ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A Comprehensive Design Approach of Power Electronic-Based Distributed Generation Units Focused On Power-Quality Improvement

K. Durga Manogna
Department of Electrical and Electronics Engineering, B.I.T.I.T College, Hindupur, AP -515201, India.

C. Viswanath
Department of Electrical and Electronics Engineering, B.I.T.I.T College, Hindupur, AP -515201, India.

Abstract

Power electronic converters have rapidly emerged as one of the main used devices to interchange energy with the utility grid, at several power and voltage levels. In this context, VSC based converters are among the most preferred interfaces to perform the interconnection, especially for integration of distributed energy sources, active filtering, and power supply applications due to the development in the devices material technology and in the control strategies development. The most important requirement of power system operations is sustained availability and quality supply of electric power. In Electrical Power Distribution System (EPDS), non-linear loads are the main cause of power quality (PQ) degradation. The level of distortion depends on the internal elements of the DGUs as well as on the characteristics of the grid, loads, and controls, among others.

The PQ problems generated by these non-linear loads are complex and diversified in nature. The power system which is not capable to handle non-linear loads faces the problem of voltage unbalance, sag, and swell, momentary or temporary interruption and ultimately complete outage of EPDS.This paper presents a comprehensive method, focused on power-quality indexes and efficiency for the design of microgrids with multiple DGUs interconnected to the ac grid through three-phase multi-Megawatt medium voltage pulse width-modulated-voltage-source inverters (PWM-VSI). Matlab/simulink simulations are presented in order to show the outstanding performance of the proposed design approach.

***Index Terms*—Harmonic analysis, design optimization, powerquality.**

I. INTRODUCTION

Power quality problems in the present-day distribution systems are frequently addressed due to the enormous use of sensitive and critical equipment pieces Such as communication network, process industries, and precise manufacturing processes. Power quality problems such as transients, sags, swells, and other distortions to the sinusoidal waveform of the supply voltage affect the performance of these equipment pieces.Power electronic systems have been widely employed in daily life applications [1]. From their usage, hugedevelopments in industrial, transportation, aerospace, commercial and residential technologies havebeen achieved over within few decades, concerning applications from very low power (portable electronicequipment) to very high power (transmission systems).

Since their main usage is related toenergy handling, there is a constant research and development focused on improving energy efficiencyat all power levels.The definition adopted in this thesis work of power electronic system (PES) [2] is: a system containingat least one power electronic switch, any number of passive electrical components (transformers,resistors, capacitors and/or inductors) and any number of ideal current and voltages sources1. As mentionedin the definition, a power system is directly tied to the presence of power

Cite this article as: K. Durga Manogna & C. Viswanath, "A Comprehensive Design Approach of Power Electronic-Based Distributed Generation Units Focused On Power-Quality Improvement", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 5 Issue 8, 2018, Page 42-49.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

electronic switcheson its topology. The above mentioned technological widespread and constant improvement has beenguided by the development of material technologies from which those power switches are constructed.The power electronic systems era began in the 50's with the first commercial thyristor, the Silicon ControlledRectifier (SCR) [3]. This was the former device from which new devices with improved capabilitieswere developed and in most cases keep the development until nowadays, such as the bipolar junctiontransistor (BJT) in 1970, the gate turn-off thyristor (GTO) in 1973, the metal oxide field effect transistor(MOSFET) in 1978, and the insulated gate bipolar transistor (IGBT) in 1983 [4].

As result of the development of fully controlled power switches, such as the BJT, GTO, MOSFETand IGBT, sophisticated applications mainly based on classical and modern control theory were ableto be implemented. Among the most developed fields, the energy conversion field excels due to highvariety of energy sources available, where power electronic converters (PEC) are the core devices usedby this field. A power electronic converter is a PES, realized through a variety of configurations, drivenby a control/protection system. The PEC's main purpose is to regulate and shape the current and/orvoltage wave-forms obtained from a source in order to be efficiently used on a load. Three main formsof power conversion devices can be summarized:

- Direct-current to direct-current (DC-DC) converters.
- Alternating-current to direct-current (AC-DC) (or vice versa).
- Alternating-current to alternating-current (AC-AC) converters, also known as cyclo-converters.

