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# Voltage Unbalance compensation using virtual impedance loop

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***Abstract:*** *In microgrids Voltage Source Inverters are most widely used for integration of distributed energy generation resources to supply the load demand. Microgrids have the capacity to meet the power demand of local loads in case of the main grid failure. .Under this condition voltage and frequency support from the main grid is not possible , so it is the responsibility of Voltage Source Inverter's(VSI) is to keep voltage and frequency of the microgrid within limits .Loads such as Unbalanced three phase loads, single phase high impedance faults, or nonlinear loads (rectifier, Asynchronous Drives, Variable Frequency Drives etc) may cause severe voltage unbalance and harmonic distortion. Voltage unbalance in an islanded microgrid is removed by implementing a novel virtual impedance loop. The proposed control strategy is based on Synchronous Reference Frame (SRF) theory. The proposed microgrid is simulated in MATLAB/Simulink SimPower System toolbox.*

***Key Words:*** *Nonlinear loads, harmonics, power factor, grid, voltage source converter, impedance loop,*

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## I. Introduction

The widespread use of non-linear loads is leading to a variety of undesirable phenomena in the operation of power systems. The harmonic components in current and voltage waveforms are the most important among these. Conventionally, passive filters have been used to eliminate line current harmonics. However, they introduce resonance in the power system and tend to be bulky. So, active power line conditioners have become more popular than passive filters , as it compensates the harmonics and reactive power simultaneously. The active power filter can be connected in series or shunt and combinations of both. Shunt active filter is more popular than series active filter because most of the industrial applications require current harmonic compensation. Different types of active filters have been proposed to increase the electric system quality. The classification is based on following criteria. i)Power rating and speed of response required in compensated system. ii)System parameters to be compensated (e.g. current harmonics, power factor and voltage harmonics) iii) Technique used for estimating the reference current/voltage. Current controlled voltage source inverters can be utilized with an appropriate control strategy to perform active filter functionality. The electrical grid contains a very large number of small producers those who use renewable energy sources, like solar power or wind power.

## II. Power Quality and its Problems

Electric systems and grids are complex dynamic systems. These systems suffer usually from unexpected or sudden changes of the currents and voltages. These changes are due to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervene into the grid. With the increasing use of power semiconductors in the most of industrial and domestic procedures, the electric grids are polluted with different harmonic currents and voltages. These harmonics affect the normal function of the most of the grid connected devices; in addition to considerable economic losses. Many classic and modern solutions have been proposed in the literary for the harmonic problems.

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

A simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern.

In power systems, different voltage and current problems are being faced. The main voltage problems can be summarized in short duration variations, voltage interruption, frequency variation, voltage dips and harmonics. Harmonics represent the main problem of currents in power systems.

The short duration voltage variation is the result of the problems in the function of some systems or the start of many electric loads at the same time. The defaults can increase or decrease the amplitude of the voltage or even cancel it during a short period of time. The increase of voltage is a variation between 10-90% of the nominal voltage. It can hold from half of a period to one minute according to the IEEE 1159-1995. According to the same reference, the increase in voltage is defined as when the amplitude of the voltage is about 110-180% of its nominal value.

The cut off of the voltage happens when the load voltage decreases less than 10% of its nominal value for a short period of time less than 1 minute. The voltage interruption can be the effect of defaults in the electrical system, defaults in the connected equipment’s or bad control systems. The cut off of the voltage happens when the load voltage decreases until less than 10% of its nominal value for a short period of time less than 1 minute. The voltage interruption can be the effect of defaults in the electrical system, defaults in the connected equipment’s or bad control systems. The main characteristic of the voltage interruption is the period over which it happens. Shown in Fig. 1

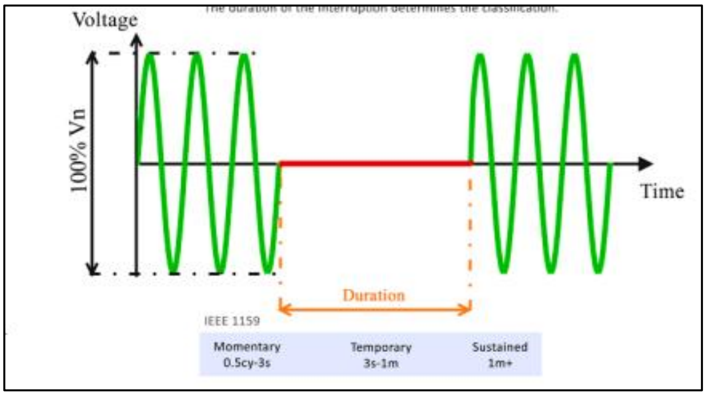


**Fig. 1:**Voltage Interruptions

The three-phase system is unbalanced when the currents and voltages are not identical in amplitude; or when the phase angle between each two phases is not 120°. In the ideal conditions, the three-phase system is balanced with identical loads. In reality, the loads are not identical, in addition to the problems of the distribution grids which can interfere. The unbalanced vectors are shown in Fig. 2

