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Total Harmonic Distortion and Power Loss Reduction in DPF Mode Operation of Harmonic Passive Filters under Presence of Nonlinear Loads in Electrical Power System

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ABSTRACT

The harmonic problems are mainly due to the substantial increase of nonlinear loads due to technological advances, such as the use of power electronic circuits and devices, in ac/dc transmission links, or loads in the control of power systems using power electronic or microprocessor controllers. Voltage distortion, overloaded neutrals and capacitors, telephone and communication system noise, increased power losses and thermal stress are the main effects of harmonics in power system. Passive filters are inductance, capacitance, and resistance elements configured and tuned to control harmonics and can be classified into tuned filters and high-pass filters. Installation of such a passive filter in the vicinity of a non-linear load is to provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. In this research the performance of a dedicated passive filter (DPF) for each phase of non-linear load is investigated and the most effective method which could lead to improve voltage distortion and to decrease power losses is presented.

Keywords: *Harmonics, total voltage distortion, power loss, passive filter.*

1. INTRODUCTION

Increases in harmonic distortion will result in additional heating losses, shorter insulation lifetime, higher temperature and insulation stress, reduced power factor, lower productivity, efficiency, capacity and lack of system performance of the plant.

Many researchers have been focuses on the passive filter design with aim of optimizing harmonic distortion due to non linear load and harmonics injection to power system.

In [1], the harmonic passive filter planning in radial distribution systems using genetic algorithms with aim of voltage harmonic reduction is addressed. In this reference, the input parameters of programmed software include the number and the relevant order of these filters. Optimum location and sizing of two passive harmonic filters, whose harmonic tuning orders are 5 and 7 in distribution networks using genetic algorithm is analyzed by [2]. Power loss reduction and minimization of total voltage harmonic distortion are considered as objective function in this reference.

Between the different technical options available to reduce harmonic distortions and improve power quality, due to implementation of shunt capacitors to compensate the load power factor; it seems the passive power filters have proved to be an important method to compensate current and voltage disturbances in power distribution system.

In [3] a new genetic algorithm based approach to design a passive LC filter for a full-bridge rectifier with aim of finding maximum power factor of the ac mains is presented. In [6] the calculation of the R-L-C parameters for a typical passive harmonic filter used in the customers' house is analyzed.

The results of related investigations show that the most of voltage and current distortions in distribution networks are arose to harmonics of third, fifth and seventh orders [4] . Due to that, in this case the implantation of three single tuned passive filters could solve this problem and therefore the sitting and sizing of filters is quite simple. However, because of distributed linear and nonlinear loads in distribution system, the passive filter planning is much difficult [5].

In [6] the genetic-algorithm-based design of passive filters for offshore application is presented and discussed.

2. MATHEMATICAL MODELING OF HARMONICS

As shown in Fig.1 in presence of sinusoidal source voltage due to non-linear load the current which drawn via source is harmonic distorted.

Harmonic distortion is the corruption of the fundamental sine wave at frequencies that are multiples of the fundamental, (e.g., 180 Hz is the third harmonic of a 60 Hz fundamental frequency; 3 X 60 = 180).

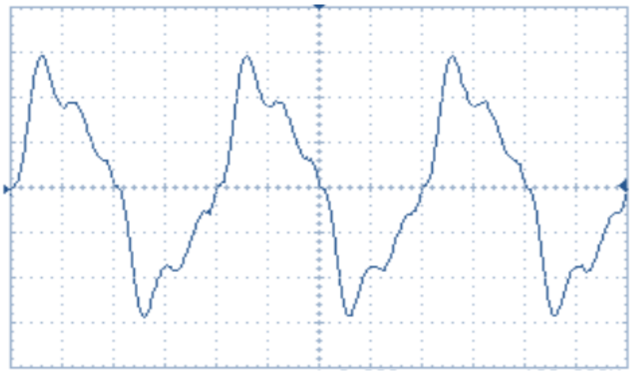

Fig.1.Harmonic distorted current wave

Total harmonic distortion, or THD, based on the IEEE definition, is the summation of all harmonic components of the voltage or current waveform M_i compared against the fundamental component of the voltage or current M_1 [7]:

$$THD = \frac{\sqrt{\sum_{i=2} M_i^2}}{M_1} \qquad (1)$$

The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

Now, consider non-sinusoidal situations, where network voltages and currents contain harmonics. While some harmonics are caused by system nonlinearities such as transformer saturation, most harmonics are produced by power electronic loads such as adjustable-speed drives and diode-bridge rectifiers. The significant harmonics (above the fundamental, i.e., the first harmonic) are usually the 3rd, 5th, and 7th multiples of fundamental component i.e. 50 Hz, so that the frequencies of interest in harmonics studies are in the low-audible range.

