A DISTRIBUTED SYSTEM HARMONIC COMPENSATION APPROACH USING DG GRID INTERFACING CONVERTERS

G.SUJITHA[1], K.MANOHAR[2]

[1]PG Student, Dept of EEE (EPS), SRIT, Proddatur, AP, India.
[2]Associate Professor & HOD, Dept of EEE, SRIT, Proddatur, AP, 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 project 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, power quality.**

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. From their usage, huge developments in industrial, transportation, aerospace, commercial and residential technologies have been achieved over within few decades, concerning applications from very low power (portable electronic equipment) to very high power (transmission systems).

Since their main usage is related to energy handling, there is a constant research and development focused on improving energy efficiency at all power levels. The definition adopted in this thesis work of power electronic system (PES) is: a system containing at 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 mentioned in the definition, a power system is directly tied to the presence of power electronic switches on its topology. The above mentioned technological widespread and constant improvement has been guided 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 Controlled Rectifier (SCR). This was the former device from which new devices with improved capabilities were developed and in most cases keep the development until nowadays, such as the bipolar junction transistor (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.

As result of the development of fully controlled power switches, such as the BJT, GTO, MOSFET and IGBT, sophisticated applications mainly based on classical and modern control theory were able to be implemented. Among the most developed fields, the energy conversion field excels due to high variety of energy sources available, where power electronic converters (PEC) are the core devices used by this field. A power electronic converter is a PES, realized through a variety of configurations, driven by a control/protection system. The PEC's main purpose is to regulate and shape the current and/or voltage wave-forms obtained from a source in order to be efficiently used on a load. Three main forms of 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 optimization and the extended harmonic domain (EHD), for the design of multiple grid-connected multi-Megawatt medium voltages PWM-VSI with LCL filters. This is carried out by means of a Nonlinear Least squares formulation (NLSQ), which calculates the filter parameters and the steady state control variables which 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 studies are presented to show the proposed design approach, one considering that the interconnections grid is unknown and the other when is known. The obtained results show the remarkable good performance of the proposed design approach on both cases, along with advantages over other design methodologies, which rely on the comprehensive consideration of multiple design objectives.

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.
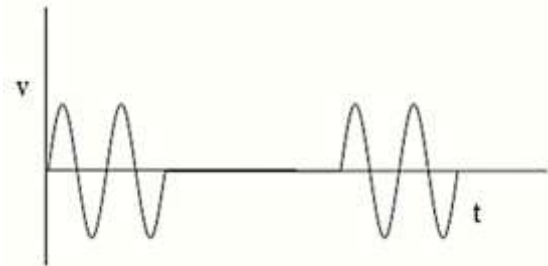

Fig.1 Voltage Signal with Long Interruption

B.Voltage Sag:

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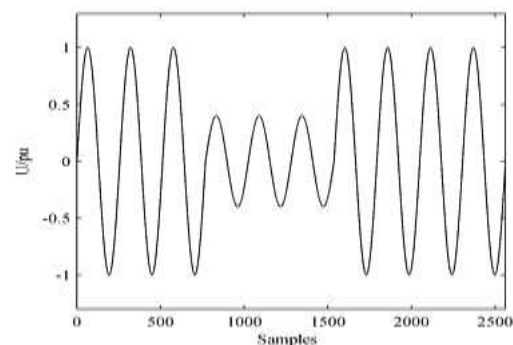

