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New Application of Active Power Filters in a Microgrid

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Abstract

Microgrids are applied not only generate power, but also producing a sinusoidal output voltage and supplying nonlinear loads. In this paper, using A current control scheme for selective harmonic compensation is proposed for shunt active power filters. In the active power filters using voltage source converters that are capable of dual-use technology to improve the quality of the selected compensation can be paid. Using this system, an improved individual harmonic and THD with these requirements will be modified. Simulation results show the effectiveness of the proposed method for compensating current harmonics to an acceptable level.

Keywords: *Active Power Filters, THD, Microgrid, Harmonic*

1. Introduction

Microgrid [1] may be defined as an agglomeration of distributed generation (DG) units usually linked through power electronic based devices (voltage source inverter) to the utility grid.

In today's environment, electronic loads are very sensitive to harmonics, sags, swells and other disturbances. So, power quality has become as important as the continuity of the electricity. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system.

Microgrid ‘s supplier often use of an interface converter (e.g. An inverter in case of DC-to-AC conversion) connected to the AC power grid system (microgrid or utility grid). The main role of this inverter is to control voltage amplitude and phase angle in order to inject the desired active and reactive power. In addition, compensation of power quality problems, such as voltage harmonics, can be achieved through proper control strategies.

A single-phase DG capable of improving the voltage waveform is presented in [2]. For voltage harmonic compensation, DG is controlled to operate as a shunt active power filter. In the other words, DG injects harmonic current to improve voltage waveform. In [3, 4], detection of fundamental and harmonic voltages and computation of the harmonic compensation current are performed by two neural adaptive filters.

The approach of [2] is based on making the output voltage of the DG no sinusoidal in a way that after voltage drop on the distribution line, voltage waveform at point of commonality.

An interesting approach for compensation of voltage harmonics in an island MG is presented in [5]. In this approach, DGs are controlled to absorb harmonic current of the load like a shunt active filter. Also, the method of harmonic compensation effort sharing among DGs is presented.

In [6], an approach for selective compensation of voltage harmonics in a microgrid through proper control of The DG interface converter is presented.

The results in [7,8] show that by using the proposed control approach fundamental and distortion powers are properly shared between DGs and also the selected harmonics (5th and 7th) are well compensated. Furthermore, the THD values of DGs output voltage is decreased.

Invertar's can play an important role in the micro-grid. The inverter's which are placed in series with a source of distributed generation on the grid can be injected active power into the grid.

In the microgrid some of resources connected to the grid with a converter's. Therefore, the proposed system has the following advantages:

1- Feeding the energy to the utility

2- Harmonic elimination Function and improved power quality

Among these resources Fuel Cells offer lower emission and higher efficiency than anther recourses such as Diesel Engines but are likely to be too expensive for many applications.

This paper investigates the effects of selective harmonic compensation will be paid when they are connected to the network.

Of course, a different thing than the other papers in this research is:

Selective APF control in harmonics reference frames, where each harmonic is detected and controlled in its own reference Frame, seems to be the most performance methods. The method is computation-time expensive, but results in better control performance [9].

Controllers may be realized in harmonics reference frames, in a stationary frame using stationary frame generalized integrator's [9] or repetitive-based control [10], or in fundamental frame using equivalent PI controllers [11], [12].

In this context, this paper proposes the application of the new strategy control approach used in the bi-directional the shunt active power filter and power flow in the grid for current harmonic compensation. The simulation results of the proposed control approach are shown.

The Selective Harmonic Compensation approach has two major advantages compared with an unselected offer. First, the greater the harmonic currents of the active power filter (APF), which is the control system's ability to select the most harmful harmonics compensation, in order to protect the load active power filter (APF). A second advantage of the robust control against parameter uncertainty. Inductor parameters may change with Frequency and such changes could easily individually when adjusting controllers for each specific frequency to be considered.

In this paper presents a new design flow control for selective harmonic compensation of shunt active power filter has been presented.

The controller using Remove the pole - zero, taking the load transfer function is designed for each harmonic frequency.

Then, this filter tested in the microgrid with 12 buses in the presence of selective harmonic compensation for nonlinear loads were studied once.

The simulation is investigated in two cases. Connected to the network and the island state. Simulation in the Matlab/Simulink and desired results have been achieved.

