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MODELING AND SIMULATION OF GRID CONNECTED HYBRID PV-WIND POWER SYSTEM USING BATTERY AND SMES BASED DVR WITH IMPROVED POWER QUALITY FEATURES

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Abstract: The series connected DVR will inject three-phase compensating voltages through the three-phase injection transformer or three single-phase injection transformers with the main supply. The filtered VSI output voltage is boosted to the desired level with the injection transformer. The transformer also isolates the DVR circuit from the distribution system. The capacity of the voltage source inverter (VSI) and the values for the link filter connected between the injection transformer and the inverter play a crucial in the design of the DVR. In this research project, new Dynamic Voltage Restorer (DVR) topology has been proposed. The capacity of the voltage source inverter (VSI) and values of the link filter is small that will improve the compensation capabilities for voltage harmonic, swell and voltage sag mitigation under various fault conditions. The new RLC filter is able to eliminate the switching harmonics. The capacity of the dc supply voltage is reduced when the value of inductance is small. The new DVR topology has high efficiency and the ability to improve the quality of voltage. Outline architecture of the RLC filter parameters for the specific model has been presented. The new DVR with proposed controlled Dynamic Voltage Restorer topology is modeled and simulated using the MATLAB. The control scheme has good control dynamics with minimum transient current overshoot. The simulation results under transient performance are good

***Keywords*:**

1. Introduction

Day to day there is an increase in the intensity of sensitive loads in power systems, so the power quality issues play a vital role in the present days. There is extreme power quality problems mentioned as voltage swell, voltage sag, harmonics, flicker etc. Voltage sag generally origin from the faults on load or supply side, maloperation, electrical motor startup, electrical heaters turning on, etc. So the DVR is mitigating the voltage sag through injecting the voltage. Power quality problems are affected due to the appearance of various non-linear loads such as diode bridge rectifiers, adjustable speed drives (ASD), switched mode power supplies (SMPS), and laser printers etc. As stated on voltage sag is the reduction in RMS voltage from 0.1pu to 0.9pu for a short time period of 0.5 cycles to few cycles. Generally, faults occurred in distribution systems having a reduction from 40% to 50% of the rated voltage until less than 2secs. Due to the above mentioned power quality problems on sensitive loads, minimization their effects are necessary. Furthermore, new power electronic devices are introduced and named as custom power devices. These devices are distribution static compensator (D-STATCOM), unified power quality conditioner (UPQC), dynamic voltage restorer (DVR). DVR is the perfect solution for restoring the load voltage at output terminals. When, the quality of source voltage is disturbed. DVR compensate the voltage sag with an appropriate injection of voltage in series with grid voltage, in order to maintain the rated load voltage with balance mode condition. Generally, DVR consists of inverter, injection transformer and energy storage device. The design of new inverter topology is to inject the voltage with proper control of the magnitude and phase angle, to maintain the constant load voltage and avoid disturbances at load voltage. The basic system model of DVR DVR is a power electronic switching device which is connected in series to the load voltage bus to inject a dynamically controlled voltage. This voltage can eliminate effects of fault of voltage bus on a sensitive load. DVR is equipment used to recover a voltage or improve the voltage quality on the load side and its position is mounted in series between the source and the load. DVRs are coupled in series with distribution systems to protect sensitive equipment against the occurrence of voltage drop. The basic function of the DVR is to detect the occurrence of voltage drops that occur on the power system channel, and then inject the voltage to compensate for the voltage drop that occurs. Therefore the DVR is placed close to the sensitive load that is protected. The DVR works depending on the type of interference or an event occurring in the system, generating the injected voltage

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obtained from the DC energy storage unit and then converted to AC voltage by the voltage source inverter (VSI. To set the controller on the DVR is used dq0 transformation or Park transformation. The dq0 method will provide information on the depth of the voltage drop and the phase shift with the starting point and end point of the voltage drop.

1.2. Literature survey

Johan H. R. Enslin and Peter J. M. Heskes,[1]

"Harmonic interaction between a large number of distributed power inverters and the distribution network,"

In this paper discussed the harmonic interaction between a large number of distributed power inverters and the distribution network. This paper is to analyze the observed phenomena of harmonic interference of large populations of these inverters and to compare the network interaction of different inverter topologies and control options.

Uffe Borup, Frede Blaabjerg and Prasad N. Enjeti ,[2]

"Sharing of nonlinear load in parallel-connected three-phase converters,"

Presented about the sharing of linear and nonlinear loads in three-phase power converters connected in parallel, without communication between the converters. The paper focuses on solving the problem that arises when two converters with harmonic compensation are connected in parallel.

Pichai Jintakosonwit Hideaki Fujita, Hirofumi Akagi and Satoshi Ogasawara, [3]

"Implementation and performance of cooperative control of series active filters for harmonic damping throughout a power distribution system,"

This paper proposes cooperative control of multipleactive filters based on voltage detection for harmonic damping throughout a power distribution system. The arrangement of a real distribution system would be changed according to system operation, and/or fault conditions. In addition, series capacitors and loads are individually connected to, or disconnected from, the distribution system.

Pedro Rodríguez, JosepPou, Joan Bergas,J. Ignacio Candela , Rolando P. Burgos and DushanBoroyevich ,[4]

"Decoupled double synchronous reference frame PLL for power converters control,"

Presented the detection of the fundamental-frequency positive-sequence component of the utility voltage under unbalanced and distorted conditions. Specifically, it proposes a positive-sequence detector based on a new decoupled double synchronous reference frame phase-locked loop (PLL), which completely eliminates the detection errors of conventional synchronous reference frame PLL's. This is achieved by transforming both positive- and negative-sequence components of the utility voltage into the double SRF, from which a decoupling network is developed in order to cleanly extract and separate the positive- and negative-sequence components.

SoerenBaekhoejKjaer, John K. Pedersenand Frede Blaabjerg,[5]

"A review of single-phase grid-connected inverters for photovoltaic modules"

presents a Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules. This paper focuses on inverter technologies forconnecting photovoltaic (PV) modules to a single-phase grid. The inverters are categorized into four classifications: 1) the number of power processing stages in cascade; 2) the type of power decoupling between the PV module(s) and the single-phase grid; 3) whether they utilizes a transformer (either line or high frequency) or not; and 4) the type of grid-connected power stage.

F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus,[6]

"Overview of control and grid synchronization for distributed power generation systems,"

This paper gives an overview of the structures for the DPGS based on fuel cell, photovoltaic, and wind turbines. In addition, control structures of the grid-side converter are presented, and the possibility of compensation for low-order harmonics is also discussed. Moreover, control strategies when running on grid faults are treated. This paper ends up with an overview of synchronization methods and a discussion about their importance in the control.