Fig.2 Voltage Sag

C. 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.
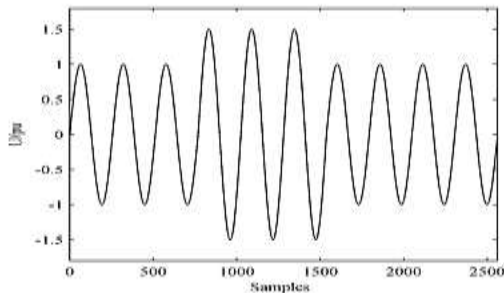

Fig.3 Voltage Swell

D. Voltage Unbalance:

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

E. 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 a DGU. (1) The Design Objectives (DO) (power quality, operating conditions, size limitations, cost, etc.), (2) the External Conditions (EC) (distributed resource, grid equivalent, weather events, faults, generation outages, etc.) and (3) the Designable Elements (DE) (topology, component values, control parameters, etc). In this context, a proper design can be summarized as the selection of certain DE that ensures the fulfillment of the DO in the presence of some EC. The VSC is an AC-DC converter in which the direction of the power flow is determined on the direction of the direct-current (DC) side of the converter. Hence, the VSC DC side is typically connected to large capacitor to resemble a DC voltage source. This allows the usage of unipolar electronic switches to construct these kinds of devices. However, VSC requires reverse-conducting switches (anti parallel diodes) or switch cells which combine both devices. The basic configuration of a two level VSC (half-bridge) is given in Figure 5. From this basic configuration more sophisticated topologies can be realized. The single-phase full bridge, three-phase two-level, neutral point clamping and multilevel configurations are among the most widely adopted and developed.
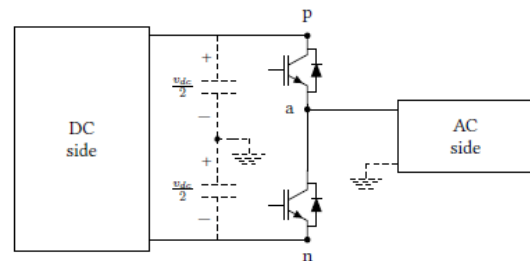

Fig:5. VSC basic structure

This requires understanding in detail the relationships and interactions among these main elements. Fig. 6 shows a very basic representation of a typical DGU and some of the above identified main elements are shown (DO, EC and 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 DE is: distributed resource topology, power electronic topology, AC and DC filter topologies, control unit topology, switching frequency, power switches ratings, DC filter component values and AC filter component values, control unit gains, among others. In order to have a selection of the DE that ensures that the reference design objectives (DOref) are met under bounded variation of certain EC, is then required to understand the relationships between these main elements.
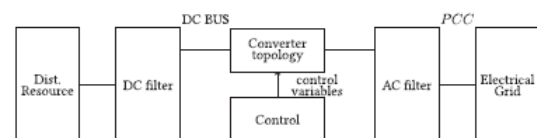

Fig. 6. Simplified layout for design.

Electrical systems can be modeled by Linear Time Periodic (LTP) systems, even in the presence of power electronics if the switching functions that drive them are periodic. However, the discrete nature of these functions make it difficult dealing with time domain periodic discontinuous models. The EHD modeling overrides this limitation and obtains LTI models by considering the harmonic content of the signals in their formulation.
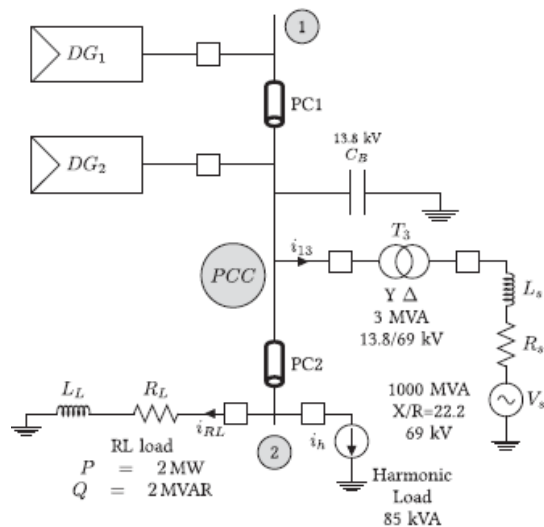

Fig. 7. Microgrid test system.

