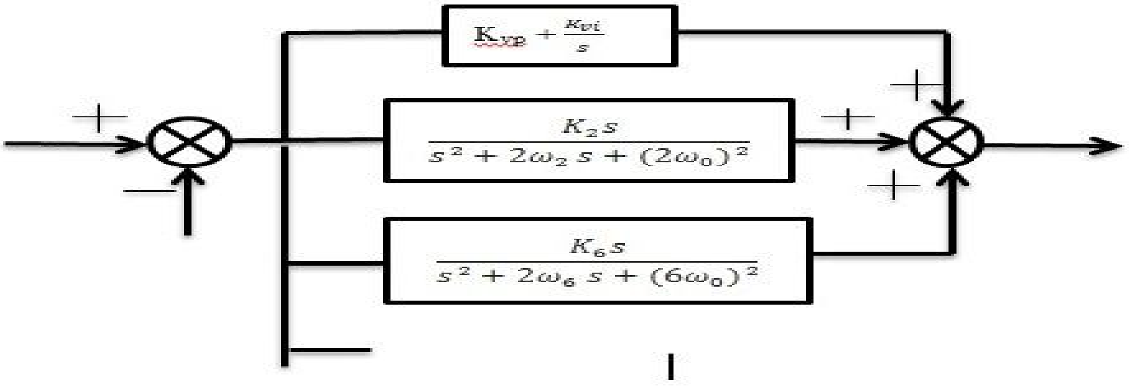

Figure 10 PI plus multi resonant controller

Bode plots are utilized to determine the inner voltage and current loops control parameters. The voltage loop PI controller's parameters K_{vp} & K_{vi} are selected to ensure high bandwidth and stability. In the same way we select the current loop PI controller's parameters K_{ip} & K_{ii}. The multi resonant controllers parameters K_2 & K_6 are chosen to obtain high loop gain of the voltage loop at the selective harmonic frequencies where ω_2 *and* ω_6 are chosen to ensure a damping ratio of 0.01 at each resonant frequencies.

5. Selective harmonic compensation

During the conversion of signal from abc to dq reference frame only the fundamental positive sequence is converted into DC form and the rest negative sequence and harmonics are present in AC form. While the conversion all (6k±1)ω harmonics in the stationary frame are transformed to ±6kω positive and negative sequence components in the rotated frame. PI plus multi resonant controller is used to compensate the selected lower order harmonics. This technique is highly suitable to use to compensate the lower order selected harmonics so that distortion will reduce a lot. Fig. 11 to fig.14 shows the output voltage compensation and harmonic analysis using controllers. Fig. 15 and 16 shows the THD comparison of non-linear loads and unbalanced loads with different sources using different controllers.

