New approach in a Microgrid : Current Controller for Selective Harmonic Compensation with Active Power Filters

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Abstract- *Microgrids are applied not only for generating power, but also producing a sinusoidal voltage to supply linear and nonlinear loads. In this paper, a current control method for selective harmonic compensation is planned 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 also be dealt with. Using this system, an improved individual harmonic and total harmonic distortion with these requirements are modified. Simulation results illustrate the efficiency of the proposed method for microgrid compensating current harmonic to an acceptable level.*

Keywords: Microgrids**,** Nonlinear loads, Selective harmonic compensation , Active power filters , Voltage source converters, THD

1. Introduction

Microgrid [1] perhaps defined as an agglomeration of Distributed generation (DG) units usually linked through converter 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. Nonlinear loads appear to be the main sources of harmonic in power system. Expanding the use of non-linear loads causes harmonic[2].

Microgrid supplier often uses an interface converter linked to the AC power grid system (microgrid or utility grid). The major work of this inverter is to control voltage phase angle and amplitude with the purpose of injecting the desired active and reactive power. Also, compensation of power quality problems, for instance voltage sag and harmonics, can be obtained through suitable control approaches.

A single-phase DG able of improving the voltage waveform is proposed in [1]. DG is controlled to operate with a shunt active power filter for voltage harmonic compensation. In other words, for improving voltage, DG injects harmonic current. In reference [1], for detection of harmonic voltages two neural adaptive filters are used.

Design criteria of new strategy for stability of system and harmonic filtering with hybrid filtering technique is presented[3]. The detailed review of power quality problems, information of harmonics have been reported in reference [1,5].

A method for compensation of voltage harmonics in an island microgrids (MG) is proposed in [5]. In this literature, DGs are controlled to attract harmonic current of the load similar to a shunt active filter. Also, the technique of harmonic compensation using sharing them among DGs has been presented.A literature for selective compensation of voltage harmonics in a microgrid through suitable control of the distributed generation interface converter is presented [6]. The results in [7] show that using the proposed control approach the selected harmonics are well compensated. Also, the total harmonic distortion (THD) value of DGs output voltage is decreased. Invertors can play an important role in the micro-grid. The inverters, which are placed in series with a source of distributed generation on the grid can inject active power into the grid. In the microgrid some resources are connected to the grid with a converter. Therefore, the proposed system has the following advantages:

1-Feeding energy to the utility

2-Harmonic elimination and improvement in power quality

This paper investigates the effects of selective harmonic compensation when they are connected to a network with a new approach. In this approach, the selective APF control in harmonics reference frames is used in which each harmonic is detected. This approach seems to be useful performance methods. The method is computation-time costly, but the obtained results seem to be in better control performance [8].

This paper proposes the application of the new strategy control approach used in the bi-directional shunt active power filter and power injection in the grid, for current harmonic compensation.

When the harmonic current is greater than the APF capability, the control system can selectively compensate merely the most harmful harmonics while maintaining the overload protection related to the APF. The second advantage includes control, robustness when facing parameter uncertainties. There may be changes in inductance parameters where these changes, in turn, can be vital when each individual controller is tuned to a particular frequency.

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

The controller uses remove pole-zero[8], takes the load transfer function which is designed for each harmonic frequency. A filter with the explained controller is tested in a microgrid with 12 buses in the presence of selective harmonic compensation for nonlinear loads.
The simulation is investigated in two cases. Connected to the network and the island state. Simulation is done in Matlab/Simulink and the desired results have been achieved.

2. Flow control strategy for active power filter Control of active power filter (APF)

The parallel active power filter structure comprised of a three-phase PWM which is basically linked to the network with an inductance of 5 percent of filter power. The storage component, a capacitor connected to fuel cell convertor is mostly greater in value than the standard power inverter. The filter functions as a harmonic current source which injects currents with the opposite phase with the same amplitude loads harmonic current into the network (Fig. 1).
This method employs the line current measurement to realize the harmonic current which needs to be compensated in the system and also controls the filter current by using filter current measurement.
The control system includes a voltage control loop and an array of harmonic and fundamental current controllers distinguished in reference frames which are synchronous with the regarding line voltage. This current control consists of two different parts namely, fundamental current control and harmonic current control.

