

Compensation of Current Harmonic Components of Nonlinear Loads in Presence of Distributed Generation Resources Using Multi-Criteria Vector Control

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Abstract – Filtering the harmonics produced by nonlinear loads in power systems is an important issue for the engineers to follow. In most cases, to this end, active filters have been used. In this paper, however, it is shown that this task can be accomplished using a Multi-Criteria algorithm and distributed generations (DGs) resources. In the proposed algorithm, when the DGs are connected to the main network, compensations of active and reactive powers as well as harmonic components are possible. To do so, first, the dynamical model of the systems will be shown in details in the static three-phase system, and then, they are transferred to a rotating orthogonal set using the necessary conversion equations. Therefore, the transferred variables are used to control the voltage source converters in order to achieve improvements in DGs' behavior when they are connected to the network. In this control method, the active and reactive powers transmitted to the load as well as the current harmonics are compensated using samples of voltages and currents taken at the connection points; thus capabilities for sinusoidal current and maximum active power transmissions are provided. Besides, the control proposed method has a fast dynamical response in active and reactive power compensations. Therefore, using this control approach, the transmitted power of DGs to the network are maximized, the power coefficient factor is improved and current harmonics of the load are decreased significantly.

Keywords: Distributed Generation resources, Nonlinear loads, Multi-Criteria vector control, Harmonic compensation

1. Introduction

The Distributed Generation (DG) resources, also known as a centric energy resources, are preferred in the power systems much higher than the central one. DGs are existed in variable kinds and different sizes. To mention a few, the wind, the Photovoltaic (PV) and hydraulic resources can be mentioned among many others. The advantages of the DGs can be analyzed from different perspectives. Firstly, they have no undesirable effects on the environments against the destructive influences of fossil resources and thus they bring no environmental and biological concerns [1-2]. Second, with the usage of DGs, dangers of frequency and voltage collapses have disappeared and the network will be more reliable. From a different viewpoint, the efficiency of the network will be increased in presence of DG as they are directly connected to the distribution networks [3, 4]. In addition, due to the advancement of the semiconductors manufacturing technologies, power electronic devices and permanent magnet materials, costs of DGs has experienced

decreasing behavior and there are much hopes to increase their benefits greatly higher [5]. The DGs' technologies, can benefit from the conventional energy resources such as diesel generators, turbines and so forth along with the renewable energy resources.

During the last two decades, intensive decrease in the electricity generation in small scales (such as DGs) and requirement to higher reliable power supply by the customers have made the utilities to widen the DGs developments, specifically in the rivalry electricity provisions [6]. At any rates, increase in DGs utilization in the whole electric network has increased the need for more studies, required more accurate control methods in order to increase in the system reliability, load compensations and probable damages to the network. Thus, as a reasonable consequence, DG controllers must able to satisfy the network requirements. This indicate that to access desirable controllers of DGs, all the network's scenarios much be taken into account. Among researches, there are varieties of control methods to upgrade the networks' conditions when they have bring DGs into usage [7]. As an example, in [8], authors have provided a survey of different control approaches and ways to realize them in practice. In other studies, different hardware designs of DGs' control methods for the network side converter, and in the presence of fault occurrence within the DG coverage areas have been analyzed [9, 10, and 11]. Various techniques have been

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implemented such as conversion of the static three phase frames into rotating orthogonal, static orthogonal, or static three phase frames and furthermore, their pros and cons have been respectively evaluated [12]. In [13], also, different types of controllers within DGs have been put into discussion and the corresponding abilities of each one in load compensation and current harmonic reduction (low level harmonic compensations) presented. Finally, [14] provided a brief survey and analysis of synchronism methods of DGS to the network, either in normal condition, or in the presence of faults in the network.

In this paper, a converter in the form of an active inductor for a specific frequency has been proposed in order for absorption of current harmonic components. The calculation of the values of the inductor is a difficult task and is prone to reduction when the performance of the proposed controller is considered. In fact, power systems confront unpredictable disturbances and uncertainties which add much complexities into the design of the network-side converter. To achieve reliability with respect to elimination of the network disturbances, inclusion of the intensive changes in converter's parameters and uncertainties, adaptive internal models are included within the current feedback structures for the voltages of capacitors and dynamics of the current in the network side. In [17], a control algorithm is designed for the three-phase voltage source (VSC) in order to integrate the renewable energy resources with the network using the output of either an RL or LCL filters. The proposed controller provided the necessary damping and performance improvement through tuning the LCL circuit to the resonance frequency of the network (and impedance uncertainties). The inclusions of uncertainties in control methods are represented in [18]; this action is essential to study their effects on the power lines and for the purposes of amendment in the voltage profile.