This paper proposes a comprehensive approach, based on optimizationand the extended harmonic domain (EHD) [5], forthe design of multiple grid-connected multi-Megawatt mediumvoltagesPWM-VSIwith LCL filters. This is carried out by meansof a Nonlinear Least squares formulation (NLSQ) [6], which calculatesthe filter parameters and the steady state control variableswhich meet certain proposed reference-operating conditions and includes power-quality restrictions and efficiency. As an example,the design of two DGUs, based on three-phase PWM-VSIs,which are connected to a microgrid is presented. Two case studiesare presented to show the proposed design approach, oneconsidering that the interconnections grid is unknown and theother when is known. The obtained results show the remarkablegood performance of the proposed design approach on bothcases, along with advantages over other design methodologies,which rely on the comprehensive consideration of multiple designobjectives.

II. POWER QUALITY PROBLEMS

The electric power network has undergone several modifications from the time of its invention. The modern electric power network has many challenges that should be met in order to deliver qualitative power in a reliable manner. There are many factors both internal and external that affect the quality and quantity of power that is being delivered. This chapter discusses the different power quality problems, their causes and consequences.

A. Interruptions:

It is the failure in the continuity of supply for a period of time. Here the supply signal (voltage or current) may be close to zero. This is defined by IEC (International Electro technical Committee) as "lower than 1% of the declared value" and by the IEEE (IEEE Std. 1159:1995) as "lower than 10%". Based on the time period of the interruption, these are classified into two types. They are,

i) Short Interruption: If the duration for which the interruption occurs is of few mille seconds then it is called as short interruption.

ii) Long Interruptions: If the duration for which the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as long interruption. The voltage signal during this type of interruption is shown in Fig.1.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

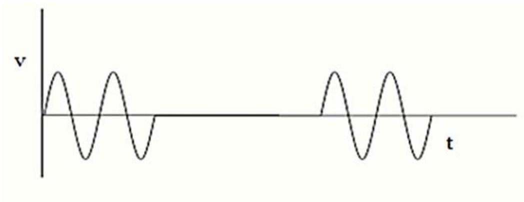


Fig.1 Voltage Signal with Long Interruption

B. Waveform Distortion:

The power system network tries to generate and transmit sinusoidal voltage andcurrent signals. But the sinusoidal nature is not maintained and distortions occur in thesignal.

C.Frequency Variations:

The electric power network is designed to operate at a specified value (50 Hz) offrequency. The frequency of the framework is identified with the rotational rate of thegenerators in the system [7]. The frequency variations are caused if there is any imbalance inthe supply and demand. Large variations in the frequency are caused due to the failure ofa generator or sudden switching of loads.

D.Transients:

The transients are the momentary changes in voltage and current signals in the powersystem over a short period of time. These transients are categorized into two typesimpulsive,oscillatory. The impulsive transients are unidirectional whereas the oscillatorytransients have swings with rapid change of polarity.

E.Voltage Sag:

The voltage sag is defined as the dip in the voltage level by 10% to 90% for a periodof half cycle or more. The voltage sag as shown in Fig. 2.

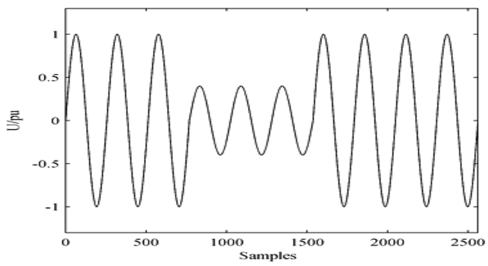


Fig.2 Voltage Sag

F. Voltage Swell:

Voltage swell is defined as the rise in the voltage beyond the normal value by 10%to 80% for a period of half cycle or more. The voltage swell as shown in Fig.3.

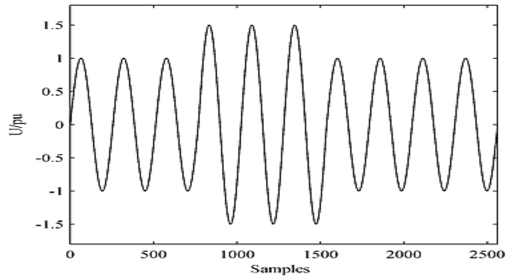


Fig.3 Voltage Swell

G. Voltage Unbalance:

The unbalance in the voltage is defined as the situation where the magnitudes andphase angles between the voltage signals of different phases are not equal.

H. Voltage Fluctuation:

These are a series of a random voltage changes that exist within the specified voltage ranges. Fig.4 shows the voltage fluctuations that occur in a power system.

