International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 1 pp. 384-391 Jan 2018-June 2018 www.csjournals.com

Harmonic and Voltage Unbalance Compensation in an Islanded Microgrids using Parallel Neural Digital Filter

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Abstract: In this paper, a novel methodology based on Parallel Neural Digital Filter (PNDF) for voltage unbalance and harmonic compensation is presented. The unbalance and harmonics voltages in the microgrid due to the unbalanced and non linear may cause severe power quality issues in the system.Non linearity arising out of the these loads connected at PCC is effectively andaccurately estimated using parallel neural digital filter (PNDF). Use of PNDF reduces computations even for highly non linear control conditions.
Key words: Microgrids, harmonic compensation, unbalance, parallel neural digital filter.

1. Introduction

It is universally established fact that use of fossil fuels is major cause of concern for degradation of environmental conditions. Since renewable energy is available in abundance in the form of solar energy, wind energy, tidal energy and geo thermal energy etc. With the advancement in the field of power electronics technology, now a days it has become economic and efficient to harness the renewable energy available naturally and convert in the most usable form of energy i.e. electrical energy. The concept of microgrid is an appropriate technique foran effective integration the Renewable energy Resources to cater to the local load demands as well as supporting the grid in case of grid tied systems. Microgrids are formed by integrating various distributed generators available locally such as solar photo voltaic systems (SPV), Wind Energy Conversion Systems(WECS), fuel cells, battery storage systems, super capacitors etc and local loads such as lighting loads, air conditioners, refrigerators etc[1,2].

Distributed Generators (DGs) can be considered as DC sources because most of the DGs give out DC power while DGs producing AC can easily be converted to DC using AC/DC converters. These Distributed Generators are integrated in microgrid through Voltage Source Inverters (VSIs). Microgrids operated in grid connected mode operates without much difficulty while supplying nonlinear, unbalanced and single phase loads at PCC. Thisease of operation is due to the support from main grid. At the same under the conditions where main grid is off i.e microgrid is in islanded condition, It causes severe problems on account of unbalance voltages, harmonics voltages and other power quality issues[2-5]. Since microgrid is an inertia less systems, cannot survive to highly polluted conditions at PCC. At the same time equipment connected at PCC as load undergo unhealthy operation resulting in over voltage, overheating, over current and excessive vibrations due to flow of negative sequence currents. The presence of single phase loads across two phases or connected between one phase and neutral is the major cause of voltage unbalances. Conventionally, the voltage unbalance compensation is achieved by installing Active Power Filters (APF). In literature lot of work is available on achieving voltage unbalance compensation through feeding negative sequence voltage in series with distribution line in case of using a series active power filter[6-9]. In literature Installation of active power filters (APF) are recommended in distributions systems to mitigate these issues. [6-9]. However, there are some works on achieving voltage unbalance compensation by injecting negative sequence current when using shunt active power filters [10-14]. But there is a maximum current limit for an active filter to inject, In case of severe unbalance current injection may be high even more than the maximum current limit. Further active power filters are not suitable to install near Distributed Generators on account of cost economy and failure to share proper amount of reactive power among other inverters operating in parallel. In [15],DG is proposed to inject negative sequence current for mitigation of voltage unbalance effect. Conventional PI, RC and Repetitive controller fails to achieve desired unbalance and harmonic mitigation under high non-linearity in control parameters[16-19]

In actual practice microgrids are not properly decoupled or are weakly coupled. Because of poor decoupling conventional linear adaptive neural filters are not applicable. Replacing linear adaptive digital filters with non-linear adaptive neural filter (PNDF) offers reduced computation and better filtering of harmonicsdue to their inherent capability to perform excellently even under the conditions of high non-linearity.

2. Brief overview of microgrid

A microgrid is capable to serve local load even under main grid outages. Thus, the microgrid should have its own distributed generation, transmission and distribution network localized to a much smaller geographical area as compared to the area under main grid. Any typical microgrid has several distributed generators (DGs) connected in parallel through voltage source inverters (VSIs) to form an AC network. Microgrid mainly comprises Renewable Energy Resources (RES) based generation such as Wind Energy Conversion Systems (WECS), solar photovoltaic system (SPV), and small capacity battery energy storage system (BES). The load can be a three phase as well as single phase that can have both balanced and unbalanced profile. Since, a microgrid has a very less or no inertia, resulting in larger impact even from smaller load variations under islanded condition, may lead to a threat to the operation of microgrid itself.

