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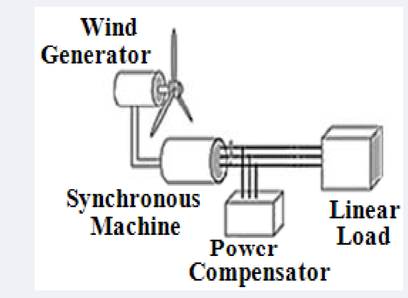
Eliminating the Consequences of Non-Ideal Waveforms on the SAPF Accuracy due to the Wind Turbine operation within a Micro-Grid

B. Rahmani and M. Tavakoli Bina, *Senior Member*, *IEEE*
Electrical Engineering Faculty, K. N. Toosi University of Technology, Tehran, Iran
E-mails: Rahmani.pwr@ee.kntu.ac.ir and tavakoli_bina@ieee.org

Abstract

The SAPF should compensate oscillating instantaneous real and imaginary powers to guarantee maximum micro-grid efficiency. Here it is demonstrated that the control of the shunt compensators, based on the generalized theory of instantaneous power definitions, produces unacceptable performance (i.e. distorted and unbalanced source voltage waveforms even under ideal unity power factor). The situation could be much worse in the presence of three-phase asymmetric voltage source.



Case study

a) Wind turbine voltage asymmetry

Compensation of a balanced linear load under asymmetrical three-phase voltages

$$\begin{cases} v = v^+ + v^- = \begin{bmatrix} v^+{}_a \\ v^+{}_b \\ v^+{}_c \end{bmatrix} + \begin{bmatrix} v^-{}_a \\ v^-{}_b \\ v^-{}_c \end{bmatrix} \\ v_a^+ \triangleq \sqrt{2}v^+ \cos w_1 t \\ v_a^- \triangleq \sqrt{2}v^- \cos w_1 t \\ i = G\,v = G\,v^+ + G\,v^- \end{cases}$$

$$\begin{cases} i_s = \dfrac{\bar{p}}{v.v} v \\ i_{Ca} = i_a - i_{sa} = \dfrac{\tilde{p}}{v.v} v \\ i_{Ca} = \dfrac{-2\sqrt{2}G(v^+ + v^-)v^+v^- \cos w_1 t \cos 2w_1 t}{v^{+2} + v^{-2} + 2v^+v^- \cos 2w_1 t} \end{cases}$$

The control algorithm based on the generalized theory of instantaneous power definition not only generates wrong references for the SAPF (injecting a distorted current into the distribution system) but also causes the supply current distortion. So the situation could be much worse in the presence of wind turbine voltage asymmetry and harmonics.

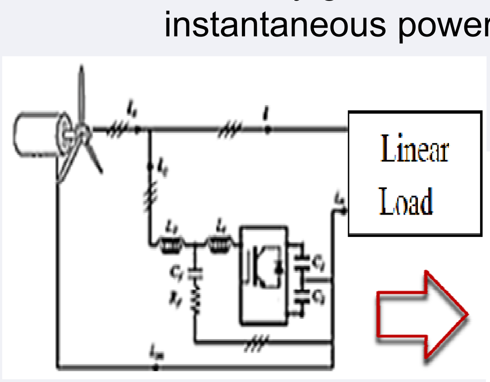
b) Wind turbine voltage harmonics

By the same mathematical methodology used in the previous part; the same results can be obtained.

