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Power Quality Improvement by Harmonic Attenuation and Power Factor Correction

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***Abstract*: The expansion of nonlinear loads and increasing number of distributed energy resources (DERs) in grid makes it difficult to achieve quality in power system. Harmonic elimination can be done by decreasing number of nonlinear loads, incorporating multilevel inverters and using different types of filters. In this paper we will discuss about active power filter (APF) and conventional power factor correctors (PFC) for harmonics attenuation and power factor correction.**

***Keywords*: Active Power Filter (APF), Power Factor Correctors (PFCs), Distributed Energy Resources (DERs), More Electric Aircraft (MEA).**

1. Introduction

The term power quality has become one of the most prolific buzzwords since late 1980's .Both electric utilities and end users of electric power are becoming increasingly concerned about quality of power. Power quality is ultimately a consumer driven issue and the end user's point of reference takes precedence. Harmonic distortion is caused by nonlinear devices in power systems. While achieving power by wire concept by the inclusion of electrical subsystems and loads which operate at high frequency switching manner results in severe harmonic generation. To ensure the proper operation of electrical subsystem an equipment Total harmonic distortions (THDs) are limited as per international standards and grid codes for electrical grids. For example a revised version of MIL-STD704F imposes strict limits on THDs in More Electric Aircrafts (MEA). Another example is IEEE Std. 519-2014 recommends the practices to be followed in electrical power systems for limiting harmonics. Harmonic distortion leads to heating in induction motors, faster aging of insulation and harmonic resonance in capacitors. A poor power factor will contribute to equipment instability failure and high energy cost. By optimizing and improving power factor, power quality is improved, reducing the load on electricity distribution system. Here we discuss about APF and PFCs which are used to maintain power quality. Power factor corrector aims to improve power factor and hence power quality by utilizing capacitors. Power factor correction is required when a system has power factor of less than 90% or 0.9Improving power factor can reduce electricity bills, power losses and maximize current carrying capacity. Simplest method of power factor correction is done using power factor correction capacitors. Lower power factor has adverse effect on generating and distribution capacity. Power factor correction is done when there is a motor failure, electric or electronic equipment failure, over heating of transformers, nuisance tripping of circuit breakers and fuses etc.

2. Conventional PFCs

PFCs are widely used in household appliances to achieve unity power factor and to ensure high efficiency in the system. Electrical power quality is improved with the help of PFC stages by incorporating an input resistance for all system frequencies. Power factor is of much importance in AC circuits. Thus when a large circuit consisting of different passive elements is considered, there will be a significant phase shift between voltage and current. The cosine of phase difference between voltage and current is called power factor. This factor represents the fraction of the total power that is used to do the useful work. The other fraction of electrical power is stored in the form of magnetic energy or electrostatic energy in the inductor and capacitor respectively.

A. Capacitors

The value of power factor is decided by the phase shift between voltage and current. All the inductive loads need to be fed with some amount of reactive power. The bank of capacitors would provide the required reactive power, thus less reactive power flows through the line. Thus the phase difference between voltage and current is reduced. The reactive power is provided by bank of capacitors in parallel. Since they provide reactive power, less reactive power flows through the line. Thus the phase shift between voltage and current is reduced. The lagging current is neutralized by static capacitors in the system. This is simplest method for power factor improvement. This method has cost benefits and requires less maintenance as there are no rotating parts. It can be easily connected with less weight. Cost benefits are due to the usage of static capacitors. This arrangement helps in attaining lower losses. However these capacitors can be easily damaged due to higher voltages and have a shorter life span of 8 to 10 years. Once the capacitors are damaged their repair is difficult.