2. Flow Control Strategy for Active Power Filter Control of Active Power Filter (APF)

Shunt active power filter for three-phase PWM converter connected to the line with a power filter inductor is approximately 5%. The storage component, a capacitor, usually greater than the amount of power inverter is standard. Active power filters act as a Harmonic current source Harmonic currents of equal amplitude and opposite phase harmonic load current is injected into the line.

The proposed APF controller block diagram in Figure 1 is shown.

In the scheme, line current to detect the harmonic current to flow equalization filter to control the flow of the filter is measured.

The control system includes a voltage control loop, dc, array controllers in ACU mainstream and the main frame of reference, along with the line voltage. Flow control is divided into two distinct pathways:

Control of the main current of reference output dc voltage controller is received. The harmonic current control line current harmonics will receive. Reference voltage, active power filter is the sum of all output controllers.

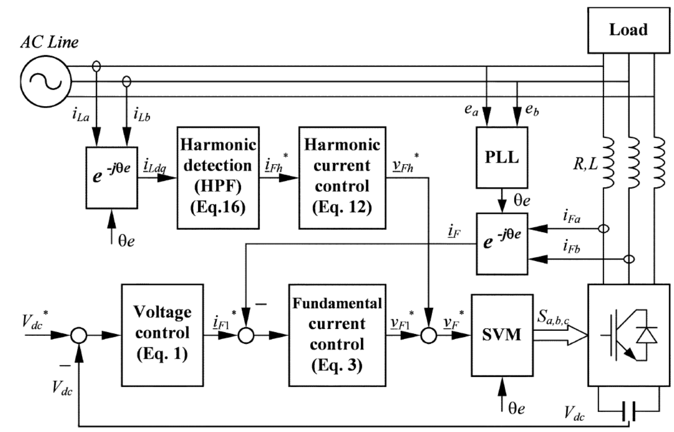

Figure 1.Block diagram of the APF control [6]

Dc voltage proportional controller unit Integrator (PI) as the input voltage and the reference voltage V_{dc}^* and the measured dc voltage V_{dc} and get active current reference output, the frame sync is as follows.

$$i_{F1d}^* = \left(K_{pdc} + K_{idc} \frac{1}{s} \right) (V_{dc}^* - V_{dc}) \tag{1}$$

The controller gain K_{pdc} and K_{idc} are constant. current control of active power filter is determined with separate control of each harmonic.

Vector model of line inductor, in the synchronous fundamental frame, is

$$\underline{v}_F - \underline{e}_{dq} = R\underline{i}_F + L\frac{d\underline{i}_F}{dt} + j\omega_e L\underline{i}_F \tag{2}$$

Where R and L are the resistance and inductance of the line inductor, $\underline{v}_F$ is the filter voltage, $\underline{i}_F$ is the filter current, and $\underline{e}_{dq} = \underline{e}e^{-j\theta_e}$ is the line voltage vector.

The fundamental current controller is a feedback controller, which provides pole-zero cancellation for the - planet. This is a complex-coefficient PI controller, with cross-coupling, decoupling and with line voltage feed forward compensation [13]

$$\underline{v}_{F1}^{*} = \left(\boldsymbol{K}_p + \left(\boldsymbol{K}_i + \boldsymbol{j\omega}_e \boldsymbol{K}_p \right) \frac{1}{\boldsymbol{S}} \right) \left(\underline{i}_F^{*} - \underline{i}_F \right) + \underline{e}_{dq} \tag{3}$$

i_F^* is the reference for the current controller. The PI gains K_p and K_i are selected so as $Kp / Ki = L / R$, to keep small, so that the controller has relatively slow response, which does not interfere with the harmonic current controllers.

The current controller loop should be faster than Voltage loop. The smallest component of the system is designed. This simplifies the design and makes it easier to adjust the PI controller.