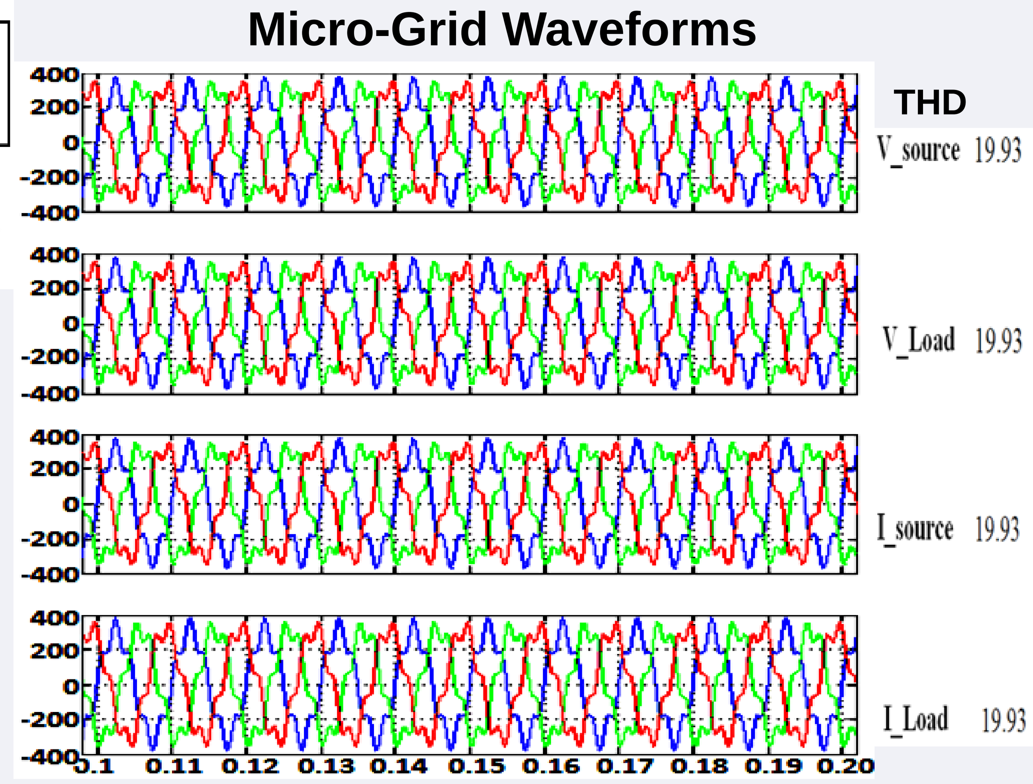
Simulation

When the wind turbine three-phase voltages are distorted by the first and fifth order dominant harmonics, the SAPF compensation algorithms based on the generalized theory of instantaneous power definitions produces distorted outcomes as shown by the following simulations.

SAPF controlled by generalized theory of instantaneous power



Micro-Grid Waveforms

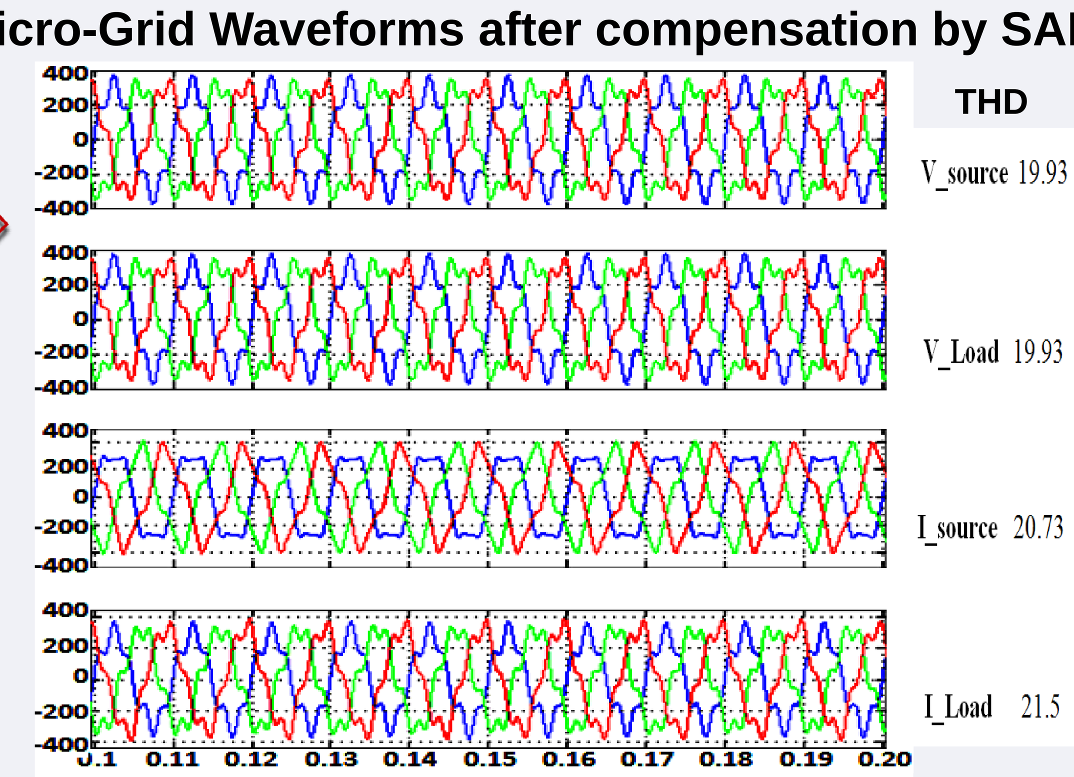


The compensation algorithm based on the generalized theory of instantaneous power definitions