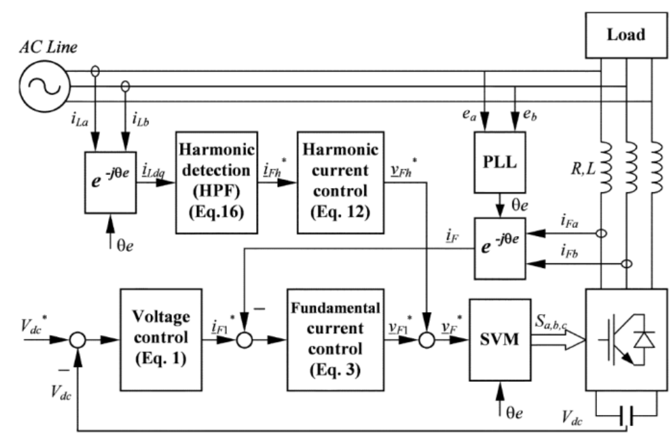

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Fig1.Block diagram of the APF control [8]

Dc voltage controller is a PI as the input voltage and the Vdc* which is reference voltage and the measured Vdc and get active current reference output, the synchronous frame is as follow.

$$i^*_{F1d} = \left(K_{pdc} + K_{idc}\frac{1}{s}\right)(V^*_{dc} - V_{dc}) \quad (1)$$

The controller gains Kpdc and Kidc are constant (0.1 and 1). Current control of active power filter is determined with control of each harmonic separately.
The line inductance in the vector model for the synchronous fundamental framework is

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

in which R and L represent:
R is the resistance
L is inductance of the line inductor
$\underline{v}_F$ is the filter voltage
$\underline{i}_F$ is the filter current
$\underline{e}_{dq} = \underline{e}e^{-j\theta_e}$ is the line voltage(2-1)
The fundamental current controller is a feedback controller, which provides pole-zero cancellation. This is a complex-coefficient PI controller, with cross-coupling, decoupling, with line voltage feed forward compensation [8].

$$\underline{v}^*_{F1} = \left(K_p + \left(K_i + j\omega_e K_P\right)\frac{1}{S}\right)\left(\underline{i}^*_F - \underline{i}_F\right) + \underline{e}_{dq} \quad (3)$$

i*F1 is the reference for the current controller.
The proportional-integral gains select by K_P and K_i with relation such as $K_P / K_i = L / R$ The controllers will comparative slow response if K_P is slight.
After designing the current control loop the voltage control loop is designed. This method is an easier controller design and the set up is easier.

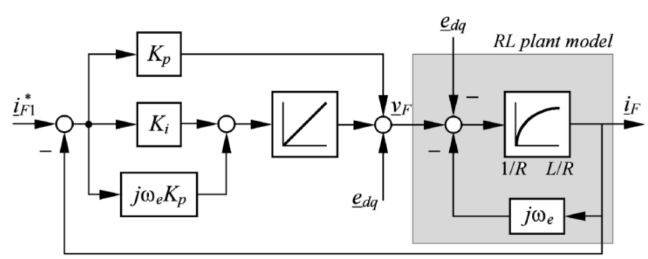


Fig 2. Block diagram of the main control loop, including the controllers and models, RL