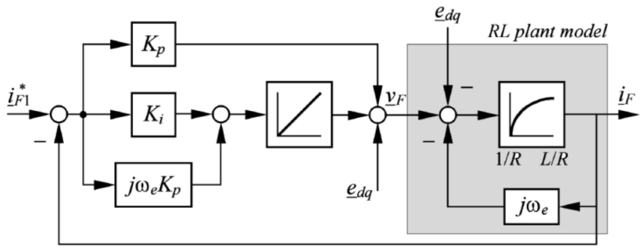

Figure 2. Block diagram of the main control loop, including the controllers and models, RL

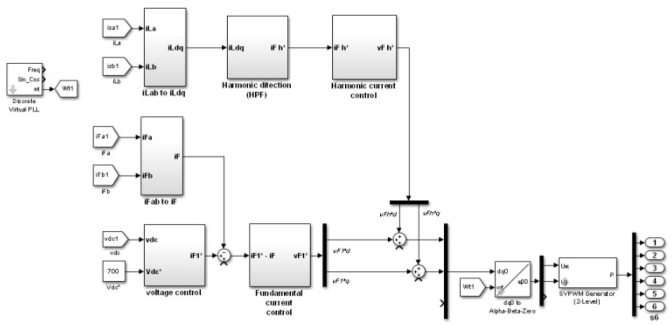

Figure 3. Block diagram of selective harmonic compensation

The transfer functions of the current control loop shown as:

$$\boldsymbol{H}_1 = \frac{\underline{\boldsymbol{i}}_F}{\underline{\boldsymbol{i}}_{F1}^{*}} = \frac{\boldsymbol{K}_p s + \boldsymbol{K}_i + \boldsymbol{j\omega}_e \boldsymbol{K}_p}{\boldsymbol{L}s^2 + (\boldsymbol{K}_p + \boldsymbol{R} + \boldsymbol{j\omega}_e \boldsymbol{L})s + \boldsymbol{K}_i + \boldsymbol{j\omega}_e \boldsymbol{K}_p} \tag{4}$$

Assuming $Kp / Ki = L / R$, remove the controller zero and first-order low-pass filter transfer function with a time constant $T = L / Kp$ is as follows:

$$\boldsymbol{H}_1 = \frac{\underline{\boldsymbol{i}}_F}{\underline{\boldsymbol{i}}_{F1}^{*}} = \frac{\boldsymbol{K}_p}{\boldsymbol{L}s + \boldsymbol{K}_p} \tag{5}$$

Since the purpose of control, sinusoidal current has been achieved, it is important that the bandwidth $(\omega_{bw} = Kp / L)$ is relatively low.

The reactive current reference is non-zero when the controller is able to compensate the reactive power. Also, when the unbalanced load compensation is desired, a negative sequence controller must be added with the same topology.

3. Harmonic Current Control for Selective Harmonic Compensation

Selective harmonic compensation is a feature which offers two important advantages in terms of flexibility, compared to a nonselective approach. First, in the case of harmonic currents larger than the APF capability, the control system has the ability to selectively compensate only the most harmful harmonics, maintaining the overload protection of the APF [6].

The other advantage is related to control of parameter uncertainty is resistant. This parameters may change the frequency with the predecessor and these changes can easily be set in the controller when you individually for any particular frequency to be considered. This method makes it possible to set up a controller with a compensative interest is not to be used unless the control is unselected. The main problem is the selected control, the computational load placed on digital control systems.

Harmonic flow control in fact produces an identical domain harmonic flow the opposite phase of the harmonic flow of time. They are based on individual controller designed for each $k = 6n \pm 1$ of the positive and negative sequence harmonic pairs is used.

For the selective compensation, each unit is individually possible. Rotating reference frame in all the main controller on frequency ω_e are implemented. Since the rotation of the coordinate frame in a changing frequency, creates the fundamental harmonic $k = 6n \pm 1$ is changed in order $k = 6n$, where n is the rated values are correct. As a result, in this frame, the harmonic sequence of positive and negative a pair of one rank are the same and both can be used simultaneously with a controller with real coefficients for certain set frequency.

Rotating reference frame with respect to the angular speed of $k\omega_e$ the model R-L line is as follows:

$$\underline{v}_F^k - \underline{e} = Ri_F^k + L(d\,\underline{i}_F^k)/dt + jk_e L\underline{i}_F^k \tag{6}$$

Where k denotes the rank of the frame of reference.

It should be noted that, this system has a single-pole $R/L + jk\omega_e$ which is mixed $k = 6n$ and n is an integer. Conventional PI controller with real coefficients with zero-pole controller removal, though, that is of interest for compensation is not enough. A flow controller for the system, remove the pole and zero for the $k\omega_e$ does have the following transfer function is complex:

$$H_{PIk}^k = K_{pk} + (K_{ik} + jk\omega_e K_{pk})\frac{1}{s} \tag{7}$$

Where k represents the harmonic order.