$$v(t) = \sum_{k=1}^{\infty} V_k \sin(\omega_0 t - \delta_k) \qquad (2)$$

$$i(t) = \sum_{k=1}^{\infty} I_k \sin(\omega_0 t - \phi_k) \qquad (3)$$

Whose rms values can be shown to be:

$$V_{rms} = \sqrt{\sum_{k=1}^{\infty} V_{k\,rms}^2} \qquad (4)$$

$$I_{rms} = \sqrt{\sum_{k=1}^{\infty} I_{k\,rms}^2} \qquad (5)$$

The average power is given by:

$$Pavg = \sum_{k=1}^{\infty} V_{k\,rms} I_{k\,rms} \cos(\delta_k - \phi_k) \qquad (6)$$
$$= P_{1avg} + P_{2avg} + P_{3avg} + ...$$

Where, we see that each harmonic makes a contribution, plus or minus, to the average power.

A frequently-used measure of harmonic levels is total harmonic distortion (or distortion factor), which is the ratio of the rms value of the harmonics (above fundamental) to the rms value of the fundamental as follows:

$$THD_V = \frac{\sqrt{\sum_{k=2}^{\infty} V_{k\,rms}^2}}{V_{1rms}} \times 100\% \qquad (7)$$

$$THD_I = \frac{\sqrt{\sum_{k=2}^{\infty} I_{k\,rms}^2}}{I_{1rms}} \times 100\% \qquad (8)$$

Obviously, if no harmonics are present, then the THDs are zero. If we substitute equations, we find that:

$$V_{rms} = V_{1rms} \sqrt{1 + (THD_V / 100)^2} \qquad (9)$$

$$I_{rms} = I_{1rms} \sqrt{1 + (THD_I / 100)^2} \qquad (10)$$

Now, with substituting mentioned equations it yields the following exact form of true power factor, valid for both sinusoidal and non-sinusoidal situations:

$$PF_{true} = \frac{P_{avg}}{V_{1rms} I_{1rms} \sqrt{1 + (THD_V / 100)^2} \sqrt{1 + (THD_I / 100)^2}} \qquad (11)$$

A useful simplification can be made by expressing (2) as a product of two components,

$$PF_{true} = \frac{P_{avg}}{V_{1rms} I_{1rms}} \times \frac{1}{\sqrt{1 + (THD_V / 100)^2} \sqrt{1 + (THD_I / 100)^2}} \qquad (12)$$

And by making the following two assumptions:

1. In most cases, the contributions of harmonics above the fundamental to average power in (6) are small, so that $P_{avg} \approx P_{1avg}$.
2. Since THD_V is usually less than 10%, then from (9) we see that $V_{rms} \approx V_{1rms}$.

Incorporating these two assumptions into (12) yields the following approximate form for true power factor:

$$PF_{true} \approx \frac{P_{1avg}}{V_{1rms} I_{1rms}} \times \frac{1}{\sqrt{1+(THD_I\ /100)^2}} \qquad (13)$$

$$= DPF \times \frac{1}{\sqrt{1+(THD_I\ /100)^2}}$$

3. PPF PRINCIPLE

Passive power filter is an appropriate combination of capacitor, inductor and resistor. It has been divided into single-tuned filter, high pass filter and double-tuned filter, and so on. Because double-tuned filter is complex in structure and difficult to tune, PPF usually consists of several single-tuned filters and a high pass filter in practice, which is showed in Fig.1. Here, SPF_k and SPF_m express single-tuned filters. HPF is a high pass filter.