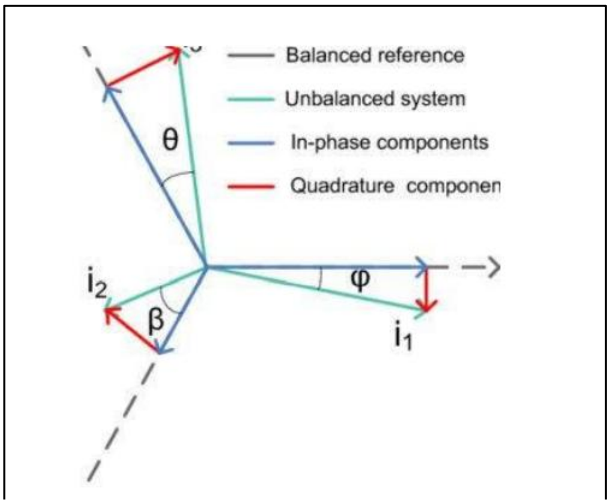


**Fig. 2:** Unbalanced System

The voltage dips are periodic perturbations. They appear as a natural effect of the switching of the transistors. They are due also to the start of big loads like motors. Lifts, lights, heaters…etc. this phenomenon causes bad functioning of the protection equipment.

There are two types of harmonics that can be encountered in a power system. i)Synchronous harmonics. Ii)Asynchronous harmonics. Harmonics are shown in fig. 3. Synchronous harmonics are sinusoids with frequencies which are multiples of the fundamental frequency. The multiplication factor is often referred to as the harmonic number. The synchronous harmonics can be subdivided into two categories. Sub-harmonics: when the harmonic frequency is less than the fundamental frequency. Super harmonics: when the harmonic frequency is more than the fundamental frequency.

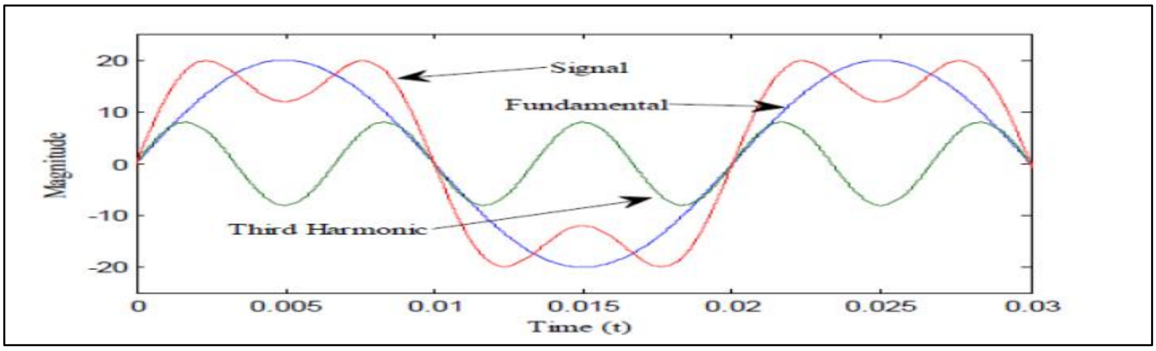


**Fig. 3:** Harmonics

Harmonic currents will flow into the utility feeder and may create a number of problems in so doing. They may be trapped by power factor correction capacitors and overload them or cause resonant over-voltages. They can distort the feeder voltage enough to cause problems in computers, telephone lines, motors, and power supplies, and may even cause transformer failures from eddy current losses. The harmonic currents may be trapped by installing series LC filters resonant at the offending frequencies. These filters should be designed to offer low impedance at the resonant frequency compared to the source impedance at that frequency.

## III. Power Converters

Shunt active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180°. This principle is applicable to any type of load considered as harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non-linear load and the active power filter as an ideal resistor. The current compensation characteristics of the shunt active power filter is shown in Fig. 4.