This paper proposes a multi-criteria control algorithm for the network side converter in the presence of DGs. In the proposed algorithm, using samples of voltages and currents at the connection points, the active and reactive powers transmitted to the load as well as the load currents harmonics are compensated, and thus capability of sinusoidal current and maximum active power transmitted to the load is provided. Moreover, the suggested control algorithm provides highly fast dynamical responses for the compensations of active and reactive powers. Lastly, the paper justifies the improvements using simulations of the dynamical system within the MATLAB/SIMULINK environment.

2. Proposed DG Model

Fig.1 illustrates the schematic diagrams of the proposed system. The formal directions of voltages and currents are shown within the figure. In this model, R_c and L_c , respectively, represent the equivalent of resistance and inductance of the ac filter (the coupling transformer and the connection cables). The R_s and L_s , depict the equivalent resistance and inductance of the power line in order to include the roles played by the Line transformer and the related cables. The v_k ($k=1, 2$ and 3) are voltages of the sources' phases at PCC point, v_{sk} , the network's phase voltage components, v_{dc} , the voltage of dc link and finally, i_{sk} , i_{ck} and i_{lk} , accordingly, the currents of the network, DG and load. In addition, the energy resource of DG and its involved accessories is modeled in this figure using a current source connected to the dc link and dc side of the converter.

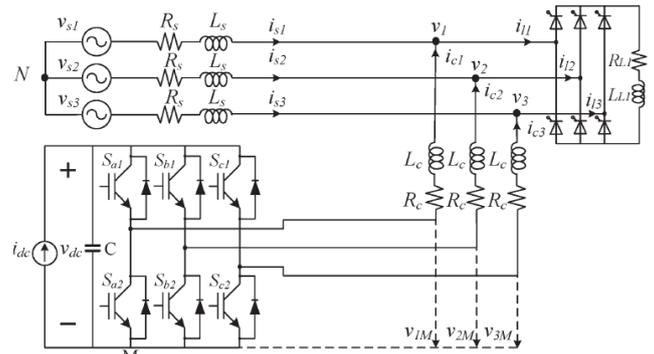


Fig. 1: The schematic circuit of the proposed system

3. Voltages and Currents Components in Different Reference Frames

The proposed control methods of this study are based on representation of the voltages and currents in different reference frames, such as, static three phase (abc), two phase orthogonal static ($\alpha\beta$) and rotating orthogonal two phase (dq). Using the Clark transform, the instantaneous voltages and currents of three phase system can be converted to the corresponding values in the $\alpha\beta$ two phase orthogonal reference frame. In the following, using the relationships between two reference frames, the $\alpha\beta$ two phase orthogonal values can be converted to the equivalent ones in the orthogonal two phase dq frame. In the steady state, it can be said that voltages and currents of the different points rotate synchronously following the rotation of dq frame from which, all the variables of the old frames would

be seen as constant versus time. In such a case, control process and filtering are much simpler than before. Figs. 2 and 3 illustrate specific voltage and current components in two reference frames, i.e., $\alpha\beta$ and dq . Using these transforms, when voltage is in the d direction, the vertical component $v_q=0$ along with all the times. Therefore, the instantaneous angle of network voltage can be derived from the following,

$$\theta = \tan^{-1} \frac{v_\beta}{v_\alpha} \quad (1)$$

In other words, if we consider the instantaneous angle of the load voltage according to (1), the reference voltage, totally, will be in the d direction and thus, there would be no vertical components at all. Considering the Fig. 2, the voltage amplitude at PCC points can be obtained as,

$$v_{ref} = |v_d| = |v_{dq}| = |v_{\alpha\beta}| = \sqrt{v_\alpha^2 + v_\beta^2} \quad (2)$$

In the next steps, the current references of the DG control method, regarding the proposed control systems are produced and applied to the system.

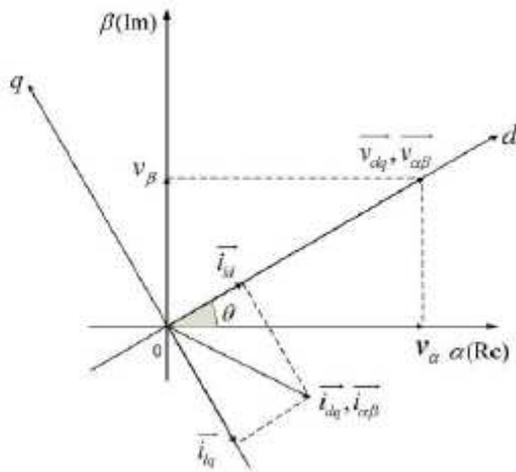


Fig. 2: The voltages and currents in difference references frames

3.1. Calculation of Current Reference for Injection to the Load Active Power at PCC points

Regarding the main frequency of the system, the injected power of DG to the load at the point PCC can be derived as:

$$P = \frac{3}{2} (v_d I_{cd} + v_q I_{cq}) \quad (3)$$

In which, the capital letters represent the main frequency of currents. Now, taking the vertical component of the voltage as zero $v_q=0$, the horizontal reference current for provisioning the horizontal current necessary to show active power on the right frequency will be:

$$I_{cd}^* = \frac{2 P_{ref}}{3 v_d} \quad (4)$$

where P_{ref} is the maximum converter power at the main frequency and I_{cd}^* , the horizontal current component of DG at the main frequency. Due to the limited output power of the VSC converter, the reference current must also be limited. Calculation of the DG's horizontal component reference current out of the proposed method will provide the conditions in which for a variety of cases, by tuning the P_{ref} , the maximum active powers would be transmitted by DG to the network. It is worthy to be noted that the values of P_{ref} depends on capacity of DG unit, values of power electronics, and the transformers.

3.2. Calculation of Reference Current Harmonics of d Direction

Within the rotating dq reference frame, the main current components can be viewed as a dc components and as a result, the harmonic currents of the load can be filtered using High Pass Filters (HPFs). The main problem of this method is the large delays when using the digital filters. In order to consider the phase effect of the high pass filter using a low pass filter, the Minimum Phase of the High Pass Filter (MPHPF) can be obtained and the corresponding cut-off frequency of this low pass filter would be as that one in the high pass filter. Therefore, the simplest high pass filter with minimum phase response can be calculated as in

$$H_{MPHPF}(s) = 1 - H_{LPF}(s)$$

To achieve this filtering goal, a Chebyshev of the second type and fifth order is suggested. Here, the cut-off frequency would be $f_c=f/2$ which is able to extract DC harmonic current components of a nonlinear load. Thus, i_{ld} can be derived as:

$$i_{ld} = \tilde{i}_{ld} + I_{ld} \quad (5)$$

in which, the i_{ld} is the alternate current of the load in the direction of straight direction, which also is related to the harmonic contents of the current load, and I_{ld} , the main harmonic of the load current which is dependent on the main load current [7].

In order to use the DG as an active filter, the harmonic

components of the nonlinear load currents must be supplied. To satisfy this end, the nonlinear reference current component in straight axis should be the sum of currents in (4) and periodic member in (5):

$$i_{cd}^* = \tilde{i}_{id} + I_{cd}^* \quad (6)$$

3.3. Calculation of Current Reference for Active Power Supply of Load

In the two phase orthogonal rotating frame dq , the vertical component of the current load is orthogonal to the horizontal voltage components. As a general conclusion, the vertical component of load current represents its demand of reactive power. In order to compensate for the reactive power of the load, DGs have to produce vertical axis component as much as load demand i_{iq} . To do so, the vertical axis current of DG needs to be equal to the vertical component of the load current:

$$i_{cd}^* = i_{iq} \quad (7)$$

In this relationship, i_{cd}^* is the vertical reference current of DG. Thus, the total reactive currents of loads as well as the vertical components of current must be compensated.

4. Modeling of Proposed System

The electrical equivalent of the proposed method must include the power network including sections such as power generation, transmission distribution and finally the electric load. DGs are also connected to the power network using a network sided converter at the PCC point. In any cases, to design and illustrate the schematic diagram of the control circuit of the network sided converter, and thus provisioning for conditions for the analysis of converter in dynamical state, the components must be detailed enough in the recommended system.

4.1. Recommended Model Analysis

To represent the modeling details, firstly, KVL and KCL rules are applied to the model in Fig. 1, when the model are given in the orthogonal three phase static status:

$$\sum_{i=1}^3 v_{iM} = \sum_{i=1}^3 \left(L_c \frac{di_{ai}}{dt} + R_c i_{ai} + v_i + v_{NM} \right) \quad (8)$$

In this model, a neutral point must be considered for the zero component of the voltage. Accordingly, the as component of this neutral point will be as:

$$v_{NM} = \frac{(v_{1M} + v_{2M} + v_{3M})}{3} = \frac{1}{3} \sum_{i=1}^3 v_{iM} \quad (9)$$

The k th base of the switching variable for the voltage source converter is described using the following relationship:

$$S_k = \begin{cases} 1, & \text{if } T_k \text{ is on and } T'_k \text{ is off} \\ 0, & \text{if } T_k \text{ is off and } T'_k \text{ is on} \end{cases} \quad (10)$$