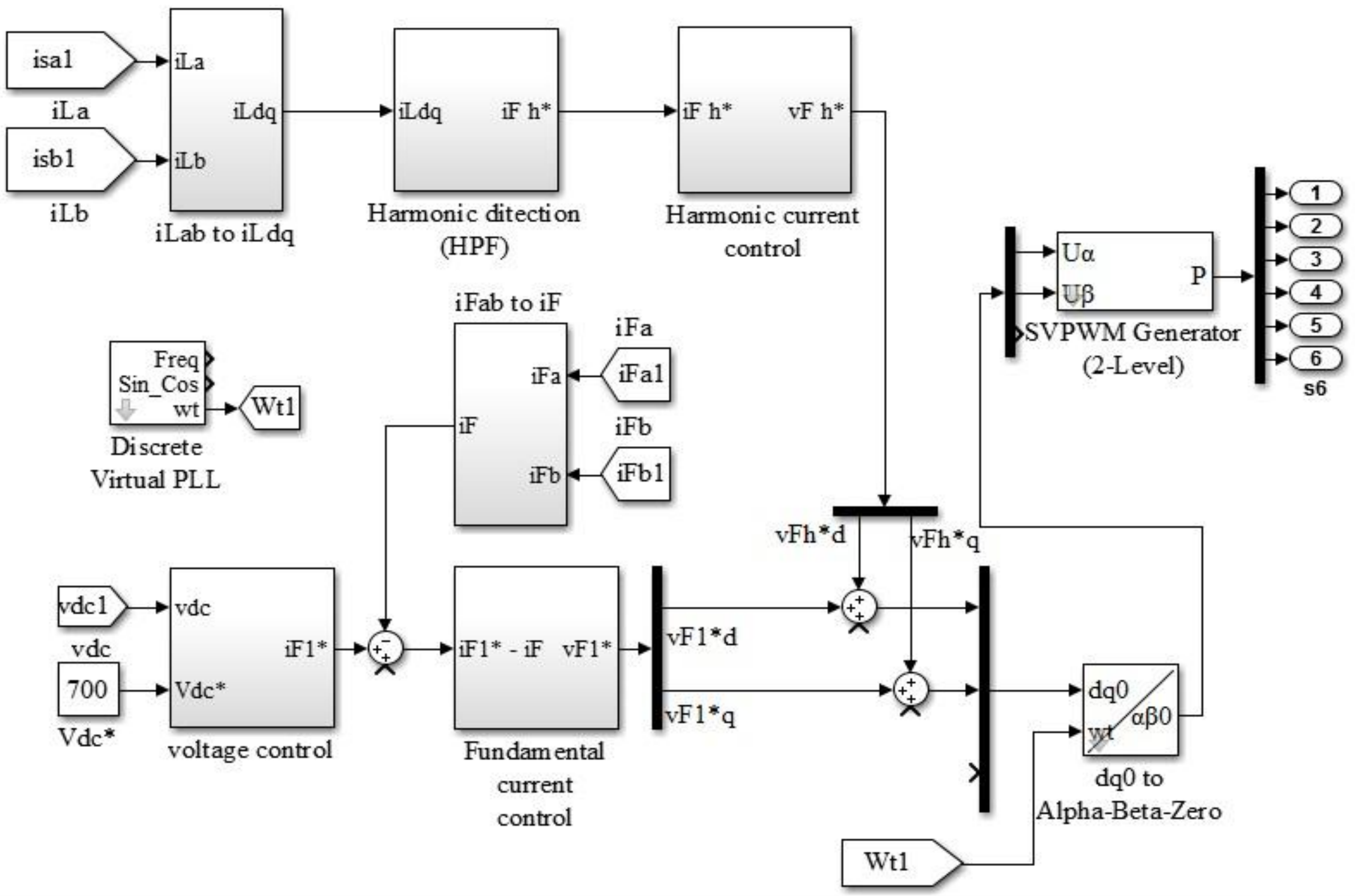


Fig 3. Block diagram of selective harmonic compensation simulation block

The transfer function of the current control loop is shown as:

$$H_1 = \frac{i_F}{i^*_{F1}} = \frac{K_p s + K_i + j\omega_e K_p}{Ls^2 + (K_p + R + j\omega_e L)s + K_i + j\omega_e K_p} \quad (4)$$

Supposing that $K_P / K_i = L / R$, transfer function turn into time constant low-pass filter. T = L / Kp is as follow:

$$H_1 = \frac{i_F}{i^*_{F1}} = \frac{K_p}{Ls + K_p} \quad (5)$$

The fundamental controller's function which is to recognize the sinusoidal current needs a relatively low bandwidth.

If the reactive current reference is non-zero, the controller will able to compensate the reactive power. Also, when the unbalanced load compensation is required, the same topology and extra negative sequence controller must be added.

3. HARMONIC CURRENT CONTROL FOR SELECTIVE COMPENSATION

Comparing the nonselective and selective harmonic compensation method reveals that selective harmonic method compensation grant more benefit than the other method. When the harmonic current is greater than the APF capability, the control system can selectively compensate merely the most harmful harmonics while maintaining the overload protection regarding the APF. The second advantage includes control robustness when facing parameter uncertainties.