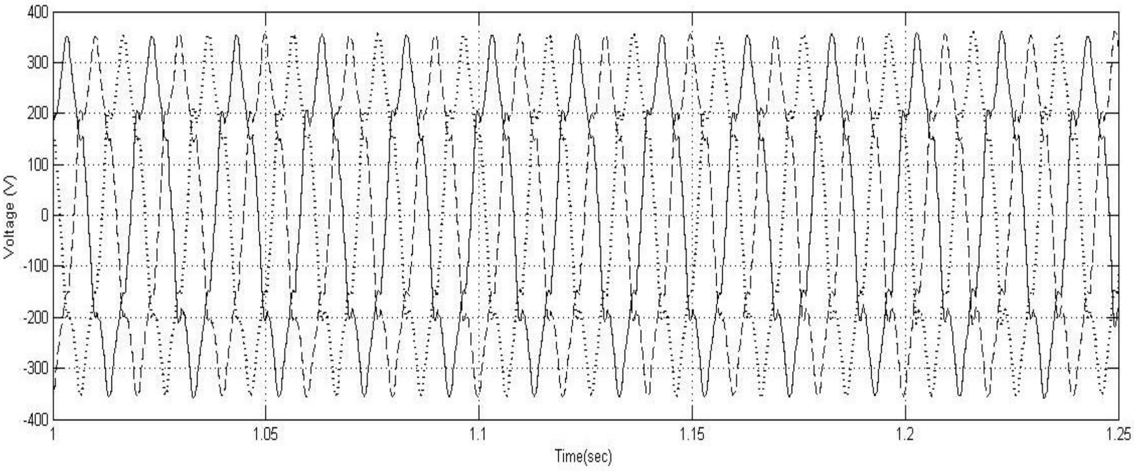

Figure 11 Waveform of output voltage drawn by the load with PI controller

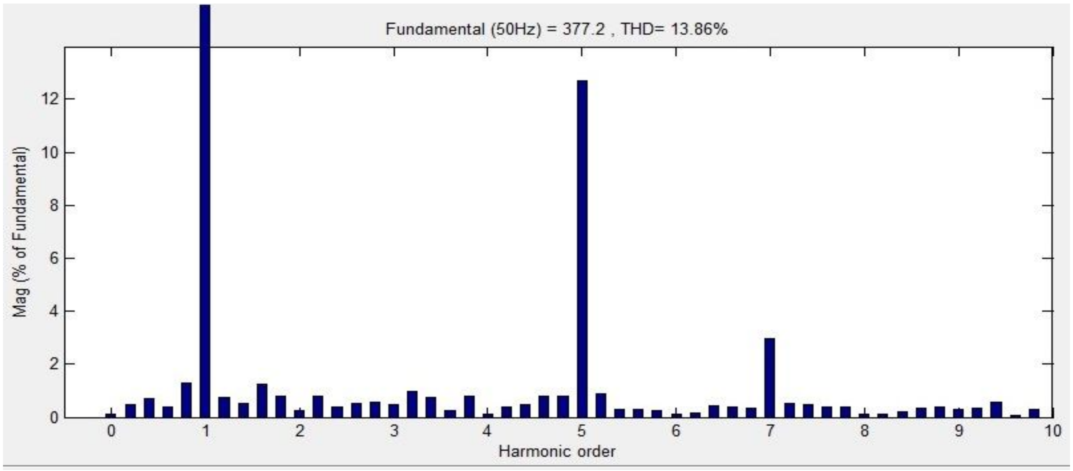

Figure 12 VTHD analysis of the output voltage with PI controller

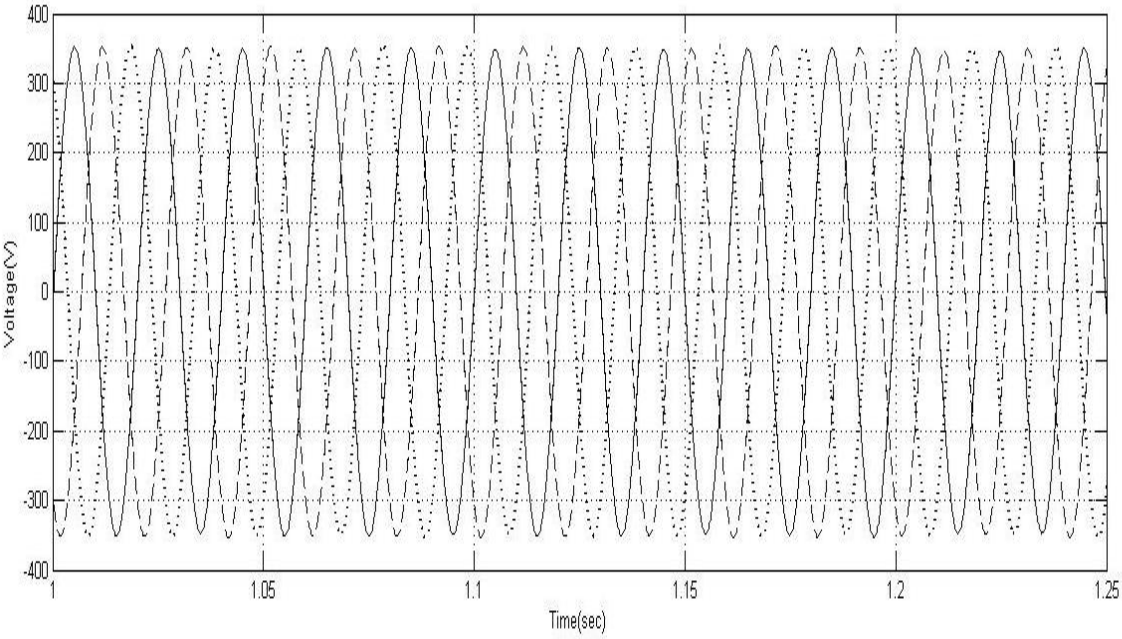

Figure 13 Waveform of output voltage drawn by loads with DC source using PI plus multi resonant controller