B. Synchronous Condenser

It is a synchronous motor without any load at its shaft. The synchronous motor is able to operate under any power factor conditions. In case of inductive loads, the condenser is connected at load side and it is overexcited. It then behaves like a capacitor. This is achieved by drawing lagging current from supply or by providing reactive power to the load. The condenser is connected in load side and over excited in the case of inductive loads. This condenser makes it to act like a capacitor. Thus it takes lagging current from supply or gives reactive power. When motor is overexcited it gives leading current. As in the case of static capacitors, it then neutralizes the lagging current and power factor improvement is done. Step less power factor can be achieved using this method. Faults in the condenser could be removed easily. The motor windings are able to offer higher thermal stability to high currents. But their maintenance costs are higher due to rotating parts. It is not suitable for lower power rating and is said to produce a significant amount of noise. Since the motor is not self-starting excitation equipment is to be given for this purpose.

C. Phase Advancer

It is used in asynchronous motors to improve the power factor. They are ac exciters which are connected to rotor circuit of the motor. Power factor improvement is done by providing ampere turns which further produces the required flux. Increased

Fig, 1. Conventional power factor capacitors

Fig, 2. A typical synchronous condenser

Fig, 3. Phase advancer

3. Active power filter

Active Power Filter (APF) is capable of correcting power factor and compensating harmonics at the same time. APF is been controlled using hysteric current control method and harmonic cancellation method. APFs developed so far uses full bridge inversion topology. But this topology would lead to hidden danger of shoot through and difficulty in handling current control methods of APF during unbalanced operations. So it is preferred to use an APF with dual buck inversion topology to attenuate the harmonics and improve the power factor. Active power filters are emerging devices that can eliminate both upper and lower order harmonics by generating a sampling current with respect to the inductive load. APF can be series, shunt or hybrid. Hybrid APFs are used to contribute to increase in power factor and in the mitigation in the effects of voltage disturbances on home appliances. The APF can also be integrated to a MEA so as to limit the harmonic and power factor within the requirements of recently modified MIL-STD-704F. The THDs of voltages and currents in MEA would vary inversely with respect to the increase in frequency creating larger phase shift .This results in low power factor and it is different for various flight phases .The load power factor indicates that the generator has to supply more reactive power to the loads which results in increased power rating. Thus the THD and the power factor values are not limited as per MIL-STD_704F. The preferred dual buck topology would reduce the risk of fly wheeling currents in intrinsic diodes and hidden danger of shoot through. If all objective are achieved together using APF The generator current will be in phase with fundamental positive sequence component of generator phase voltage. By integrating APF with dual buck inversion topology into MEA there would be significant drops in harmonic contents of generator voltages and currents during different flight phases. Thus phase shift between voltage and current drops significantly and results in high power factor. The proposed APF is able to correct power factor without affecting system operation. APF is a highly advanced power regulation technology. It has high feasibility and wider prospect. It does not vary with respect to system impedances and frequency. Most of APF applications are of 50Hz frequencies. A Digital Signal Processor based control strategy is used in aeronautical APF so as to decrease the time for detection and calculation. Passive and active filtering can be used to suppress harmonics. The passive filters can be easily used to mitigate harmonic distortion. Passive elements do not always respond accurately to dynamics of power system. These filters would cause resonance thus affecting the stability of the system. Passive filter characteristics would be affected by the variation in frequency. Thus these filters wouldn't be able to meet future revisions of a particular standard. There has been an increase in demand for APFs in mitigation of harmonic distortion. Active filtering technology is used for the past four decades. APF produces specific sampling currents to cancel out both higher and lower order harmonics. APFs have more advantages than passive filters. Such as, they can suppress both supply as well as reactive currents. Compared to passive filters, there is no generation of harmonic resonance in the system. Performance of APF is independent of the system characteristics. APF technologies are still under research. An active power filter consist of three stages, namely signal conditioning, Derivation of compensating signal and generation of gating signal. Signal conditioning means detection of harmonics in power line. The reference signal given by the controller ensures proper operation of the APF. The proper detection of voltages and currents are made to analyze the proper value of reference signal to be given. These voltage and current variables are detected by potential transformers, current transformers etc. The variables to be detected are AC source voltage, DC bus voltage of APF, and voltage across interfacing transformer. The current variables to be detected are load current, AC source current. Stage two is the derivation of compensating signal from the distorted way. Frequency domain approach and time domain approach are used for the derivation of this signal. Fourier transformation technique is used in frequency domain approach. But different methods like Instantaneous Reactive Power Theorem, Synchronous Reference Frame Theorem and Synchronous Detection Theorem are used for time domain approach. Stage three is the generation of gating signal. Control schemes like space Vector PWM, repetitive control, hysteresis current control etc. are used in various configurations for active power filters. APF could be connected in various power circuit configurations. In general there are three main sections, namely shunt, series and hybrid APF.