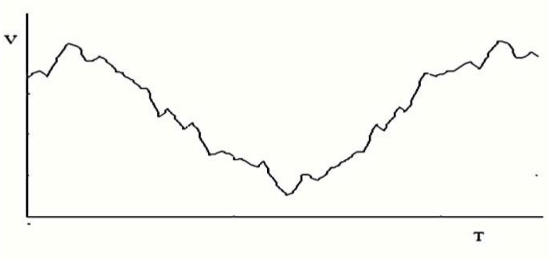


Fig.4 Voltage Fluctuation

III. SYSTEM MODELING

Three main elements could be identified in the design of aDGU. (1) The Design Objectives (DO) (power quality, operatingconditions, size limitations, cost, etc.), (2) the ExternalConditions (EC) (distributed resource, grid equivalent, weatherevents, faults, generation outages, etc.) and (3) the DesignableElements (DE) (topology, component values, control parameters,etc). In this context, a proper design can be summarized asthe selection of certain DE that ensure the fulfillment of the DOin the presence of some EC [8]. This requires understanding in detailthe relationships and interactions

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

among these main elements.Fig. 5 shows a very basic representation of a typical DGU andsome of the above identified main elements are shown (DO, ECand DE). From Fig. 5 the DO could be established, for example:DC bus voltage, DC voltage ripple, RMS voltage at *PCC*,active power at *PCC*, reactive power at *PCC*, THD voltage at*PCC*, current ripple at *PCC*, among others. Some of the DEis: distributed resource topology, power electronic topology,AC and DC filter topologies, control unit topology, switchingfrequency, power switches ratings, DC filter component valuesand AC filter component values, control unit gains, among others.In order to have a selection of the DE that ensures thatthe reference design objectives (DOref) are met under boundedvariation of certain EC, is then required to understand the relationshipsbetween these main elements.

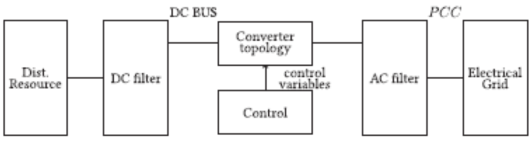


Fig. 5. Simplified layout for design.

Electrical systems can be modeled by Linear Time Periodic(LTP) systems, even in the presence of power electronics if theswitching functions that drive them are periodic. However, thediscrete nature of these functions make it difficult dealing withtime domain periodic discontinuous models [9]. TheEHDmodelingoverrides this limitation and obtains LTI models by consideringthe harmonic content of the signals in their formulation.

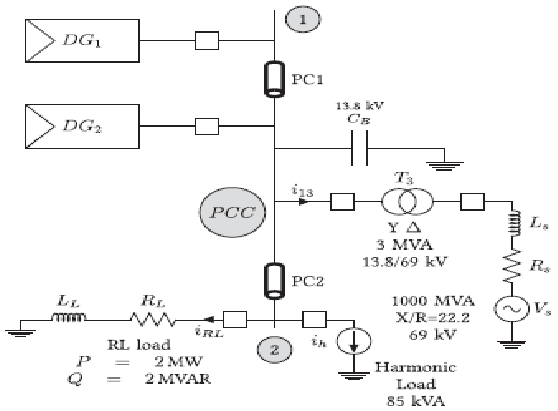


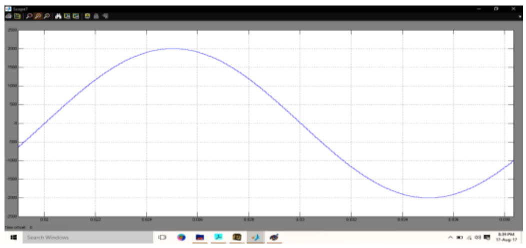
Fig. 6. Microgrid test system.

The proposed microgrid to design is shown in Fig. 6. Threenodes are clearly identified in this system, labeled 1, 2 and*PCC* respectively. PC1 and PC2 are power cables of differentlengths, modeled by a three phase π equivalent line which connectsthese nodes. Distributed generation units *DG*1 and *DG*2are connected to nodes 1 and *PCC* respectively. The grid isrepresented by its Thevenin equivalent and is connected to node*PCC* by means of a power transformer *T*3. A capacitor bank*CB* is also connected to this node in order to improve the powerfactor of the microgrid interconnection. A linear load, modeledby*LL* and*RL*, along with a three-phase harmonic load, modeledbi_h,are connected in node 2.A modular approach, which can easily be automated, is usedin order to obtain the EHD modeling of the case study. Forthis purpose, the test system can be divided into individualsubsystems in order to derive their individual EHD matrices,and plug them in into the EHD matrices of the test systemmodel [10].