J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galván, R. C. P. Guisado, M. Á. M. Prats, J. I. León, and N. M. Alfonso,[7]

"Power electronic systems for the grid integration of renewable energy sources: A survey,"

This paper proposes about distributed energy resource is increasingly being pursued as a supplement and an alternative to large conventional central power stations. The specification of a power electronic interface is subject to requirements related not only to the renewable energy source itself but also to its effects on the power-system operation, especially where the intermittent energy source constitutes a significant part of the total system capacity.

2. 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 mainly to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervener 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. In this chapter, the

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harmonic problem as one of the most common power quality problems will be presented. The different modern and traditional solutions will then be discussed.

Definition of Power Quality

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.

Power quality can also be defined as 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. Power distribution systems should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in power systems, especially the distribution systems have many nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the pure sinusoidal waveform is lost. This ends up producing many power quality problems.

Power Systems Distortion and Problems

In power systems, different voltage and current problems can be 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 of power systems.

Voltage Variation for Short Duration

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 1 minute according to the IEEE 1159-1995. According to the same reference, the increase in voltage is defined when the amplitude of the voltage is about 110-180% of its nominal value.

Voltage Interruption

The cutoff 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.

Frequency Variations

In the normal conditions the frequency of the distribution grid must be within the interval 50±1 Hz. The variations of the frequency of the grid can appears to the clients who are using auxiliary electric source (solar system, thermal station…etc.). These variations are rare and happen in the case of exceptional conditions like the defaults in the turbines.

Unbalance in Three Phase Systems

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.

Voltage Dips

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 phenomena causes bad functioning of the protection equipment’s.

Harmonics

Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of loads produces currents and voltages with frequencies that are integer multiples of the 50 or 60 Hz fundamental frequency. These frequencies components are a form of electrical pollution known as harmonic distortion. There are two types of harmonics that can be encountered in a power system.

- ❖ Synchronous harmonics.
- ❖ Asynchronous harmonics.

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.

Harmonics are familiar to the musicians as the overtones from an instrument. They are the integer multiples of the instrument’s fundamental or natural frequency that are produced by a series of standing waves of higher and higher

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order. Exactly the same thing happens in power circuits when non-linear loads create harmonic currents that are integer multiples of the supply fundamental frequency. The rapid growth of solid-state power electronics has greatly increased the number and size of these loads.

The concept of harmonics was introduced in the beginning of the 19th century by Joseph Fourier. Fourier has demonstrated that all periodic non-sinusoidal signals can be represented by infinitive sum or series of sinusoids with discontinuous frequencies as given by Equation (2.1).

$$i(t) = I_0 + \sum_{h=1}^{\propto} I_h \cos(h\omega t + \varphi_h) \quad \ldots\ldots \quad (2.1)$$

The component I_0 in the Fourier series is the direct component. The first term of the sum with the index h=1 is the fundamental of the signal. The rest of the series components are called the harmonics of the range h. Fig. 2.1 Shows the form of a wave containing the third harmonic (h=3). In the three phase electric grid, the principle harmonic components are the harmonics of ranges (6*h±1).

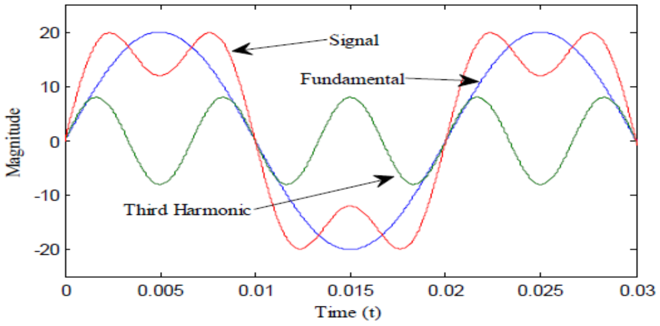

Fig. 2.1 Harmonic Content of a Signal and its Fundamental.

Transformer exciting current, arc furnaces, rectifiers and many other loads will produce harmonics in the utility lines. Most utilities limit the allowable harmonic current levels to the values shown in IEEE 519.

Total Harmonic Distortion (THD)

The total harmonic distortion of a signal is a measurement of the harmonic distortion present in current or voltage. It is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Harmonic distortion is caused by the introduction of waveforms at frequencies in multiples of the fundamental.

$$THD(\%) = \frac{\sqrt{\sum_{i=2}^{\alpha} x_i^2}}{|x_1|} \quad (2.2)$$

The THD is a very useful quantity for many applications. It is the most commonly used harmonic index. However, it has the limitation that, it is not a good indicator of voltage stress within a capacitor because that is related to the peak value of voltage waveform.

Distortion Factor

The distortion factor F_d is defined as the ratio between the fundamental and the signal in RMS values. It is given by:

$$F_d = \frac{I_{L1}}{I_{rms}} \quad (2.3)$$

It is then equal to unity when the current is purely sinusoidal and decreases when the distortion appears.

Crest Factor

The crest factor of a signal Fc is defined by Equation (2.4):

$$F_c = \frac{\text{crest value}}{\text{effectivevalue}} \quad (2.4)$$

For sinusoidal waves, the crest factor is 1.41. It can achieve the value of 5 in the case of highly distorted waves.

Effects of 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. But, again, there is a hidden “gotcha.” If a filter is installed that has a series resonance at the 7th harmonic, it will also have a parallel resonance with the utility at a lower frequency when the source inductance is added to the filter inductance. If this parallel resonance should lie on or near the 5th harmonic, there is the possibility of the resonant over-currents described earlier. The installation of series resonant traps will always introduce parallel resonances at frequencies below the trap frequencies. Good practice dictates that multiple resonant traps be installed first at the lowest harmonic frequency of concern and then in sequence at the higher-frequency harmonics. If switched, they should be switched on in sequence starting with the lowest frequency trap and switched out in sequence starting from the highest frequency trap.

The voltage or current distortion limit is determined by the sensitivity of loads (also of power sources), which are influenced by the distorted quantities. The least sensitive is heating equipment of any kind. The most sensitive kind of equipment’s is those electronic devices which have been designed assuming an ideal (almost) sinusoidal fundamental frequency voltage or current waveforms. Electric motors are the most popular loads which are situated between these two categories.

Power Factor

Power factor is defined as the ratio of real power to volt-amperes and is the cosine of the phase angle between the voltage and the current in an AC circuit. These are neatly defined quantities with sinusoidal voltages and currents.

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Power factor can be improved by adding capacitors on the power line to draw a leading current and supply lagging V_{Ars} to the system. Power factor correction capacitors can be switched in and out as necessary to maintain V_{Ar} and voltage control.

