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

A Mechanism to Improve the Power Quality of Power Electronic-Based Distributed Generation Units

P Rambabu
Department of Electrical and Electronics Engineering,
SSN Engineering College,
Ongole, Prakasam (Dist.),
A.P - 523002, India.

K Srinivas
Department of Electrical and Electronics Engineering,
SSN Engineering College,
Ongole, Prakasam (Dist.),
A.P - 523002, India.

B Nagaraju
Department of Electrical and Electronics Engineering,
SSN Engineering College,
Ongole, Prakasam (Dist.),
A.P - 523002, India.

ABSTRACT

Distributed generation refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels and combined heat and power. Distributed generation may serve a single structure, such as a home or business, or it may be part of a microgrid (a smaller grid that is also tied into the larger electricity delivery system), such as at a major industrial facility, a military base, or a large college campus. When connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines.

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 widthmodulated-voltage-source inverters (PWM-VSI). The proposed design method is based on a least square solution using the harmonic domain modeling approach to effectively consider explicitly the harmonic characteristics of the DGUs and their direct and cross-coupling interaction with the grid, loads, and the other DGUs. Extensive simulations and analyses against PSCAD are presented in order to show the outstanding performance of the proposed design approach.

Index Terms: ***Harmonic analysis, design optimization, power quality, PWM-VSI***

INTRODUCTION

The electric power system consists of three major functional blocks:-generation, transmission and distribution. As per reliability consideration in power system, generation unit must generate adequate amount of power, transmission unit should supply maximum power over long distances without overloading and distribution system must deliver electric power to each consumer's premises form bulk power systems. Distribution system is located at the end of electric power system and is directly to the consumer, so the power quality depends upon the state of distribution system [1]. The reason for this is that failure in the electric distribution network accounts for about 91% of the average consumer's interruptions. Earlier, power system reliability focussed on generation and transmission system due to capital investment in these.

But today, distribution system is receiving more attention as reliability is concerned. The main cause of terminal voltage fluctuation, transients and waveform distortions on the distribution system are the utility and customer-side disturbances. Now days, power quality engineers are progressively more worried about the quality of electrical power [2]. In modern industries, electronic controllers are used by load equipment, as they are sensitive to poor voltage quality and if supply voltage is depressed they will shut down and may

Cite this article as: P Rambabu, K Srinivas & B Nagaraju, "A Mechanism to Improve the Power Quality of Power Electronic-Based Distributed Generation Units", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 5 Issue 3, 2018, Page 9-21.

operate, if harmonic distortion of the supply voltage is excessive. Electronic switching devices used by new load equipments, can supply poor network voltage quality. Power quality issues are achieving a major concern due to the increase in number of sensitive loads. Also the extensive use of electronic equipment, such as information technology equipment, adjustable speed drives (ASD), arc furnaces, electronic fluorescent lamp ballasts and programmable logic controllers (PLC) have entirely altered the electric loads nature. These loads are the foremost sufferers of power quality problems. The nonlinearity of these loads cause disturbances in the voltage waveform. a utility will likely to deliver a low distortion balanced voltage to its customers, particularly those with sensitive loads.

The design of two DGUs [3], 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.

Electrical Power Distribution System (EPDS)

EPDS holds a pivotal position in entire electrical power system. An electrical power system consists of mainly three components:
1) Generating stations
2) Transmission systems
3) Distribution systems
These three components of electrical power systems are integrated together to supply electricity to consumer. The typical EPDS consists of power distribution networks which consist of high voltage distribution lines having a rating of 11kV, 22kV or 33kV. The traditional power distribution network [4] will have these high voltage lines as overhead lines coming out of the substation. With the modern power distribution network the overhead high voltage distribution lines are being replaced by underground lines to ensure safety, reliability and considering the environmental impact of the power distribution network. In addition to high voltage distribution lines power distribution network consists of transformers and other auxiliary equipment in substations to ensure smooth availability of quality supply power to consumers. PQ [5] has become widely important and is a matter of concern to all of its stakeholders as it directly affects the running of their smooth operations.

PQ Disturbances

PQ is gaining a lot of attention nowadays as the users are more conscious about the quality of electrical supply. However, most of the problems like harmonics, flicker, voltage sag and swell, voltage unbalance, etc., are caused due to the non-linear loads installed by the customers on the demand side of the electrical power system [6]. These non-linear loads draw current that is rich in harmonics, thus making the voltage harmonically polluted (Integral Energy Power Quality and Reliability Center, 2008). Power utilities across the board aim to maintain the voltage with constant amplitude and frequency without any distortion. For linear loads e.g. heaters, incandescent lamps and any equipment containing only resistive elements, the current drawn is also linear i.e. sinusoidal. However, when the customer's load gets non-linear the current drawn also gets non-sinusoidal which leads to harmonic distortion. For non-sinusoidal conditions the harmonically distorted waveforms are made up of harmonic frequencies with different amplitudes (Hossam-Eldin & Hasan, 2006). The normal, sag and swell waveform for a power distribution network is shown Figure 2-1.