Harmonic flow control loop block diagram in the frame of reference in the figure 5 has been shown, that the relationship (6) and RL model (7) the controller indicates the harmonic values. Since the sequence of positive and negative direction of rotation is the opposite of each other, Figure 5 only control loop for a sequence, according to the sign $k\omega_e$ show.

Due to this, both of which have been simultaneously compensation sequence, automatic connection (7) with consideration of changing the frequency $-k\omega_e$ of positive and $k\omega_e$ negative sequence in a frame of reference for resident has become.

Due to a change of frequency, the harmonic transfer function $\boldsymbol{H}_{PIk}^{k}$ for positive sequence harmonic $\boldsymbol{H}_{PIk+}^{k}$ and negative sequence harmonic $\boldsymbol{H}_{PIk-}^{k}$ as below:

$$\mathrm{H}_{\mathrm{PIk}+} = \frac{K_{pk}\mathrm{s} + \mathrm{K}_{\mathrm{ik}}}{\mathrm{s} - \mathrm{jk}\omega_{\mathrm{e}}} \quad , \quad \mathrm{H}_{\mathrm{PIk}-} = \frac{K_{pk}\mathrm{s} + \mathrm{K}_{\mathrm{ik}}}{\mathrm{s} + \mathrm{jk}\omega_{\mathrm{e}}} \tag{8}$$

In order to control the harmonic positive and negative sequence at the same time with just one controller requires that the transfer function $\boldsymbol{H}_{PIk}^{k}$ of the compliance $\boldsymbol{H}_{PIk+}^{k}$ and $\boldsymbol{H}_{PIk-}^{k}$ following comes:

$$H_{PIk} = H_{PIk+} + H_{PIk-} = 2\frac{K_{pk}s^2 + K_{ik}s}{s^2 + \left(k\omega_e\right)^2} \tag{9}$$

This is the original reference frame controller for each harmonic up to order k = 36 runs. Assuming an ideal inverter and to consider the relationship between (2) and (9) and line voltage as flow control loop transfer function disorder, harmonics, Harmonic, reside in the frame fork is as follows,(10)

$$H_k = \frac{\underline{i}_{Fk}}{\underline{i}_{Fk}^*} = \frac{2(K_{pk}s^2 + K_{ik}s)}{Ls^3 + \left(2K_{pk} + R\right)s^2 + \left(2K_{ik} + L\left(k\omega_e\right)^2\right)s + R\left(k\omega_e\right)^2} \tag{10}$$

Assuming $K_p / K_i = L / R$ the current loop transfer function, a second-order band-pass filter setting for the frequency $k\omega_e$, becomes:

$$H_k = \frac{\underline{i}_{Fk}}{\underline{i}_{Fk}^*} = \frac{2K_{pk}s}{Ls^2 + 2K_{pk}s + L\left(k\omega_e\right)^2} \tag{11}$$

Frequency response Hk at the frequencies fixed frame for positive, linear scale in shape (6) has been shown. The answer for k = 6 and two values for the Kp=1 and Kp=5 is obtained. Other parameters are R = 1, L = 10mH, $K_i = K_p R / L$ all rights reserved.

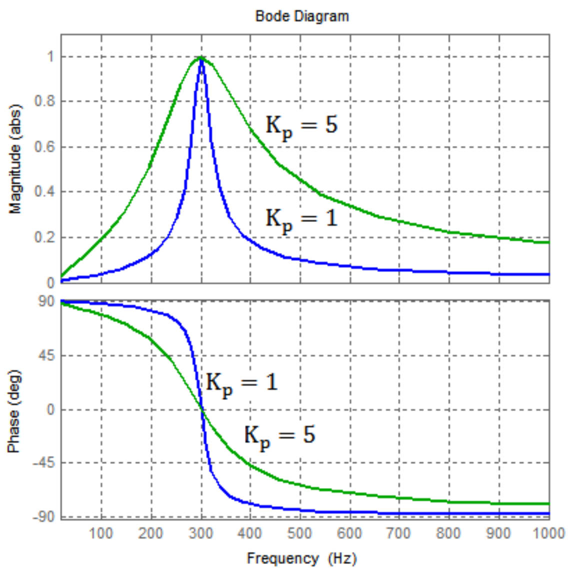

Figure. 4. Frequency response of harmonic current control loop in stationary Frame the function point

The desired frequency for a single interest circle (300 Hz in figure (6) for any two sequences regardless of the value Kp it provides.The gain Kp take advantage of automatic choice for lower amounts, the more selective the controller as well as the transient reaction slower, but since the performance lasting mode is more important so small is selected for all controllers $K_p \le 1$.