IV. SIMULATION RESULTS

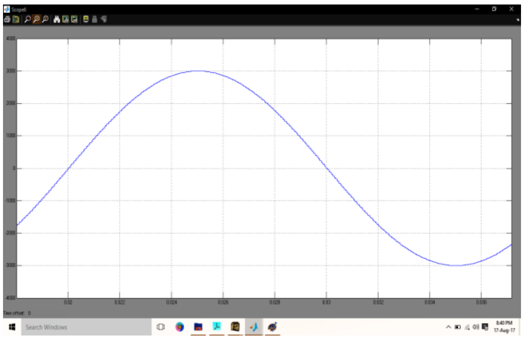
In order to show the flexibility of the proposed design approach, two design cases studies are presented in this Section for the microgridtest system proposed. The first case considers that no information of the microgrid test system where *DG*1 and*DG*2 will be connected is available, named as isolated design. The second case considers that the microgrid test system where *DG*1 and *DG*2 will be connected is known, named as comprehensive design. The main objective in both cases is to find the designable elements proposed in Section for *DG*1 and *DG*2 which meet as close as possible the reference design objectives of an steady state operation of the case study system.

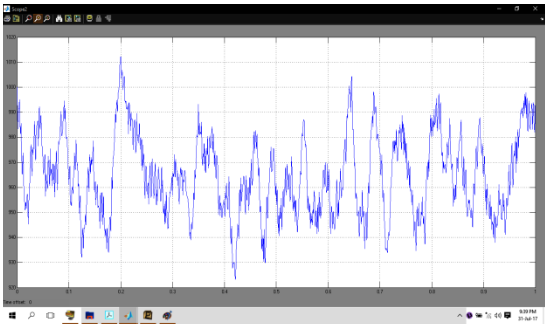
CASE-1: MICROGRID TEST SYSTEM OF AN ISOLATED DESIGN

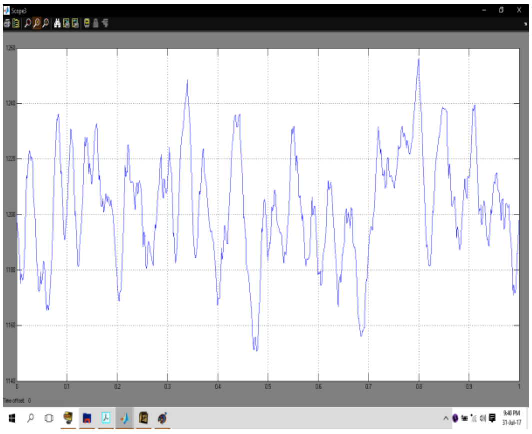


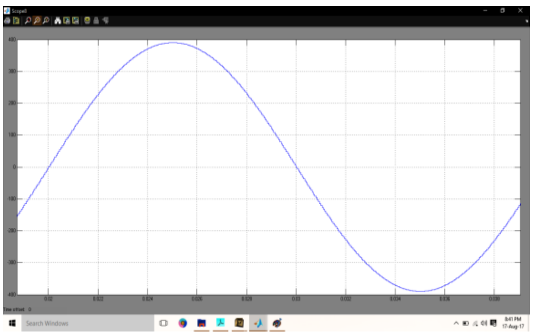
*(a) DG*1 *i*11 converter current.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal


(b) *DG*2 *i*21 converter current.


(c) *DG*1 *v*1*dc* voltage.


(d) *DG*2 *v*2*dc* voltage.


(e) *DG*1 node 1*A* voltage.

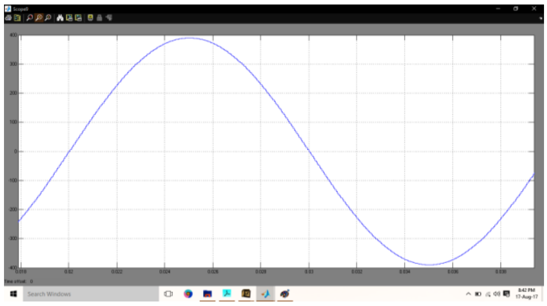

(f) *DG*2 node 2*A* voltage.