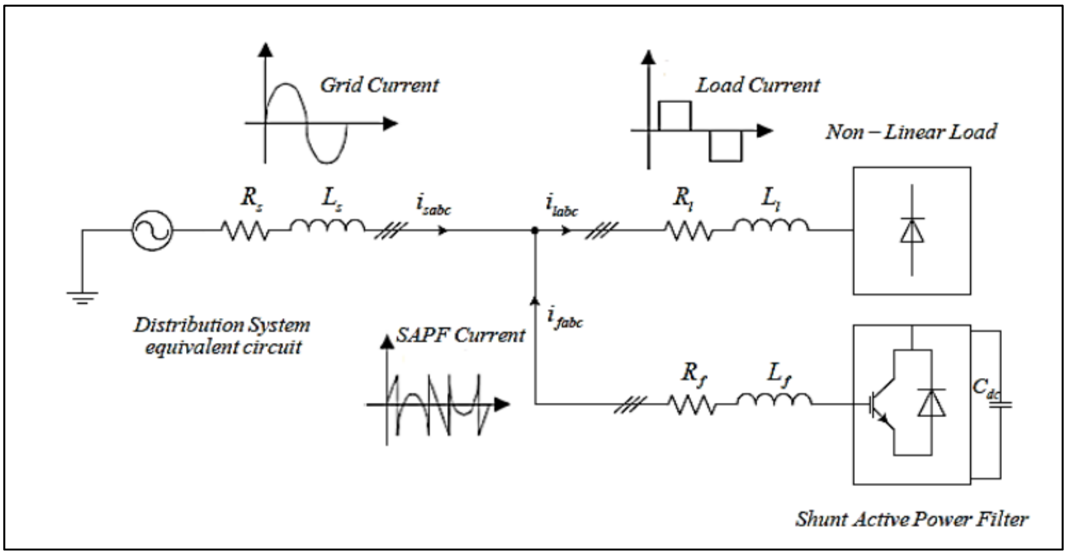


**Fig. 4:** Compensation Characteristic of Shunt Active Power Filter

Most Active Power Filters (APFs) have been designed on the basis of instantaneous active and reactive power theory (p-q), first proposed by Akagi et al in 1983. Initially, it was developed only for three-phase systems without neutral wire, being later worked by Watanabe and Aredes for three-phase four wires power systems. The method uses the transformation of distorted currents from three phase frame abc into bi-phase stationary frame αβ. The basic idea is that the harmonic currents caused by nonlinear loads in the power system can be compensated with other nonlinear controlled loads. The p-q theory is based on a set of 31 instantaneous powers defined in the time domain. The three-phase supply voltages (ua, ub, uc) and currents (ia, ib, ic) are transformed using the Clarke (or α-β) transformation into a different coordinate system yielding instantaneous active and reactive power components. This transformation may be viewed as a projection of the three-phase quantities onto a stationary two-axis reference frame. This is illustrated in Fig. 5

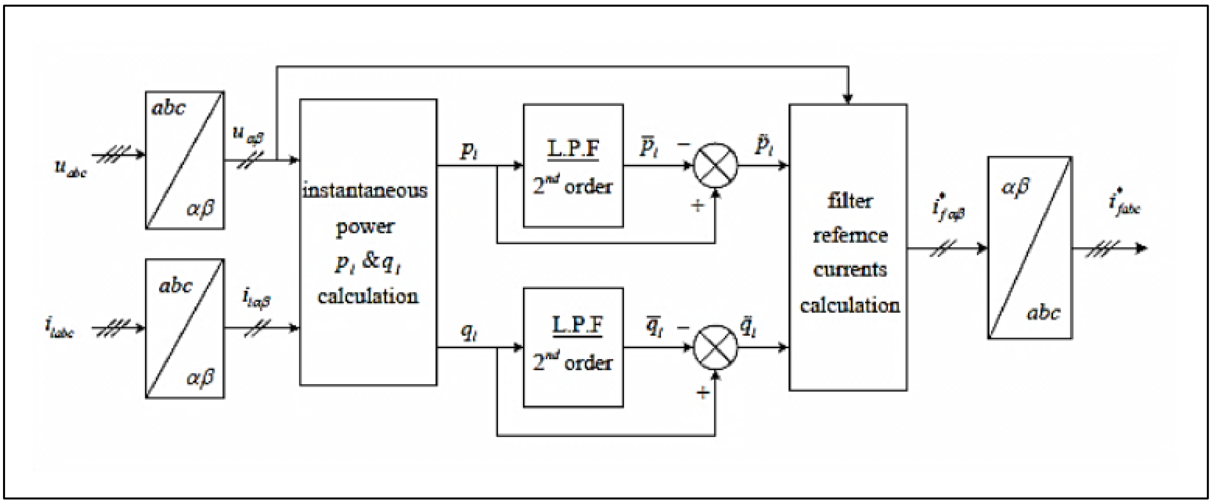


**Fig. 5:** Principle of Instantaneous Active and Reactive Power Theory.

Voltage source inverters (VSI) are one of the most important applications of power electronics. The main purpose of these devices is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. The important development of VSI is a result, from the one hand to the development of fast, controllable, powerful, and robust semi-conductors, from the other hand to the use of the so-called pulse width modulation (PWM) techniques. In the high power applications, the three level VSIs are the most adopted in comparison with two levels ones. Because the THD of the output voltage and current of the three levels VSI is clearly lower.