For a sinusoidal signal, the power factor is given by the ratio between the active and the apparent power. Electrical equipment's' parameters are normally given under nominal voltage and current. A low power factor can indicate bad use of this equipment's. The apparent power can be defined by:

$$S = V_{rms} . I_{rms} = V_{rms} . \sqrt{\frac{1}{T}\int_0^T i_L^2 \, dt} \qquad (2.5)$$

The active power P can be given by the relation:

$$P = V_{rms} . I_{rms} . \cos(\propto 1) \qquad (2.6)$$

The reactive power Q is defined by:

$$Q = V_{rms} . I_{rms} . \sin(\propto 1) \qquad (2.7)$$

The power factor in this case can be given by Equation 2.8.

$$P.F = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}} \qquad (2.8)$$

In the case where there is harmonics, a supplementary power called the distorted power D appears. This power can be given by the relation.

$$D = V_{rms} . \sqrt{\sum_{n=2}^{\alpha} I_{Ln}^2} \qquad (2.9)$$

The apparent power can then be expressed as:

$$S = \sqrt{P^2 + Q^2 + D^2} \qquad (2.10)$$

The power factor is then given by:

$$P.F = \frac{P}{\sqrt{P^2+Q^2+D^2}} \qquad (2.11)$$

From equation (2.11), we can notice that the power factor decreases because of the existence of harmonics in addition to the reactive power consumption. The Fresnel diagram of the power is given in Fig. 2.2.

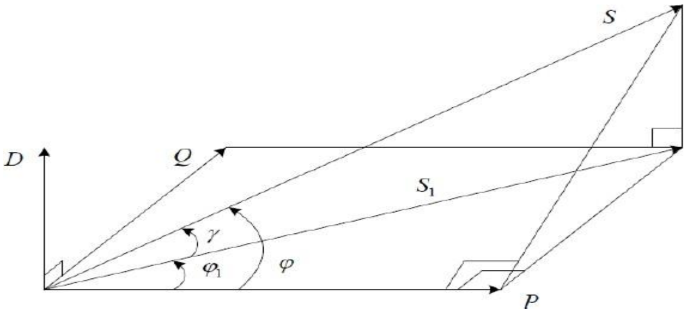

Fig. 2.2 Fresnel Representation of the Power

Harmonic Currents Sources

The main cause of harmonics is the injection of harmonic currents by the non-linear loads. The bridges of diodes are the most non-linear loads present in the power applications because they don't need a control and they have long life duration with low cost. There are also many other harmonic producing loads such as:

- ❖ Industrial equipment's (welding machines, arc furnaces, induction furnaces, rectifiers).
- ❖ Offices equipment's (computers, photocopiers,…etc.).
- ❖ Domestic devices (TVs, micro-wave furnaces, neon lightening,…etc.).
- ❖ Power inverters.
- ❖ Power transformers when working in the saturation zone also are considered as non-linear loads that produce harmonics.

The feeding of non-linear loads generates harmonic currents which spread into the electrical grid. The spread of current harmonics into the feeding impedances (transformers and grid) creates harmonic voltages in these feeders. Remembering that the conductor impedance increases with the frequencies of the currents which pass through it, different impedance will appear for each range of current harmonics. The harmonic current of range h will create through the impedance harmonic voltage. All the loads connected to the same point will be fed with the same perturbed voltages. The equivalent circuit per phase of a non-linear load connected to the grid is given by Fig. 2.3.

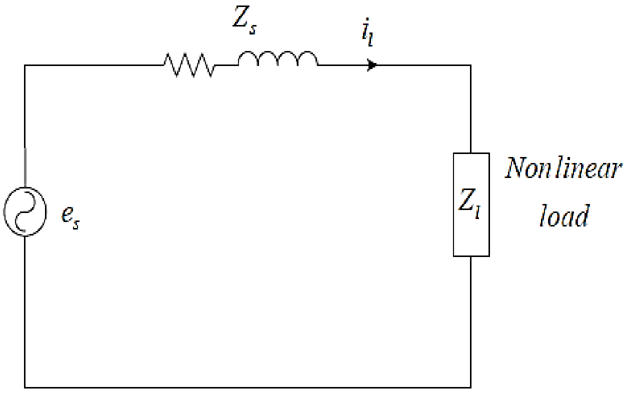

Fig. 2.3 Equivalent Circuit Per Phase of a Non-Linear Load Connected to the Grid.

The spread of harmonic currents from different loads can be represented as in Fig. 2.4.

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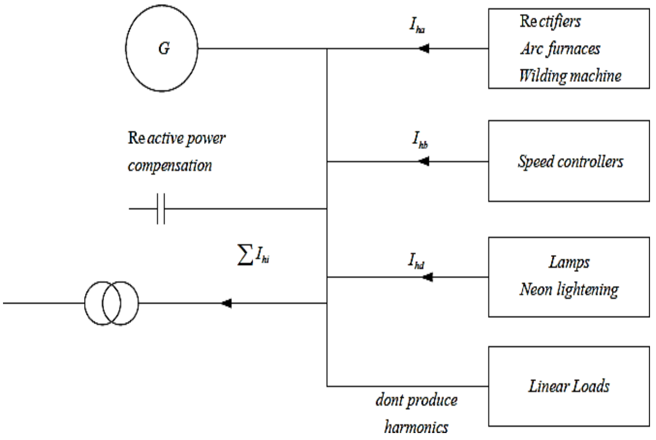

Fig. 2.4 Spread of Harmonic Currents into the Grid

Economic effects of harmonics

❖ Premature aging of materials which forces its replacement, in addition to an initial over sizing of these materials.

❖ The overloading of the grid which implies to increase the nominal power and to oversize the installations, causing more and more losses.

❖ The current distortions cause sudden triggers and the stop of production equipment's.

These material costs, energetic and production losses affect the competitiveness and the productivity of factories and companies.

Solutions for the Harmonics

The filtering of the grid currents and voltage is a priory problem for the distributer as like as the client. Because the limits on harmonic emission are not equally applied in the low of the different countries, the producers of the different electrical devices try to construct devices that satisfy for the conditions and limits of the international standards. The electric companies, from its side, use different filtering equipment's and encourage the researches toward finding new efficient solutions for the power quality problems. The clients install also sometimes reactive power and harmonic compensation batteries to ameliorate the power factor and reduce the energy consumption bill.

Many traditional and modern solutions for harmonics mitigation and power quality improvement were proposed in literary. Some of these solutions investigate in the load to minimize the harmonic emission while the others propose the use of external filtering equipment's that prevent the spread of harmonics into the grid.

In-Line Reactors

In-line reactor or choke is a simple solution to control harmonic distortion generated by adjustable speed drives. The solution is come up with inserting a relatively small reactor, or choke, at the input of the drive. The inductance prevents the capacitor to be charged in a short time and forces the drive to draw current over a longer time and reduces the magnitude of the current with much less harmonic content while still delivering the same energy.

Transformers with Passive Coupling

Some types of triangle zigzag coupling of transformers allow the elimination of the harmonics of order 3 and its multiples. The cost of these coupling types is the augmentation of the source impedance, and then the augmentation of voltage harmonic distortion.