Finally, automatic flow of all of the separate controller conformity harmonic relationship (9) can be achieved. The controller full harmonics are as follows:

$$H_{PI} = \sum_{n=1}^{7} 2 \frac{K_{pk} s^2 + K_{ik} s}{s^2 + (k\omega_e)^2}, \qquad k = 6n \tag{12}$$

Block diagram of harmonic controller with harmonic detector in the form (7) has been shown.

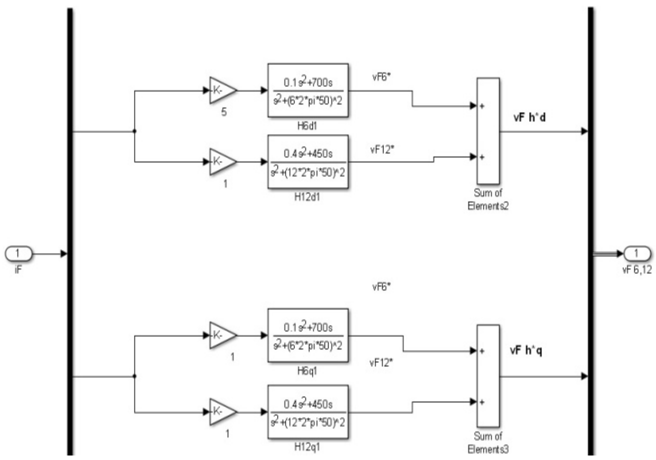

Figure. 5. Harmonic current controller

Because the parameters are not precisely known predecessor is possible with the frequency change, the relationship between transfer function (12) virtually run by

Kpk,Kikthe interest separately for each harmonic order is set to k. This method easily selects harmonic will be compensated.

3.1 Harmonic Detection Method

High-pass filter based on harmonic on the left side of the figure (7) have been shown to be identified. High-pass filter a detector (HPF) is a fourth-order that the mainstream and its output will be compensated by the APF harmonic current.

$$H_{HPF} = \frac{i_{FH}^*}{\underline{i}_L} = 1 - \left(\frac{\omega_0^2}{s^2 + 2\beta\omega_0 s + \omega_0^2}\right)^2 \quad (13)$$

Where the cutoff frequency is $\omega_0 = 300 rad/s$ and $\beta = 0.8$. HPF runs in the main frame in which the mainstream DC and can be removed without a phase change.

4. Simulation

Figure (8) shows a Microgerid with 12 buses includes non-linear load and distribution generator connected to the main network. Source distribution generation DG1 source, in fact some sort of battery with the ability to recharge is where the electrolyte (consisting of one or more electrolyte soluble substance) within a cell of electrochemical energy that chemical energy directly into electrical current can be converted to. Electrolyte and battery out mainly in additional tanks for storage and injection reactor pump into the cell by the system, although there are also fed by gravity. if supplies can be quickly replaced with liquid electrolyte, they recharge. While at the same time the energy consumption for the article will be restored again. Since the dissolution of the rechargeable in the active ingredients in the battery electrolyte, outer material save reactants gives the energy density profile and as a result, it is independently notable.

DG2 scattered production source fuel cell (Fuel Cell) which is common to other DG, will take advantage of the higher technology. This source is also covered by a system of inverter power supply can be connected to its distribution. Since electric power generation fuel cell with low-speed, low-voltage dc is done, so is the fuel processor unit accessories (for hydrogen production), common dc-dc converter to increase the rising level of dc link voltage, set in a fuel cell is required to set this system, called a fuel cell.

Three-phase full-wave rectifier diode as a nonlinear load is considered. Nominal voltage and frequency microgrid to arrange 230 V (rms phase voltage) and is 50Hz. Power and control on the part of the parameters of the tables are provided. Simulation in the Simulink environment/MATLAB use the Toolbox has been doing SimPowerSystems.

Given that the microgrid can connect mode and the function of the figure (5-8) once connected mode.

