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Analysis of Active Power Filter for Harmonic Mitigation in a Distributed Power Generation System

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Abstract

Considerable increase in distributed power generation system (DPGS) has been marked in the literature during the last few years. Some DPGS are interconnected with its corresponding load from a micro grid where most of the loads are fed from renewable sources. Power quality has dragged the attention of many power system engineers as it affects the performance of generation, transmission, distribution utilities. Generation of harmonics at the point of common coupling is a serious issue as it affects the performance of other loads connected to the same point of coupling. Production of harmonics due to various sources must be limited to its standard value for improvement of power quality. This paper will describe about the concept of active power filter for mitigating the harmonics produced at the point of common coupling. The experimental validation of a concept is carried out through MATLAB/SIMULINK model as it is universally accepted. The performance of the system is realised based on total harmonic distortion, power factor level of improvement and cost wise reduction which correspond to the annual saving from consumer side as well as the generation side.

Keywords: *Active Power Filter (APF), Distribute Power Generation System (DPGS), Non-Linear Load, Point of Common Coupling (PCC), Proportional-Integral (PI) Controller, Phase Locked Loop (PLL).*

1. INTRODUCTION

With the incremental change in the population of world, demand for more amount of energy in terms of electricity is also increasing from both commercial & industrial users. This leads to decrease in natural available non-renewable sources from its present value to a lower one. At the same time the demand of clean energy is increase in throughout the globe because the present technologies adopted the energy production produces a lots of pollution, which ultimately effects the humanity. Therefore, to maintain the sustainable environment it is required to inter-connect naturally & abundantly available renewable sources based energy generation system. Again, these sources are intermittent in nature. Which cause a variant in the production of the energy. Interconnection of these sources improves the energy losses, efficiency, power quality, and decrease in the emission of harmful gases from various sources.

Electricity authority of various countries has provides a number of guidelines for interconnecting the renewable sources with the transmission system. These guide lines has strictly monitored through the quality of power that injected to the grid from renewable sources, the Total Harmonic Distortion present at the PCC, fault ride through capabilities of the inverter connected at the grid side. Power quality has different meaning to the different level of costumers like the end user rate the power in terms of its voltage, current, THD values, whereas a manufacturer rate the power quality in terms of the quality of power that is suitable to drive the system under its normal operating condition.

Most of the loads i.e. connected to the grid at its end point are of non-linear type, which introduces a number of harmonics into the existing system, therefore to make the generation units more efficient it is required to mitigate the harmonic at the source side from where it is generated. This is required to maintain the stability & power quality of the consult grid under its acceptance value. This can be achieved through Shunt Active Power Filter. The power quality assessment is basically based on the amount of harmonics produced in the system.

Total harmonic distortion is used to calculate the disturbance present in the power system due to the introduction of non-linear devices. It also represents the amount of deviation of the steady signal from its corresponding ideal characteristics.

Odd Harmonics	Maximum Harmonic Current Distortion
< 11^{th} harmonic	< 4%
11^{th} – 15^{th}	< 2%
17^{th} – 21^{st}	< 1.5%
23^{rd} – 33^{rd}	< 0.6%
> 33^{rd}	< 0.3%

Table: 1 Maximum Harmonic Current Distortion w.r.t. Odd Harmonics

$$THD = \frac{\sqrt{\sum_{2}^{\infty} I_n^2}}{I_1} \quad \text{.......................................} (1)$$

Where I_1 represents the current magnitude in terms its rms value, I_n represents the n^{th} harmonic current present in the system.

Filters are used in power system to reduce and eliminate the harmonics i.e. present in the system. Generally, two types of filters are their i.e. (i) Passive Filter & (ii) Active Filter. Passive filters are those filters which does not have an energy source where as active filters contains the source of energy. The use of passive filter in the power system have been discussed in a number of papers. This filter basically consists of R, L, & C elements to mitigate the harmonics by producing resonance within itself. It is used extensively in the power system because of its bulky nature & large size restricts its uses in the utility cause of resonance problem. Growth in the field of power electronic devices leads us to design APF, which mitigates the harmonics by introducing the negatively generated current harmonics as compared to the harmonics present in the power system.