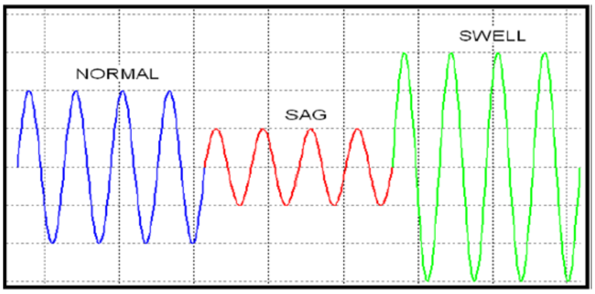


Fig:2.1. Sag, Swell and Normal waveform (Paracha & Kalam, 2009)

The Root Mean Square (RMS) value of voltage to detect variation in voltage is given

$$V_x^{rms} = \sqrt{\frac{1}{N}\sum_{y}^{V_y^2} V_y^2} \qquad (2.1)$$

Where N is the number of samples of voltage waveform, is the sample and is the sample of the measured voltage respectively.

The most common issues on utility side are voltage sag and swell. They occur frequently in a power distribution network. Power utility engineers are concerned with these PQ disturbances as they can be disastrous for customer's equipment. Sag and swell noise and overvoltage disturbances are not strictly unaffordable, especially in industrial sector where the equipment is very costly. These voltage disturbances beside other abnormalities can cause permanent damage to the sensitive equipment, if they occur frequently or remain in the power distribution system for longer duration then the limits set by the power utilities [7].

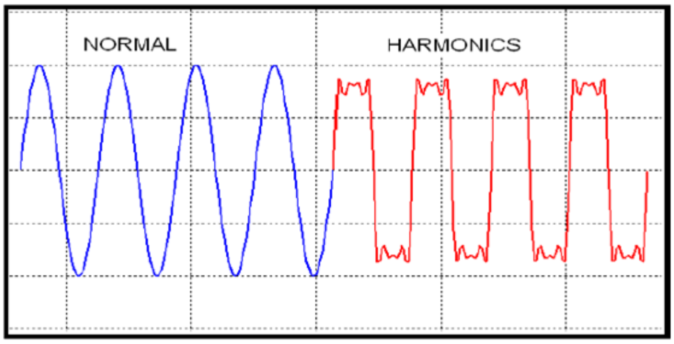


Fig:2.2. Normal and harmonic waveforms (Paracha & Kalam, 2009)

Thus it becomes essential for power utility engineers to analyse the wave shape of the current drawn by non-linear loads. These loads include modern electronic equipment like super computers, variable speed drives, modern electronic ballasts, and other equipment which operates on continuous switching mechanism. Harmonic distortion is found in both the voltage and the current waveforms in power distribution networks and can be given as

$$V_{rms} = \sqrt{\sum_{h=1}^{h_{max}} (\frac{1}{\sqrt{2}}V_h)^2} = \frac{1}{\sqrt{2}}\sqrt{(V_1^2 + V_2^2 + V_3^2 + \dots\dots\dots + V_{h_{max}}^2)} \qquad (2.2)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{h_{max}} (\frac{1}{\sqrt{2}}I_h)^2} = \frac{1}{\sqrt{2}}\sqrt{(I_1^2 + I_2^2 + I_3^2 + \dots\dots\dots + I_{h_{max}}^2)} \qquad (2.3)$$

Equations (2.2) and (2.3) give the RMS values of voltages and currents for the non-sinusoidal waveforms where and are the amplitude of voltage and current respectively at the harmonic component h. The total harmonic distortion (THD) [8] which is a measure of the harmonic component present in a distorted waveform can be expressed as in equation (2.4)

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} (M_h)^2}}{M_1} \qquad (2.4)$$

where is the RMS value of harmonic component h.

PQ Monitoring

In electrical power system the monitoring and management of PQ data has become immensely important because of demand of continuous availability of quality power supply to consumers on sustainable basis. The main problem faced by modern power utilities today is the unpredictability of the power system behaviour due to unexpected PQ problems. PQ monitoring is necessary to characterize the electric phenomenon at a particular location of the power distribution network. It is done by power utilities to run the power system operations with a view to provide quality power supply to customers without interruption on sustainable basis.

With the increased customer completion and greater regulatory requirements more efficient and advanced signal processing techniques (Bollen & Gu, 2006) are required to monitor the PQ issues for enhanced system performance of the EPDS [9]. PQ is measured and recorded by sensors installed at various locations of the utility networks. Mostly these sensors are modern sophisticated technology based equipment that can store the data for a very long time. Power utilities face the challenge to manage their large network for PQ monitoring and intelligent decision and separation of useful PQ data from the raw PQ data. Engineers and researchers are working towards the efficient data mining techniques to fetch useful data out of the huge recorded data (Price, 1993).

Conventional Methods of PQ Monitoring

The conventional methods of monitoring PQ data in electrical power system is based on collecting the power system operating data, inspecting the waveform visually and identifying the PQ disturbance that is present in that data. The greatest disadvantage of this methodology is that it is very slow and cannot address the requirement of modern electrical power system [10]. Moreover, lot of manual work leads to inaccuracy and rectification of problems becomes a huge task for the power system engineer. Today, PQ monitoring cannot be compromised and power utilities consider it as an essential service for their industrial and commercial customers (Gunther, 1999).

PQ Monitoring In Present Power Distribution Networks

PQ monitoring is becoming a necessity for every industry working in power transmission, distribution and generation, as load is becoming sensitive and is likely to be damaged by slight change in voltage parameters. The present day EPDS employ the technology i.e. installation of PQ meters are various point of the distribution network to do the PQ analysis.