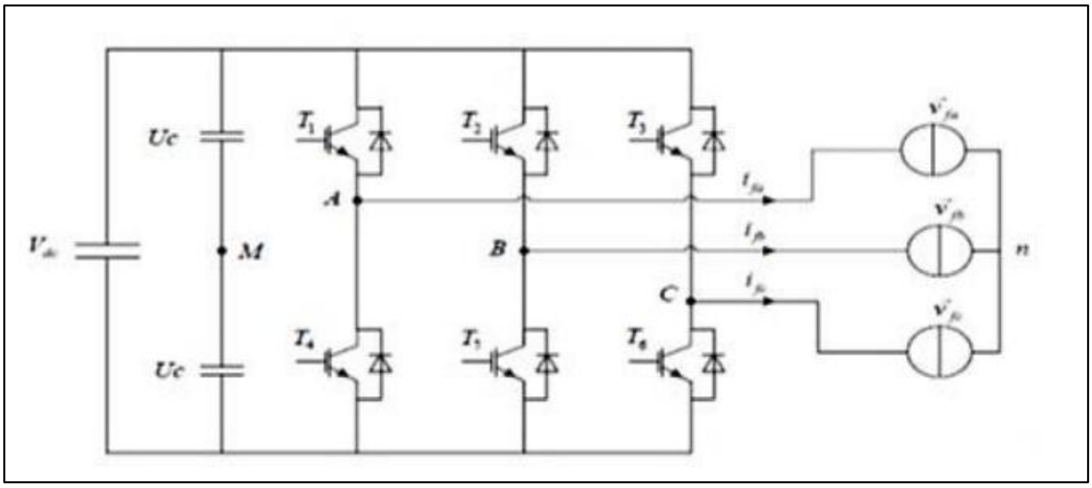


**Fig. 6:**Three-phase Two Level VSI Topology

The aim of the control of the VSC is to force the output currents of the inverter to follow their predefined reference currents. The main principle is based on the comparison between the actual current of the filter with the reference currents generated by the different extraction methods.

1 Hysteresis Control Method: The hysteresis current control method is the most commonly proposed control method in time domain. This method provides instantaneous current corrective response, good accuracy and unconditioned stability to the system. Besides that, this technique is said to be the most suitable solution for current controlled inverters. Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform.

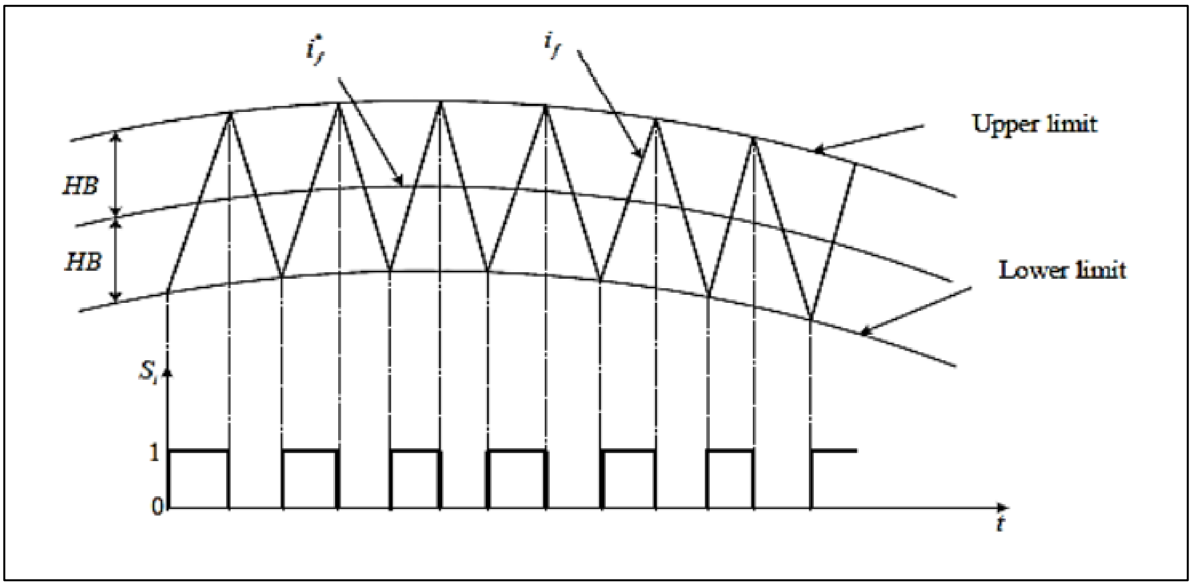


**Fig. 7: Hysteresis** control method

2 Sinusoidal Pulse Width Modulation (SPWM) : The most simple and well known PWM technique is the sinusoidal PWM. This technique uses a controller which determines the voltage reference of the inverter from the error between the measured current and its reference. This reference voltage is then compared with a triangular carrier signal (with high frequency defining the switching frequency). The output of this comparison gives the switching function of the VSI.