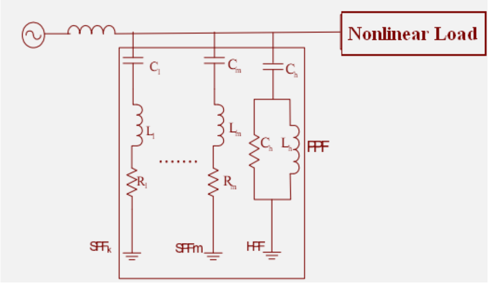

Fig.1. Typical structure of PPF

Suppose ***n*** is the resonant frequency. The impedance of each single-tuned filter ***Zn*** is shown as follows.

$$Z_n = R_n + j\left(n\omega_s L_n - \frac{1}{n\omega_s C_n}\right) \qquad (14)$$

Where ω_s is the fundamental angle frequency of power system; R_n , L_n , and C_n are the resistor, inductor, and capacitor in the filter, respectively. We know that the resonance will occur when $n\omega_s L_n = \frac{1}{n\omega_s C_n}$.

When above condition is satisfied, the filter has the minimal impedance, which is equal to R_n. Because R_n is very small, the n-th harmonic current will mainly flow into the filter and seldom flow into the power system. For other harmonic currents, the impedance is much bigger than R_n. So other harmonic currents seldom flow into this filter.

As a result, once the order of the harmonic frequency equals to the resonant frequency of the filer, the harmonic current will flow into this filter. Therefore, this harmonic current will be eliminated from the power system.

The high pass filter has lots of forms, in which the 2-order high pass filter is most commonly used. The impedance of 2-order high pass filter Z_h is:

$$Z_h = \frac{1}{jn\omega_s C_h} + j\left(\frac{1}{R_n} + \frac{1}{jn\omega_s L_n}\right)^{-1} \qquad (15)$$

For harmonics whose frequency is larger than ***n-th*** order, high pass filter is adopted as a low-impedance. It makes these harmonic currents flowing into the high pass filter.

The target of PPF's optimal design is to meet requirements and to maximize overall efficiency. Optimal parameters shall meet the following requirements:

- Lower total harmonics distortion of voltage or current;
- Lower initial investment costs;
- Higher power factor, whereas reactive power can't be overcompensation;
- No series or parallel resonant with impedance of the system results in the amplification of harmonic;
- The design should ensure that in the normal fluctuation of frequency, the filter can also meet the technology requirements.

4. THE EFFECTS OF HARMONICS ON SYSTEM

Harmonics increase the equipment losses and thus the thermal stress. The triple harmonics result in the neutral carrying a current which might equal or exceed the phase currents even if the loads are balanced. This dictates the derating or over sizing of neutral wires. Moreover, harmonics caused resonance might damage the equipment. Harmonics further interfere with protective relays, metering devices, control and communication circuits, and customer electronic equipment. Sensitive equipment would experience mal-operation or component failure. Waveform distortions can drastically alter the shape of the sinusoid. However, no matter the level of complexity of the fundamental wave, it is actually just a composite of multiple waveforms called harmonics.

Failure, tripping or overheating of capacitors, filters and related equipment, abnormally high noise levels in capacitors, cables, transformers and lightning equipment, overheating of transformers, cables, switchgear, conductors, an abnormally high rate of failures of thyristors and converter equipment, frequent failures of capacitors in lighting equipment or tripping of associated low voltage circuit breakers, nuisance failures of fuses, nuisance tripping of protection relays, in particular sensitive earth fault relays or earth leakage relays, apparent errors in electronic power transducers, apparent inconsistencies in metering equipment. interference with computer equipment and an abnormally high cable failure rate or an increase in cable failures are some of main effects of harmonics in power systems.

Each element of the power system must be examined for its sensitivity to harmonics as a basis for recommendations on the allowable levels. The main effects of voltage and current harmonics within the power system are [8-10]:

- Transformer secondary voltage distortion

- Overloaded neutrals and capacitors
- Telephone and communication system noise
- Increased power losses and thermal stress

5. MATLAB/SIMULINK based simulation

The simulation model of test system in order to analysis the performance of passive filter under DFP states is presented in Fig.2.

The power system elements, including power source, interconnecting cable, transformer, variable frequency drives (VFDs) as non-linear load which is considered as harmonic source, and passive filter bank, is modeled in MATLAB.