Several researchers have devised and implemented indices for PQ monitoring in distribution networks (Nicholson et al., 2008). Until recently the main focus of research was to perform statistical analysis and characterize typical quantities such as magnitude and duration of the disturbances. In essence, estimate/predict the tendencies of particular phenomenon as a function of historical indices. However, there is marked shift in present day research and the main focus is now on the reliability and performance enhancement of electric power system, while considering PQ disturbances (Mertens et al., 2007).

PQ Monitoring in Future Power Distribution Networks

Over the years numerous techniques, methods and tools have been employed for PQ monitoring in power distribution network. However, newer systems based on intelligent techniques like Artificial Intelligence (AI), Fuzzy logic, Artificial Neuro-Fuzzy Inference Systems (ANFIS) based on computational intelligence are reducing the difficulty of data mining (Chuang et al., 2005, Morsi & El-Hawary, 2009, Nath & Sinha, 2009, Njoroge, 2005).

In recent times the extensive use of non-linear loads especially in industry has made it quite difficult to achieve accuracy for the measurement of amount of harmonics generated by customer’s equipment. Cheng-Long et al. worked on recognition of multiple PQ disturbances in two parts using wavelet-based neural networks (Chuang et al., 2005). He was successful in implementing his technique by graphical user interface (GUI) computer program but the proposed intelligent system lacked the actual measurement of real PQ events. A. K. Chandel et al. in his research work has also developed a wavelet based artificial neural network classifier using MATLAB/SIMULINK to recognize PQ disturbances but his research also lacks the actual field results of different PQ problems encountered by electrical power distribution network (Chilukuri et al., 2004).

DISTRIBUTED GENERATION

Distributed Generation (DG) is not a new phenomenon. Prior to the advent of alternating current and large-scale steam turbines during the initial phase of the electric power industry in the early 20th century - all energy requirements, including heating, cooling, lighting, and motive power, were supplied at (or) near their point of utilization. Technical advances, economies of scale in power production and delivery, the expanding role of electricity in human life, and its accompanying regulation as a public utility, all gradually converged to enable the network of giga watt-scale thermal power plants located far from urban centers that we know

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

today, with high-voltage transmission and lower voltage distribution lines carrying electricity to virtually every business, facility, and home in the country.

Distributed generation can be defined as an electrical source connected to the power system, in a point very close to/or at consumer's site, which is small enough compared with the centralized power plants. At the same time this system [11] of central generation was evolving, some customers found it economically advantageous to install and operate their own electric power and thermal energy systems, particularly in the industrial sector.

ISLANDING OF A POWER NETWORK

According to islanding occurs when the distributed generator (or group of distributed generators) continues to energize a portion of the utility system that has been separated from the main utility system. Moreover, islanding only can be supported if the generator(s) can self excite and maintain the load in the islanded area. This situation is shown in Fig.3.1 below.

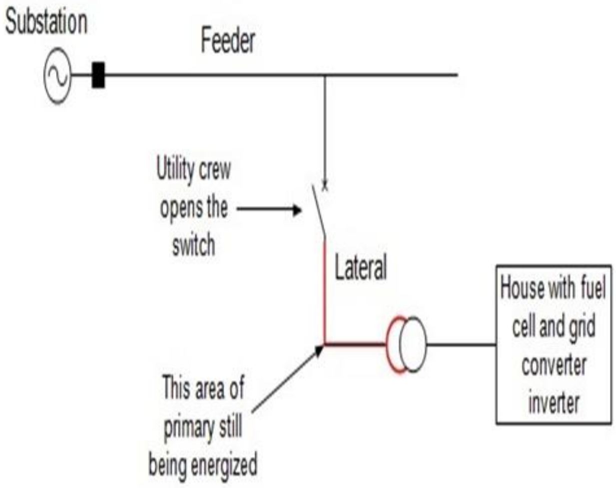


Fig.3.1. Islanded mode of an area in the power system.

This separation could be due to operation of an upstream breaker, fuse, or automatic sectionalizing switch. As it is shown in Fig. 3.1, manual switching or "open" upstream conductors could also lead to islanding. In most of the cases this is not desirable as the reconnection of the islanded part becomes complicated, mainly when automatic reclosing is used.

FORMS OF DISTRIBUTED GENERATION:

MICRO-TURBINES:

Micro-turbines are scaled down turbine engines with integrated generators and power electronics. They are generally characterized by having only one rapidly moving part (moving at 100,000 rpm) supported either by air- or liquid-lubricated bearings. The micro-turbine generates high-frequency AC power that is rectified by a power electronics package into utility grid-quality, three-phase 400-480v AC power. Micro-turbines can operate on a wide variety of gaseous and liquid fuels, and have extremely low emissions of nitrogen oxides.

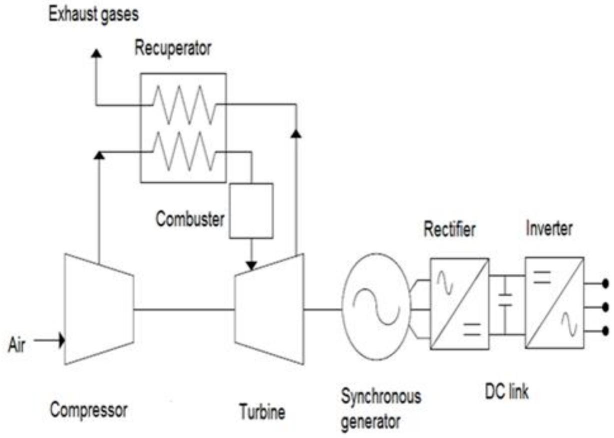


Fig.3.3 Schematic diagram of a micro-turbine

Fig.3.4 Capstone Microturbine, 30Kw

Although the latest combined cycle gas turbines can achieve maximum output efficiencies nearing 60 percent, the US Environmental Protection Agency and the Department of Energy [12] notes that average power plant efficiency in the country is 34 percent. Since 5-10 percent of that is lost in transmission and distribution, the national average may actually be about the same as that of on-site microturbines without heat recovery.