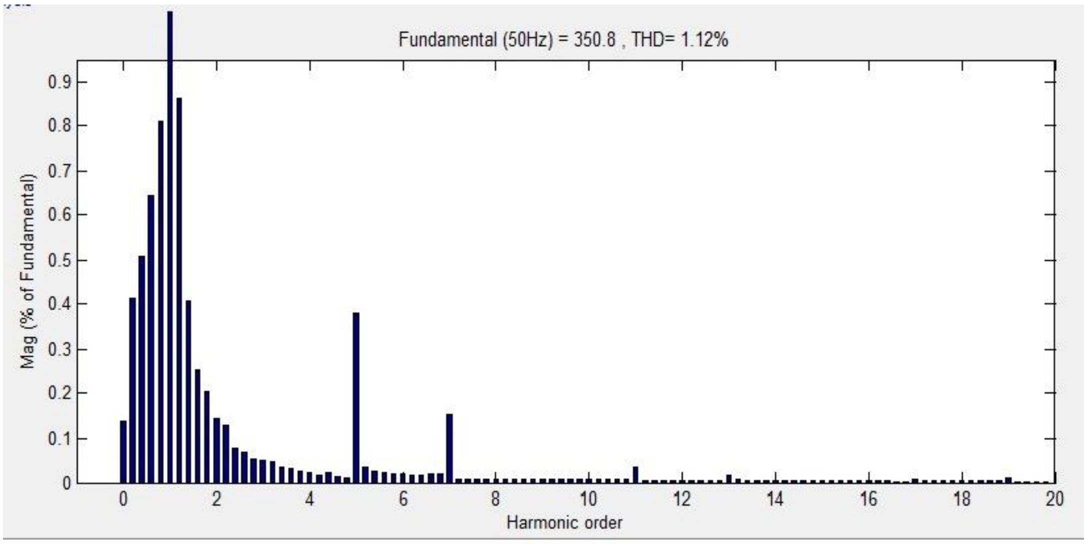

Figure 14 VTHD analysis of current with DC source using PI plus multi resonant controller

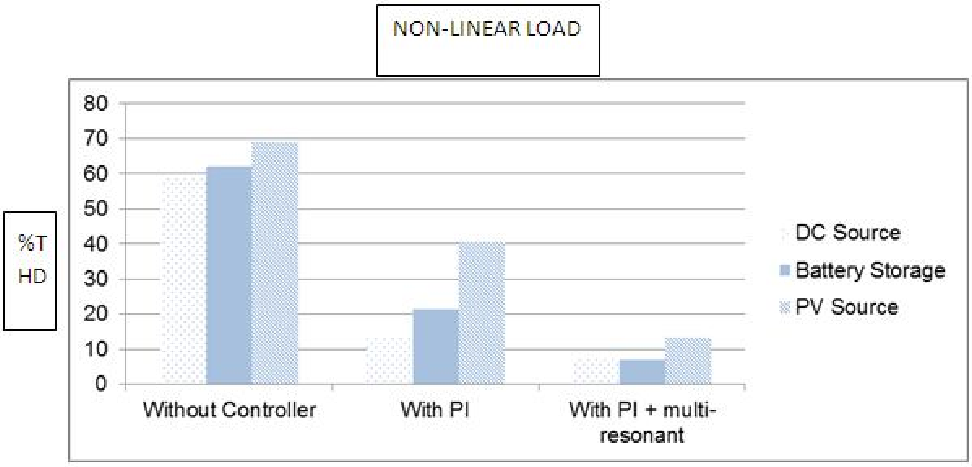

Fig.15 THD comparison for non-linear load using different sources and controllers

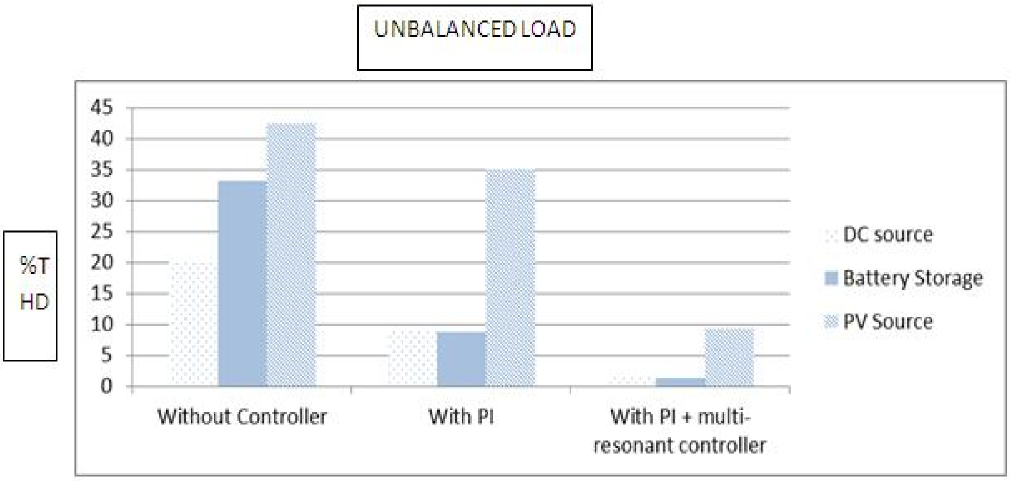

Figure 16 THD comparison for unbalanced load using different sources and controllers