Thus, an unbalanced load may lead to severe unbalance in supply voltage profile. Therefore, this necessitates the Voltage Source Converters be controlled in such a way that the supply to the local load be maintained as perfect set of three phase sinusoidal voltages. This control strategy enables all the parallelly operating DG's to share a proportionate load in proportion to their respective capacities. In the proposed research work, Parallel Neural Digital filter is used in a novel way to compensate ill effects of unbalance and non-linear loading on voltage profile at point of common coupling (PCC). The proposed microgrid controlmodel is presented in fig.1. The Parallel Neural Digital Filter (PNDF) is capable of tracking the reference with minimal error.

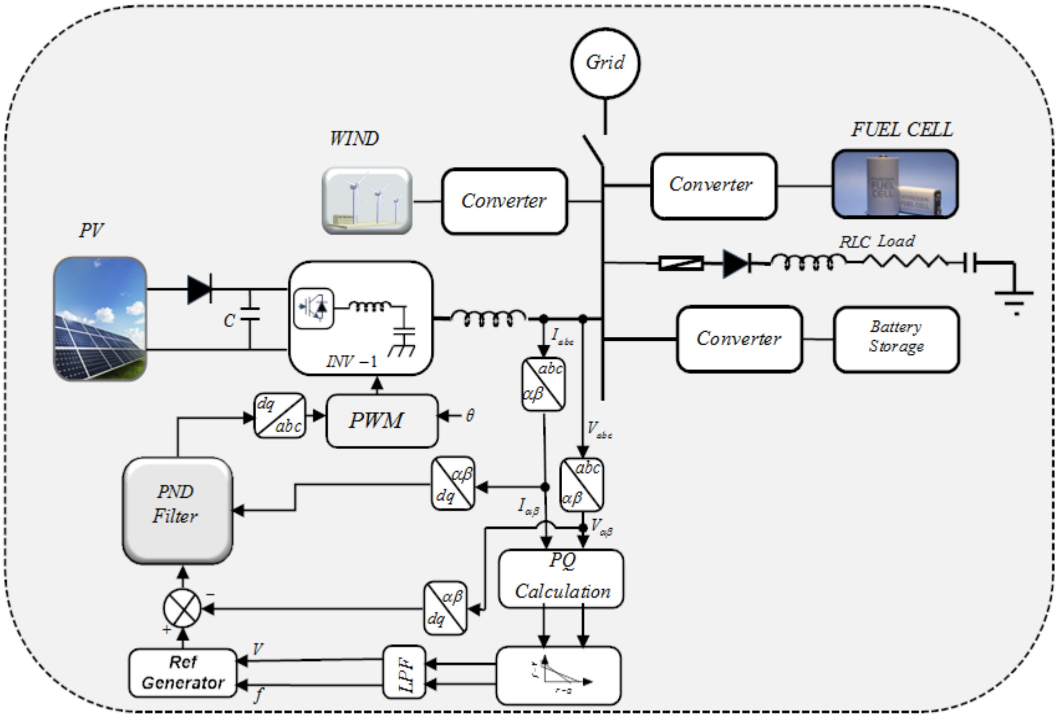

Figure-1: Proposed Microgrid control structure

3. Development of Parallel Neural Digital Filter(PNDF)

For any unknown nonlinear system it is difficult to compute the controller parameter using linear modelling. In literature, non-linear adaptive digital filters have shown excellent performance with unknown non-linear system [20]. For an unknown discrete time non -linear plant:

$$\Delta(t) = f(\,x, \alpha(t), \alpha(t-1), \dots \dots \dots, \alpha(t-n)) + u(t) \qquad (1)$$

Where α(t) and $\Delta(t)$ are corresponding input and output signals. F(.) represents a nonlinear function, x represents vector of parameters and n is maximum permissible time delay. Noise considered is white and stationary and is represented as u(t).

The estimation of unknown system as described by Eq. (1) is given by:

$$\beta(t) = F\big(\omega(t), \alpha(t), \alpha(t-1), \dots \dots \dots., \alpha(t-n)\big) \qquad (2)$$

In above equation, $\beta(t)$ gives the estimation of $\Delta(t)$, and $\omega(t)$ represents vector of weights, $\alpha(t)$ is input, F (.) is a non linear function.

N =(1,2) basic neural digital filters are connected in parallel to constitute a single Parallel Neural digital Filter (PNDF) as shown in figure (2).