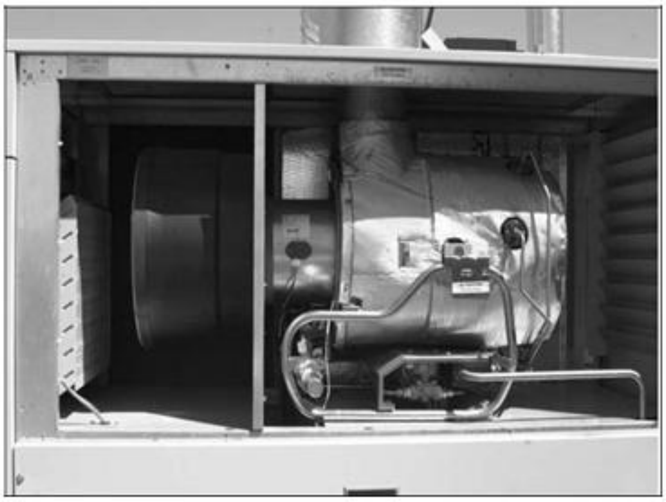


Fig.3.5 Capstone Microturbine, 60kW

MODELING OF VOLTAGE SOURCE CONVERTER BASED ON THE EXTENDED HARMONIC DOMAIN

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.

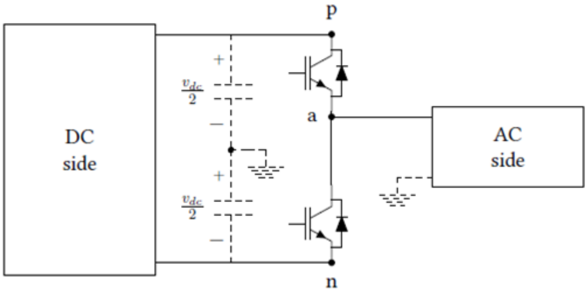


Fig:4.1. VSC basic structure

Advantages of EHD models for power electronic converters

The main purpose of using the EHD models on power switched based systems is to work with a mathematical model that explicitly includes the harmonic distortion in its formulation. From these models, the performed analysis is much more accurate because it explicitly considers the switching functions of the power switches. The effects of these discontinuous functions over the systems signals are directly related to the switching frequency and the modulation technique used.

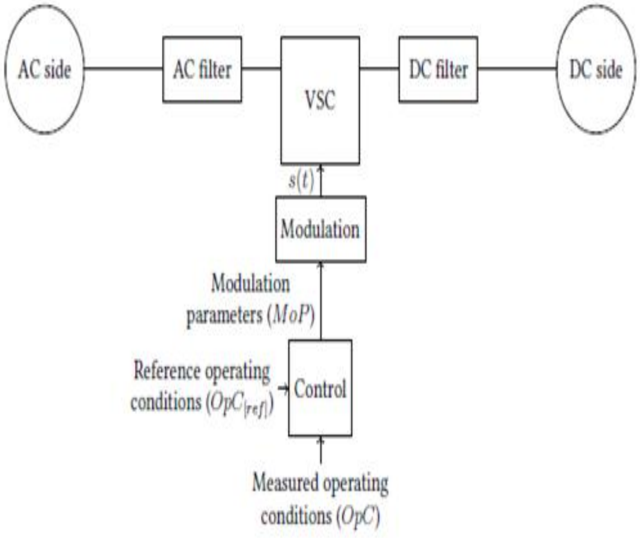


Fig:4.2. General structure of a VSC based power system.

Since the EHD modeling approach properly includes those characteristics on its formulation, the decisions made and the conclusions obtained, especially those relating to harmonic behavior, will be more reliable than the ones offered by other models that do not explicitly include the harmonic distortion in their formulation. A general structure of a two level three phase VSC-based converter is presented in Figure 4.2. In this Figure, the VSC control inputs are a set of discrete signals (s(t)) generated in the modulation block. The inputs to this block are the modulation parameters (MoP), i.e. for SPWM, THPWM and SVPWM modulation techniques. These parameters could be fixed or established by the control strategy as controls signals. If the control block works as designed, the MoPs eventually will settle around steady-state values for which the system meets imposed references. The AC filter and DC filter mitigate the harmonic distortion on both sides of the converter, for which, their passive component values (PCV) have to be designed to maintain the filter output signals within the required levels of harmonic distortion. Hence, the overall steady-state performance of the system is determined by the values of both, the PCV s and the MoPs. Any modification in the PCV s of any filter will be reflected in the MoPs required to meet the reference operating conditions (OpC[ref]) of the control system. Average time domain models are unable to properly perform detailed analyses and designs of VSC-based systems since they do not provide enough information about the interaction between the PCV s, theMoPs and the operating conditions (OpC) in the system while the harmonic content of the signals is considered. The EHD is a better modeling domain since the consideration of the harmonics in the power network is allowed as state variables in a linear time-invariant (LTI) model [9].