The non-linear load has been modeled with a diode rectifier with a smoothing capacitance of $300\ \mu F$ and an ac drive as equivalent resistance which represents the real power consumed by the load. This equivalent resistance corresponds to a 10.4-kW drive.

The parameters of system including cable impedance, transformer equivalent parameters, passive filter parameters, main source and non-linear load are listed in Table 1.

Table 1- System parameters

Elements	Parameter Value
AC mains	$230\,V, 50\,Hz$
Load impedance	$VFD1: R_L = 15\Omega \quad C_L = 300\ \mu F$ $VFD2: R_L = 15\Omega \quad C_L = 300\ \mu F$ $VFD3: R_L = 10\Omega \quad C_L = 300\ \mu F$
Transformer equivalent	$0.15\Omega, \quad 6\,mH$
Passive filter	$L_5 = 10.34\,mH \quad C_5 = 36.34\ \mu F$ $L_7 = 10.34\,mH \quad C_7 = 18.86\ \mu F$
Cable impedance	$0.6\Omega / km, 0.3mH / Km, 3\mu F / km$

Table 2 clearly shows that the application of passive filters reduces the net rms source current from 73.3 to 72.8A for multiple DPFs for each VFD. It can be clearly seen that the THDs of current and voltage have been improved further with DPF performance of passive filters.

Table 2- Simulation results for DPF application of PPF

Current/Voltage	RMS value	THD%
Load current	73.29 A	38.13
Source current with DPF	72.88 A	1.27
Voltage at PCC	313.92 V	27.52
Voltage at PCC with DPF	328.57 V	6.93