Fig:7. simulation waveforms for isolated design Case Study. (a) *DG*1 *i*11 converter current. (b) *DG*2 *i*21 converter current. (c) *DG*1 *v*1*dc* voltage. (d) *DG*2 *v*2*dc* voltage. (e) *DG*1 node 1*A* voltage. (f) *DG*2 node 2*A* voltage.

Fig.7, shows some MATLAB/SIMULINK simulated waveforms of *DG*1 and *DG*2 when connected to the test system.

From the simulations shown in Fig.7 it can be seen that waveforms are practically overlapped. This validates the EHD model used to obtain the designable elements and the design approach proposed. The achieved power-quality indexes are excellent considering the high power capability and low switching frequency considered in the design. When interconnected to the microgrid, each DGU behaves very close to an ideal harmonic free voltage source and their overall harmonic distortion impact over the microgrid is practically negligible. However, since each DGU was designed without considering all the elements interconnected to them, they obtained design is decoupled and the isolated operating conditions have to be verified when interconnected. From this point of view, a better design could be obtained if the complete system model is considered in the proposed design approach.

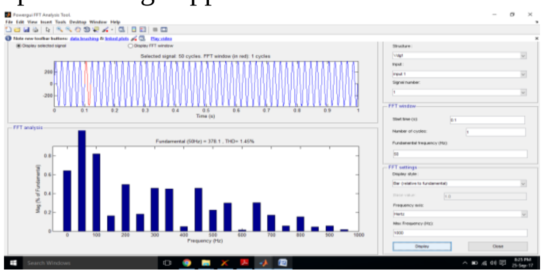


Fig: 8(a)

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

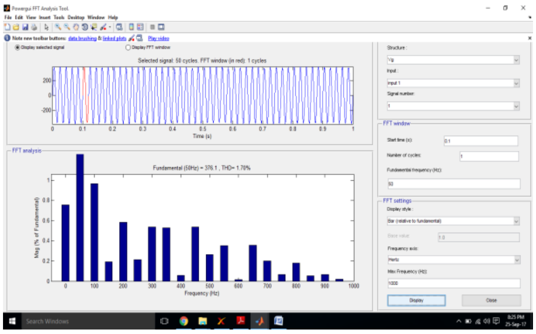
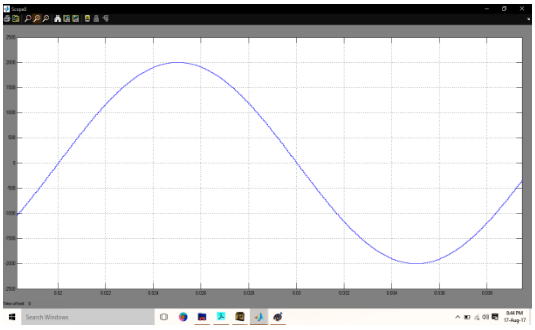


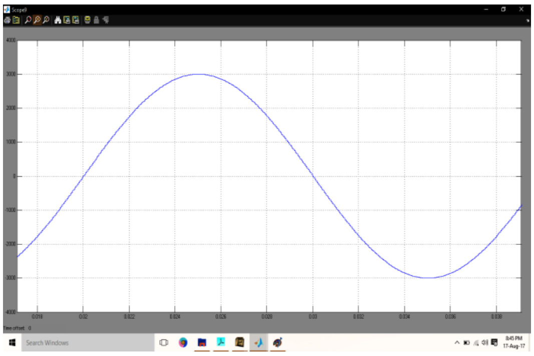
Fig:8(b)

Fig:8(a) & (b) shows the THD analysis of isolated design.