Passive Filters

Passive filter, which is relatively inexpensive in comparison with the other harmonic reduction methods, is the most used method. Inductance, capacitor and the load as a resistance are tuned in a way to control the harmonics. However, they suffer from interfering with the power systems. Actually, passive filters are designed to shunt harmonics from the lines or block their flow through some parts of the systems by tuning the elements to create a resonance at the selected frequency. These filters are tuned and fixed according to the impedance of the point at which they will be connected and hence cannot be adjusted instantaneously in accordance to the load. As a result their cutoff frequency changes unexpectedly after any change in the load impedance resulting in producing a resonance with other elements installed in the system.

Modern Solutions for Harmonic Problems

Modern solutions were proposed as efficient solutions for the elimination of electric grid harmonics in order to defeat the disadvantages of the traditional methods like passive filters. Between these solutions we find two categories which are the most used:

❖ Active filters (series, parallel, or a combination of both of them in Unified Power Quality Conditioner (UPQC)).

❖ Hybrid filters composed of active and passive filters at once.

Active Power Filters

The function of the active power filters (APF) is to generate either harmonic currents or voltages in a manner such that the grid current or voltage waves conserve the sinusoidal form. The APFs can be connected to the grid in series (Series APF), shunt (SAPF) to compensate voltage harmonics or current harmonics respectively. Or can be associated with passive filters to construct the hybrid filters (HAPF).

Active filters are relatively new types of devices for eliminating harmonics. This kind of filter is based on power electronic devices and is much more expensive than passive filters. They have the distinct advantage that they do not resonate with the power system and they work independently with respect to the system impedance characteristics. They are used in difficult circumstances where passive filters don't operate successfully because of resonance problems and they don't have any interference with other elements installed anywhere in the power system.

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The active filters present many other advantages over the traditional methods for harmonic compensation such as:

- Adaptation with the variation of the loads.
- Possibility of selective harmonics compensation.
- Limitations in the compensation power.
- Possibility of reactive power compensation.

Series Active Power Filter (Series APF)

The aim of the series APF is to locally modify the impedance of the grid. It is considered as harmonic voltage source which cancel the voltage perturbations which come from the grid or these created by the circulation of the harmonic currents into the grid impedance. However, series APFs can't compensate the harmonic currents produced by the loads.

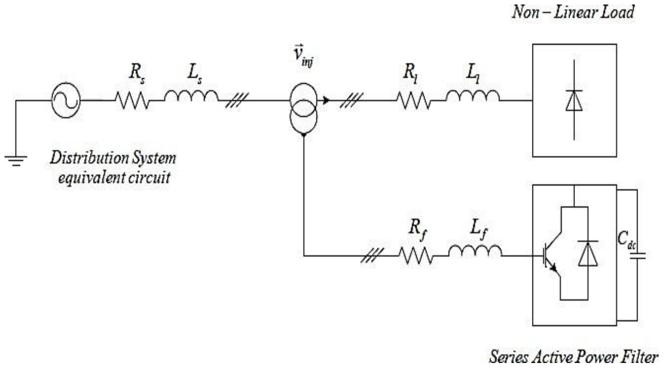

Fig. 2.5 Series Active Power Filter Connected to the Grid

Shunt Active Power Filter (SAPF)

The SAPFs are connected in parallel with the harmonic producing loads. They are expected to inject in real time the harmonic currents absorbed by the pollutant loads. Thus, the grid current will become sinusoidal.

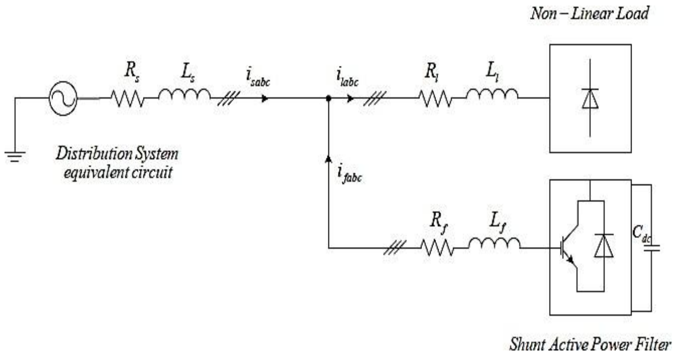

Fig. 2.6 Shunt APF Connected in Parallel with Non-Linear Load

Combination of Parallel and Series APF (UPQC) Fig. 2.7 explains the combination of two APFs parallel and series, called also (Unified Power Quality Conditioner). This structure combines the advantages of the two APF type's series and parallel. So it allows simultaneously achieving sinusoidal source current and voltage.

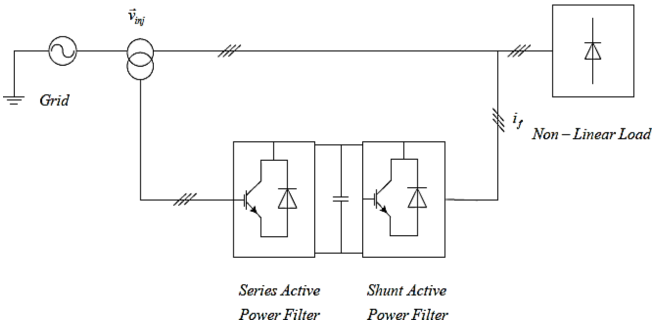

Fig. 2.7 Unified Power Quality Conditioner's Diagram

Hybrid Filters

Hybrid filter is a filter topology which combines the advantages of the passive and active filters. For this reason, it is considered as the best solution to eliminate the harmonic currents from the grid. The principal reason for the use of hybrid filters is the development of the power semiconductors like MOSFETs and IGBTs. Over more, from an economical point of view, the hybrid power filters allow reducing the cost of APF.

Hybrid power filters can be classified according to the number of elements used in the topology, the treated system (single phase, three phase three legs or four legs) and the used inverter type (current source inverter or voltage source inverter).

Non-Linear Loads

When the input current into the electrical equipment does not follow the impressed voltage across the equipment, then the equipment is said to have a nonlinear relationship between the input voltage and input current. All equipment's that employ some sort of rectification are examples of nonlinear loads. Nonlinear loads generate voltage and current harmonics that can have adverse effects on equipment designed for operation as linear loads. Transformers that bring power into an industrial environment are subject to higher heating losses due to harmonic generating sources (nonlinear loads) to which they are connected.