$$\begin{cases} i_p = [i_{ap}, i_{bp}, i_{cp}]^t \overset{\text{def}}{=} \dfrac{p}{v.v} v \\ i_q = [i_{aq}, i_{bq}, i_{cq}]^t \overset{\text{def}}{=} \dfrac{q}{v.v} v \\ S \overset{\text{def}}{=} vi \\ PF \overset{\text{def}}{=} \dfrac{P}{S} \\ v = \sqrt{v_a^2 + v_b^2 + v_c^2} \\ i = \sqrt{i_a^2 + i_b^2 + i_c^2} \end{cases}$$

$$\begin{cases} p = v \cdot i = v_a i_a + v_b i_b + v_c i_c \\ q \overset{\text{def}}{=} v \times i \end{cases}$$

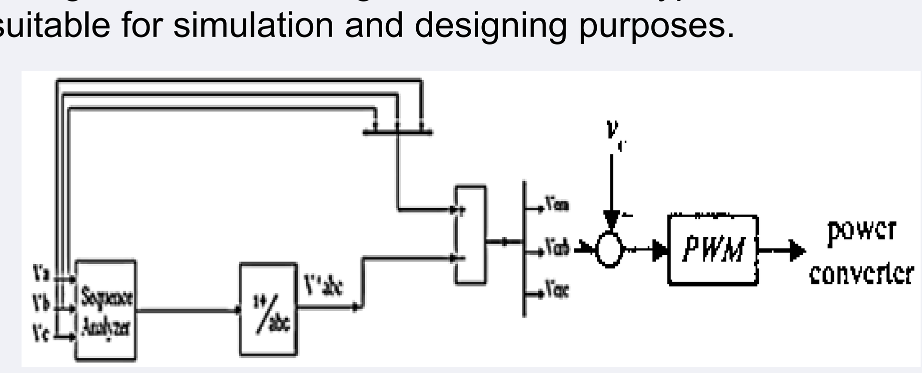
Micro-Grid Waveforms after compensation by SAPF