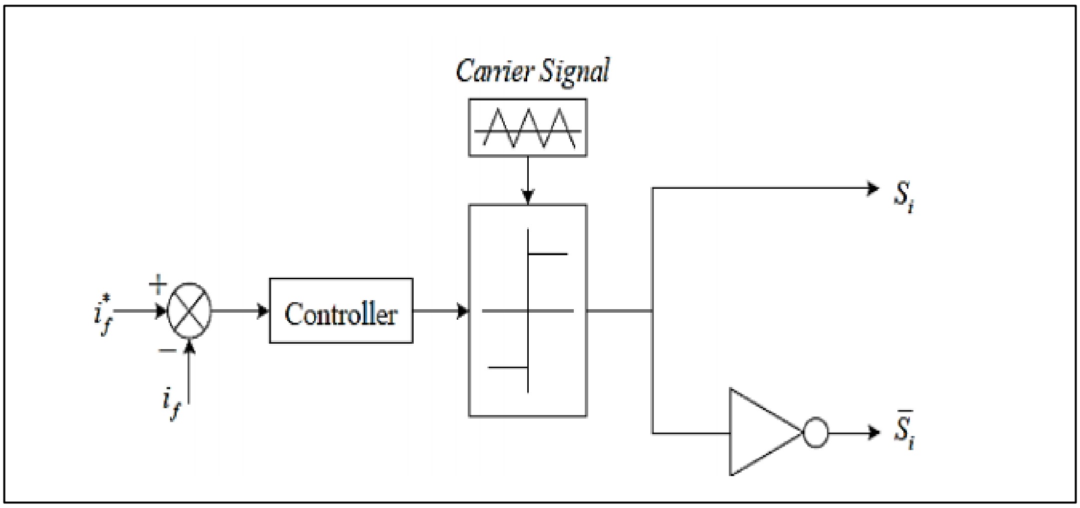


**Fig. 8:** Principal of Sinusoidal Pulse Width Modulation Control

3 Space Vector PWM Control (SVPWM) : The basic principle of the SVM technique is that it treats the inverter as a whole unit, which is different when compared to PWM technique. This technique is based on the decomposition of a reference voltage vector into voltage vector realizable on a six-pulse inverter.

## IV. Control of the Active Power

Filter The researchers are always at the point of the research to ameliorate the control methods of the SAPF to achieve better results either from the point of view of better perturbation extraction methods, the amelioration of the dynamic regimes, decreasing the value of the THD,…etc., or the development of new control methods to ameliorate the performance of the APF with the different non-linear loads. There are principally two methods for the compensation of the harmonic currents dependent on the measured current.

Direct Control Method :In this method the load currents are measured and the harmonic currents are extracted from the load currents. Fig. 9 shows the diagram of the direct control method. Using this method, the SAPF injects the harmonic currents without any information about the grid currents. All the errors in the system like the parameters uncertainty, the measurement or control errors will appear in the grid current as unfiltered harmonic contents. The main advantage of this method is the system stability. However, this method needs an expanded control algorithm with large number of sensors.