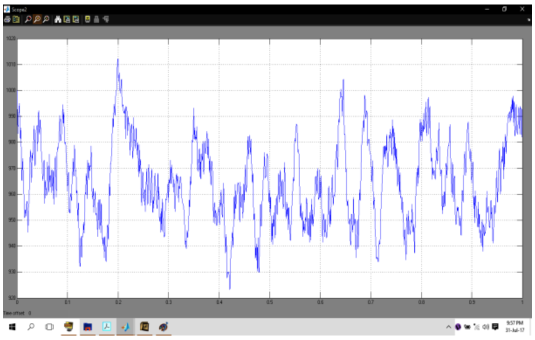
CASE-2: MICROGRID TEST SYSTEM OF A COMPREHENSIVE DESIGN



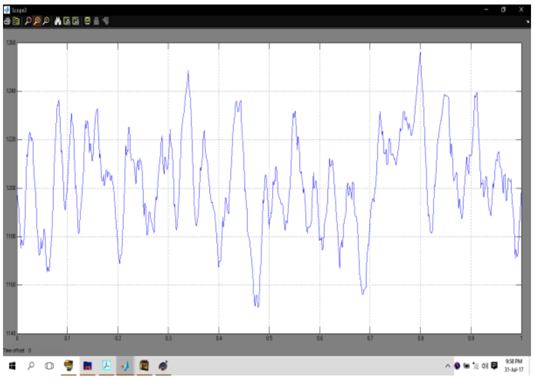
(a) $DG1$ $i11$ converter current.



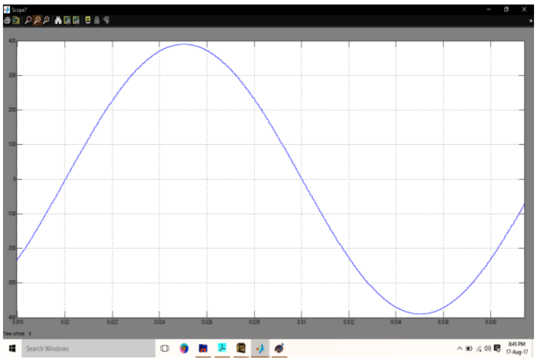
(b) $DG2$ $i21$ converter current.



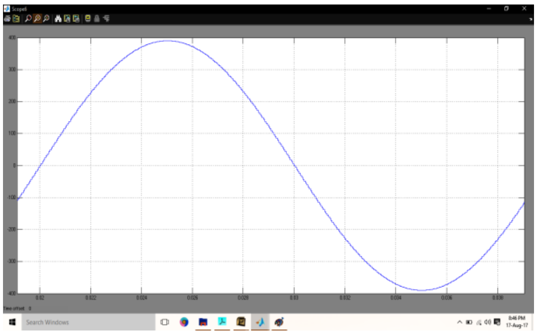
(c) $DG1$ $v1dc$ voltage.



(d) $DG2$ $v2dc$ voltage.



(e) $DG1$ node $1A$ voltage.



(f) $DG2$ node $2A$ voltage.

Fig:9. simulation waveforms for comprehensive design Case Study. (a) $DG1$ $i11$ converter current. (b) $DG2$ $i21$ converter current. (c) $DG1$ $v1dc$ voltage. (d) $DG2$ $v2dc$ voltage. (e) $DG1$ node $1A$ voltage. (f) $DG2$ node $2A$ voltage.

In both design cases, the design of both DGUs is performed simultaneously, considering all the elements interconnected in the microgrid, using the overall model derived for the system. As in the previous case, these DE results are used to perform matlab/simulink simulations

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

of the test system in order to validate the design. Fig.9 shows some matlab/simulink simulated waveforms of *DG*1 and *DG*2 when connected to the test system, considering the DE results. As in the previous case study, the matlab/simulink simulation validates the obtained results and the proposed design approach. The results of both case studies show a remarkable performance of the proposed design approach. Multiple and diverse DOrefare closely met, while the grid side power-quality standards are easily fulfilled with a very reduced converter current ripple; even in the presence of low switching frequencies and harmonic loads, with the best efficiency possible. In both design Case Studies, the performance of each DGU is seen by the network almost as an ideal harmonic free voltage source and prevents any harmonic related issue in the network caused by the operation of the DGUs. For this reason, the overall performance of the system and the obtained DE are very close in both case studies.