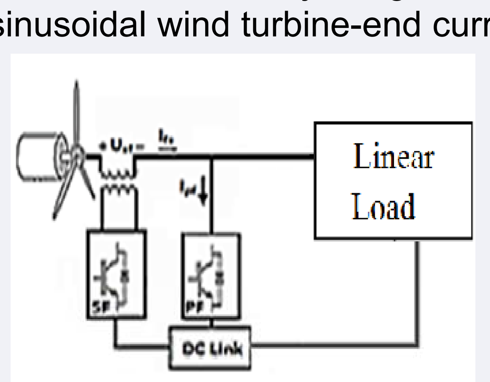
The First Solution

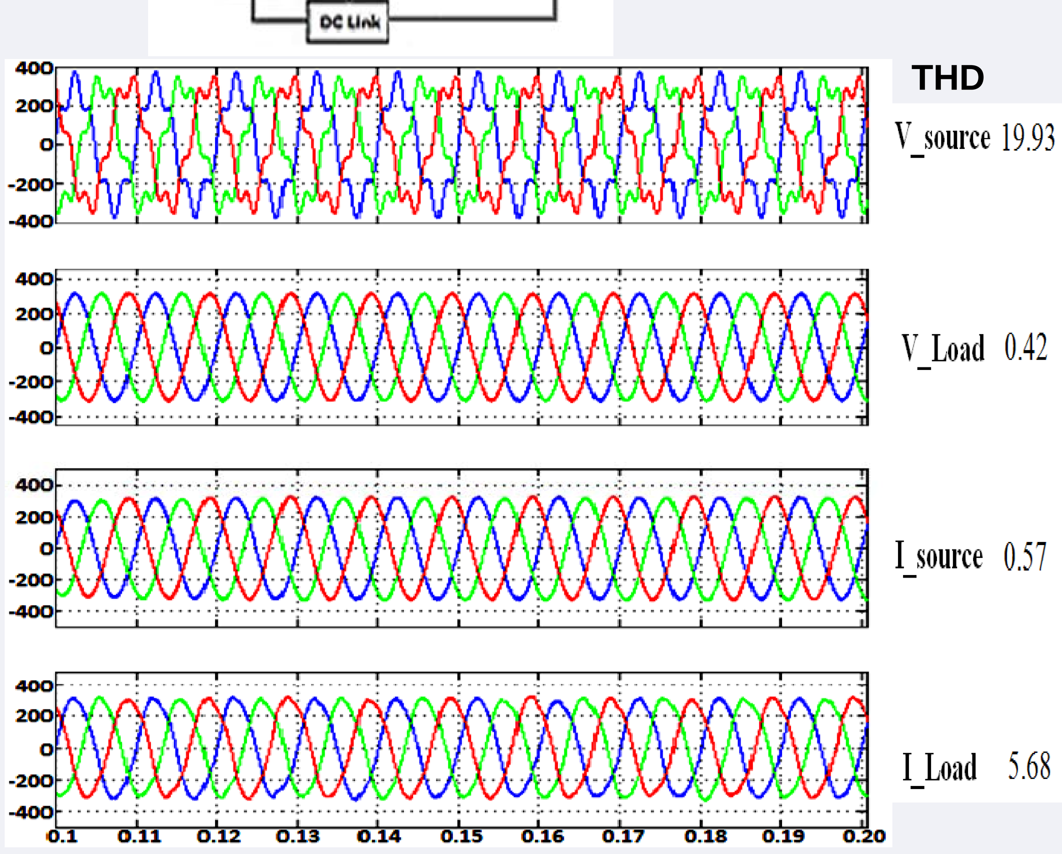
Series Active Filter

the series active power filter is used to compensating the source voltage deficiencies. Figure introduces a typical series active filter suitable for simulation and designing purposes.



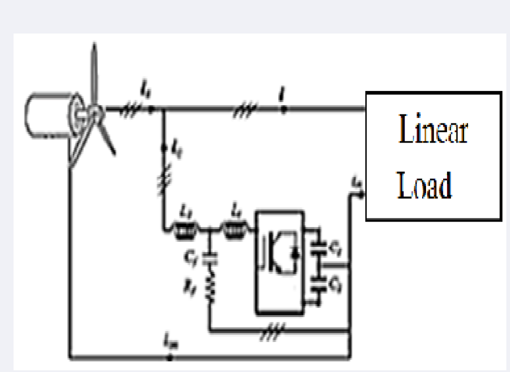
This controlled voltage source injects the compensation voltage needed to mitigate voltage sags and total harmonic distortion into the utility. Now the control algorithm based on the generalized theory of instantaneous power definitions generates satisfactory reference signals for the SAPF in the presence of a balanced linear load; therefore, the injecting current of the SAPF would be led to a sinusoidal wind turbine-end currents.





The Second Solution

Advanced Generalized Theory of Instantaneous Power (A-GTIP) theory



SAPF controlled by A-GTIP theory

if **v+** (t) , **v-**(t) and v^0 (t) respectively indicate positive, negative and zero sequences of **v**(t), the wind turbine-end currents, using the optimal solution (os), can be rewritten as :

$$\begin{cases} i_s(t) = i_s^+(t) + i_s^-(t) + i_s^0(t) \\ i_s^+(t) = \lambda v^+(t) \\ i_s^-(t) = \lambda v^-(t) \\ i_s^0(t) = \lambda v^0(t) \\ \lambda = \dfrac{\bar{p}(t)}{v(t).v(t)} \end{cases}$$