The proposed microgrid to design is shown in Fig. 7. Three nodes are clearly identified in this system, labeled 1, 2 and PCC respectively. PC1 and PC2 are power cables of different lengths, modeled by a three phase pi equivalent line which connects these nodes. Distributed generation units $DG1$ and $DG2$ are connected to nodes 1 and PCC respectively. The grid is represented by its Thevenin equivalent and is connected to node PCC by means of a power transformer $T3$. A capacitor bank CB is also connected to this node in order to improve the power factor of the microgrid interconnection. A linear load, modeled by LL and RL, along with a three-phase harmonic load, modeled by ih, are connected in node 2. A modular approach, which can easily be automated, is used in order to obtain the EHD modeling of the case study. For this purpose, the test system can be divided into individual subsystems in order to derive their individual EHD matrices, and plug them in into the EHD matrices of the test system model.

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 microgrid test system proposed. The first case considers that no information of the microgrid test system where $DG1$ and $DG2$ will be connected is available, named as isolated design. The second case considers that the microgrid test system where $DG1$ and $DG2$ 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 $DG1$ and $DG2$ which meet as close as possible the reference design objectives of an steady state operation of the case study system.
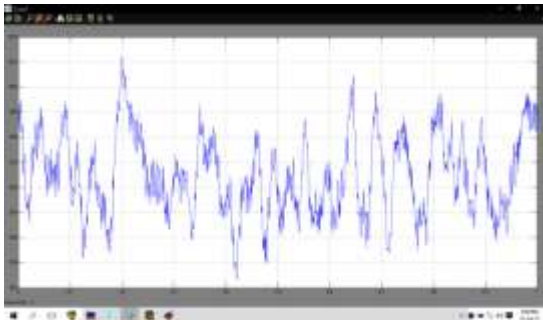
CASE-1: MICROGRID TEST SYSTEM OF AN ISOLATED DESIGN
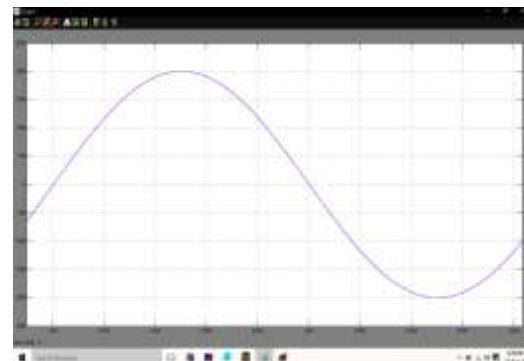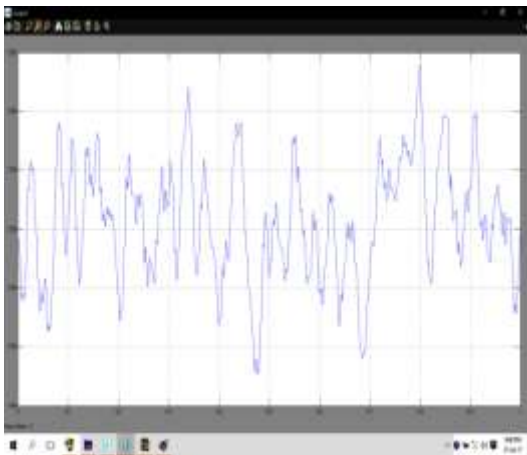

(a) DG1 i11 converter current.
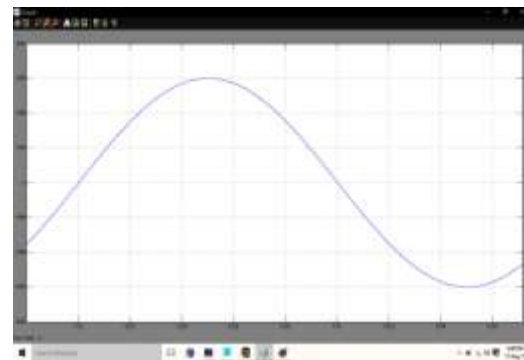
(b) DG2 i21 converter current.
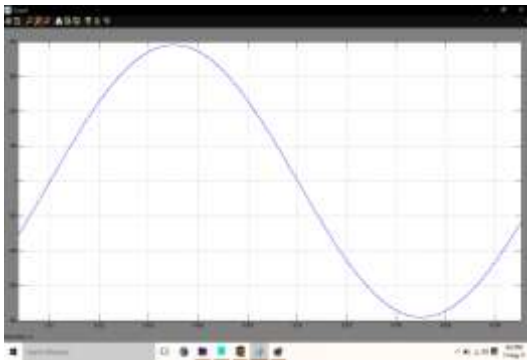
(c) *DG*1 *v1dc* voltage.