6. CONCLUSION

Due to the unbalanced and non-linear loads the distortion in harmonics and unbalance voltage of fast switching converters is being presented. In this paper a SRF based control strategy i.e., PI controller and PI plus multi resonant controller for voltage unbalance and harmonic compensation of VSI is being used to minimize the harmonics and compensate the output voltage. The voltage compensation loop is integrated with inner current control loop. The proposed control strategy is being operated in a single SRF with a PI controller for the voltages fundamental component regulation and harmonics compensation. The PI plus multi resonant controller helps in tuning the zero-error tracking capability to extract the reference current from the distorted line current and hence improving the harmonic current due to non-linear load. It improves the lower order harmonic frequencies for selective harmonic compensation. The performance of PI controller and PI plus multi resonant controller is verified under different types of sources and loads with the simulation results. Hence we obtained undistorted output voltage and the harmonics are decreased by using these two controllers.

References

[1] Quanwei Liu, Yong Tao, Xunhao Liu, Yan Deng, Xiangning He: 'Voltage unbalance and harmonics compensation for islanded microgrid inverters' , IET Power Electron., 2014, Vol. 7, Iss. 5, pp. 1055–1063 doi: 10.1049/iet-pel.2013.0410

[2] Rocabert, J., Luna, A., Blaabjerg, F., Rodri, X., Guez, P.: 'Control of power converters in AC microgrids', IEEE Trans. Power Electron., 2012, 27, (11), pp. 4734–4749

[3] Quanwei, L., Yan, D., Xiangning, H.: 'A novelAC–AC shunt active power filter without large energy storage elements'. Proc. 2011– 2014th European Conf. Power Electronics and Applications (EPE 2011), 2011, pp. 1–9

[4] Yun, W.L., Vilathgamuwa, D.M., Poh, C.L.: 'A grid-interfacing power quality compensator for three-phase three-wire microgrid applications', IEEE Trans. Power Electron., 2006, 21, (4), pp. 1021–1031

[5] F. D. Kanellos, A. I. Tsouchnikas, N. D. Hatziargyriou, Senior Member, IEEE, 'Micro-Grid Simulation during Grid-Connected and Islanded Modes of Operation' , e International Conference on Power Systems Transients (IPST'05) in Montreal, Canada on June 19-23, 2005 Paper No. IPST05 – 113

[6] Yunwei, L., Vilathgamuwa, D.M., Poh, C.L.: 'Microgrid power quality enhancement using a three-phase four-wire grid-interfacing compensator', IEEE Trans. Ind. Appl., 2005, 41, (6), pp. 1707–1719

[7] Majumder, R., Ledwich, G., Ghosh, A., Chakrabarti, S., Zare, F.: 'Droop control of converter-interfaced microsources in rural distributed generation', IEEE Trans. Power Deliv., 2010, 25, (4), pp. 2768–2778

[8] A. Mansoor, W.M.Grady, R.S.Thallam, M.T.Doyle, S.D.Krein : 'Effect of supply voltage harmonics on the input current of single phase diode bridge rectifier loads,' IEEE Trans. On Power Delivery, Vol. 10, No. 3, July 1995, pp. 1416-1422.

[9] Lazaro, I. Quesada, C. Raga, A. Barrado, R. Vazquez, I. Gonzalez : 'Extension of harmonics elimination technique in presence of nonlinear loads,' IEEE trans. Ind. App. , Vol. 43, No. 25, December 2007.

[10] Chiasson, J.N., Tolbert , L.M., Mc kenzie, K.J., and Du, Z.: 'A complete solution to the harmonics elimination problem' . IEEE Applied Power Electronics Conf. (APEC), Dallas, TX, USA,2002

[11] Jose Antinor Pomilio, Sigmar Maurer Deckmann, "Characterization and Compensation of Harmonics and Reactive Power of Residential and Commercial Loads," IEEE Trans. Power Delivery, Vol. 22, No.2, April 2007,pp.l049-1055

[12] Y. W. Li, D. M. Vilathgamuwa, and P. C. Loh, "Design, analysis and realtime testing of controllers for multi-bus micro grid system," *IEEE Trans. Power Electron.*, vol. 19, no. 5, pp. 1195–1204, Sep. 2004.

