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Filters Applied to Photovoltaic Grid Connected System for Harmonic Mitigation

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ABSTRACT

Harmonics is the main power quality issue while using Photovoltaic system as the system uses different power electronic equipments. Also the nonlinear loads are the major cause of harmonics. Nonlinear loads alter the sinusoidal property of current, which results in the drift of distorted current waveform in power system. Various methods are accessible to lower the harmonics in power system. Each method has its own merits and demerits. The type of method to be used is dependent on the situation, requirement and cost. This paper represents a description of active harmonic filter and passive harmonic filters to mitigate harmonics, aiming to represent an analysis report of various harmonic filters methods so as to help the readers in analysis and application of the information to own circumstances in power system.

Keywords: *Harmonics, THD, Active Filter, Passive Filter, IEEE 519*

1. INTRODUCTION

Harmonics are severe alteration of sinusoidal waveforms, also can be defined as the choppy, non-linear or non sinusoidal current which is drawn by electrical loads. It is indeed the Fundamental frequency element plus various integer multiples ie 2f, 3f etc of the fundamental frequency. The integer or numeral multiples are simply higher order of fundamental frequency component. There are two phenomena of Harmonics: (a) Current distortion or Harmonics and (b) Voltage distortion or Harmonics. Current distortion results in voltage distortion. When the Harmonic current flows through the network impedance, they generate a drop-in voltage at the similar frequency as that of Harmonic current.

The harmonic alteration of any recurring current or voltage waveform is normally described through the term total harmonic distortion (THD) that is described to be as ratio of root of square of the summation of squares of simply the magnitude values of the each harmonic component to the fundamental component magnitude.

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \quad \text{or} \quad THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

Here V_1 and I_1 are the fundamental voltage and current respectively. The Fundamental component is frequency of interest and is often assumed to be the largest component. For power system, this fundamental frequency is power system frequency.

Basically, Harmonics are introduced from two sources in PV grid connected system: Firstly, from the connected PV system and secondly from the non-linear loads connected to the system. Intermittent power flow from Photovoltaic system and the use of power electronic equipments introduces harmonics in power distribution network. The other source of drawing current harmonic from the distribution network is the non-linear loads, leading to harmonic pollution.

Fundamentally, the two approaches are utilized to reduce the harmonic problem. First method is known as load conditioning that assures the load connected is resistant to harmonics, which is practically not possible as the devices are designed so as to have high resistivity towards harmonics along with other power disturbances but cannot provide complete resistant. Second approach is to provide line conditioning. In this process line conditioning system is positioned at PCC (point of common coupling) which represses or neutralizes the harmful effects of the harmonics, generated by the nonlinear loads [1].

2. CONSEQUENCES OF HARMONICS

Harmonics are not visible or usually not measurable by any meter, but are open to harm the power distribution system. If not diminished, the harmonics can worsen the system performance. Results of Harmonic Distortion can be briefly described as follows:

- Temperature increase in all linked devices, thereby causing increased loss of power.
- Overheating causes reduction of the insulating materials which gives rise to failure of equipments.
- Electrical resonance.
- Rise in temperature decreases operating efficiency and life of motor.
- Damage to sensitive electronic equipments.
- Interference with the communication networks resulting in wrong information transfer.
- The harmonic current flowing through the neutral wire of 3 phase system causes false tripping of circuit breakers, overheating of cables etc.

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Therefore, it is essential to lessen the harmonics under the specified limit of IEEE 519 harmonic standards.

3. IEEE STANDARD FOR HARMONICS

The IEEE 519 Std provides two different limits, one for the voltage wave and other for the current. Limits of Voltage depends on the bus voltage at PCC, while the current limits vary by the proportion of short circuit current Isc, at PCC to the load current. It is to be analyzed that as the ratio increases, that is to say that load current decreases, higher the limits are allowed. This is on account of the reality that even though high distortion is permissible the overall value of the distorted current is less. This will lead to have less important cause on the complete power system. Table 1 and 2 shows the voltage limits and current distortion limit respectively.