Then, by substitution $v_{km} = S_k V_{dc}$ into (8) and (9), the dynamical behavior of the proposed switching system of the converter would be developed. At this point, the model can be written in the following form, which can be claimed to be completed for further analysis:

$$\frac{di_{ck}}{dt} = -\frac{R_c}{L_c} i_{ck} + \frac{v_{dc}}{L_c} \left(S_k - \frac{1}{3} \sum_{j=1}^3 S_j \right) - \frac{v_k}{L_c} \quad k = 1, 2, 3 \quad (11)$$

The (11) suggests the dynamics of the k th phase of the VSC model. Using (11), the switching state function can be represented as:

$$D_{rk} = \left(S_k - \frac{1}{3} \sum_{j=1}^3 S_j \right) \quad (12)$$

The (12) shows that the value of D_{rk} depends on on-off states of the k th branch; that is, it is dependent upon the switching state and the k th phase. In other words, D_{rk} is determined simultaneously by the three switching statuses of VSC. In fact, (12) illustrate the mutual interactions between the phases [20]. Inserting (12) into (11), the dynamical relationship of the proposed model will be given as follows:

$$\frac{d}{dt} \begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = -\frac{R_c}{L_c} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} + \frac{1}{L_c} \begin{bmatrix} D_{n1} \\ D_{n2} \\ D_{n3} \end{bmatrix} v_{dc} - \frac{1}{L_c} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \quad (13)$$

5. State Space of the Proposed System

Using the Park matrix transform, the dynamical equations of the proposed system can be driven for the two phase orthogonal rotating frame dq :

$$\frac{d}{dt} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} -\frac{R_c}{L_c} & \omega \\ -\omega & -\frac{R_c}{L_c} \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \frac{1}{L_c} \begin{bmatrix} D_{nd} \\ D_{nq} \end{bmatrix} v_{dc} - \frac{1}{L_c} \begin{bmatrix} v_d \\ v_q \end{bmatrix} \quad (14)$$

Since summation of the current of all the three phase system must be equal to zero, therefore, the current of the zero sequence components of DG will be equal to zero ($i_{c0}=0$). Hence, the ac voltage of the neutral point would have no effect on the converter currents.

5.1. Control Method of Current for Proposed Model

Within the recommended approach, in order to achieve low overshoot, high accuracy and fast dynamical response such that active and reactive power compensations and those of the harmonic components of the load currents are reached, (14) needs to be controlled using two individual as well as independent control loops. As mentioned before, all the DG parameters, when transformed by the Park transformation, would be n steady state and thus constants. In this way, current controllers based on appropriate control loops and without any need to complex time-varying control loops can be implemented. According to (14) and using the relationship $\lambda = L (di_c/dt) + R_c i_c$, the switching state function can be represented as follows,

$$D_{nd} = \frac{\lambda_d^* - L_c \omega i_{cq} + v_d}{v_{dc}} \quad (15)$$

$$D_{nq} = \frac{\lambda_q^* + L_c \omega i_{cd}}{v_{dc}} \quad (16)$$

Now, with paying enough attentions to (15-16), the correlating parts $L_c \omega i_{cq}$ and $L_c \omega i_{cd}$ can be eliminated from the current control loop and furthermore, blocks including $L_c \omega$ whose aim is individualization and decorrelation of the two current control loops in vertical and horizontal directions, can be applied for individual control of active and reactive powers [19]. It also have to take into account that basic input control variables D_{nd} and D_{nq} include combinations of a nonlinear cancelling and linear correlative compensators. To lock fast on the dynamical response and elimination of the steady state errors, specifically when nonlinear loads are connected to the network and thus, create harmonic pollutions in the power system, there is a need to employ the necessary Proportional-Integral (PI) controllers. The proposed adjustment control parameter is introduces as to be:

$$\lambda_{dq}^* = k_p (\Delta i_{cdq}) + k_i \int (\Delta i_{cdq}) dt \quad (17)$$

in which, k_p and k_i , accordingly, are proportional and integral gains, and $\Delta i_{cdq} = i_{cdq}^* - i_{cdq}$, shows portions depicting the relation between calculated reference currents and actual injected currents by DGs through the mediating converter (which produces the error signal and control the inverter switches). For the given study, the transfer function of the PI controllers for current control loops, are as:

$$G_i(s) = \frac{\lambda_d^*(s)}{\Delta I_d(s)} = \frac{\lambda_q^*(s)}{\Delta I_q(s)} = k_p + \frac{k_i}{s} \quad (18)$$

In order to design PI controllers for the given current control loops, and for the purpose of individualizations of controls, the measured voltage is added to the horizontal direction and the L^* and v^* , as being shown in Fig. 3, are added to the separated section; these are, respectively, the estimated values of the inductance and voltage of the network. In this way, the internal control loop of current can be simplified as in Fig. 4. As it has been shown in Fig. 4, the control loops of i_{cd} and i_{cq} are similar. Consequently, in the dq reference frame, separated control of active and reactive powers can be realized through separation (independent controls) of the vertical and horizontal

currents.