*(d) DG*2 *v2dc* voltage.

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

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

Fig:8. simulation waveforms for isolated design Case Study. (a) *DG*1 *i*11 converter current. (b) *DG*2 *i*21 converter current. (c) *DG*1 *v1dc* voltage. (d) *DG*2 *v2dc* voltage. (e) *DG*1 node 1*A* voltage. (f) *DG*2 node 2*A* voltage.

Fig.8, shows some MATLAB/SIMULINK simulated waveforms of *DG*1 and *DG*2 when connected to the test system. From the simulations shown in Fig.8 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.
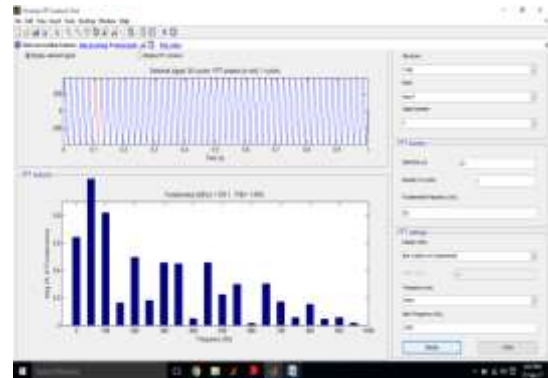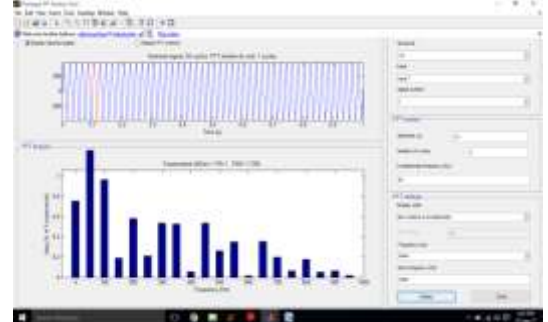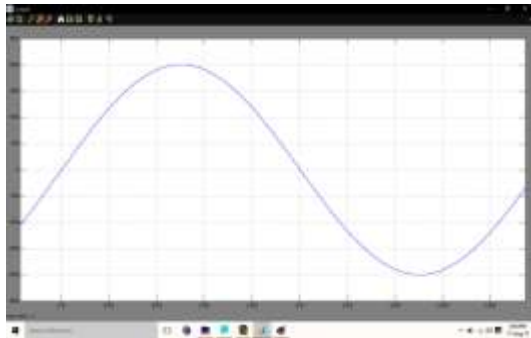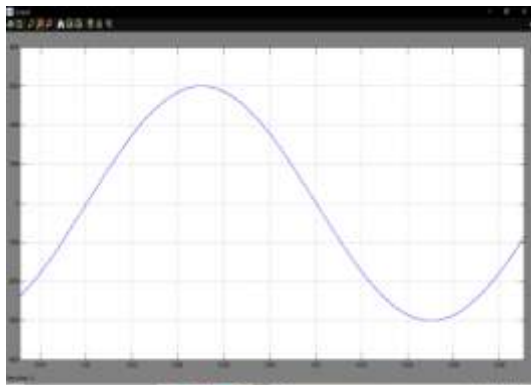

Fig: 9(a)

Fig:9(b)

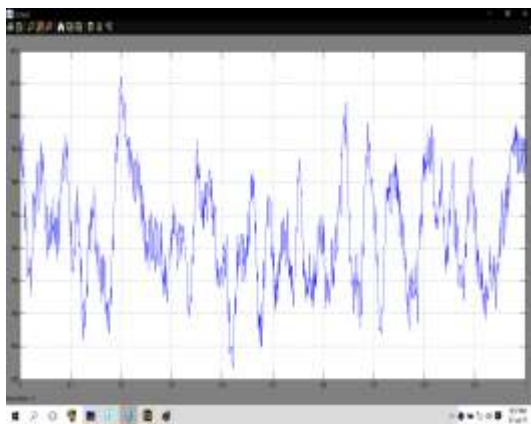Fig:9(a) & (b) shows the THD analysis of isolated design.