TABLE 1. IEEE STD 519-2014 VOLTAGE DISTORTION LIMITS

Bus Voltage V at PCC	Individual harmonic (%)	THD (%)
$V \leq 1kV$	5.0	8.0
$1kV < V \leq 69$ kV	3.0	5.0
$69kV < V \leq 161$ kV	1.5	2.5
$161kV < V$	1.0	1.5[a]

[a]High voltage system can have upto 2.0% THD where basis is a HVDC terminal and whose potency will have decreased at network points where further users might get connected in future.

TABLE 2. IEEE STD 519-2014 CURRENT DISTORTION LIMITS FOR SYSTEM RATED 120V THROUGH 69KV

Maximum Harmonic Current Distortion in percent of I_L						
Individual Harmonic Order (odd harmonics)[a,b]						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h < 50$	TDD
<20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

[a]Even harmonics are restricted to one fourth of odd harmonics limits specified above.
[b]Current Distortion that occurs through dc offset eg. Half wave converters are disallowed.
[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L where
I_{SC} = maximum short circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC under normal load operating condition.

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4. PASSIVE HARMONIC FILTER

Passive harmonic filters are built using basic AC components namely capacitors, inductors and resistors. Filters can acquire the structure of easy line reactors or may possibly employ a sequence of shunt resonant filters so as to reduce harmonics. A lot of passive techniques exists and are available to diminish the intensity of harmonics in any electrical system, which includes the linking of line reactors, and tuned harmonic filter. In such methods, the unwanted harmonic currents can be prohibited from flowing through the electrical network by either inducing a large series impedance so as to prevent the harmonic current flow or by diverting the path of flow for harmonic currents by applying a low-impedance path in parallel [3].The various form of passive filter for harmonics are described below:

A. Line Reactors:

The line reactors are the simplest means of attenuating harmonics. Series impedance is connected to an individual nonlinear load as can be seen in figure 1, also for eg ASDs can be placed to provide series reactance in a circuit. The reactance so connected not only cause attenuation of harmonic pollution but also takes in voltage transients that may trip the devices due to over-voltage.

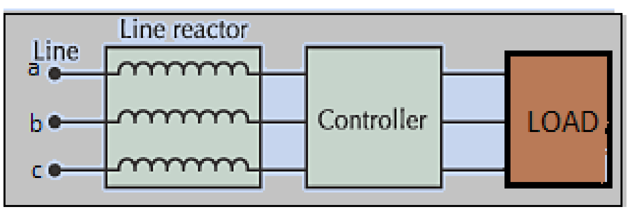

Fig 1. Line reactor linked with load

The level of harmonic reduction depends on the actual impedance affecting the line. May not lower the harmonic level below the IEEE 519 Std 2014 guidelines.

B. Tuned Harmonic Filters:

Such type of PHF provide series or shunt association of tuned LC filter and high pass circuit filter so that low impedance flow path is produced for a specific unwanted frequency or harmonics. Filters are fixed in parallel or in series to that of nonlinear load, providing a diversion to the harmonic current of tuned frequency from the main power supply, to drift away. In contrast to line reactor, this type of harmonic filter does not reduce or eliminate all higher order frequencies but get rid of only single frequency which is tuned at. Eradicating harmonics on their source end has shown up to have the most valuable method to lessen harmonic loss in the remote power system. Conversely, the higher first cost involved presents a difficulty toward this approach [5]. These are of various types as illustrated in figure 2 and briefly described beneath:

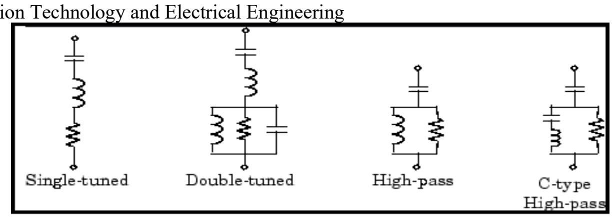

Fig 2. Group of tuned filters

1) *Single Tuned:* Filter tuned at only a single frequency.
2) *Double Tuned:* Filter tuned at two frequencies.
3) *High Pass:* High-pass filter has a resistor attached in parallel to a reactor. This attachment helps in dropping the "Q" magnitude of filter, that in turn will help lower the higher order frequencies. Use of High pass filter along with band-pass mitigates moderate levels found in medium level voltage and sub-transmission level voltage networks.
4) *C-type filter:* These are utilized for complex nonlinear loads, cyclic converters, welders ,electric furnaces etc and are special designed high pass filter. This filter will provides the load with leading and lagging reactive power anavoids condition of parallel resonance with the load.