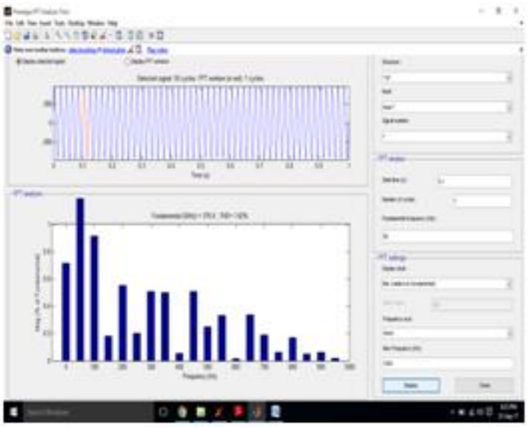


Fig:10(a)

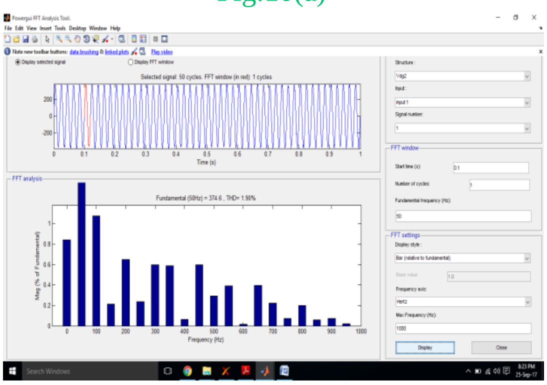


Fig:10(b)

Fig:10(a) & (b) shows the THD analysis of comprehensive design.

V. CONCLUSION

This paper has introduced a novel design methodology based on optimization and the extended harmonic domain (EHD) for interconnected distributed generation units (DGUs) in which the harmonic distortion and its effects over multiple design objectives are explicitly considered. The design results of the presented case studies have shown a remarkable performance when both, the grid parameters are available and not available, offering an excellent power quality with the best efficiency possiblein the presence of low switching frequencies. Compared with other design methodologies, this proposal offers an advanced performance, which relies on the comprehensive consideration of multiple design objectives.

REFERENCES

[1] A.Medina, J. Segundo, P. Ribeiro,W. Xu, K. Lian, G. Chang, V. Dinavahi, and N.Watson, “Harmonic analysis in frequency and time domain,” IEEETrans. Power Del., vol. 28, no. 3, pp. 1813–1821, Jul. 2013.

[2] J. Segundo-Ram´ırez, A. Medina, A. Ghosh, and G. Ledwich, “Stability boundary analysis of the dynamic voltage restorer in weak systems with dynamic loads,” Int. J. Circuit Theory Appl., vol. 40, no. 6, pp. 551–569, Jun. 2012.

[3] X. Wang, F. Blaabjerg, and W. Wu, “Modeling and analysis of harmonic stability in an AC power-electronics-based power system,” IEEE Trans.Power Electron., vol. 29, no. 12, pp. 6421–6432, Dec. 2014.

[4] I. Standards, “IEC61000-X-X-Electromagnetic compatibility (EMC),” 1994.

[5] “IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems,” IEEE Standard 1547-2003, pp. 1–28, Jul. 2003.

[6] EN50160, “Voltage characteristics of electricity supplied by public distribution systems,” 1994.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

[7] X. Tang, W. Deng, and Z. Qi, “Investigation of the dynamic stability of microgrid,” IEEE Trans. Power Syst., vol. 29, no. 2, pp. 698–706, Mar. 2014.

[8] I. N. Santos, V. C´ uk, P. M. Almeida, M. H. J. Bollen, and P. F. Ribeiro, “Considerations on hosting capacity for harmonic distortions on transmission and distribution systems,” Elect. Power Syst. Res., vol. 119, pp. 199–206, Feb. 2015.

[9] X. Zong, P. Gray, and P. Lehn, “New metric recommended for IEEE Std. 1547 to limit harmonics injected into distorted grids,” IEEE Trans. PowerDel., 2015.

[10] J. He, Y. W. Li, F. Blaabjerg, and X. Wang, “Active harmonic filtering using current-controlled, grid-connected DG units with closed-loop power control,” IEEE Trans. Power Electron., vol. 29, no. 2, pp. 642–653, Feb. 2014.

Author Details

C.Viswanath received his B.Tech (EEE) degree from JNTU, Hyderabad, Andhra Pradesh, India in 2005, and M.Tech in Advanced Power System from JNTUCE, Kakinada, and Andhra Pradesh, India in 2007. He is currently working as Associate Professor in BIT Institute of Technology, A.P, India. His areas of interest are Power System operation and control, control systems, Power distribution systems &Distributed Generation.

K.Durga Manogna received her B.Tech (EEE) degree from B.I.T.I.T Hindupur, Anantapur, Andhra Pradesh, India in 2016. Her area of interest are Power system Protection and Control, Power Distributed Systems.