3. Proposed DVR Configuration

Overview

Series active power filter compensates current harmonics by injecting equal-but-opposite harmonic compensating currents into the grid. In this case the series 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 series active power filter is shown in Fig. 3.1

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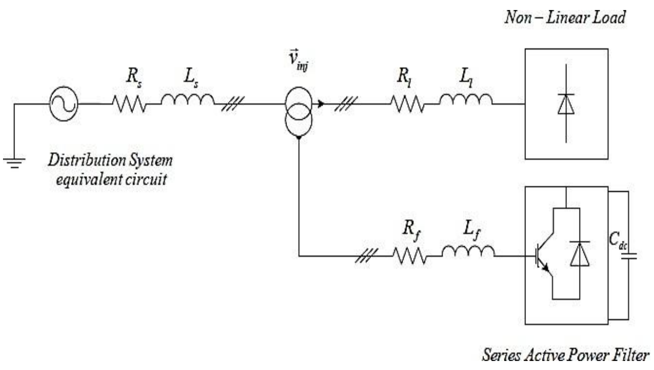

Fig. 3.1 Compensation Characteristic of DVR

Harmonic Current Extraction Methods

The aim of active power filtering is to compensate the harmonic currents produced by the non-linear loads, and to ensure the sinusoidal form of grid currents and voltages. The first step in active filtering is the harmonic currents extraction to be injected into the grid. The good extraction of harmonics is a keyword for a good active power filtering. Many extraction methods were proposed in literary. They can be divided into two families: the first family uses the Fast Fourier Transform (FFT) in the frequency domain to extract the current harmonics. The main disadvantages of this method are the bad results in transient, the heavy amount of calculations, and the use of considerable memory. In addition to a delay in the extraction of harmonics which can be at least one period.
The second family is based on the time domain calculations in the extraction of harmonics. Some of its methods are based on the instantaneous active and reactive power. Others are based on the calculation of direct and indirect current components. Recently, the neural networks and the adaptive linear neural networks have been used in the extraction of harmonic components of current and voltage.

Instantaneous Active and Reactive Power Theory Most APFs have been designed on the basis of instantaneousactive and reactive power theory (p-q), first proposed byAkagi 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 (u_a, u_b, u_c) and currents (i_a, i_b, i_c) 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. The Clarke transformation for the voltage variables is given by

$$\begin{bmatrix} u_\propto \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \qquad (3.1)$$

Similarly, this transform can be applied on the distorted load currents to give:

$$\begin{bmatrix} i_{l\propto} \\ i_{l\beta} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \qquad (3.2)$$

The instantaneous active power *p(t)* is defined by:

$$p(t) = u_a i_{la} + u_b i_{lb} + u_c i_{lc} \qquad (3.3)$$

This expression can be given in the stationary frame by:

$$\begin{cases} p(t) = u_\propto i_{l\propto} + u_\beta i_{l\beta} \\ p_o(t) = u_o i_{lo} \end{cases} \qquad (3.4)$$

Where, *p(t)* is the instantaneous active power, *p0(t)* is the instantaneous homo-polar sequence power. Similarly the instantaneous reactive power can be given by:

$$q(t) = -\frac{1}{\sqrt{3}}[(u_a - u_b)i_{lc} + (u_b - u_c)i_{la} + (u_c - u_a)i_{lb}] = u_\propto i_{l\beta} - u_\beta i_{l\propto} \qquad (3.5)$$

It is important to notice that the instantaneous reactive power *q(t)* signify more than the simple reactive power. The instantaneous reactive power take in consideration all the current and voltage harmonics, where as the habitual reactive power consider just the fundamentals of current and voltage.
From equations (3.4) and (3.5) the instantaneous active and reactive power can be given in matrix form by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} u_\propto & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \qquad (3.6)$$

In general, each one of the active and reactive instantaneous power contains a direct component and an alternating component. The direct component of each presents the power of the fundamentals of current and voltage. The alternating term is the power of the harmonics of currents and voltages.
In order to separate the harmonics from the fundamentals of the load currents, it is enough to separate the direct term of the instantaneous power from the alternating one. A Low Pass Filter (LPF) with feed-forward effect can be used to

accomplish this task. Fig. 3.2 shows the principle of this extraction filter.

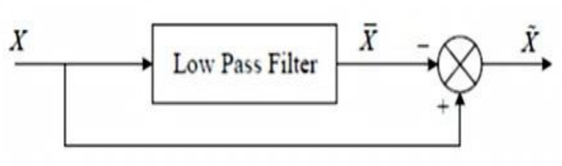

Fig. 3.2 Diagram of the Low Pass Filter with Feed-Forward.

After the separation of the direct and alternating terms of instantaneous power, the harmonic components of the load currents can be given using the inverse of equation (3.6) which gives:

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \frac{1}{v_{s\alpha}^2+v_{s\beta}^2}\begin{bmatrix} v_{s\alpha} & -v_{s\beta} \\ v_{s\beta} & v_{s\alpha} \end{bmatrix}\begin{bmatrix} \tilde{p}_l \\ \tilde{q}_l \end{bmatrix} \quad 3.7)$$

Where, the "$\sim$ "sign points to the alternating.

The APF reference current can be then given by:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} \tilde{i}_{l\alpha} \\ \tilde{i}_{l\beta} \end{bmatrix} \quad (3.8)$$

Fig. 3.3 presents the principle of the active and reactive instantaneous power. This method offers the advantage of the possibility of harmonic compensation and/or reactive power compensation. In the case of reactive power compensation it is enough to send the reactive power q(t) directly to the reference current calculation bloc without the use of any extraction filter.

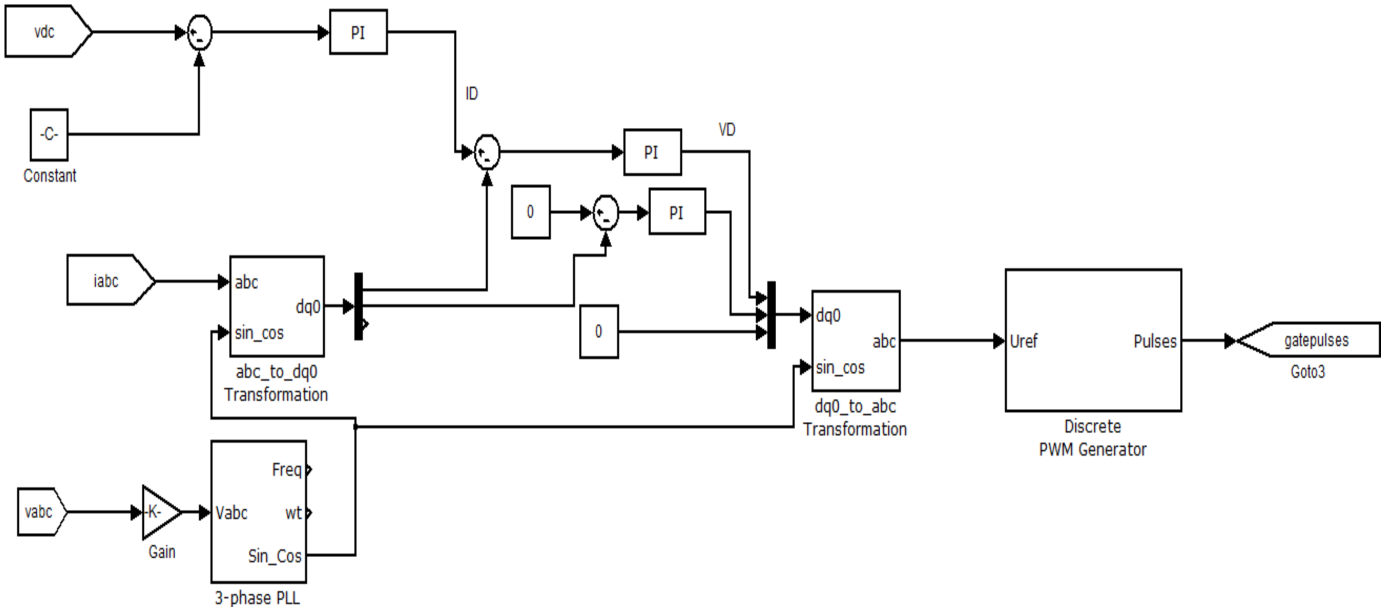

Fig. 3.3 proposed controller.