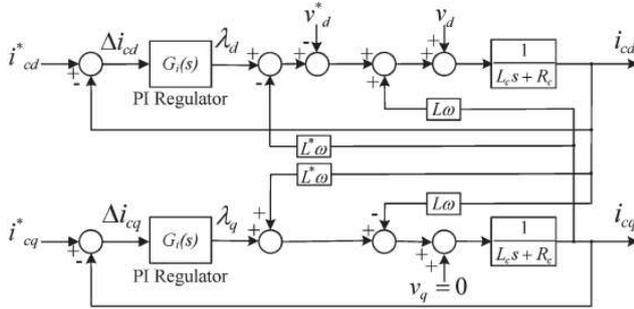


Fig. 3: Internal control loops of i_{cd} and i_{cq}

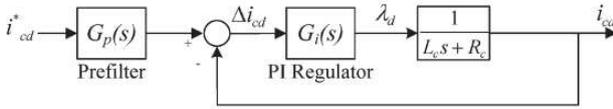


Fig. 4: The equivalent horizontal axis control loop block diagram (the horizontal current control loop)

The close control loop (of the current loop), then and be extracted:

$$\frac{I_{cd}(s)}{I_{cd}^*(s)} = \frac{I_{cd}(s)}{I_{cd}^*(s)} = \frac{k_p}{L_c} \frac{s + \frac{k_i}{k_p}}{s^2 + \frac{(R_c + k_p)}{L_c}s + \frac{k_i}{L_c}} \quad (19)$$

Assuming zero values for this equation, the transient current responses will show the related effects. As an example, the percentages of actual overshoot is much higher than the expected one. For the optimal damping coefficient, $\xi = \sqrt{1/2}$ has been applied. For this value of damping coefficient, the overshoot percentage is equal to 20.79%. In order to eliminate the zeros in the transient responses, a pre-filtering, as shown in Fig. 4, has been employed. As a result, responses of the current loops appear to be the outputs of a second order transfer function without any zeros. Comparisons between a general second order transfer function and that of (19) will give rise to the followings:

$$k_p = 2L_c \zeta \omega_n - R_c \quad (20)$$

$$k_i = L_c \omega_n^2 \quad (21)$$

in which, ω_n is the angular frequency of the source, that depends on the specific time domain response.

6. Simulations and Analysis

In this section, performance of the system under study will be assessed in the presence of the introduced controller in previous sections. It has been assumed that a nonlinear load including a three-phase thyristor bridge is used to supply an RL load connected to the PCC point with corresponding values $R=5\Omega$ and $L=10\text{mH}$. In the first scenario, DG is assumed to be not connected to PCC and network, alone, supplies the nonlinear load. Respectively, for this case, load absorbs 41kW off the network; thus, using a three phase balanced voltages of 380V and frequency 50Hz, and in the presence of the rectifier, voltages and currents as shown in Fig. 5, can be delivered to the load. Fig. 6, also illustrates the received active and reactive powers of the rectifier. From this figure, it can be clearly seen that the rectifier provides the RL load with 41kW at unity power factor. However, the most important problem, in this scenario, is existence of absorbed low frequency harmonic currents from the network. In these conditions, currents and voltages' waveforms of the network are depicted in Fig. 7 in the absence of DG's connection to the PCC. The figure shows that the low frequency harmonics, specifically, the fifth, seventh and eleventh ones have notable values which result in a THD of 29.8%, as shown in Fig. 8. The existence of high frequency harmonics within the absorbed currents causes a variety of problems to the network. These low frequency harmonics are created by the network inductance and pass through the power lines by unfiltered transformers. The presence of current harmonics would lead to increase of power losses, destruction of voltage profiles, affecting conversely the other network loads and electromagnetic saturations of the network's transformers.