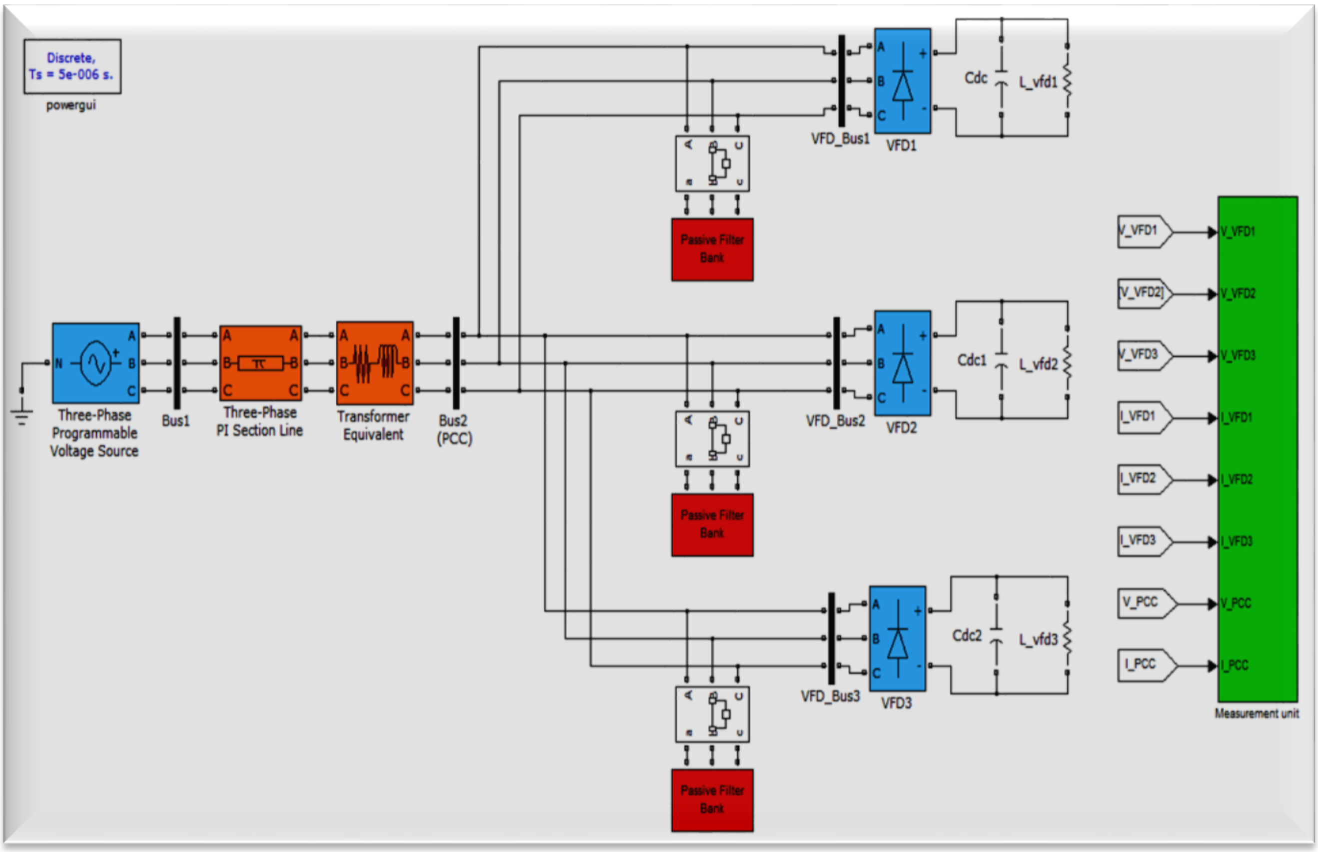

Fig.2. Matlab/Simulink developed model of the test system including of power system and VFD loads for passive filter in DPF state

In fig.3 the voltage at PCC without passive filter is shown. Fig.4 shows the source and load current without passive filter.

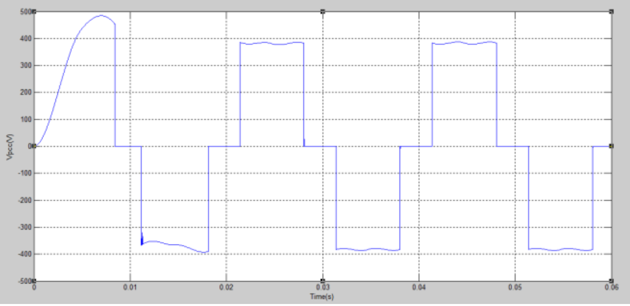

Fig.3.Voltage at PCC without passive filter

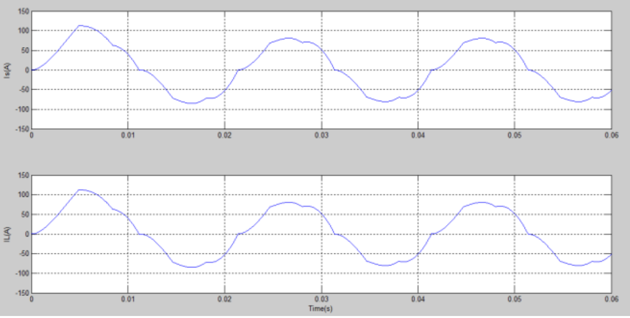

Fig.4.Source and load current without passive filter

In fig.5 the non-linear phase a, b, c currents without passive filter is presented.

Fig.6 shows the voltage at PCC with passive filter under DPF state.

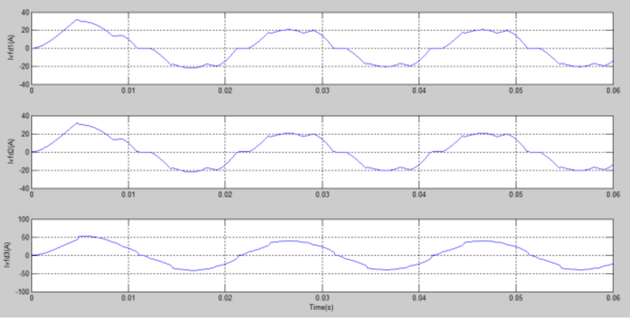

Fig.5.Non-linear phase a, b, c currents without passive filter

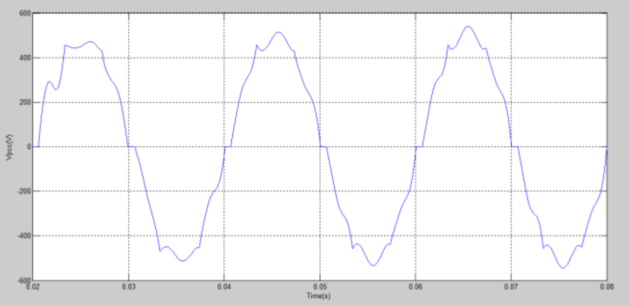

Fig.6.Voltage at PCC with passive filter under DPF state

In fig.7 the source and load current with passive filter under DPF state is shown.