Voltage Source Inverter

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.

The standard three-phase VSI topology is shown in Fig. 3.4. It is composed of three legs with current reversible switches, controlled for the open and close. These switches are realized by controlled switches (GTO or IGBT) with anti-parallel diodes to allow the flow of the free-wheeling currents.

The switches of any leg of the inverter (T1 and T4, T2 and T5, T3 and T6) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity.

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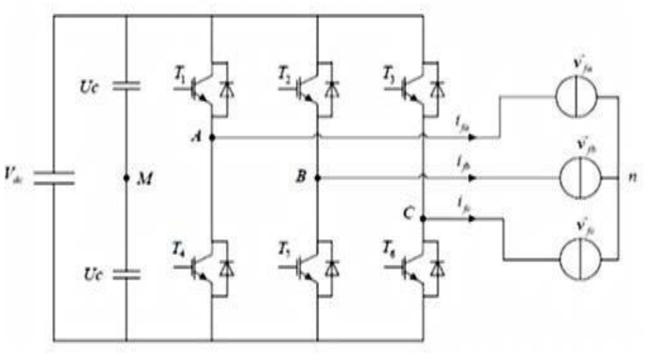

Fig. 3.4 Three-phase Two Levels VSI Topology

Modeling of Voltage Source Inverter

The output of the VSI which is shown in Fig. 3.4 can take two levels of voltage (+V_{dc}, - V_{dc}) dependent on the dc source voltage and the switches states. Actually, the control of the two switches on the same leg is complementary: the conduction of one of them implies the blocking of the other.

The state of each one of the switches is defined by the control signals (S_a, S_b and S_c) as follow:

$$S_a = \begin{cases} 1 \ if \ T_1 close \ , T_4 open \\ 0 \ if \ T_1 open \ , T_4 close \end{cases}$$

$$S_b = \begin{cases} 1 \ if \ T_2 close \ , T_5 open \\ 0 \ if \ T_2 open \ , T_5 close \end{cases}$$

$$S_c = \begin{cases} 1 \ if \ T_3 close \ , T_6 open \\ 0 \ if \ T_3 open \ , T_6 close \end{cases}$$

Modeling of Active Power Filter

The connection of the series active power filter to the point of common coupling of the grid is done mostly by the mean of a RL low pass filter as shown in Fig. 3.1. The voltage equation for each phase can be given by:

$$v_{sk} = v_{fk} - v_{L_{fk}} - v_{R_{fk}}$$

$$v_{fk} - L_f \frac{di_{fk}}{dt} - R_f i_{fk} \text{ , k=a,b,c} \qquad (3.9)$$

The three phase equations are then given by:

$$L_f \frac{d}{dt}\begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} = -R_f \begin{bmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{bmatrix} + \begin{bmatrix} v_{fa} \\ v_{fb} \\ v_{fc} \end{bmatrix} - \begin{bmatrix} S_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \qquad (3.10)$$

And for the dc side:

$$C_{dc} \cdot \frac{dV_{dc}}{dt} = S_a i_{fa} + S_b i_b + S_c i_f \qquad (3.11)$$

The equation system defining the SAPF in the three phase frame is then given by:

$$\begin{cases} L_f \frac{di_{fa}}{dt} = -R_f i_{fa} + v_{fa} - v_{sa} \\ L_f \frac{di_{fb}}{dt} = -R_f i_{fb} + v_{fb} - v_{sb} \\ L_f \frac{di_{fc}}{dt} = -R_f i_{fc} + v_{fc} - v_{sc} \end{cases} \qquad (3.12)$$

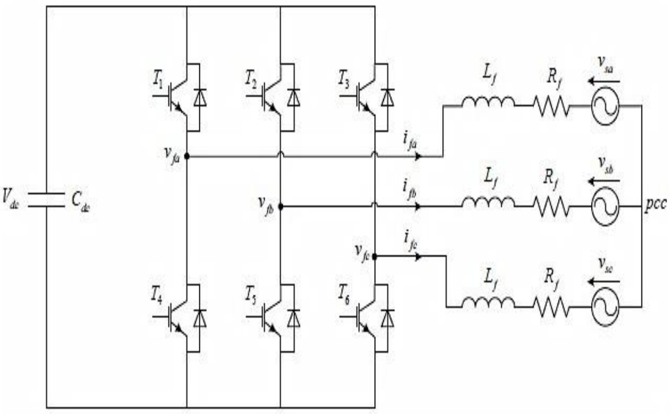

Fig. 3.5 SAPF Connection to the PCC

Control Methods of VSI

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. In the next section, we are going to discuss some different methods in VSC control.

The current control strategy plays an important role in fast response current controlled inverters such as the active power filters. 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.

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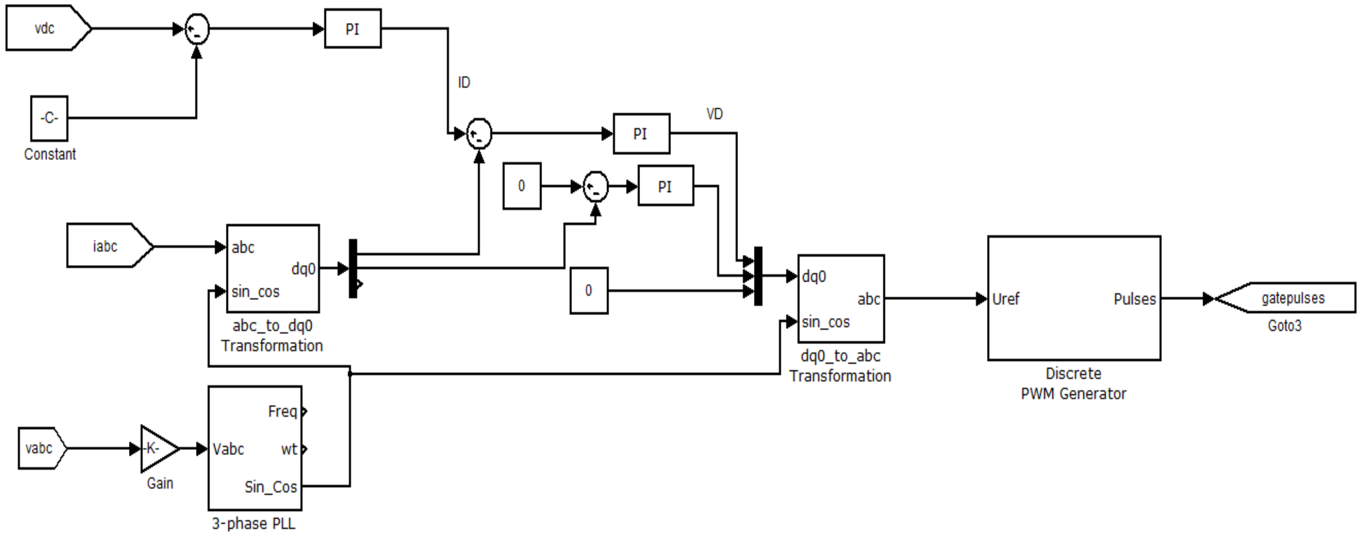