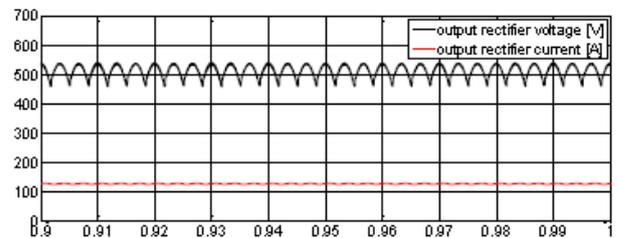


Fig. 5: The rectified voltage by Thyristor rectifier

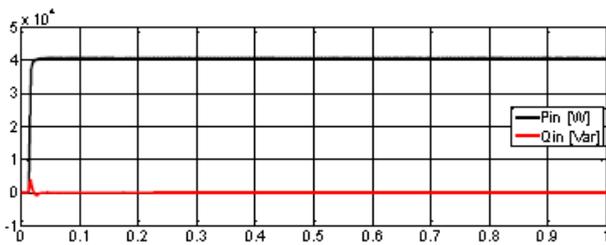


Fig. 6: The active and reactive powers absorbed by the rectifier in the power system

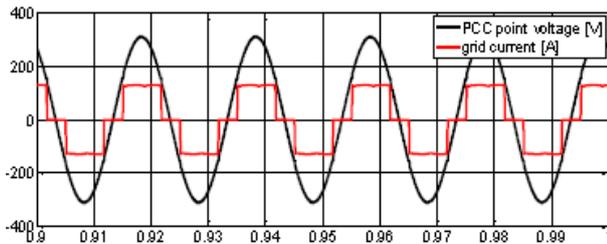


Fig. 7: The waveforms of voltages and currents absorbed off the network in the absence of DG connection to PCC

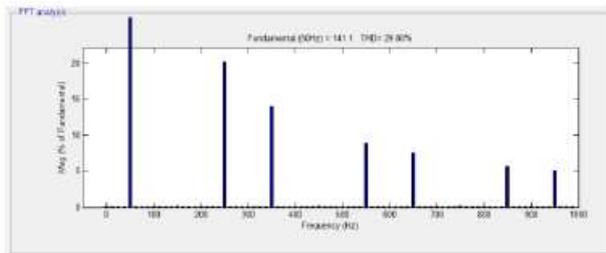


Fig. 8: Harmonic distribution of the absorbed current off the network in the absence of DG connection to PCC

The method and bases of nonlinear load current filtering using DGs was explained in section 4. One of the aims of this study has been the implementation of a control system representing the low frequency current harmonics and produced by the DG at the PCC point. Simply put, the control system has been implemented in such a way that with sampling off the nonlinear current load, the DGs produce low frequency current harmonics. Therefore, these low frequency current components are created but DGs and not the network. To show this, Fig. 9 has shown the injected current of DG to the PCC point. The reason of the existence of such low frequencies in the current is given rise to by the harmonic components produced using the nonlinear load connected to PCC. Fig. 10 demonstrates these nonlinear currents and those of the DG.

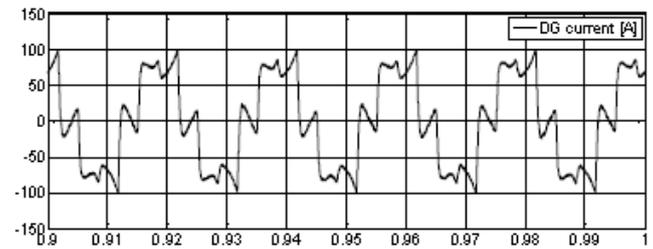


Fig. 9: The injected current of DG to PCC

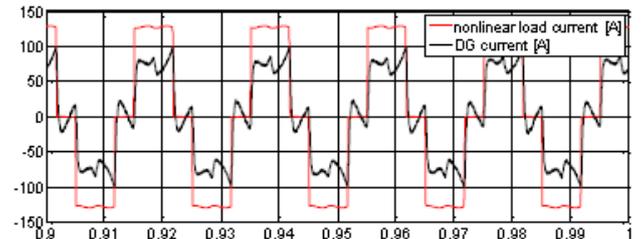


Fig. 10: The injected current caused by DG connection to PCC and the currents absorbed by the nonlinear load

Fig. 11, also, shows the unfiltered voltage of DG unit. These voltages are produced using a 15 kHz switching frequency and the method of spatial vector modulation. Fig. 12 illustrates the produced voltages and currents of DG. Paying attentions to more detail, this figure shows that DG delivers the total power produced by the wind to the network in unity power factor. Fig. 13 shows the active and reactive powers, generated by DG, too. Again, it can be observed that 24kW out of the required power of the nonlinear load has been supplied by DG in unity power factor.