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. This requires understanding in detail the relationships and interactions among these main elements. Fig. 5.1 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. 5.1 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 are: 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.

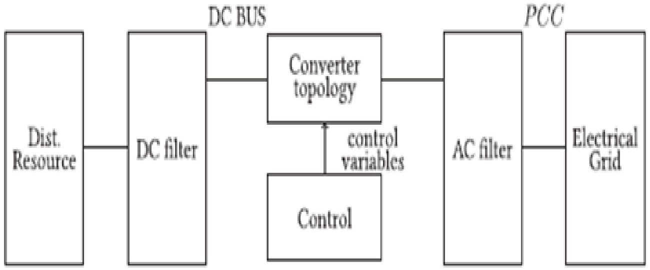


Fig:5.1. Simplified layout for design.

DESIGN CHALLENGES OF DGUS

It is clear that the relationships between the DO and the DE are far from linear and decoupled. Fig. 5.2 shows schematically an insight of the intricate relationships among the DO, DE and EC; depicted by grey circles, blue ovals and green squares, respectively. The pointing arrows between these elements are links with the elements that have influence on or relation to the final value of them. Solid and dashed lines represent strong and weak interactions, respectively.

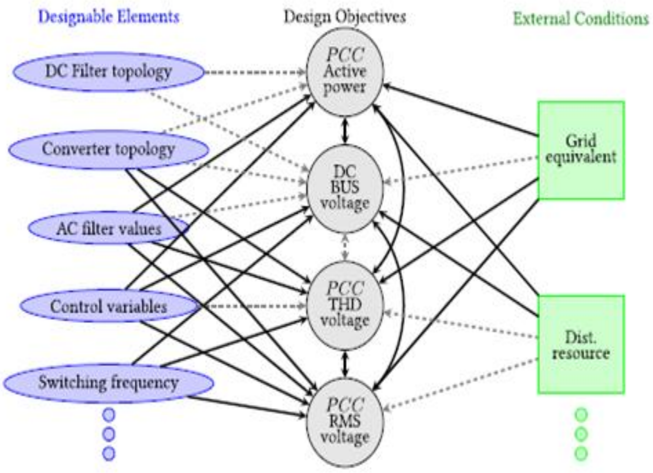


Fig:5.2. Relationship between designable elements (DE), design objectives (DO) and external conditions (EC).

Fig. 5.2 shows an insight of the challenges in the designing of DGUs. Some of the most common practices used to tackle them are: (1) settle many of the designable elements based on experience and a priory knowledge, especially those in respect the topology, (2) decouple the relationships by considering only the most relevant designable elements for each design objective, (3) neglect some design objectives focusing only on the most important. However, it is clear that as long as more and better mathematical representations of these relationships are provided, better and more reliable designs will be obtained; this is the basis of the presented design proposal, to use the vast amount of information provided by using the harmonic domain model in order to describe the relationships and formulate the nonlinear problems enabling to accurately calculate the designable elements [11].

EXTENDED HARMONIC DOMAIN MODELING OF DGUS

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 [9-12] over rides this limitation and obtains LTI models by considering the harmonic content of the signals in their formulation. In this way, any time domain LTP system can be modeled as an LTI EHD model. The design proposal can be used in power electronic systems able to be modeled in the EHD. A proper implementation considers that the Designable Elements (DE) are involved in the matrices A and/or B of the EHD model.

In this way, for a given set of DE arranged in the unknown vector x, a set of calculated design objectives (DOcal) can be obtained from Xss. Hence, an optimization problem based on the nonlinear least square (NLSQ) methodology is proposed where the unknown vector x is calculated in order to obtain an EHD model performance in which the DOcal meet (as close as possible) their corresponding reference values DOref.

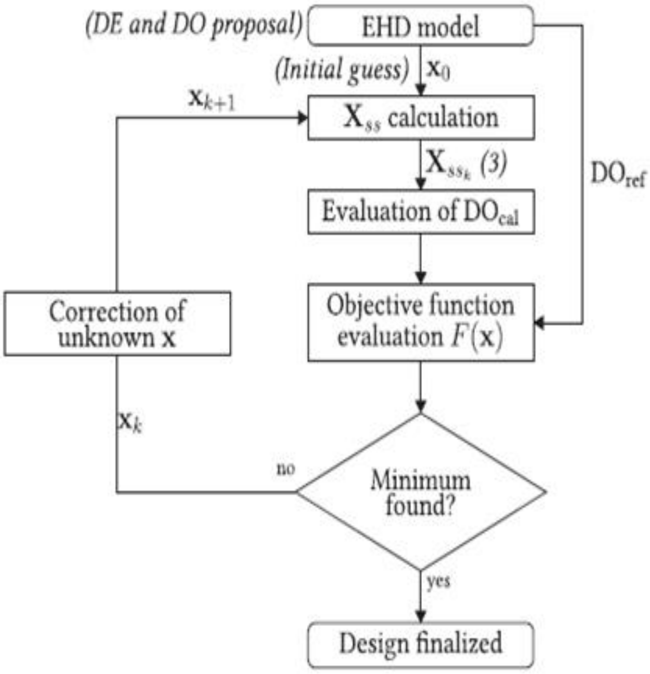


Fig:5.3. Design algorithm of power converter optimization.