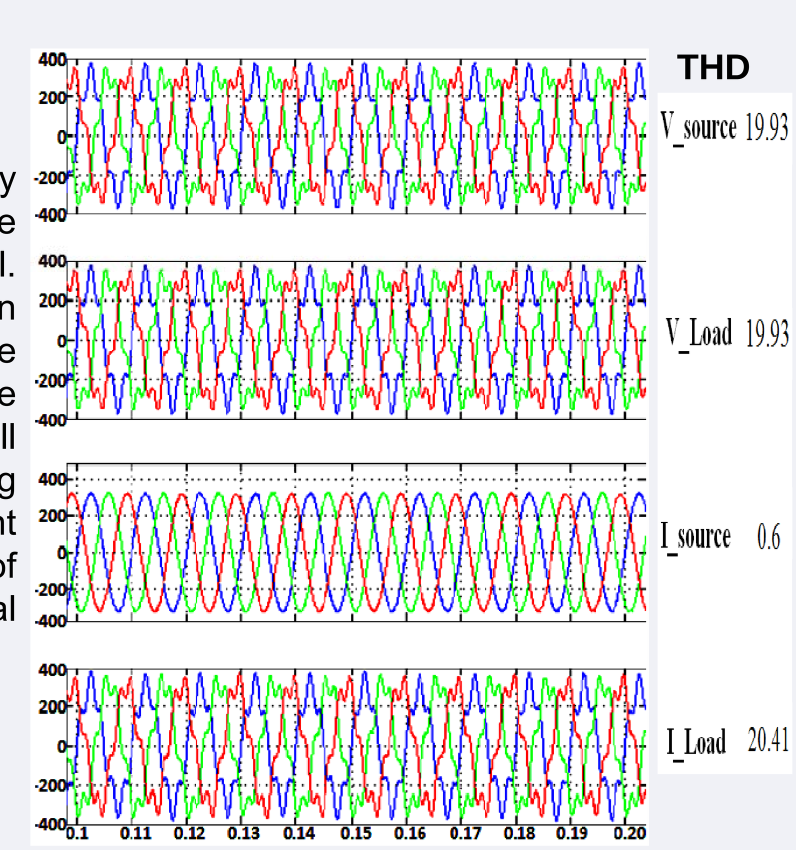
Equations demonstrate that the term v(t).v (t) has an oscillating part on the top of the average part due to the presence of the different voltage sequences. This may cause that the control algorithm based on the generalized theory of instantaneous power definitions generates wrong reference signals for the SAPF; therefore, it will inject a distorted current into the distribution system and also imposes various harmonic orders to the source-end currents. The A-GTIP theory is proposed further solution to overcome these defects:

A) One suggestion to overcome voltage asymmetry is to replace **v**(t) by **v+** (t). Hence the new source-end currents and the SAPF injected currents can be obtained as follow:

$$\begin{cases} i_s(t) = \dfrac{\bar{p}(t)}{v^+(t).v^+(t)} v^+(t) \\ i_c(t) = i(t) - \dfrac{\bar{p}(t)}{v^+(t).v^+(t)} v^+(t) \end{cases}$$

B) As long as **v+**(t) doesn't have any harmonic components, the source currents remain purely sinusoidal. Otherwise, the non-sinusoidal **v+** (t) in the term **v+** (t). **v+** (t) acting as the source of distortion; Therefore, the SAPF compensation algorithm will inject a distorted current. By defining $\mathbf{v}_1$+(t) as the fundamental component of **v+**(t) the new injecting current of the SAPF would be led to a sinusoidal wind turbine-end currents as follow:

$$\begin{cases} i_s(t) = \dfrac{\bar{p}(t)}{v_1^+(t).\,v_1^+(t)} v_1^+(t) \\ i_c(t) = i(t) - \dfrac{\bar{p}(t)}{v_1^+(t).\,v_1^+(t)} v_1^+(t) \end{cases}$$



Conclusion

This paper presents the effects of wind turbine voltage asymmetry and distortion on the accuracy of compensation algorithm, which is a commanding sub-system of shunt active filters in extracting the reference signals. Having done mathematical analysis, this paper proposes two solutions for eliminating these negative effects; first, a series active filter is suggested for eliminating the source voltage waveform deficiencies. Second, a compensation algorithm is presented for the SAPF controlled by the advanced generalized theory of instantaneous power definitions (A-GTIP). This latter is more economical because of avoiding the usage of two inverters. Effectiveness of the proposed suggestions is verified by MATLAB-SIMULINK simulations to confirm the elimination of the wind turbines negative effects; therefore, ensuring the maximum electrical micro-grids efficiency.

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