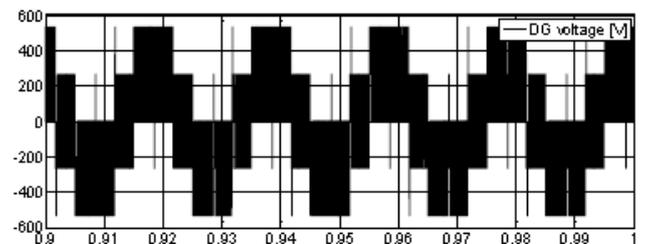


Fig. 11: The unfiltered voltage of DG at PCC point

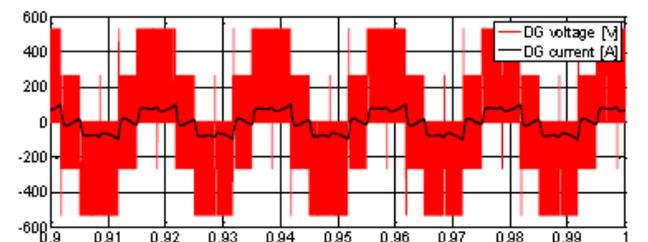


Fig. 12: The instantaneous voltage and current of DG at it connection point to PCC

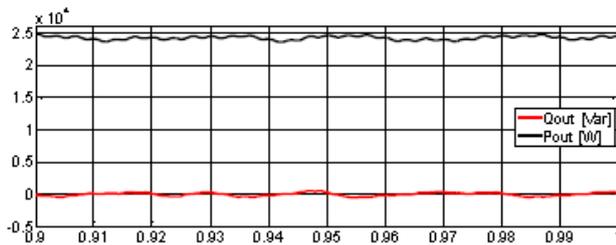


Fig. 13: The generated active and reactive powers by DG at PCC

In Fig. 14, voltages of DG and those off the corresponding phases of the network have been shown. From this figure, it is seen that there is no flowing active power between the two sources, all the power generated by DG is delivered to the nonlinear load, while some other portions are supplied by the network. In Fig. 15, the instantaneous voltage and current of network when DG is connected to PCC, are shown. From the figure, it can be seen that the low frequency components of the load are produced by DG and network's current include only a tiny portion of higher frequency harmonics. Similarly, Fig. 16 illustrates distribution of harmonics within the absorbed current. In fact, when DG is connected to PCC, the THD has improved from 29.8% to 4.69%. Finally, the delivered of active and reactive powers of the network to the nonlinear load have all been shown in Fig. 17.

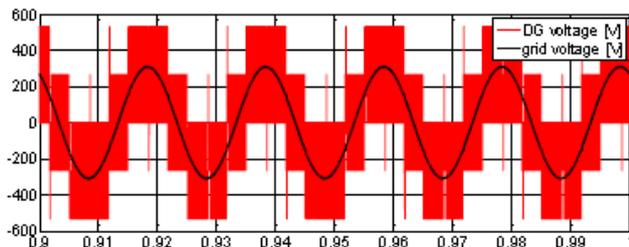


Fig. 14: The instantaneous co-phase voltages of DG and network at zero power factor

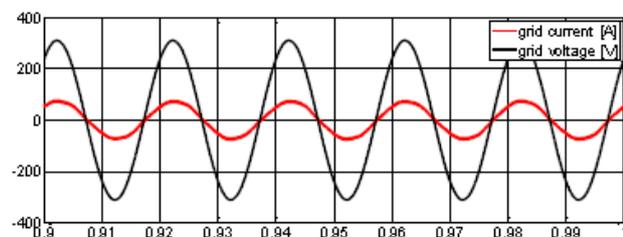


Fig. 15: The instantaneous voltages and currents of network when DG is connected to PCC

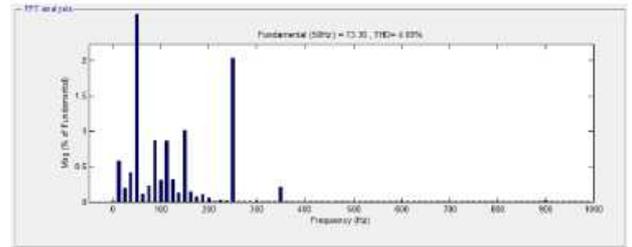


Fig. 16: The harmonics' distribution of network current when DG is connected to PCC

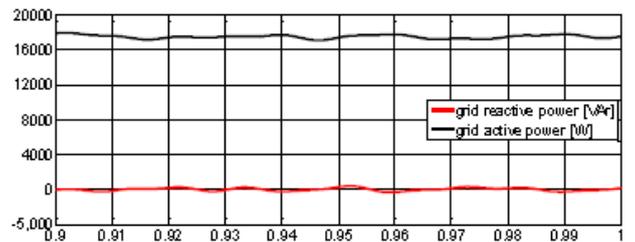


Fig. 17: The delivered active and reactive powers by network to the load at PCC

7. Conclusions

In this paper, a multi-criteria control method has been proposed for connections of Distributed Generation (DG) resources to the power system. Using the proposed control method, DGs play the role of a small power station at the point of their connections to the network, while compensating for the load using PCC voltage and eliminating the low frequency components hidden in the nonlinear load. In other words, it can be said that the DGs could be seen as smart filters and load compensators using the recommended control approach.

