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A Comparative Study of Harmonic Compensation Techniques in Micro-Grids using Active Power Filters

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***Abstract*—Power quality issues like voltage sag, voltage swell, harmonics, etc are common in micro-grids. These power quality issues are arising due to the increased usage of non-linear loads and power electronics interfaced Distributed - Generation system. Various methods are used for the improvement of power quality of which one of the most advanced technologies is the employment of an Active Power Filter. In this paper comparative study on various methods of harmonic compensation in micro-grids using active power filters is done. Analysis have been done based on their topology and control strategies and the conclusions so arrived are represented using comparison tables. This could help the designers to select appropriate topology or control strategy for an APF which is employed in a particular micro-grid. The review is done by analyzing many publications and is appended here for reference.**

***Index Terms*—Micro-grid, Power quality, Active power filers, APF Topologies, Time domain control algorithms.**

I. INTRODUCTION

Micro-grids can be also termed as a group of Distributed Generation units that can be interfaced with an electrical distribution network using Power electronic devices like voltage source converters. The first mode is termed as Grid-connected operation and the second case is termed as Island mode of operation. If the voltage unbalance is severe, the circuit breaker between the micro-grid and utility grid opens, the micro-grid now operates in island mode. If the voltage unbalance is solemn, the circuit breaker remains in closed condition, which is called as Grid connected operation of micro-grid. Islanding can happen if the converter isn't prevented from injecting current within a short period of time and continues to feed local loads after tripping the grid. Islanding can pose a safety risk to utility workers if they assume that the line is de-energized after disconnecting it from the grid. Moreover, closing the upstream circuit breakers during islanding can cause major damage to the converters due to unsynchronized reconnection to the grid. Another issue is that due to a mismatch between active and reactive power delivered by the converters and consumed by the loads, the voltage and frequency of an islanded DG system might shift considerably from the nominal values. Therefore, islanding is potentially a hazard to people and to grid-connected converters, and should be effectively detected and avoided, Khani et al. (2013).Based on IEEE Standard 1547, which is applicable for converters with rated power of less than 10MVA connected to primary or secondary distribution systems, the converters shall detect islanding and cease to energize the area within two seconds of formation of an islanding event Diarmaid J. Hogan et al.(2014), Jayawardena et al.(2012), Wang Jinquan et al.(2012), JinweiHe et al.(2014).

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II. REVIEW OF VARIOUS PQ PROBLEMS IN MICRO-GRID

The power quality problems which are commonly affecting the utility grid are presence of harmonic content, load unbalance, increased reactive power demand and fluctuation in system voltage. Generally, current harmonic and voltage-frequency imbalance increase losses in ac power lines. The current control loop based on synchronous reference frame and conventional PI regulator is used for voltage-frequency regulation, Fujita et al.(2000). The power quality parameters are made conditioning with the support of voltage source inverter interfaced distributed energy resources. Since, they need of Conventional filter in order to detect apparently, the unbalance in voltage and harmonic in the main system. The art of designing of filter in three phase power system indulged adopting of band pass and band stop filter to eliminate the harmonic in micro-grid, Shuai, (2011). Flexible Distributed Generation (FDG), which relates in the functional of FACTS is proposed to active power flow control and to mitigate harmonic, unbalance load and voltage flickering, Gupta et al(2012). The current controller functions to inject sinusoidal current to grid, although in presence of non- linear load and unbalance voltage distortion, Dash et al.(2013), Wang Jinquan et al.(2012). So as to attain fixed switching frequency, the controller complexity will be raised, although hysteresis controller is used. One of the major concerns in electricity industry today is power quality problems to sensitive loads. Presently, the majority of power quality problems are due to different fault conditions. These conditions cause voltage sag. Voltage sag may cause the apparatus tripping, shutdown commercial, domestic and industrial equipment, and miss process of drive system. The proposed system can provide the cost effective solution to mitigate voltage sag by establishing the appropriate voltage quality level, required by the customer. It is recently being used as the active solution.