The output of PNDF may be expressed as

$$\beta(t) = \sum_{j=1}^{N} \beta^{(j)}(t) = \sum_{j=1}^{N} F^{(j)}\left(\omega^{(j)}(t), \alpha^{(j)}(t), \alpha^{(j)}(t-1), \ldots\ldots, \alpha^{(j)}(t-h/N)\right) \quad (3)$$

The factor h/N represents the order of Neural Digital Filter. In order to make h/N an integer valueif necessary some zero weights may be added. In case, N =1 PNDF is nothing but NDF itself.

The performance index W may be represented as

$$W = \frac{1}{2}(\Delta(t) - \beta(t))^2 = \frac{1}{2}\left(\Delta(t) - \sum_{j=1}^{N} \beta^{(j)}(t)\right)^2 \quad (4)$$

Considering the j^{th} basic Neural Digital Filter as having a multilayer perceptron, the relationship between input and output can be represented as

$$\beta_{l,n}{}^{(j)}(t) = S_{\eta}^{(j)}\left(\sum_{j=0}^{N_{l-1n}} \omega_{l,n,k}^{(j)}(t-1)\, \beta_{l-1,k}^{(j)}(t)\right) \quad (5)$$

In the jth basic NDF, $\beta_{l,n}$ represents the output of nth node in layer l, $\omega_{l,n,k}$ represents weight that connects kth node in layer l-1, to the nth node in layer l K_l is the number of nodes in layer l After adding bias weights, the 0^{th} component of input vector of each layer is 1or $\beta_{l,0} = 1$, and $\omega_{l,n,0}$ are bias weights. The input vector components are accepted on 0^{th} layer of the network.

The sigmoid non linear function $S_{\eta}^{(j)}(.)$ may be defined as

$$S_{\eta}^{(j)}(g) = \frac{1-\exp(-\gamma g)}{1+\exp(-\gamma g)}, \qquad \gamma > 0 \quad (6)$$

The optimal value of weights of Parallel Neural Digital Filter (PNDF) are computed by using the overall error given by $e(t) = \Delta(t) \sum_{j=1}^{N} \beta^{(j)}(t)$ for the training of weights in each basic NDF. Similarly the weights updating equation of each ith basic NDF may be represented as

$$\omega_{l,n,k}^{(j)}(t+1) = \omega_{l,n,k}^{(j)}(t) - \rho \frac{\partial \omega}{\delta \omega_{l,n,k}^{(j)}(t)}\Bigg|_{\omega^{(i)}(t)}, \rho > 0 \quad (7)$$

Here, backpropagation learning algorithm adopted for training of the PNDF. Further,the partial derivative of performance index (W) with respect to each weight may be expressed as

$$\frac{\partial \omega}{\delta \omega_{l,n,k}^{(j)}(t)} = \frac{\gamma}{2}\left(1 - \beta_{l,n}{}^{(j)}\right)\left(1 + \beta_{l,n}{}^{(j)}\right) X \left[\sum_{k=0}^{n} \frac{\partial \omega}{\delta \beta_{l+1,p}^{(j)}} \frac{\gamma}{2}\left(1 - \beta_{l+1,p}^{(j)}\right) x \left(1 + \beta_{l+1,p}^{(j)}\right) \omega_{l,+1,p,k}^{(j)}\right] \quad (8)$$

In case, l = L – 1, $\frac{\delta W}{\delta \beta_{L-1,n}^{(j)}}$ can be calculated as

$$\frac{\delta W}{\delta \beta_{L-1,n}^{(j)}} = \Delta(t) - \sum_{j=1}^{N} \beta_{L-1,k}^{(j)}(t)$$

To test the PNDF, we can consider a reference input as pure sinusoidal input i.e.

$$x(t) = A\sin(\omega t)$$

Which is applied to the plant transfer function (of voltage source inverter) and disturbance noise (a non-linear load) as a harmonics of input signal. Therefore, disturbance signal is

$$d(t) = \sum_{i=1}^{n} (2n+1)^{-1} \sin((2n+1)\omega t)$$

Reference of tracking capability of PNDF is tested against PID controller over same condition. Figure 3 shows the performance of PID controller, in which error is very high and output signal distortion is very high. However, in Figure 4 with PNDF error reduced to less the 0.001 after sometime showing far better performance.