References

- [1] Proger Lawrence & Stephen Middle kauff, "Applying Distributed Generation Tools in Power Design System", IEEE Industry Applications Magazine, Jan/Feb 2005.
- [2] A. Bhowmik, A. Maitra, S. M. Halpin, J. E. Schatz, "Determination of allowable penetration levels of distributed generation resources based on harmonic limit considerations", IEEE Trans. On Power Delivery, Vol. 18, No. 2, April 2008.
- [3] Wang, J., Wei, S., Gu, Y, "Lumping and electromechanical transient modeling of large-scale wind farm" IEEE Conf. Power System Technology, China, 2014.
- [4] A. Bhowmik, A. Maitra, S. M. Halpin, J. E. Schatz, "Determination of allowable penetration levels of distributed generation resources based on harmonic limit

considerations”, IEEE Trans. On Power Delivery, Vol. 18, No. 2, April 2003.

[5] Blaabjerg, F. “Future on Power Electronics for Wind Turbine Systems”, IEEE Industry Applications Society, 2013.

[6] I. J. Balaguer, Q. Lei, S. Yang, U. Supatti, and F. Z. Peng, “Control for grid-connected and intentional islanding operations of distributed power generation,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 147–157, Jan. 2011.

[7] Cosby, M.C., Nelms, R.M, “Designing a parallel-loaded resonant inverter for an electronic ballast using the fundamental approximation,” Applied Power Electronics Conference and Exposition, pp. 418 - 423, Jan. 1993.

[8] L. Wei, Y. Wu, C. Li, H. Wang, S. Liu, and F. Li, “A novel space vector control of three-level PWM converter,” in Proc. IEEE PEDS’99 Conference, vol. 2, July 1999, pp. 745–750.

[9] Bose, “Modern Power Electronics and AC Drives” 7th Edition, Springer Publisher, 2012.

[10] K. Hartani, Y. Miloud; "Control Strategy for Three Phase Voltage Source PWM Rectifier based on the SVM" EFEEA’10 International Symposium on Environment Friendly Energies in Electrical Applications, 2-4 November 2010, Ghardaia, Algeria.

[11] Zhixiang, Luo., Yongzheng and Luiz A. C. Lopes, “A simple Control Circuit for a controlled Voltage Three -Level Hysteresis Current Source Converter,” IEEE ISIE 2006, Montreal, Quebec, Canada July 9-12, 2006.

[12] Zare, F. and name, A, “A new random current control Technique for single -phase Inverter with Bipolar and unipolar Modulation,” Power Conversion Conference IEEE- Nagoy, 2-5 April 2007 .pp:149-156.

[13] Shuhui Li, Timothy A. Haskew, Richard P. Swatloski, and William Gathings, “Optimal and Direct-Current Vector Control of Direct-Driven PMSG Wind Turbines,” IEEE Trans. on Power Elect., vol. 27, no. 5.

[14] Edris Pouresmaeil “Advance Control of Multilevel Converters for Integration of Distributed Generation Resources into AC Grid” PhD Thesis, Barcelona, March 2012.

[15] F. Velenciaga and P. F. Puleston, “High-order sliding control for a wind energy conversion system based on a permanent magnet synchronous generator,” IEEE Trans. Energy Convers., vol. 23, no. 3, pp. 860–867, Sep. 2008.

[16] P. Rodriguez, A. Timbus, R. Teodorescu, M. Liserre, and F. Blaabjerg, “Reactive power control for improving wind turbine system behavior under grid faults,” IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1798–1801, Jul. 2012.

[17] k. Taniguchi and H. Irie, "PWM technique for

power MOSFET inverter." IEEE Transaction on Industrial Electronics, 1981, pp. 199-204

[18] Ijumba, N.M.; Jimoh, A.A.; Nkabinde, M.; “Influence of distributed generation on distribution network performance” AFRICON, 1999 IEEE, Volume: 2, 28 Sept.- 1 Oct. 2010, pp. 961-964 .

[19] T.Ackermann, G.Anderson, L.Soder, “Distributed Generation: a definition”, Elsevier science, pp.195-204, Dec 2000.

[20] W. El-Khattam, M. M. A. Salama, “Distributed Generation Technologies, Definitions and Benefits”, Electric Power Syst. Res., pp. 119-128, 2004.