Distributed Generation is a back-up electric power generating unit that is used in many commercial buildings, industrial facilities, hospitals, campuses and department stores. Most of these back-up units are used primarily by customers to provide emergency power during times when grid-connected power is not available and they are installed within the premises of the consumer where the electric demand is needed. The installation of the back-up units close to the demand center avoids the transmission losses and cost of transmitting the power. The generating units called back-up units are currently defined as distributed generation to differentiate from the traditional centralized power generation model, which has proven to be economical and a reliable source of energy production. However, without significant increase in building new generating capacity or even in expanding existing ones to meet the needs of today's power demand, the whole electrical power industry is facing serious challenges and is looking for a solution, Jayawardena et al. (2012), Khani et al. (2013).

The advancements in the power technology have proven a path to the modern industries to extract and develop the innovative technologies within the limits of their industries for the fulfillment of their industrial goals. Optimization of the production while minimizing the production cost and thereby achieving maximized profits while ensuring continuous production throughout the period has become the ultimate goal, Menniti et al.(2008), Shuai et al.(2011). A stable supply of un-interruptible power has to be guaranteed during the production process. The modern manufacturing and process equipment, which operates at high efficiency, requires high quality defect free power supply for the successful operation of their machines. So, the reason for demanding high quality power is basically of such importance. To be precise, most of the modern machine components are designed to be very sensitive for the power supply variations. Adjustable speed drives, automation devices, power electronic components are only some of the examples for such equipment. Failure to provide the required power quality in the output may sometimes cause complete shutdown of the industries which leads to a major financial loss to the industry concerned, Anjana et al. (2014), Jelani et al. (2012).

Thus the industries always needs high quality power from the supplier or the utility. But the responsibility for degraded quality cannot be solely put on to the hands of the utility itself. It has been found out most of the conditions that can disrupt the processes are generated within the industry itself. Most of the non-linear loads within the industries cause transients which can affect the reliability of the power supply. Improvement of power quality has been given considerable attention due to the increase of the power quality issues in addition to the limitations required by international standards such as IEEE519-1992, IEC1000-3-2, and IEC1000-3-4. Those limitations were set in order to limit the disturbances and avoid major problems in distribution power systems. Conventionally, passive filters are used for current harmonics mitigation while capacitor banks are utilized for Power factor correction. Neither of them solves the problem in a suitable way, and usually causes other problems, such as resonances. Moreover, their performance depends on system impedance and also suffers from filter passive components ageing effect, Fahmy et al. (2014), Shuai et al. (2011).

III. Review on General Active Solutions for Mitigation of PQ Issues in Micro-Grid

The mitigation of harmonics was done by using conventional passive filters at first. But these passive filters were having certain drawbacks like low efficiency, higher filter size, resonance problem. If the network voltages consist of frequency at which passive filters have low impedance, that voltage component may cause severe rise current in passive filters. Occurrence of anti-resonance between the source impedance and filter impedance, flowing harmonic current and causing severe voltage increase. The above mentioned problem can be solved by simultaneous use of passive and active series filters. Shunt active power filters (APF) have attracted considerable attention as an efficient way to perform power conditioning tasks such as harmonic elimination, reactive power compensation, load balancing, and neutral current elimination. Also APFs offer high efficiency and perform effectively on lower-order harmonics such as 3rd, 5th, 7th which are generated by the nonlinear loads, Jayawardena et al. (2012). Shunt APF's DC-link voltage must be kept constant in order that it can compensate both of harmonics, reactive power and mitigates the neutral current effectively. Because of their simple implementation and tuning, PI controller gains extensive application in the DC-link voltage controllers for shunt APFs, Fahmy et al. (2014), Tiwari et al. (2014), Zamani et al. (2014).
However, PI controllers require exact system mathematic model and also offer poor robustness in transient state. Occasionally, DC-link voltage overshoot and inrush source current occur, which may result to protection tripping or even semiconductors failure when APF's operation is started. Recently, Fuzzy Logic Controller (FLC) has received a noticeable attention regarding their application as APFs' controller. FLCs offer strong robustness to variable parameters, good dynamic response and limited overshoot in the transient response. The active and passive filters are connected in series with each other. The hybrid filter is connected in parallel with other loads in the vicinity of the secondary of a distribution transformer installed at the utility-consumer point of the common coupling (PCC). It is, therefore, different in the point of installation from pure active filters and hybrid active filters which have been installed in the vicinity of harmonic-producing loads. The purpose of installing the hybrid filter proposed in this paper is to damp the harmonic resonance in industrial power systems, as well as to mitigate harmonic voltages and currents. When an over current flows into the passive filter, the active filter controls the gain to be a positive value. Thus, the active filter acts as a positive resistor, preventing the passive filter from absorbing an excessive 5th-harmonic current. The 5th-harmonic current flowing into the passive filter.