This filter injects line harmonic currents with the similar amplitude and opposite phase to the load's harmonic current. These are based on individual controller designed for each $k = 6n \pm 1$ of the negative and positive sequence harmonic pairs. Rotating reference frame in all the main controller on frequency ω_e is implemented while coordinating rotation present a frequency shift of $-\omega_e$ in the fundamental harmonic orders in which the $k = 6n \pm 1$ order is changed into $k = 6n$ where n is the rated integer values. As a result, in this frame, the harmonic sequence of positive and negative of a pair of one rank is the same and both can be used simultaneously with a controller with real coefficients for certain set of frequency.

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

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

Where k is the rank of the reference frame.

It should be noted that, this system has a single-pole $\boldsymbol{R}/\mathbf{L}+\boldsymbol{jk\omega_e}$ where $k = 6n$ and n is an integer.

Although a conventional proportional-integral unit controller with real coefficients and zero-pole controller removal is necessary, it does not seem to be enough.

A current controller for the system, remove the pole and zero for the $k\omega_e$, that has the following transfer function:

Transfer function is shown in equation 7.

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

Where k represents the harmonic order.

Harmonic current control loop block diagram in the frame of reference has been shown in Fig 5. The RL model (6) and the controller (7) indicates the harmonic values. while the sequence of negative and positive direction of rotation are opposite of each other, Fig. 5 shows only control loop for a sequence, according to the sign of $k\omega_e$.

As these two have been together compensated, the controller (7) with consideration of changing the frequency $k\omega_e$ negative sequence and $-k\omega_e$ of positive is transferred.

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

$$\mathrm{H}_{\mathrm{PIk+}} = \frac{K_{pk}\mathrm{s} + \mathrm{K_{ik}}}{\mathrm{s} - \mathrm{jk\omega_e}} \quad , \quad \mathrm{H}_{\mathrm{PIk-}} = \frac{K_{pk}\mathrm{s} + \mathrm{K_{ik}}}{\mathrm{s} + \mathrm{jk\omega_e}} \quad (8)$$

To control the harmonic negative and positive sequence with one controller simultaneously, the transfer function $\boldsymbol{H}_{PIk}^{k}$ which consists of $\boldsymbol{H}_{PIk+}^{k}$ and $\boldsymbol{H}_{PIk-}^{k}$ should be as follow:

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

This is implemented in fundamental reference frame controller for each harmonic up to order k=36. Assuming an ideal inverter and relation between (2) and (9). The harmonic, reside in the frame for order k is as follows.

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

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

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

Frequency response Hk at the frequencies fixed frame for positive, linear scale has been shown in Fig. 4. The result for k = 6 , Kp=1 and Kp=5 is obtained. Other parameters are preserved R = 1, L = 10mH, $K_i = K_p R / L$.

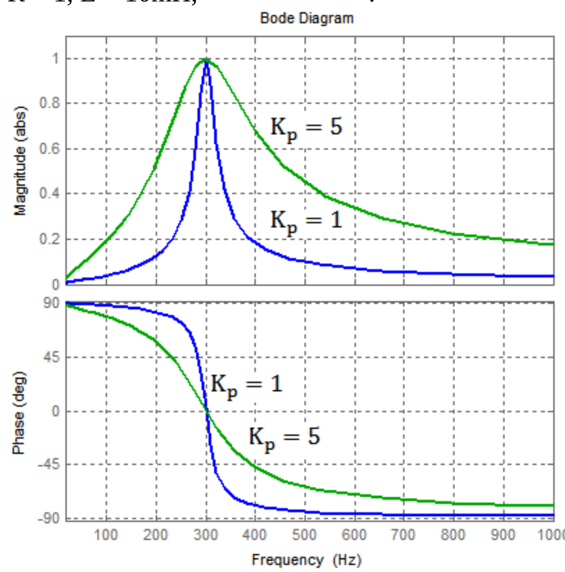


Fig. 4. Frequency response of harmonic current control loop in stationary Frame the function point

It provides the desired frequency for a single interest circle (300 Hz in Fig. 4 regardless of the amount Kp for each sequence. The gain Kp takes the advantage of automatic choice for lower amounts, the more selective the controller the slower transient reaction slower, but since the performance lasting mode is more important so a small value is selected for all controllers $K_p \le 1$.