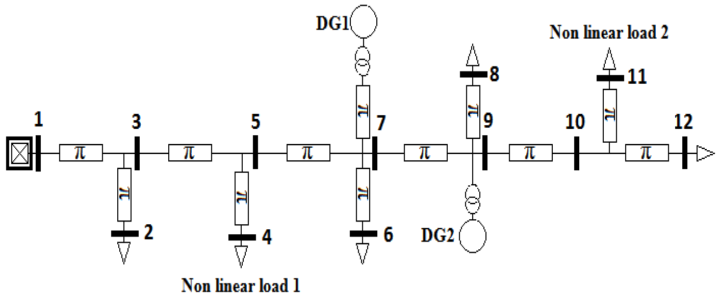

Figure 6. Schematic diagram of the microgrid

5. The Microgrid Connected to the Grid

Compensation for harmonic selective active filters are designed to be placed on the bus with the highest THD. It is obvious that buses No 4 and 11 due to the presence of non-linear loads are more THD than other buses. Thus, two active filters put on buses No 4 and 11. The order harmonic spectrum contains harmonics k = 6n ± 1 harmonics components that k+ = 6n +1 and k-= 6n-1 positive and negative components are harmonic. In the previous conversion function Bnhvh flow controller was designed at a time when for every pair of positive and negative components of compensation are done so k = 6n ± 1 is converted to k = 6n.

The results of the simulations for selective harmonic compensation during the first and second case, k = 12 and k = 6 is shown in Table I in microgrid Figure 8.

Table 1. The Results of Harmonic Compensation

Buses	Current THD without compensation	Current THD with selective compensation K=6	Current THD with selective compensation K=12
BUS1	6.43	2.97	4.51
BUS2	1.34	1.03	1.31
BUS3	9.15	3.76	5.85
BUS4	30.65	9.02	12.7
BUS5	3.52	1.3	2.33
BUS6	5.17	3.92	5.01
BUS7	4.06	1.8	3.02
BUS8	6.55	4.84	6.31
BUS9	7.87	3.65	6.11
BUS10	7.87	3.65	6.11
BUS11	24.7	6.81	12.85
BUS12	8.31	6.5	7.78

As can be seen in Table 1, the THD after selective compensation at bus 4, or K = 6 is reduced from 30.95 to 9.02.

Also, reduction of 5th and 7th current harmonics of the Bus No.4 output current is clearly shown in Figs 7and 8.

Respectively In these Figs., the T HD rms values of harmonic current they are shown.

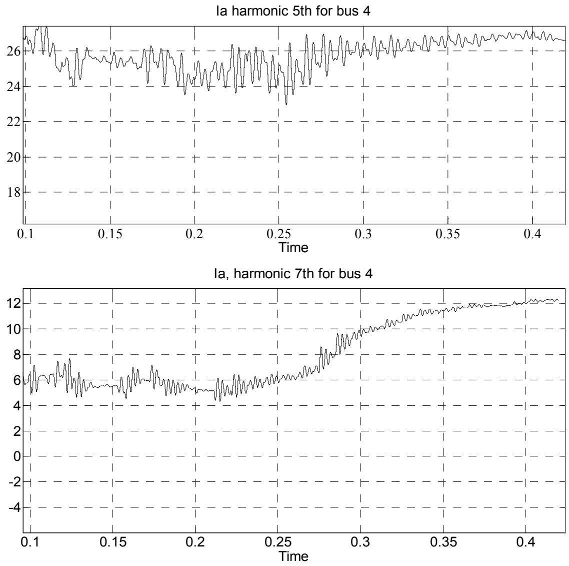

Figure 7. 5th and 7th harmonics of network current for bus 4 before compensation

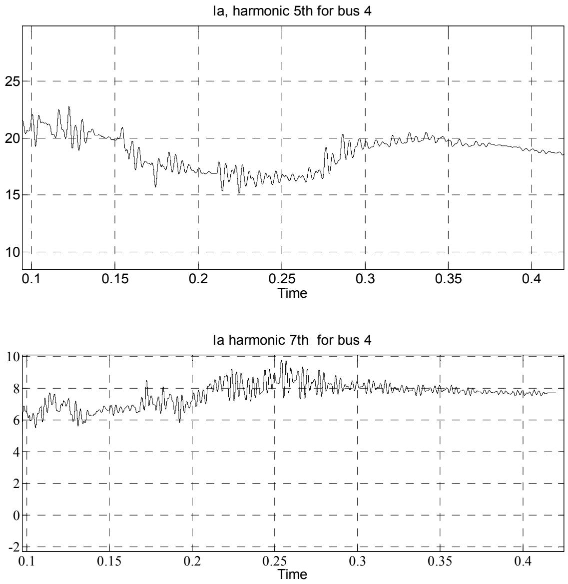

Figure 8. 5th and 7th harmonics of network current for bus 4 after selective compensation with K=6