Fig. 5.3 depicts the proposed design algorithm. Notice that in order to evaluate the objective function F(x), it is required to calculate the values of DOcaln (x) at the k-th evaluation of the iterative numerical solution. This information is obtained from the steady state solution of the EHD model, which can be calculated from the k-th unknown vector x of DE. The flexibility offered by the NLSQ gives the possibility to obtain many different solutions for the same system, depending on the approach used in the formulation. These approaches are mainly dictated by the proposed design objectives along with their weight constants. As long as the number of DO is equal or greater than the number of DE and a mathematical relationship between them exist, the algorithm is able to be used. More complex design objectives can be included, such as, price, the reliability, size, weight, temperature and switching losses, etc., if those are calculated from the EHD model steady state solution Xss. The DOref of this paper are based on power-quality indexes, in order to show the capability of the proposed design approach and give an insight of its potential.

HARMONIC MODEL OF THE MICROGRID TEST SYSTEM

The proposed microgrid to design is shown in Fig. 5.4. 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 connect these nodes. Distributed generation units DG1 and DG2 are connected to nodes 1 and PCC [11] respectively.

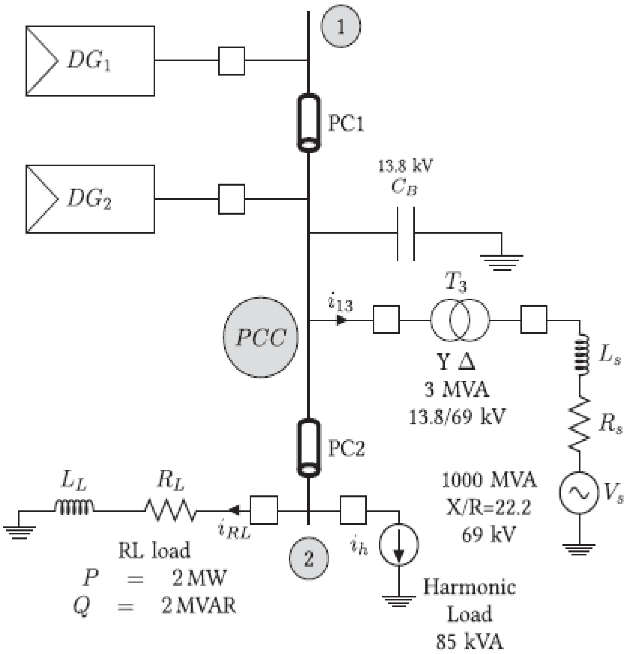


Fig:5.4. Microgrid test system.

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 in Fig. 5.4. The first case considers that no information of the microgrid test system where DG1 andDG2 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.

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

CASE-1: MICROGRID TEST SYSTEM OF AN ISOLATED DESIGN

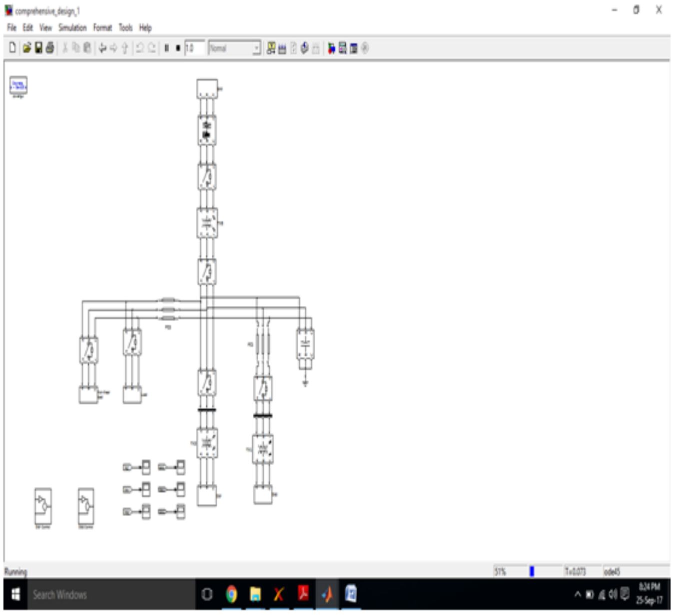
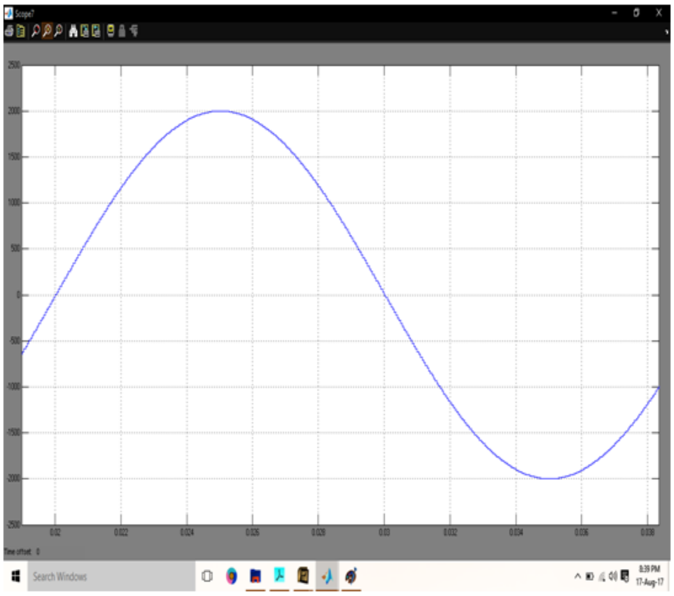
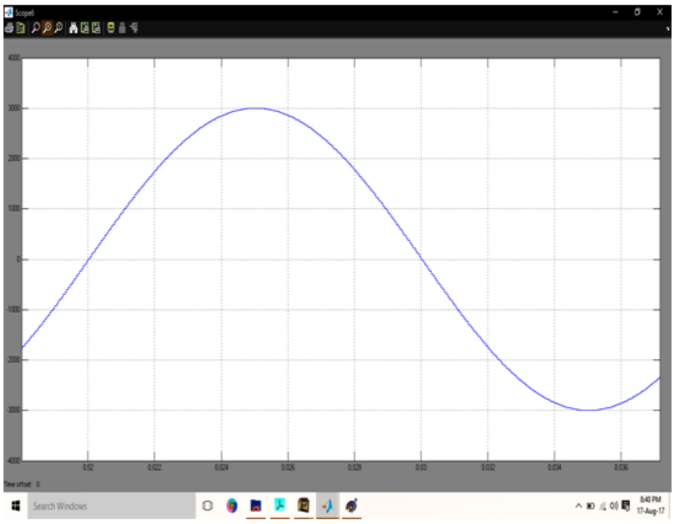