Automatic current of all the separate controller conformity harmonic can be achieved by (9). The controller of the all harmonics is as follows:

$$\boldsymbol{H}_{PI} = \sum_{n=1}^{7} 2\frac{\boldsymbol{K}_{pk}\boldsymbol{s}^2 + \boldsymbol{K}_{ik}\boldsymbol{s}}{\boldsymbol{s}^2 + (\boldsymbol{k\omega_e})^2}, \qquad \boldsymbol{k} = 6\boldsymbol{n} \quad (12)$$

Block diagram of harmonic controller has been shown with harmonic detector in Fig. 5.

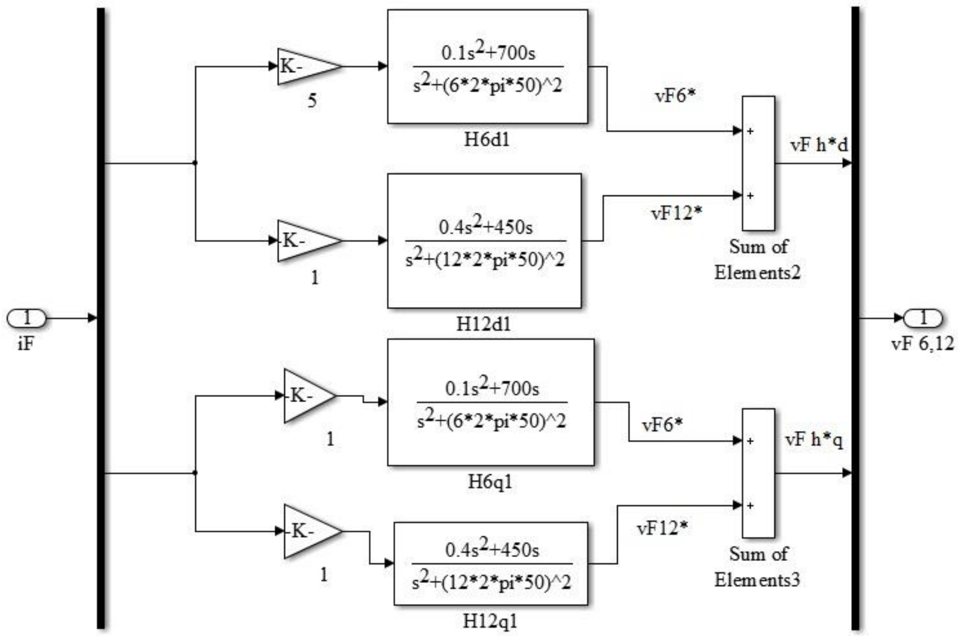


Fig. 5. Harmonic current controller simulation block

The inductance parameters are not exactly known with possible change of the frequency. The relationship between transfer function (12) virtually run by Kpk, Kik . This method easily selects the harmonic to easily compensate it.

4.Harmonic detection method

High-pass filter detector (HPF) is a fourth-order that the mainstream and its output will be compensated by the APF harmonic current.

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

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 is without a phase change.

5. Simulations

Fig. 6 shows a Microgerid with 12 buses, including non-linear load and distribution generator connected to the main network. Distribution generation DG1, is a battery with the recharged ability.

Distribution generation DG2, is a fuel cell. Advantage of this DG is the higher technology. This source is also covered by a system of inverter power supply which can be connected to its distribution. Since electric power generation fuel cell with low-speed, low-voltage dc is done, so it should be used a

common dc-dc converter to increase the rising level of dc link voltage.

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 uses the Toolbox in SimPowerSystems.

Given that the microgrid can connect mode and the function of the Fig. 6 once connected mode.