5. LIMITATIONS OF PASSIVE FILTER

Few limitations of the PHFs can be summarized as follows:

- These are not adaptable to the changing system conditions and once installed are rigidly in place. Neither the tuned frequency nor the size of the filter can be changed so easily. The passive elements in the filters are close tolerance components.
- A change in the system or operating condition can result in detuning and increased distortion. This can go undetected, unless there is on-line monitoring equipment in place.
- The design is largely affected by the system impedance. To be effective, the filter impedance must be less than the system impedance, and the design can become a problem for stiff systems. In such cases a very large filter will be required. This may give rise to overcompensation of reactive power, and overvoltages on switching and undervoltages when out of service.
- Often, passive filters will require a number of parallel shunt branches. Outage of a parallel unit totally alters the resonant frequencies and harmonic current flows. This may increase distortion levels beyond permissible limits. Power losses in the resistance elements of passive filters can be very substantial for large filters.
- The parallel resonance between filter and the system (for single- or double tuned filters) may cause

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amplification of currents of a characteristic or no characteristic harmonic. A designer has a limited choice in selecting the tuned frequency to avoid all possible resonances with the background harmonics. System changes will alter this frequency to some extent, however carefully the initial design might have been selected.

- Damped filters do not give rise to a system parallel resonant frequency; however, these are not so effective as a group of ST filters. The impedance of a high-pass filter at its notch frequency is higher than the corresponding ST filter. The size of the filter becomes large to handle the fundamental and the harmonic frequencies.
- The aging, deterioration, and temperature effects detune the filter in a random manner (though the effect of maximum variations can be considered in the design stage).
- If the converters feedback dc current into the system (with even harmonics), it can cause saturation of the filter reactor with resulting increase in distortion.
- Definite-purpose breakers are required. To control switching surges, special synchronous closing devices or resistor closing is required.
- The grounded neutrals of wye-connected banks provide a low-impedance path for the third harmonics. Third-harmonic amplification can occur in some cases. Special protective and monitoring devices (not discussed) are required.

6. ACTIVE HARMONIC FILTER

The newest technology available for reduction of harmonics is the active power filter or active harmonic filter(AHF). By injecting harmonic distortion into the system, which is equal to the distortion caused by the nonlinear load, but of opposite polarity, the waveform can be corrected to a sinusoid. AHFs make use of fast-switching IGBTs to generate an output current of the requisite shape so as to cancel the original load produced harmonics when get injected to the AC main lines. The voltage distortion is caused by the harmonic currents flowing to the system impedance. If a nonlinear current with opposite polarity is fed into the system, the voltage will revert to a sinusoid.

Active filters are classified in accordance to the way they are connected in the circuit:

A. Series Active Filter: It is fixed in series with the load. It acts as a controlled voltage source.

B. Shunt Active Filter: It is connected in parallel with the load. It acts as a controlled current source.

Advantages:

- Assured compliance with Std 519-2014 of IEEE, if sized accurately
- Harmonic elimination from 2nd to 51^{st} order harmonic
- Provide trouble-free installation with no major system modification
- Provides VAR current, thereby improving power system pf.

Limitations:

- Can be extra expensive in comparison to other approaches because of increased functionality control and power control sections.
- The filter's semiconductors are exposed to line transients.

7. CONCLUSION

Electrical power system consistency and regular functioning of electrical equipments depends upon a clean and distortion less power supply. A lot of harmonic mitigation techniques exist for engineers to lower the harmonic level. Because of the huge numbers and variance of existing methods, choice of the well-suited technique for a specific application is not at all times a simple or easy process. A brief categorization of AHFs and PHFs mitigation techniques has been carried out to offer a general point of view on this widespread and speedily developing topic. PHFs were conventionally used to take in harmonic currents for the reason that they have low cost and uncomplicated robust structure. However, they offer fixed compensation and generate system resonance offers various functions such that harmonic elimination, isolation, PF correction, damping and termination, load balancing and regulation of voltage.

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