Fig:6.1. Simulation diagram of a microgrid test system of an isolated design

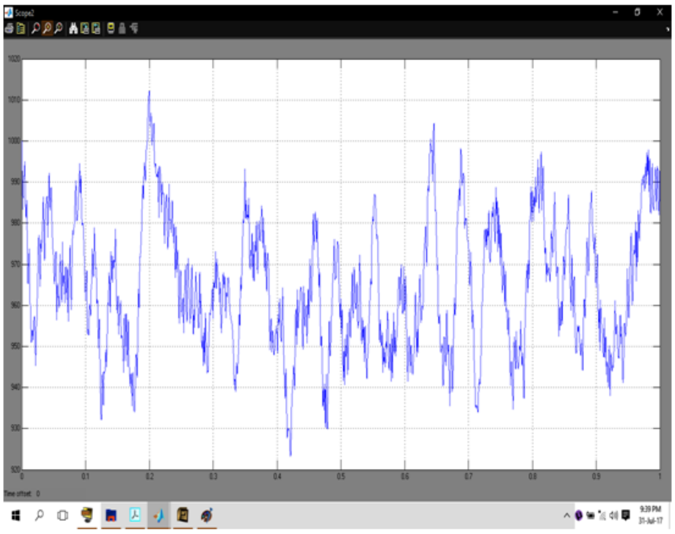
Fig. 6.2, shows some MATLAB/SIMULINK simulated waveforms of DG1 and DG2 when connected to the test system. From the simulations shown in Fig. 6.2 it can be seen that waveforms are practically overlapped. This validates the EHD model used to obtain the designable elements and the design approach proposed.



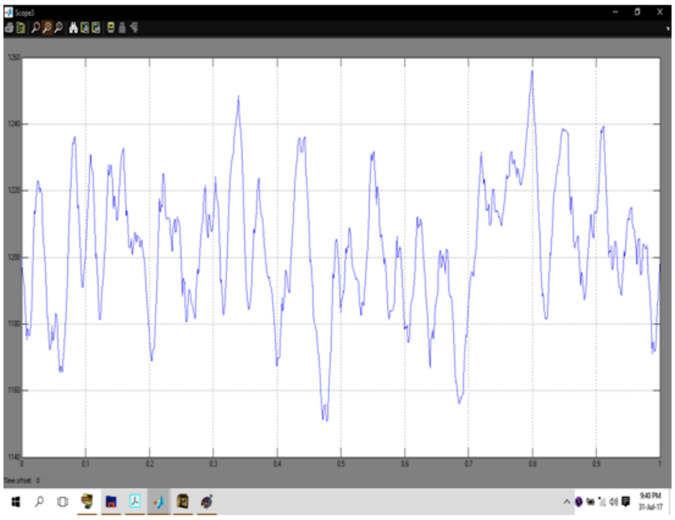
(a) DG1 i11 converter current.



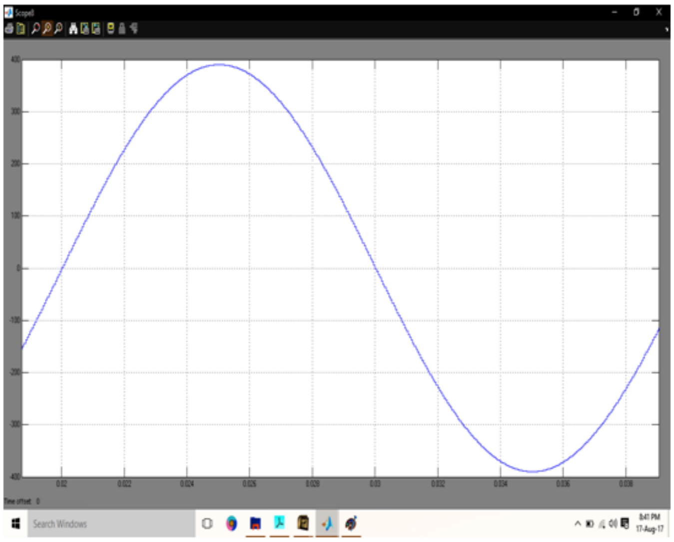
(b) DG2 i21 converter current.