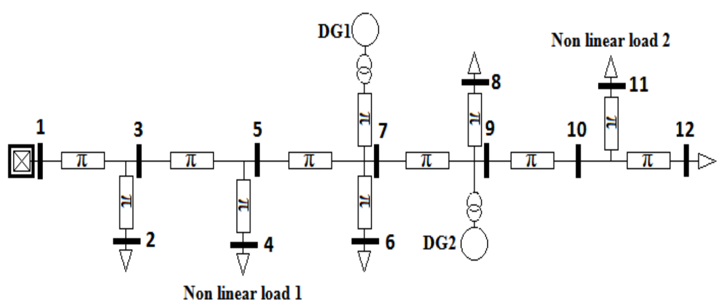


Fig 6. Schematic diagram of the microgrid

6. 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 has higher THD than the other buses. Thus, two active filters put on buses No.4 and 11. The harmonic spectrum contains harmonics k = 6n ± 1 where k+ = 6n +1 and k-= 6n-1 are the positive and negative components of harmonic. In the previous conversion, function current 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 for the first and second case, k = 12 and k = 6 are shown in Table I and Figs. 7, 8, 9 and 10.
As can be seen in Table I, the amount of 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 obviously shown in Figs. 7 and 8. correspondingly. In these Figures, the THD rms values of harmonic current are shown.

TABLE I. 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

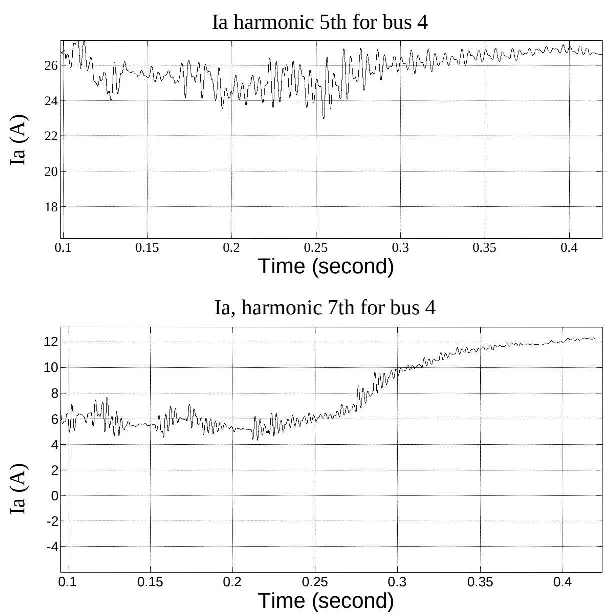


Fig. 7. 5th and 7th harmonics of network current for bus 4 before compensation

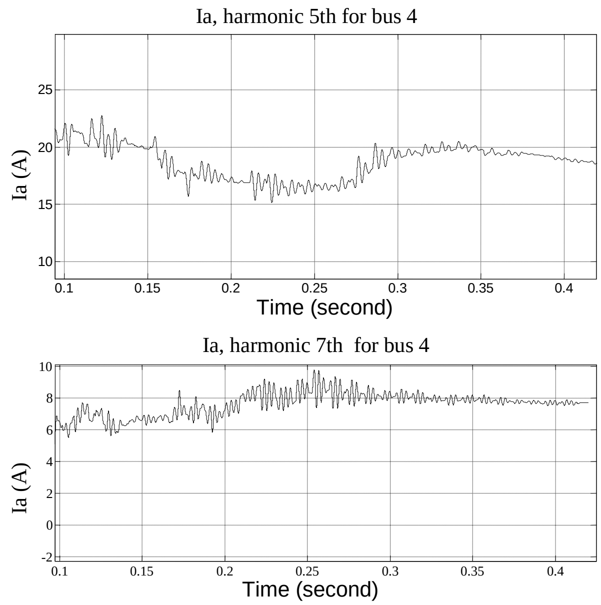


Fig. 8. 5th and 7th harmonics of network current for bus 4 after selective compensation with K=6

Finally, the results 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 decrease of individual harmonic distortion as a result of compensation is obvious.