Fig. 3.6 proposed controller.

The basic structure of PWM voltage source inverter with hysteresis controller is shown in Fig. 3.6. The hysteresis control strategy aims to keep the controlled current inside a defined rejoin around the desired reference current. The status of the switches is determined according to the error. When the current is increasing and the error exceeds a certain positive value, the status of the switches changes and the current begins to decrease until the error reaches a certain negative value, then the switches status changes again.

In the fix hysteresis band control of the VSI, the switching frequency is a function of the derivative of the output current. This one depends on the value of the inductance of the decoupling filter and the voltage drop around it. It is important to notice that the coupling filter affects the switching frequency and the dynamic behavior of the active filter. The simple implementation procedure is the main advantage of this control method. However, the variable switching frequency is the major draw-back of this method. This variable frequency affects mainly the function of power electronic elements which can’t support high switching frequency in high power applications. In order to solve the problem of variable switching frequency, a new hysteresis control strategies like “modulated hysteresis control” and “variable hysteresis band” were proposed. In the modulated hysteresis control it is difficult to define the hysteresis band width. Over more, the fix switching frequency achieved using this method affects the rapidity obtained by hysteresis control.

The control techniques based on the PWM solve the problem of switching frequency of the VSI. They use a fix switching frequency which makes it easier to cancel the switching harmonics. The PWM can be realized using different techniques such as carrier based PWM, PWM with harmonics minimization, and space vector PWM. The carrier PWM can be natural PWM, symmetric PWM, and asymmetric PWM.

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. The choice of the ratio between the frequency of the reference signal and the frequency of the carrier signal is very important in the case of symmetric and periodic reference. As a consequence, in the case of sinusoidal reference, the ratio between the two frequencies must be integer to synchronize the carrier with the reference. Over more, it is preferable that the carrier frequency be odd to conserve the reference symmetry. In all cases this ratio must be sufficiently high to ensure the fast switching and to take the switching harmonics away from the fundamental produced by the inverter.

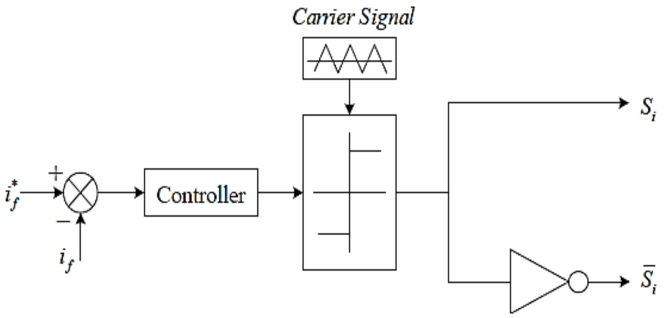

Fig. 3.7 The Principle of Sinusoidal PWM Control Method

ecently, new control techniques called space vector PWM were implemented. The difference between this technique and the sinusoidal technique is that it doesn’t use carrier signal to define switching orders.

Space Vector PWM Control (SVPWM)

Space vector modulation technique was first introduced by German researchers in the mid of 1980s. This technique showed several advantages over the traditional PWM technique and has been proven to inherently generate superior

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PWM waveforms. By implementing the SVM technique, the number of switching is reduced to about 30% at the same carrier frequency of the sinusoidal pulse width modulation (SPWM) method. It offers better DC bus utilizations with lower THD in the AC current and reduces of switching losses too. The maximum modulation index for the SPWM method is 0.785 with the sinusoidal waveform between the phase and the neutral current of the system. However, the modulation index can be increased to 0.907 for the 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.

The SVPWM technique is widely used in inverter and rectifier controls. Compared to the sinusoidal pulse width modulation (SPWM), SVPWM is more suitable for digital implementation and can increase the obtainable maximum output voltage with maximum line voltage approaching 70.7% of the DC link voltage (compared to SPWM's 61.2%) in the linear modulation range. Moreover, it can obtain a better voltage total harmonic distortion factor. There are different algorithms for using SVPWM to modulate the inverter or rectifier. Many SVPWM schemes have been investigated extensively in literatures. The goal in each modulation strategy is to lower the switching losses, maximize bus utilization, reduce harmonic content, and still achieve precise control.

In the SVPWM scheme, the 3-phase output voltage is represented by a reference vector which rotates at an angular speed of $\omega = 2\pi f$. The task of SVM is to use the combinations of switching states to approximate the reference vector. To approximate the locus of this vector, the eight possible switching states of the inverter are represented as 2 null vectors and 6 active vectors.

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.

4. Renewable Energy Sources

Introduction

The most common definition is that renewable energy is from an energy resource that is replaced by a natural process at a rate that is equal to or faster than the rate at which that resource is being consumed. Renewable energy is a subset of sustainable energy.

India has done a significant progress in the power generation in the country. The installed generation capacity was 2300 megawatt (MW) at the time of Independence i.e. about 60 year's back. Which includes the generation through various sectors like Hydro, Thermal and Nuclear. The power generation in the country is planned through funds provided by the Central Sector, State Sector and Private Sector. The power shortages noticed is of the order of 22%. In the opinion of the experts such short fall can be reduced through proper management and thus almost 20% energy can be saved. It has been noticed that one watt saved at the point of consumption is more than 2.5 watts generated. In terms of Investment it costs around Rs.20 million to generate one MW of new generation plant, but if the same Rs.20 million is spent on conservation of energy methods, it can provide up to 3 MW of avoidable generation capacity.

There are about 80,000 villages yet to be electrified for which provision has been made to electrify 62,000 villages from grid supply in the Tenth Plan. It is planned that participation of decentralized power producers shall be ensured, particularly for electrification of remote villages in which village level organizations shall play a crucial role for the rural electrification programme.