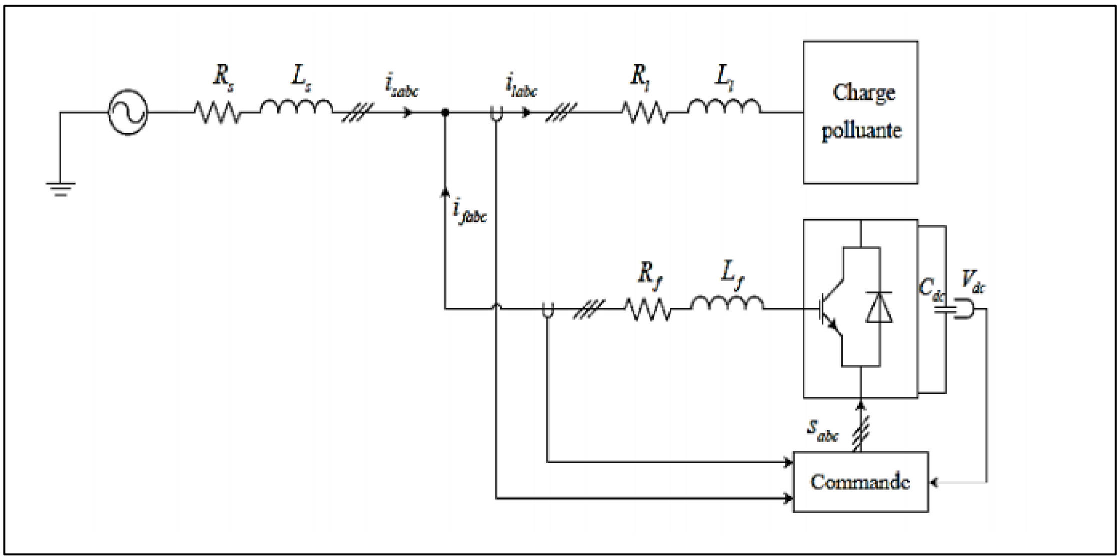


**Fig. 9:**Direct Control of Active Filter

Indirect Control Method :This method based on the measurement of the source currents, and then to impose the sinusoidal form on these currents. The control algorithm is less complicated and needs fewer sensors than the direct control. Fig. 10 shows the diagram of the indirect control method of the SAPF.