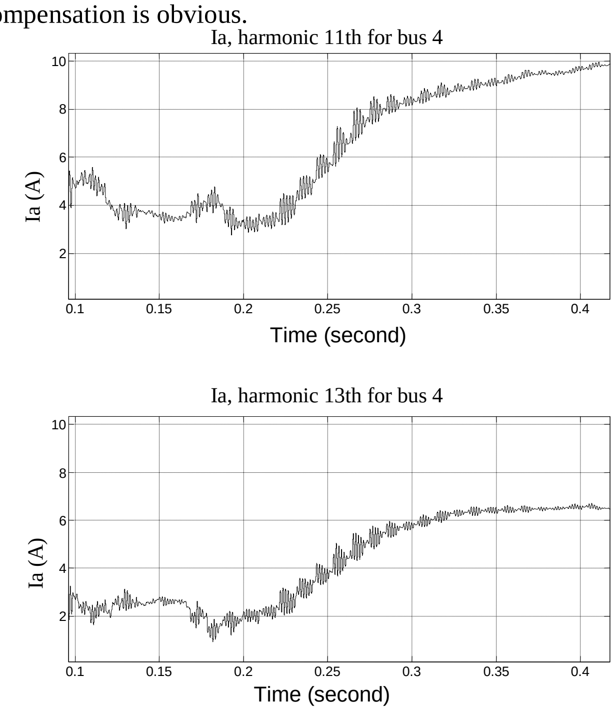
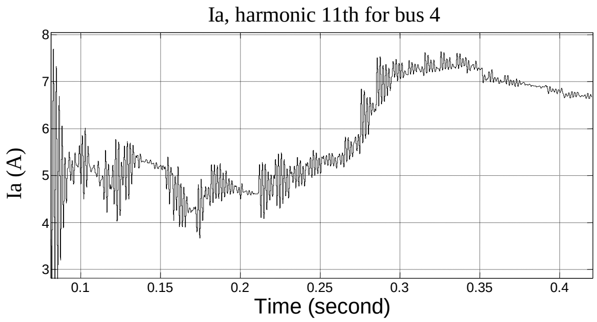
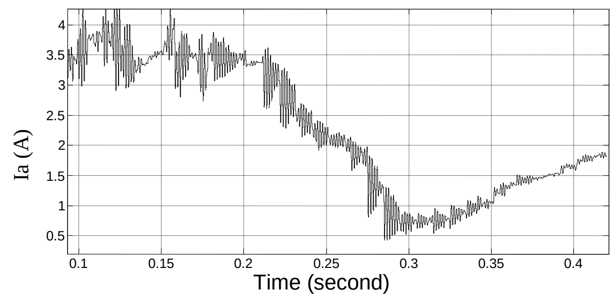


Fig. 9. 11th and 13th harmonics of network current for bus 4 before compensation





Ia, harmonic 13th for bus 4

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

The figures 11 , 12 ,13 and 14 show the current waveform before and after compensation. Simulation results show that the current waveform is improved.