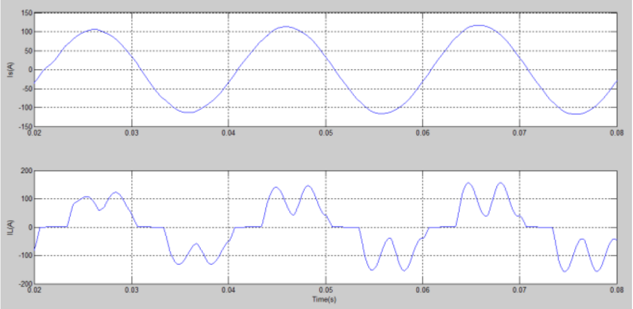

Fig.7.Source and load current with passive filter under DPF state

6. CONCLUSION

In this research the performance of a dedicated passive filter (DPF) for each phase of non-linear load is investigated and the most effective method which could lead to improve voltage distortion and to decrease power losses is presented. Increases in harmonic distortion will result in additional heating losses, shorter insulation lifetime, higher temperature and insulation stress, reduced power factor, lower productivity, efficiency, capacity and lack of system performance of the plant. The good performance of harmonic passive filters under dedicated passive filter mode in this research showed that in practical application in power electrical industry, passive filters can help to system and compensate the harmonics arisen due to non linear load in power system.

REFERENCES

[1] J. L. Afonso, C. Couto, J. S. Martins, “Active Filters with Control Based on the p-q Theory”, IEEE Industrial Electronics Society Newsletter, vol. 47, nº 3, Set. 2000, pp. 5-10.

[2] M. Erhan Balci, M. Hakan Hocaoglu, Effects of Source Voltage Harmonics on Power Factor Compensation in AC Chopper Circuits, Electrical Power Quality and Utilization, Journal Vol. XIV, No. 1, 2008.

[3] Sueker K.H., Hummel S.D., and Argent R.D., Power factor correction and harmonic mitigation in a thyristor controlled glass melter, IEEE Transactions on Industry Applications 1989, 6: 972–975.

[4] W. Mack Grady and et.al, Harmonics and how they relate to power factor, Proc. of the EPRI Power Quality Issues & Opportunities Conference (PQA’93), San Diego, CA, November 1993.

[5] Prachi Godbole, Effect of harmonics on active power flow and apparent power in the power system, IOSR Journal of

Electronics and Communication Engineering (IOSR-JECE), PP: 39-43.

[6] I. Daut, H.S. Syafruddin, Rosnazri Ali, M. Samila and H. Haziah, the Effects of Harmonic Components on Transformer Losses of Sinusoidal Source Supplying Non-Linear Loads, American Journal of Applied Sciences 3 (12): 2131-2133,2006.

[7] W. Mack Grady and et.al, Harmonics and how they relate to power factor, Proc. of the EPRI Power Quality Issues & Opportunities Conference (PQA'93), San Diego, CA, November 1993.

[8] Sueker K.H., Hummel S.D., Argent R.D., Power factor correction and harmonic mitigation in a thyristor controlled glass melter, IEEE Transactions on Industry Applications 1989; 6: 972‑975.

[9] João Afonso, Maurício Aredes, Edson Watanabe, Júlio Martins, "Shunt Active Filter for Power Quality Improvement", International Conference UIE 2000 - Electricity for a Sustainable Urban Development, Lisboa, Portugal, 1-4 November 2000, pp. 683- 691.

[10] Ninomiya, T. Chun-feng Jin Shoyama, M. Ohmae, T. "Line-harmonics reduction techniques for consumer electronics and low-power electronic equipment", Industrial Electronics Society, 2000. IECON 2000. 26th Annual Confjerence of the IEEE, Print ISBN: 0-7803-6456-2, p766, 2000.