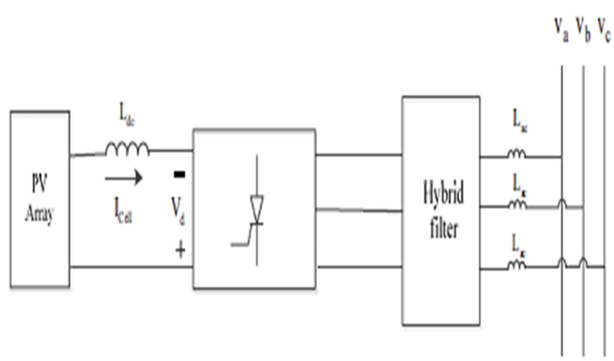

Fig 2.1 series Active power filters in a D-G system

In some applications, combining several different types of filters into a hybrid system can achieve better performance. Several hybrid configurations were reported, including parallel active filter with series active filter, series active filter with parallel passive filter, parallel active filter with parallel passive filter and active filter in series with parallel passive power filter, Dash et al. (2013), Fujita et al. (2000), Shuai et al. (2011). Among these configurations, the active filter in series with parallel passive filters, also known as the hybrid active power filter (HAPF), shows great promise. In particular, the concept of injection-type hybrid active

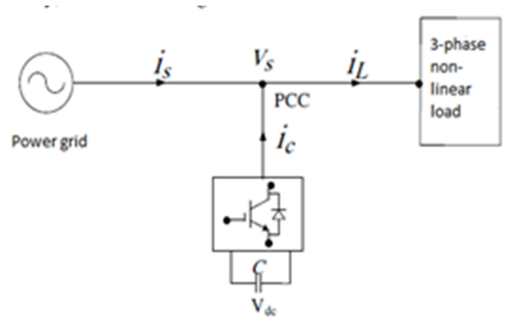

Fig 2.2 Shunt Active power filters in a D-G system

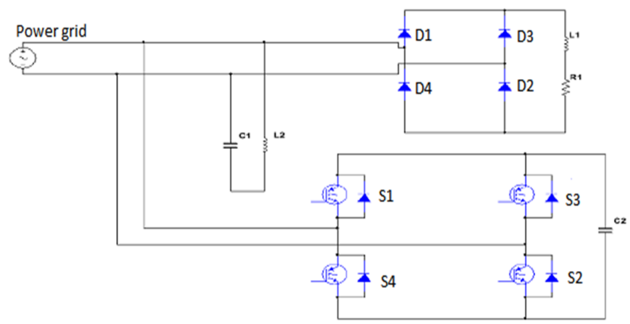

Fig 2.3 Hybrid Active power filters in a D-G system

power filter (IHAPF), owing to its lack of fundamental wave voltage and suitability for high-voltage grids, becomes a focal point of extensive research, Wang Jinquan et al. (2012), Ilango et al. (2012).

A unified power quality conditioner is an advanced concept in the power quality control field. The unified power quality conditioner is implemented based on the idea of integration of a series active filter and shunt active filter that share a single DC link. Unified power quality conditioner can be applied in a power system for current harmonic compensation, voltage compensation and reactive power control, but the main drawback is that it cannot compensate frequency regulation. This drawback is overcome by introducing constant frequency unified power quality conditioner **(**CF-UPQC**)**.CF-UPQC which is a combination of unified power quality conditioner and matrix converter. This modified unified power quality conditioner enables the PWM converter to perform active filtering, and the matrix converter also performs the function of frequency regulation. The Pulse Width Modulation technique (PWM) is commonly used to control all these converters. The switching rate is high so the PWM converter can produce controlled current or voltage waveform with high fidelity. It can simultaneously compensate the load current harmonics**,** supply voltage harmonics and frequency regulation.