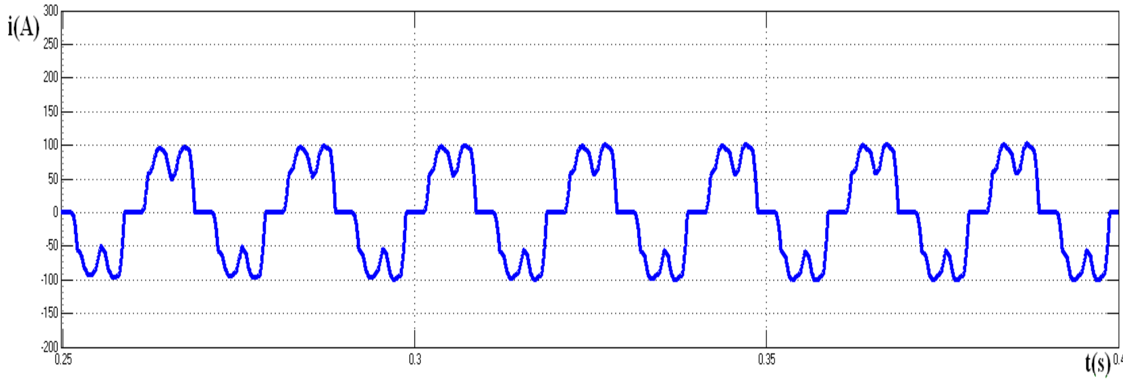


Fig11: Current waveform at bus 4 before compensation

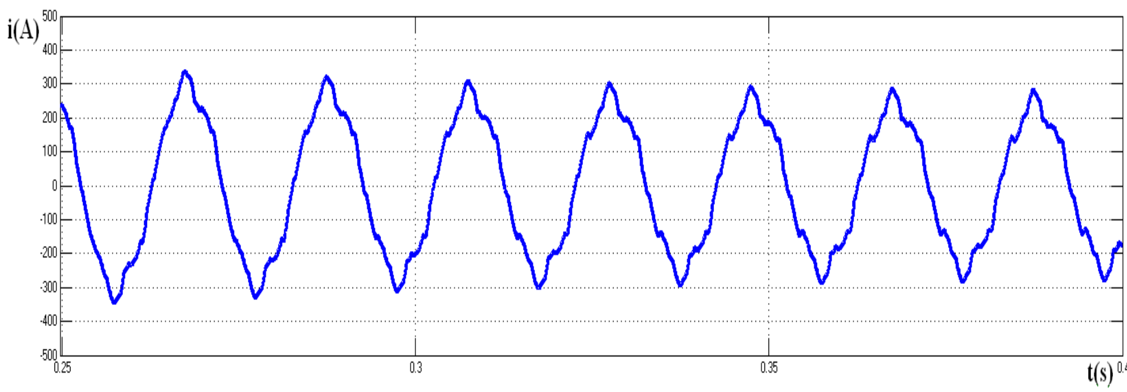


Fig12: Current waveform at bus 4 after compensation with k=12

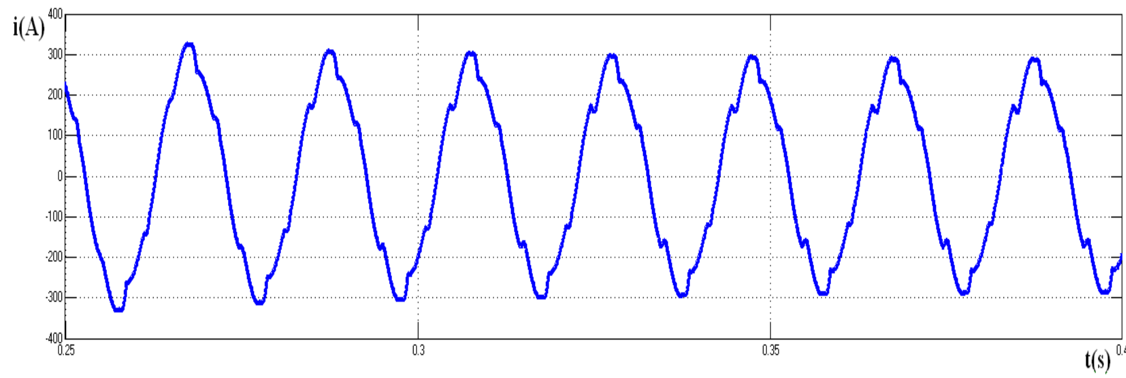


Fig13: Current waveform at bus 4 after compensation with k=6

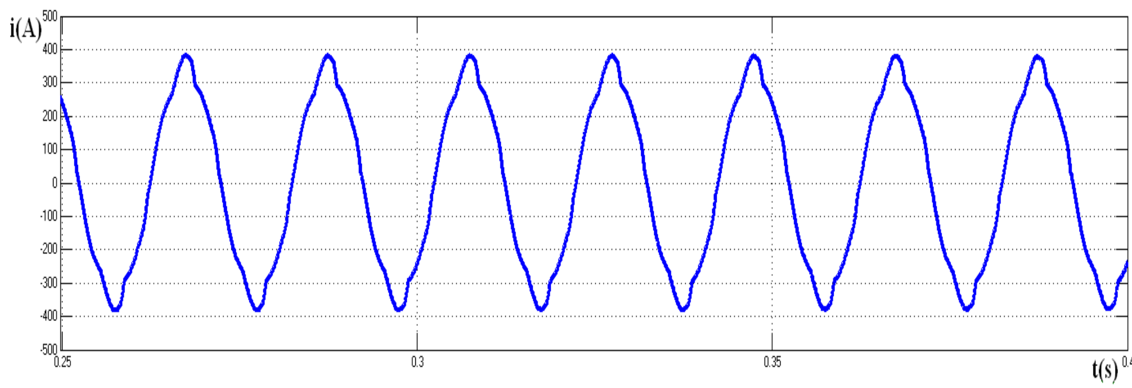


Fig14: Current waveform at bus 4 after compensation with k=6,12

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. 9 and 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.

7. 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 effecs 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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