[13] Tahri A.; et al, "A Fast Current Control Strategy of a PWM Inverter used for Static VAr Compensation", Industrial Electronics Society Conference, Vol: 1, Aug 1998.

[14] Jang S.-I.; Kim K.-H., "An Islanding Detection Method for Distributed Generations using Voltage Unbalance and Total Harmonic Distortion of Current", IEEE Transactions on Power Delivery, Vol: 19, Issue: 2, April 2004.

[15] F. Magueed, and J. Daalder, "Operation of Distributed Generation in Weak Grids with Local Critical Load," accepted to be published in the *32nd Annual Conference of the IEEE Industrial Electronics Society (IECON'06)*, Paris, France, 7-10 November 2006.

[16] R. Teodorescue, F. Blaabjerg, M.Liserre and P.C. Loh, "Proportional- resonant controllers and filters for grid-connected voltage source converters", IEEE Proc.- Electr. Power Appl., Vol. 153, No. 5, September 2006.

[17] Escobar, G. Martinez, P.R. Leyva-Ramos J., Valdez A.A and Hernandez- Gomez M., " A repetitive-based controller for a power factor pre- compensator with harmonic compensation" , Proc. IEEE PESC, Recife, Brazil, 2005, pp. 2363-2369.

[18] Zmood, D.N., and Holmes D.G, "Stationary frame current regulation of PWM inverters with zero steady-state error", IEEE Trans. Power Electron., 2003, 18, pp. 814-822.

[19] Ye Zhang. "Energy management strategy of islanded microgrid based on power flow control", 2012 IEEE PES Innovative Smart Grid Technologies (ISGT), 01/2012

[20] Masahide Hojo. "A method of three-phase balancing in microgrid by photovoltaic generation systems", 2008 13th International Power Electronics and Motion Control Conference, 09/2008.

[21] Kim, Jaehong, Josep M. Guerrero, Pedro Rodriguez, Remus Teodorescu, and Kwanghee Nam. "Mode Adaptive Droop Control with Virtual Output impedances for an Inverter-based Flexible AC Microgrid", IEEE Transactions on Power Electronics, 2011.

[22] Savaghebi, M., Jalilian, A., Vasqez, J.C.,Guerrero, J.M.: ‘Autonomous voltage unbalance compensation in an Islanded Droop-controlled microgrid’, IEEE Trans. Ind. Electron., 2013, pp. 1390-1402.

[23] Majumder, R., Ledwich, G., Ghosh, A. Chakrabarti, S. Zare, F., ‘Droop control of converter-interfaced microsources in rural distributed generation’,IEEE Trans. Power Deliv., 2010, 25, (4), pp. 2768-2778.

[24] Seyed Mahdi Ashabani and Yasser Abdel-Rady I. Mohamed, ‘A flexible control strategy for grid connected and islanded microgrids with enhanced stability using nonlinear microgrid stabilizer’, IEEE Transactions on smart grid, vol. 3, No. 3, September 2012.

[25] Jinwei He, ‘An enhanced microgrid load demand sharing strategy’, IEEE Transactions on power electronics, vol. 27, No. 9, September 2012.

[26] Salvador P. Litran and Patricio Salmeron, ‘Reference voltage optimization of a hybrid filter for nonlinear load compensation’, IEEE Transactions on industrial electronics, vol. 61, No. 6, June 2014.

[27] Jinwei He, Li, Y.W., ‘Generalized closed-loop control schemes with embedded virtual impedances for voltage source converters with LC or LCL filters’, IEEE Transactions on power electron., April 2012, 27, (4), pp. 1850-1861.

AUTHOR

Pradeep Kumar received his B Tech degree in Electrical and Electronics Engineering from Maharaja Agrasen Institute of Technology, New Delhi in 2012 and M Tech degree from NIT Calicut, Kerala, India in Power Systems Specialization in 2015.

Priyabrta Nayak received his B Tech degree in Electrical Engineering from Bijupatnaik University of Technology, Orissa in 2012 and M Tech degree from NIT Calicut, Kerala, India in Power Systems Specialization in Electrical Engineering department in 2015.

Kanhu Charan Patra received the B-Tech in Electrical and Electronics engineering from National institute of science and technology, Berhampur and M-Tech degree in Electrical engineering from National institute of technology (NIT) Calicut, Kerala