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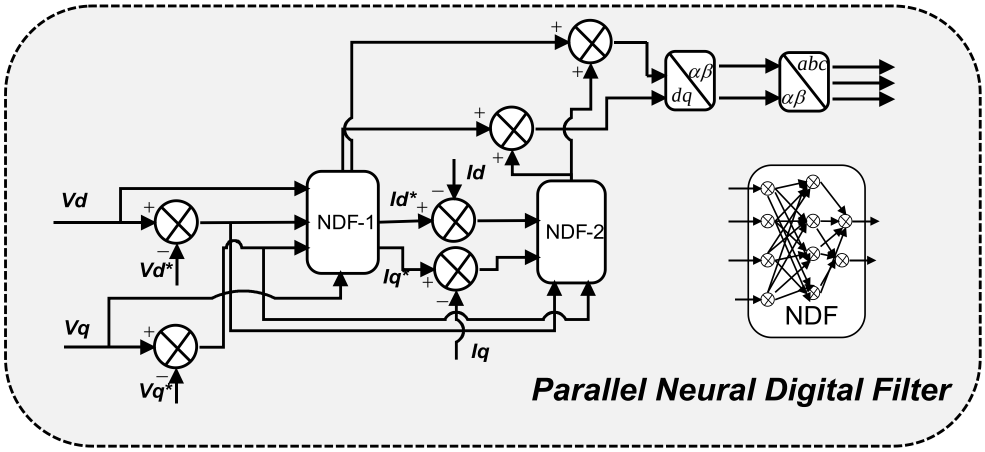