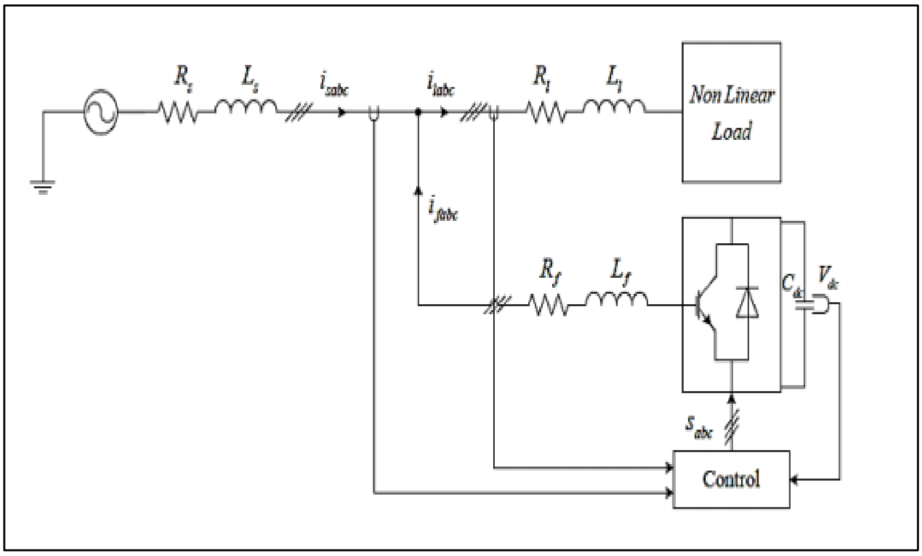


**Fig. 10 :** Indirect Control of Active filter

## V. Block Diagram

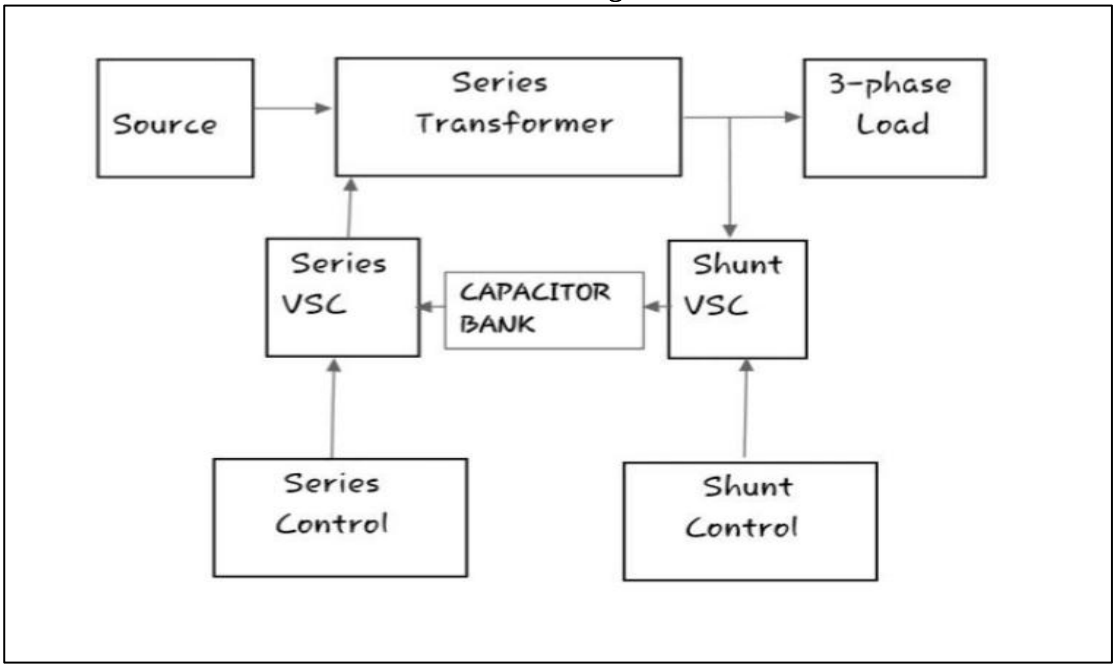


**Fig. 11** Block Diagram

## VI. Simulation And Results

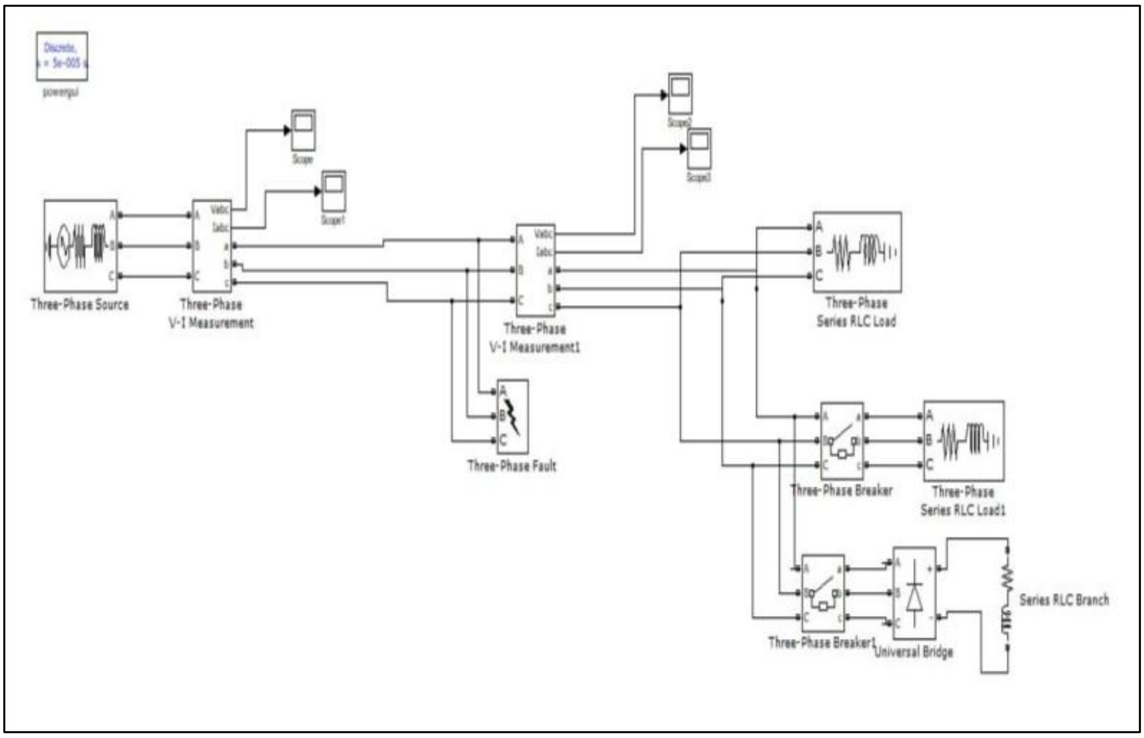


**Fig. 12** Grid with Non Linear Loads

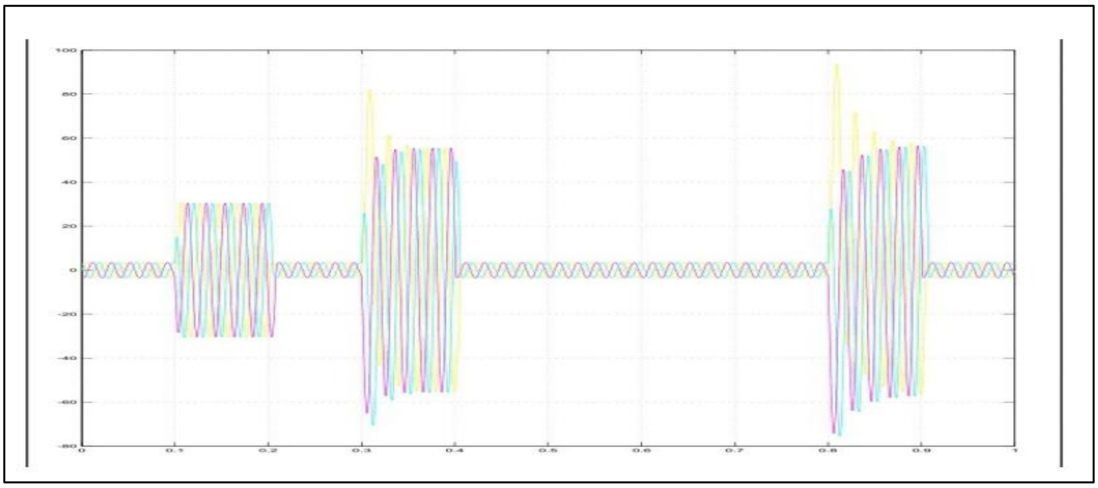