Finally, the results of harmonic compensation are summarized in Table I. The values in the table show the decrease of "Total Harmonic Distortion THD". Compensation is achieved through injections of harmonic current and compensation effect of DG1 is high.

Also, the reduction of individual harmonic distortion as a result of compensation is Obvious.

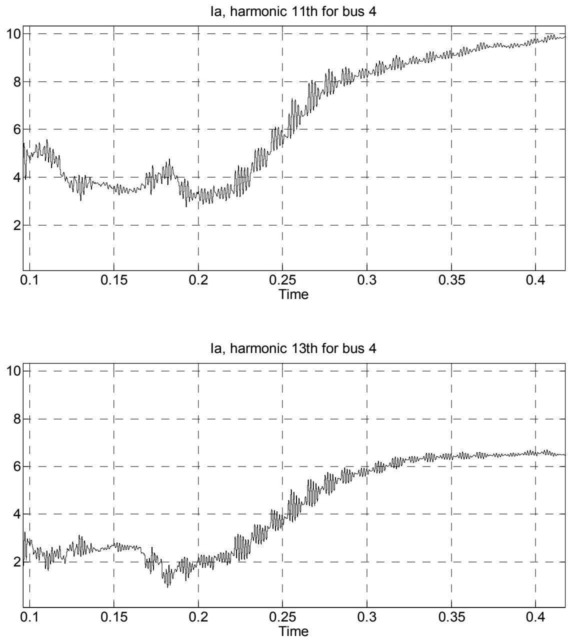

Figure 9. 11th and 13th harmonics of network current for bus 4 before compensation

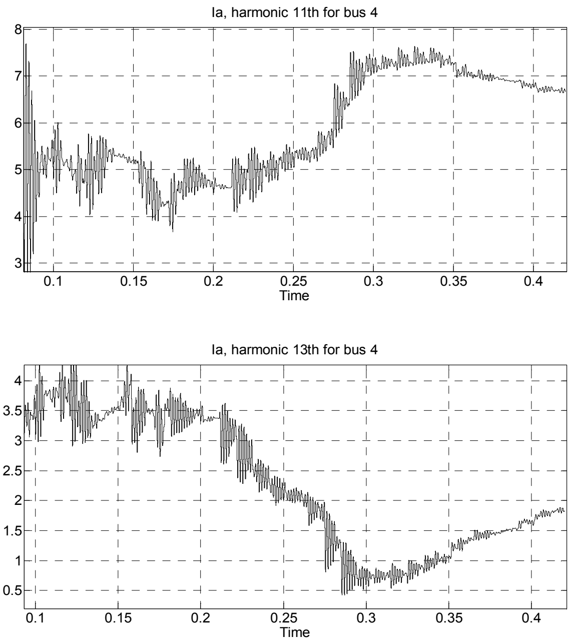

Figure 10. 11th and 13th harmonics of network current for bus 4 after selective compensation with K=12

As it can be seen in Table I, the THD after selective compensation at bus 4, or K = 12 is reduced from 30.95 to 12.7.

Also, reduction of 11th and 13th current harmonics of the Bus No.4 output current is clearly shown in Figs 9and 10.

As it can be observed in Table 1 when compensation is done with k = 6, harmonics orders 5 and 7 are also reduced. This results in reducing the amount of THD. For k = 12 harmonic order 11 and 13 are reduced.

6. Conclusion

A cooperative harmonic filtering strategy for microgrid interface converters in a connected network are proposed.

A current control scheme for a Selective harmonic compensation method for an MG with parallel APF has been presented in this paper.

With the active power filter that uses voltage source converter with capability of dual-use technology, the quality of the selected harmonic can be improved. The order of harmonics to be compensated has effects on the quality of compensation. The number of controllers is reduced compared to the case when each harmonic is compensated by one separate controller. This method was used in a microgrid with the ability of reducing the THD and selective harmonics.

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