Figure-2: PNDF implementation in VSI in microgrid

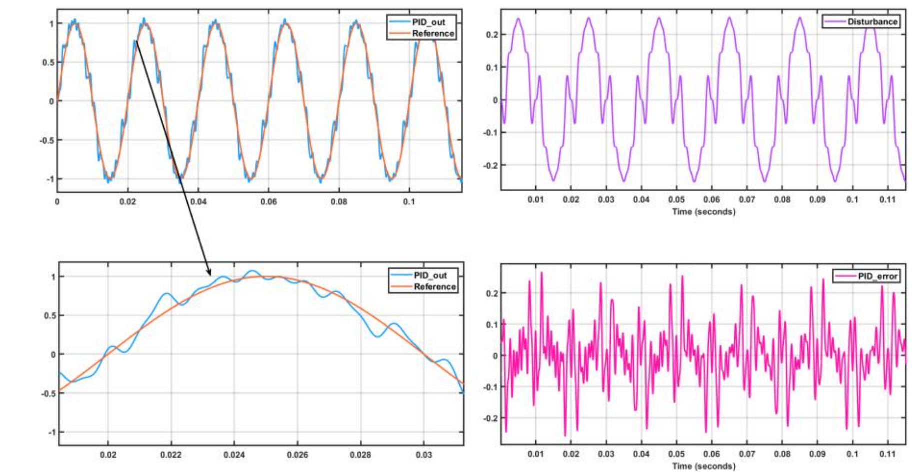

Figure-3: Reference tracking with conventional PID control

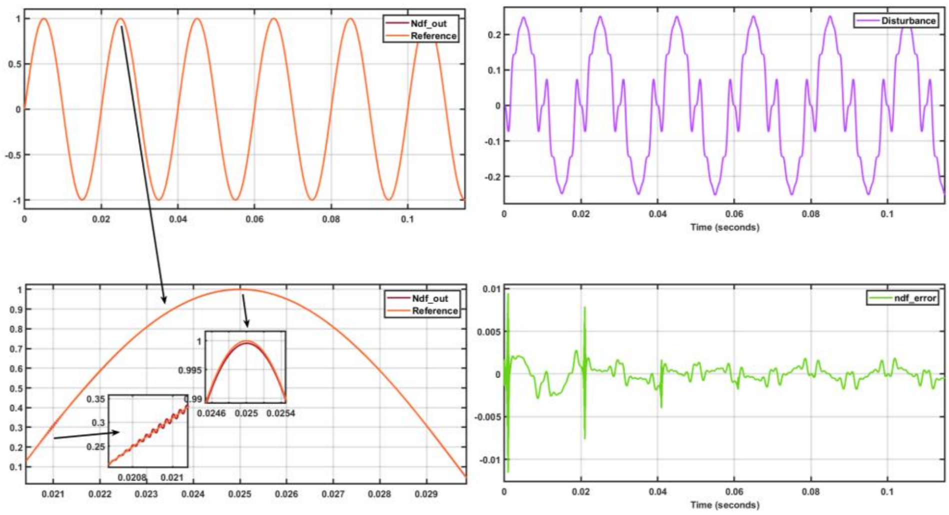

Figure-4: Reference tracking with PNDF

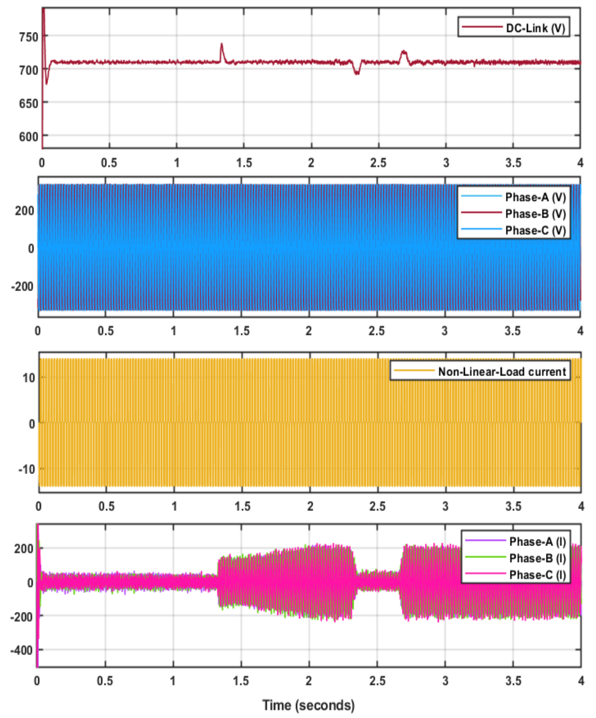

Figure-5: Voltage and Current profile at PCC in conventional PID control

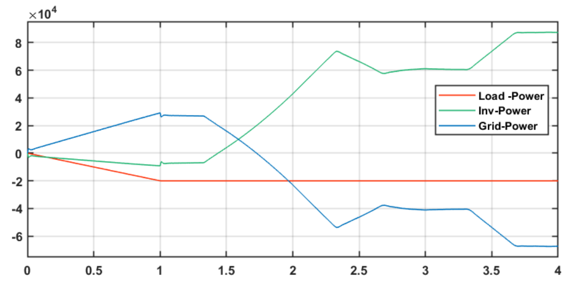

Figure-6 Power balance at PCC with PID

4. Result and discussion

In the microgrid, any deformation in the load current can leads to lowering the power quality of the whole system. Here, A controller must be designed to compensate for the effect of any non-linear current at the point of common coupling (or local load). Doing this at each source end can improve the power quality of the system. However, placing additional devices for this purpose can increase the cost of the system exponentially. The PNDF controller proposed in this paper imposes no additional hardware to the system while improving its power quality.

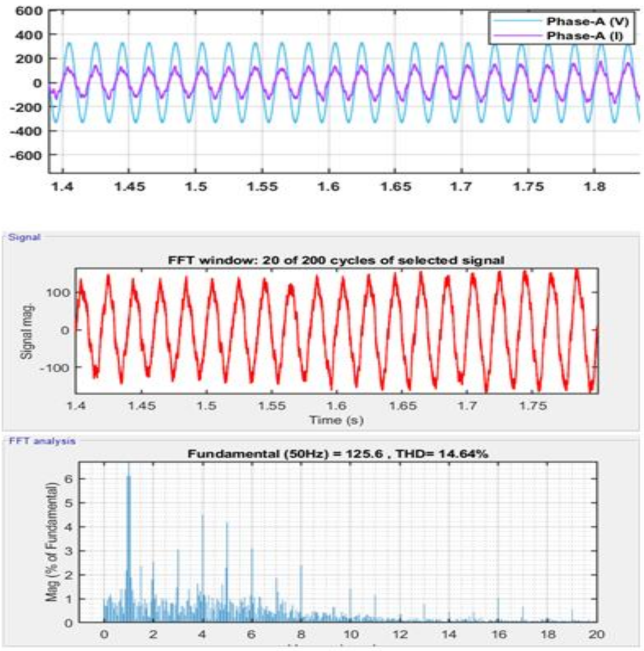

Figure-7: (a) Voltage and Current at PCC (b) FFT of PCC to Grid Current (with PID)

To test the performance of the PNDF controller a comparison has been made with classical PID controller. Figure-5 shows the voltage and current waveform of the inverter output at DC link where a local non-linear load has been also connected. Due to the non-linear load the, current injected into the microgrid has waveform distortion that may further become

a reason of the poor power quality of the microgrid. However, the controller can maintain power balance at the PCC with good dynamic performance as shown in Figure-6. Further, FFT of injected current into microgrid is shown in figure-7. After computing the FFT up-to 20th harmonic order, THD of current waveform is almost 15, which is too high.