CASE-2: MICROGRID TEST SYSTEM OF A COMPREHENSIVE DESIGN

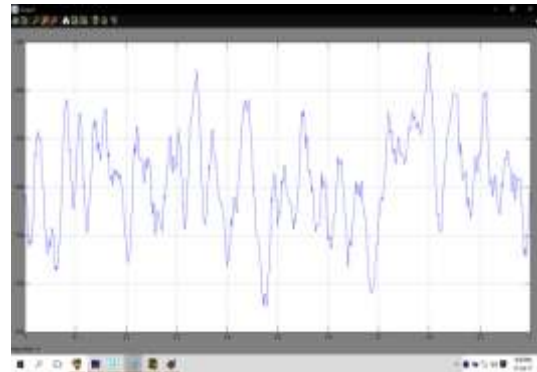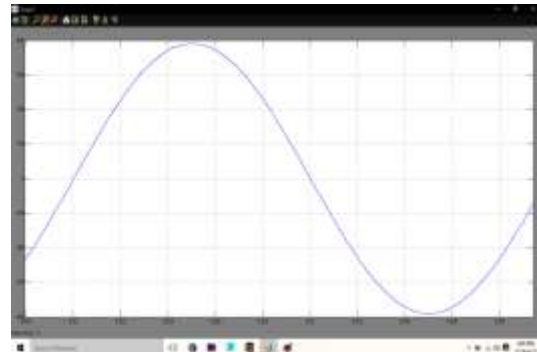(a) $DG1$ $i11$ converter current.
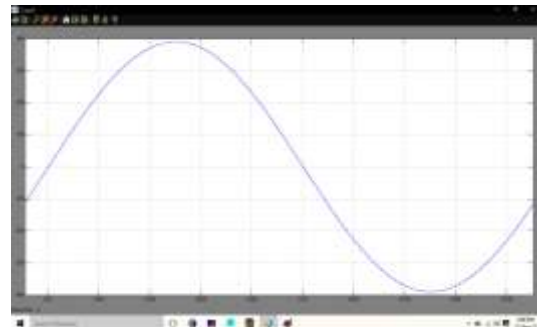

(b) $DG2$ $i21$ converter current.

(c) $DG1$ $v1dc$ voltage.

(d) $DG2$ $v2dc$ voltage.

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

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

Fig:10. 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 this case study, 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

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matlab/simulink simulations of the test system in order to validate the design. Fig.10 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 DOref are 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.
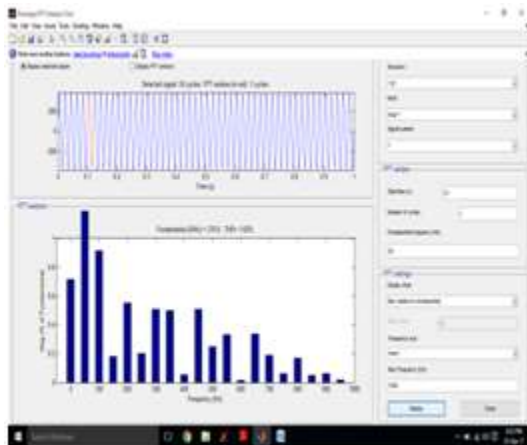

Fig:11(a)

Fig:11(b)

Fig:11(a) & (b) shows the THD analysis of comprehensive design.

V. CONCLUSION

This project 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 possible in 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.

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