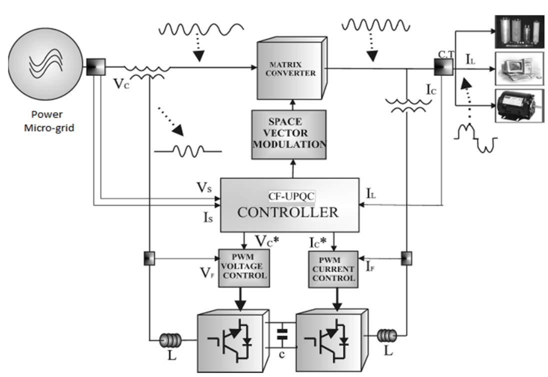

Fig 2.4 CF-UPQC for PQ improvement in a D-G system

TABLE I: COMPARISON OF VARIOUS APF TOPOLOGIES IN MICRO-GRID

APF Topology	Compatibility in Micro-grid
Series APF	**
Shunt APF	***
Hybrid APF	****
UPQC	****

*Poor performance, **Average performance, ***More than average performance, ****Good performance, *****Superior performance

IV. COMPARATIVE STUDY OF VARIOUS APF CONTROL STRATEGIES

The analysis has been made out based on several factors such as compactness of configurations, nature of supply systems and economic aspects. The control strategies were analyzed based on various types of supplies that is balanced sinusoidal supply, unbalanced sinusoidal supply, and balanced non-sinusoidal supply. Control scheme to calculate the compensation voltage for the active filter. The voltage vector in the side of the load and the source current vector are the input signals. By means of a calculation block the components α-β can be determined. The product of these vectors allows the real instantaneous power to be calculated, obtaining its mean value with a low pass filter (LPF). This power is consumed by the set passive filter and load. The mean power is divided by the square of rms value of fundamental current component. Various conclusions derived from the survey are tabulated, which helps the designers to select a particular control strategy compatible with a particular configuration and application. After analyzing various control strategies, the results are tabulated.

TABLE II: COMPLEXITY OF VARIOUS APF CONTROL STRATEGIES

Formulation	Compactness
p-q	Simple strategy
Modified p-q	Moderately complex strategy
d-q	Complex strategy
p-q-r	Moderately complex strategy
vectorial	Complex strategy

Obtaining sinusoidal source current in phase with the positive-sequence symmetrical component of the applied voltage fundamental harmonic is considered as compensation target, the configuration used as ideal reference. At this conditions: P-q, modified p-q, p-q-r and vectorial formulation suppose a null compensator average power and d-q requires a compensator average power not null; p-q, p-q-r, d-q and vectorial formulations get a null neutral current and modified p-q does not get to clear the neutral current. Only vectorial and d-q formulations achieve to get a null distortion in all the cases. P-q and p-q-r allow to obtain control algorithms in cases 2 and 3 with a distortion below the 10%. Modified p-q goes over that value. In summary, it can be said that only vectorial formulation is adequate to establish APLC compensation strategies with any kind of load and any kind of supplies. Nevertheless, original formulation presents a good performance, which can be improved, to look for adequate compensation strategies, if its representation through the mapping matrix is changed by a vectorial representation.

TABLE III: CONTROL STRATEGIES IN MICRO-GRID OPERATION

Formulation	Effectiveness in micro-grid
p-q	***
Modified p-q	**
d-q	***
p-q-r	**
vectorial	****

*Poor performance, **Average performance, ***More than average performance, ****Good performance, *****Superior performance

V. Conclusion

Theoretical analysis has investigated how to maintain the power quality in a micro-grid by using various configurations of Active power filters. The control based on the instantaneous power theorems like p-q, d-q, vectorial formulation were analyzed. The main advantage of this control approach lies on the fact that all sensitive loads connected to the PCC are immunized from the power quality problem. The parallel active filter will increase harmonic current and may cause overcurrent of the load when the load is a harmonic voltage source. Instead, it has been verified that the series active filter is better suited for compensation of a harmonic voltage source such as a diode rectifier with smoothing dc capacitor. When a parallel active filter is installed in a power system network such as at a point of common coupling, the network impedance and main harmonic sources downstream from the installation point should be investigated in order to get good performance and to minimize influence to the loads downstream. In some cases, a combined system of parallel active filter and series active filter may be necessary by utilizing the harmonic isolation function of the series active filters. Without any doubt we can say that active filters are superior to passive filters if used in their niche applications.

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