**Fig. 13**: Output of Grid with Non-Linear Loads

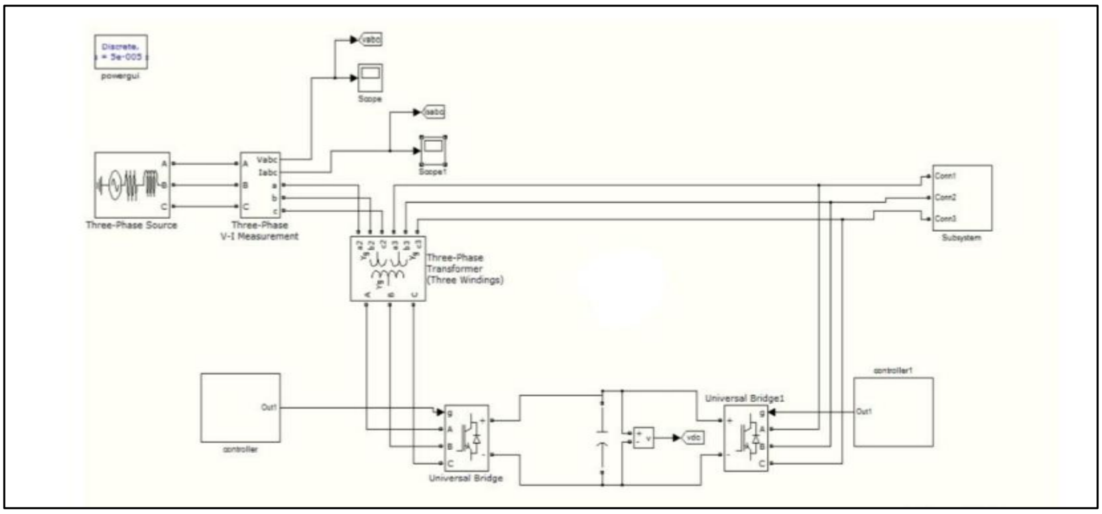


**Fig. 14.:** Grid with Virtual Impedance Loop

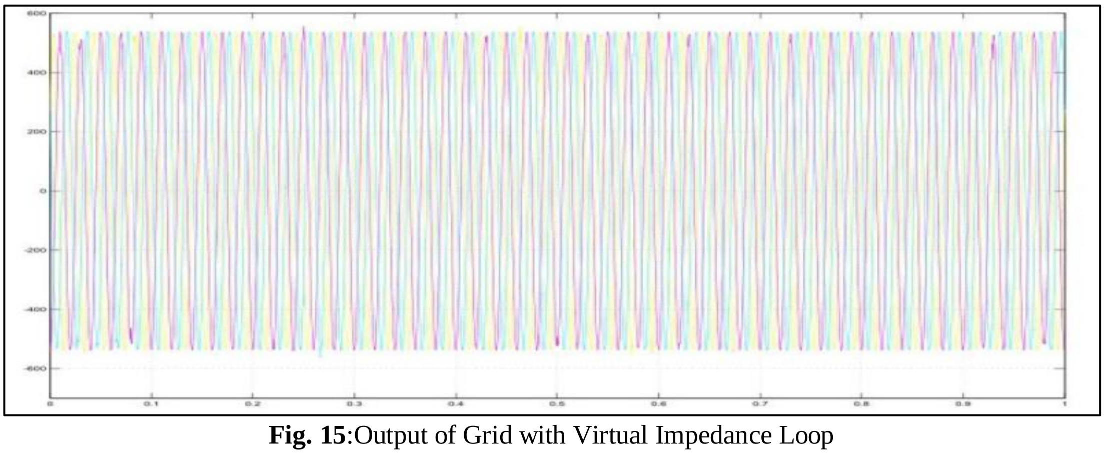


**Fig. 15**:Output of Grid with Virtual Impedance Loop

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