The control strategies for active power filter is mainly divided into three parts i.e. (i) Detection of load current, (ii) Detection of source current, & (iii) Detection of source voltage. Two types of connection can be achieved through active power filter namely, series connected active power filter and parallel connected active power filter or shunt active power filter. Series APF is used to mitigate the harmonics present in the source voltage whereas, parallel or shunt APF is used to mitigate the source current harmonics. Shunt active power filter requires a steady maintenance of DC voltage across the input terminal of the inverter. This again requires charging of a capacitor in equal interval period of times. The present model is based on PI controller based SAPF which is used to mitigate the current harmonics in the system.

The structure of the paper is arranged as follows;

a. The first part introduces the concept of SAPF & gets practical requirement.
b. The second part consists of the literature survey & the concept to build the APF in order to mitigate the harmonics.
c. Control strategies require to operate the SAPF is introduced in this part.
d. It represents about the modelling & validation of the controller.

1.1 SHUNT ACTIVE POWER FILTER

Shunt active power filter injects the negatively generated harmonic current at the point of common coupling to mitigate the line current harmonic present in the system. Active power filter can be introduced for both the single phase and three phase, however three phase APF requires a phase locked loop (PLL) which is not required in single phase controller. However, single phase connection requires a zero crossing detector (ZCD) to track the frequency and corresponding phase angle. This paper utilities the concept of three phase SAPF with VSI-configuration to validate the design as it is the most simple & cost effective design. This system utilities the PLL concept to generate the reference current as well as the compensating current. Initially the load current is sensed through PLL & supplied to the compensating current by varying or changing the firing angle of the converter. The controller requires a conditioning device for smoothing of the injected current which is exactly a replica of the harmonics to be mitigated. Among the differently available control strategies this paper utilities the concept of p-q control theory based on proportional-integral (PI) theory in order to generate the required current. This controller controls the value of VSI for generating the required amount of compensating current.

1.2DRIVER FOR VSI

The discussed APF must be capable of nullifying the harmonic present in the system. The instantaneous active & reactive power i.e. present in the system for which the control strategies applied must be sensed with two dimensional rotating equivalent DC in order to generate the compensation current. This can be achieved with two stage transformation i.e. converting the grid parameter into a stationary reference frame & transforming into a rotating system through proper conversion. The phase angle ϴ is the important parameter for generating the equivalent amount of compensating current. So, here the angleϴ is traced through a phase locked loop which connected to the grid side as shown in figure: 1.

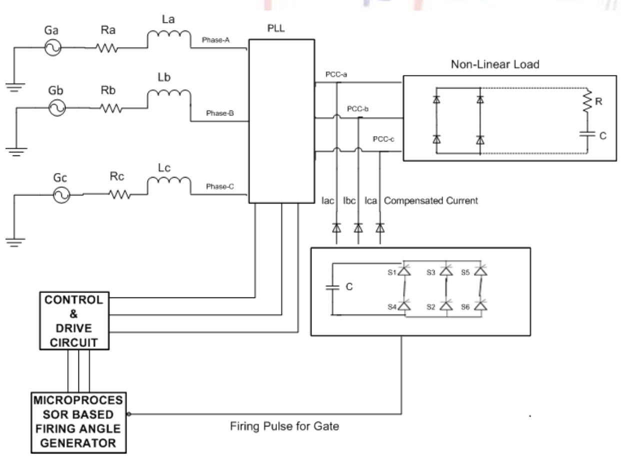

Figure: 1 Block Diagram of DPGS with SAPF

α, β, & zero transformation is applied on the grid side parameter to extract the synchronously rotating d-q parameter from the present system. Again, the α, β, & zero parameter into d-q parameter through a suitable transformation matrix shown in equation 2.

$$\begin{bmatrix} i_o \\ i_d \\ i_q \end{bmatrix} = \frac{1}{V_{\alpha\beta}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad \text{.................} (2)$$

In the above equation, if the voltage space vector is invariant then, the corresponding transformation can be written as,

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = K \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad \text{...} (3)$$