A. Shunt active power filter

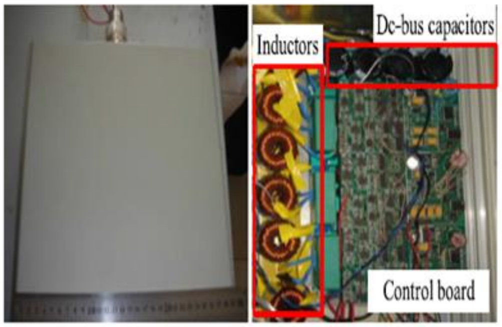
This is the most widely used type of APF. It is used to mitigate load harmonics given to supply by connecting it to main circuit. It is used to balance the phase currents and to compensate reactive power. These filters can carry the compensation current and a little amount of fundamental current given to compensate the losses in the system. These filters can be used for a wider range of power ratings by connecting them in parallel.

B. Series active power filter

A PWM voltage waveform is added or subtracted in order to withdraw pure sinusoidal waveform from the source. The inverter used is voltage fed inverter without current control loops. These filters are used rarely in industries when compared to passive filters. The reason is that they have series connection which leads to increased current rating. Series filters are good at eliminating Voltage waveform harmonics and in balancing phase voltages. Thus this filter is used to improve system voltage.

C. Hybrid active power filters

Hybrid APF has the advantages of both series and parallel APF. These filters are cost effective and portraits better performance than conventional filters. The switching noise and Electro Magnetic Interference (EMI) are considerably reduced. This technique is proposed in various research works. Here the high pass filter is combined with the APF. Thus both the filters help in harmonic mitigation. The APF is used to eliminate lower order harmonics and the High Pass Filters are used to reduce higher order harmonics. Hybrid shunt APF is widely used in the industry. Thus this filter has the ability to perform the function of eliminating both lower and higher order harmonics at the same time. Function properly. Harmonic distortion is a main cause for many power quality disturbances that are actually transients. Harmonic currents produced by nonlinear loads are injected back into the system and these currents can interact adversely with power system equipment's.



Fig, 4. Laboratory prototype of a 3KVA active power filter

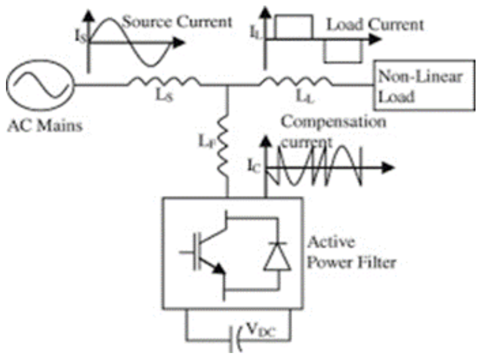


Fig. 5. An active power filter

4. Conclusion

Power quality is an umbrella concept for a multitude of individual types of power system disturbances. The issues that fall under this umbrella are not new. There is a continued push for increasing productivity for all utility customers. Power quality is said to be those characteristics of power supply that enable equipment to voltage, reducing losses and lowering electricity bills. The easiest method to improve power factor is by adding power factor correction capacitors in the system. These capacitors would now act as reactive current generators. They improve power factor by the offset of unused power in inductive loads. APFs are newly introduced devices which can perform perfect harmonic cancellation. For proper implementation of active filters a good method for current or voltage method is to be used. The paper gives a broad perspective about APFs.

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