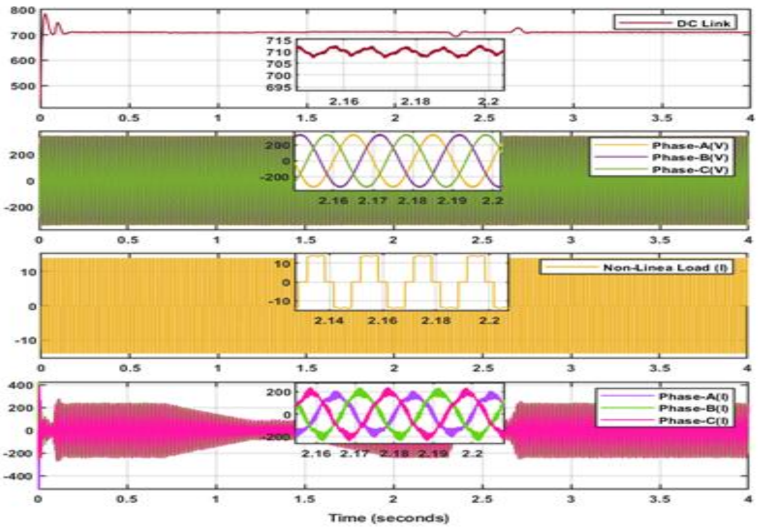

Figure-8: Voltage and Current profile at PCC with PNDF controller

However, with PNDF controller as shown in Figure-8, voltage, and current waveform clearly more sinusoidal in comparison with Figure-5. The DC link voltage in both the cases is maintained almost at 710 V dc. Dynamic response of DC link control is almost similar. Similarly, Power balance at PCC is quite same as in PID controller figure-8. Moreover, as shown in figure10 THD of current injected into microgrid has been reduced to 50 % in comparison to conventional PID. This shows a good improvement over conventional control method.

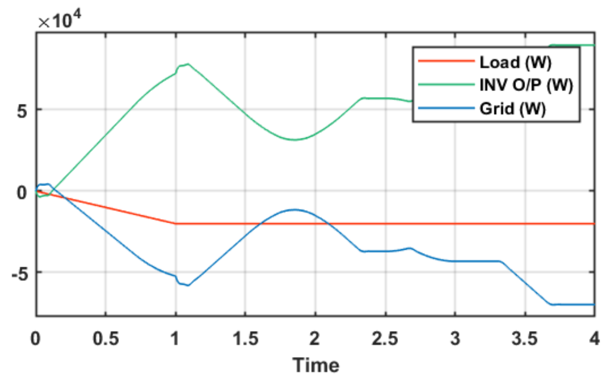

Figure-9: Power balance at PCC with PID controller

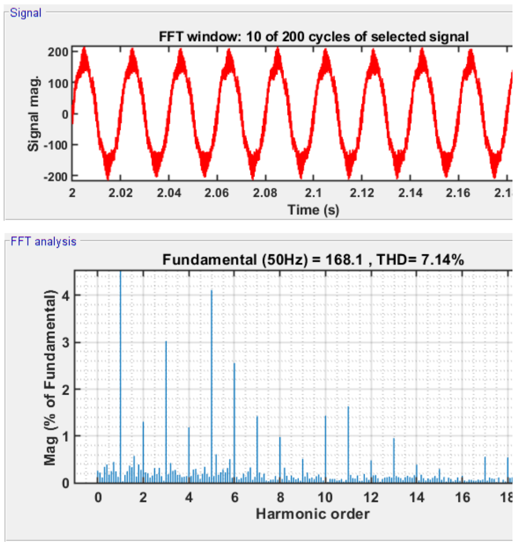

Figure-10: FFT of PCC to Grid Current with PNDF controller

5. Conclusion

In, this paper, a Novel Parallel Neural Digital Filter (PNDF) has been designed and implemented in a microgrid for the mitigation of severe voltage unbalance and harmonics. The performance of PNDF in terms of voltage unbalance and harmonic mitigation, its performancehas been much better as compared to conventional PID controllers. The proposed PNDF not only exhibits fast dynamics and accurate reference tracking performance of the system but also improve the disturbance rejection in an islanded microgrid. The simulation results of this technique clearly shows good performancein an islanded microgrid system even under severe non linear loading.

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