Where, K represents the co-efficient of constant whose value depends upon the voltage vector.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{V_{\alpha\beta}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \quad \text{...................................} (4)$$

Again K can also be written as,

$$K = \frac{1}{\sqrt{V_\alpha{}^2 + V_\beta{}^2}} \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \quad \text{..........................} (5)$$

The above deduction introduce two number of components for both direct axis and quadrature axis current. They are shown in equation (6) & (7).

$$i_d = \overline{i_d} + \tilde{i}_d \quad \text{...} (6)$$

$$i_q = \overline{i_q} + \tilde{i}_q \quad \text{...} (7)$$

The i_d & i_q as shown above consists of both AC & DC components. However, the production of the compensation current it is required to introduce the reference current therefore, the compensating strategies must calculate the average of the above two quantities.

2. SIMULATION MODEL

In order to validate the above described model a SAPF connected to the point of common coupling on the three different condition such as constant load of operation, variable load of operation & constant load of operation without SAPF. For fixed loading system resistive load are consider. Models were developed using Matlab/Simulink environment. The driving circuit information as mentioned is section-2 of earlier discussion is shown in figure: 2.

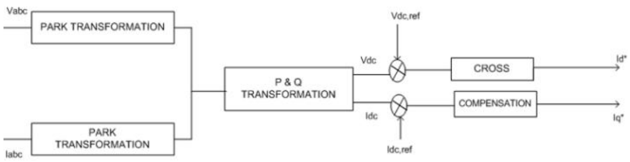

Figure: 2 Driving Circuit

The V_{dc}&$I_{dc}$is collected from the source through a PLL. After transferring the signal through a park transformation. The require data are collected through p-q transformation logic. Here cross comparison method is applied to calculate the i_d&i_q as mentioned in equation (6) & (7).

The DC capacitor reference voltage selected in this paper is two times of the boost in DC voltage i.e. required to reach the peak of phase AC voltage at the Point of common coupling. $V_{dc,ref}$ can be found as by using equation (8).

$$V_{dc,ref} = \frac{2\sqrt{2}}{\sqrt{3}}\frac{V_L}{m} \quad \text{……………………………………} (8)$$

Where, V_L is the peak line voltage at the PCC & 'm' represents the suitability factor.

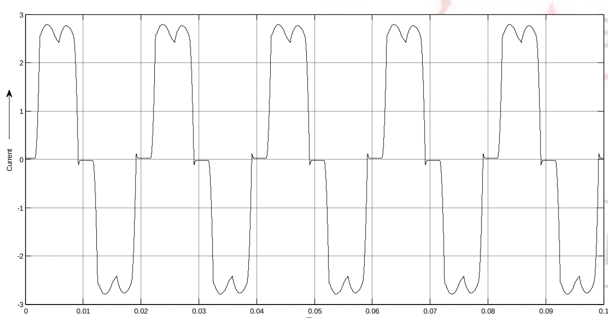

Fig- 3:- Grid Side Current before Compensation

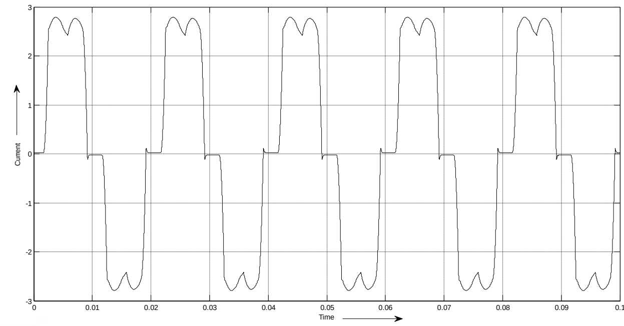

Fig- 4:- Load Side Current before compensation

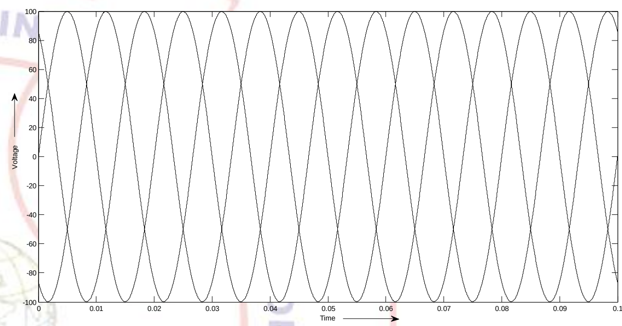

Fig- 5:- Source Voltage at the grid side

The rating of DC capacitor must be selected based upon the estimated variation of load. Therefore, the DC capacitor require for active power filter can be found out.