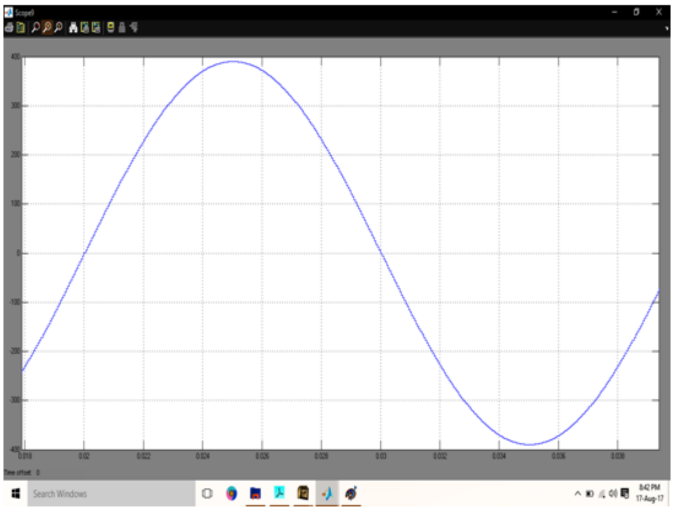
(c) DG1 v1dc voltage.



(d) DG2 v2dc voltage.



(e) DG1 node 1A voltage.



(f) DG2 node 2A voltage.

Fig:6.2. simulation waveforms for isolated 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.

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.

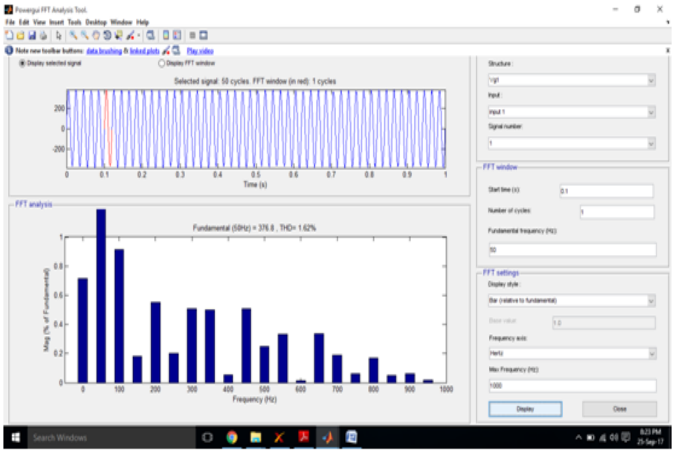


Fig:6.3(a)

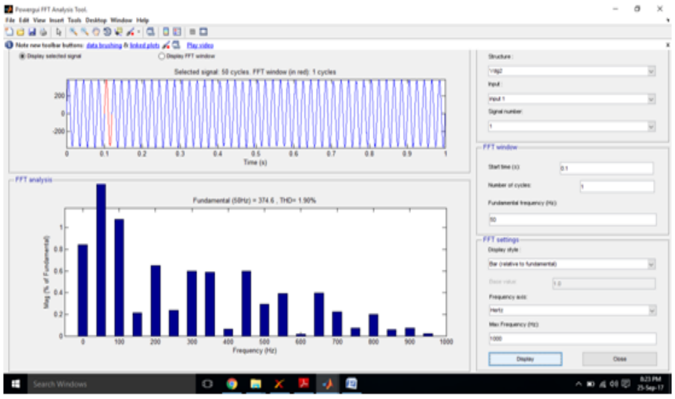


Fig:6.3(b)

Fig:6.3 THD waveforms of the isolated design system.

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.

CONCLUSION

Based on the modeling proposals mentioned above, several applications were proposed to show the benefits and capabilities offered by the system modeling. The Exact Design (ED) methodology for the selection passive component values, based on the fulfillment of power quality indexes was introduces. This methodology is based on the also introduced computation of steady-state modulation parameters (CMMPS) methodology which allows the obtaining of the required modulation parameters form which the VSC-based system behaves under certain desired operating conditions. This project has introduced a novel design methodology based on optimization and the system design system 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.

FUTURE SCOPE

The present study is performed with two inverters having identical anti-islanding mechanism. In a high penetration PV case, inverters with distinctly different anti-islanding mechanisms may be operating in parallel. Such a scenario needs to be studied to evaluate the interaction of the different anti-islanding methods and their efficacy when used in parallel. With an increasing PV penetration level, it becomes imperative to analyze the impact of PV generation on the sub-transmission system. During a power ex-port scenario the distribution system behaves like a generating source, which has both single phase, and three phase generation with a power electronic interface. Developing suitable models of these sources and studying their impact on the sub-transmission system could be an interesting research avenue.

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,” IEEE Trans. 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.

[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. Power Del., 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.

[11] X. Wen, Y. W. Li, and J. He, “A distribution system harmonic compensation approach using DG-grid interfacing converters at low switching frequency,” in Proc. 29th Annu. IEEE Appl. Power Electron. Conf. Expo., Mar. 2014, pp. 995–1001.

[12] J. He, Y. W. Li, R. Wang, and C. Zhang, “Analysis and Mitigation of Resonance Propagation in Grid-Connected and Islanding Microgrids,” IEEE Trans. Energy Convers., vol. 30, no. 1, pp. 70–81, Mar. 2015.