$$\Delta E_{dc} = \frac{1}{2}C_{dc}(V_{dc,ref} + V_{dc})(V_{dc,ref} - V_{dc}) \quad \text{………..} (9)$$

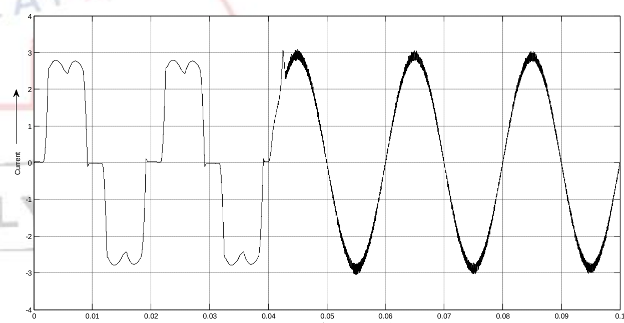

Fig- 6:- Grid Side Current after Compensation

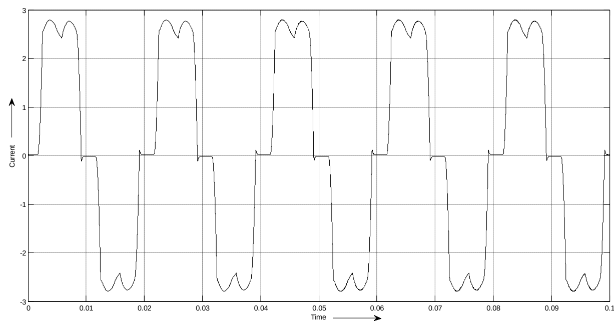

Fig- 7:- Load Side Current after Compensation

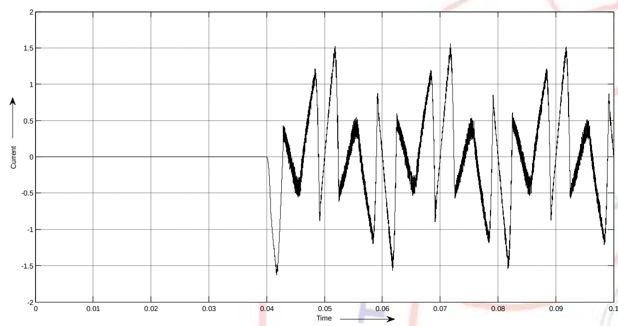

Fig- 8:- Filter Current

From equation (9), capacitance (C_{dc}) can be formulated as,

$$C_{dc} = \frac{2\Delta E_{dc}}{(V_{dc,ref} + V_{dc})(V_{dc,ref} - V_{dc})} \quad \text{………...…….. (10)}$$

To generate a ripple free condition compensated conditioned current, it is required to introduce some line inductance will produce a ripple free current. The value of the inductor is selected based upon the amount of Hysteresis & carrier frequency signal required for the active power filter.

3. CONCLUSION

The use of power electronics devices is very much essential in the present day as most of the house hold & industrial loads requires a variable supply starting from a few volt to kv. These non-linear power electronic devices draws only the non-linear currents & thereby injects harmonics at the PCC. These harmonic currents has a number of inputs on the power system equipment's such as saturation point transformer core thereby limiting the efficiency of the transformer. Again these harmonic current also produces large amount of heat in the rotating machine. So use of SAPF can mitigate these harmonics at the PCC thereby aline the source to delivery maximum power as compared to its K_{var} rating. The performance of SAPF was validated through the Simulink in the comparison is carried out with three different models. Based on the comparison it is found that introduction of APF not only reduces the THD also strengthening the existing conductor of transmission line to deliver maximum amount of power. From the experiment it is found that APF is most suitable at source side as compared to the generation side.

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