Emphasis is given to the renewable energy programme towards gradual commercialization. This programme is looked after by the Ministry of Non-Conventional Sources of energy. Simultaneously private sector investments in renewable energy sources are also increased to promote power generation. So far an excessive reliance was preferred on the use of fossil fuel resources like coal, oil and natural gas to meet the power requirement of the country which was not suitable in the long run due to limited availability of the fossil fuel as well as the adverse impact on the environment and ecology. Since the availability of fossil fuel is on the decline therefore, in this backdrop the norms for conventional or renewable sources of energy (RSE) is given importance not only in India but has attracted the global attention.

Types of Renewable Energy Sources

The main types under RES are as follows

i) Hydro Power
ii) Solar Power
iii) Wind Power
iv) Bio-mass Power
v) Energy from waste
vi) Ocean energy
vii) Alternative fuel for surface transportation

Wind Power

The wind power development in the country is largely of recent period which has been found to be quite impressive. As per available data, it is 5320 MW by March 32, 2006, through wind power. Earlier it was estimated that the potential for wind power in the country was 20,000 MW which has been revised to 25000MW after collecting the data on the potential

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available in the coastal and other areas of the country. At present India is fifth in the world after Germany, USA, Denmark and Spain in terms of wind power. It has been observed that the private sector is showing interest in setting of wind power projects.

The unit size of wind turbine generators which were earlier in the range of 55-200 kw are now preferred in the range of 750-2000 kw. It has been observed that the productivity of the larger machine is higher as compared to the smaller machine. In respect of cost consideration, it has been noticed that the cost of such a project is about Rs.20 million to Rs.50 million per MW which includes all local civil, electrical works and erection also. The life of a wind power project is estimated to be about 20 years.

China has guaranteed all certified renewable energy producers in its service area that the grid will purchase their power and the price will be spread out to all the users across the grid. According to sources, such commitments can only spur further development in the renewable energy sector.

Wind energy is transformed into mechanical energy by means of a wind turbine that has one or several blades. The turbine is coupled to the generator system by means of a mechanical drive train. It usually includes a gearbox that matches the turbine low speed to the higher speed of the generator. New wind turbine designs use multi pole, low speed generators, usually synchronous with field winding or permanent magnet excitation, in order to eliminate the gearbox. Some turbines include a blade pitch angle control for controlling the amount of power to be transformed. Stall controlled turbines do not allow such control. Wind speed is measured by means of an anemometer. A general scheme of Wind energy conversion system is shown in Fig. 2.2.

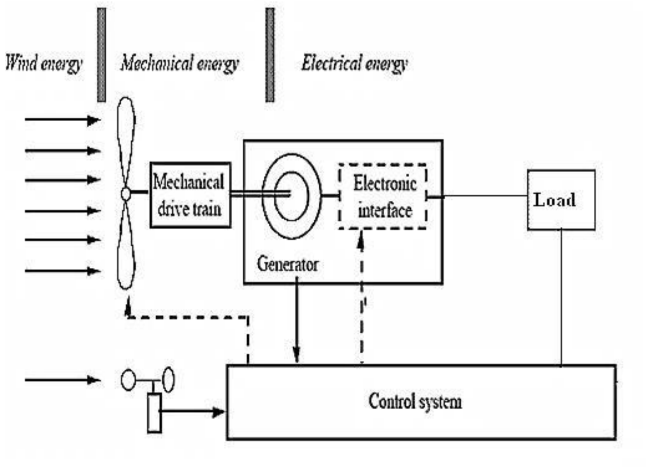

Fig. 4.1 Block Diagram of Wind Energy Conversion System

The electrical generator transforms mechanical energy from the wind turbine into electrical energy. The generator can be synchronous or asynchronous. In the first case, an excitation system is included or permanent magnets are used. Variable speed systems require the presence of a power electronic interface, which can adapt to different configurations. The compensating unit may include power factor correction devices (active or passive) and filters.

Types of wind turbines

Wind turbines can be separated into two types based on the axis about which the turbine rotates. Turbines that rotate around a horizontal axis are most common where as vertical-axis turbines are less frequently used

Horizontal- and Vertical-Axis Wind Turbines

Wind turbines can be categorized based on the orientation of their spin axis into horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT).In horizontal-axis wind turbines, the orientation of the spin axis is parallel to the. The tower elevates the nacelle to provide sufficient space for the rotor blade rotation and to reach better wind conditions. The nacelle supports the rotor hub that holds the rotor blades and also houses the gearbox, generator and, in some designs, power converters. The industry standard HAWT uses a three blade rotor positioned in front of the nacelle, which is known as upwind configuration. However, downwind configurations with the blades at the back can also be found in practical applications. Turbines with one, two or more than three blades can also be seen in wind farms.

In vertical-axis wind turbines, the orientation of the spin axis is perpendicular to the ground. The turbine rotor uses curved vertically mounted airfoils. The generator and gearbox are normally placed in the base of the turbine on the ground. The rotor blades of the VAWT have a variety of designs with different shapes and number of blades. The design given in the figure is one of the popular designs. The VAWT normally needs guide wires to keep the rotor shaft in a fixed position and minimize possible mechanical vibrations. The vertical axis machine has the shape of an egg beater, and is often called the Darrieus rotor after its inventor. However, most modern turbines use horizontal axis design. In this paper the dynamic model of a horizontal axis turbine is developed and simulated in the MATLAB/SIMULINK 2009a.

Mathematical Model of wind turbine

A wind energy conversion system is basically comprised of two main components, the aerodynamic component and the electrical component. The turbine forms a major constituent of the aerodynamic system. The energy that could be captured from wind by a specific turbine depends on its design particulars and operating conditions. In this section all aspects related to the power conversion, from kinetic wind energy to rotational energy, that are of relevance for the stability model are explained.

The kinetic energy E_k of a mass of air m having the speed V_w is given by:

$$E_K = \frac{m}{2} V_w^2 \qquad (2.2)$$

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The power associated to this moving air mass is the derivative of the kinetic energy with respect to time can be expressed as follows:

$$P_o = \frac{\partial E_K}{\partial t} = \frac{1}{2}\frac{\partial m}{\partial t}.V_w^2 = \frac{1}{2}.qV_w^2 \quad (2.2)$$

Where q represents the mass flow given by the expression:

$q = \rho V_W .A$ (2.3)

Where ρ: Air density;

A: Cross section of the air mass flow.

E_k: kinetic energy of the air

Only a fraction of the total kinetic power can be extracted by a wind turbine and converted into rotational power at the shaft. This fraction of power (P_{wind}) depends on the wind speed, rotor speed and blade position (for pitch and active stall control turbines) and on the turbine design. The aerodynamic efficiency C_p is defined as follows:

$$C_P = \frac{P_{wind}}{P_o} \quad (2.2)$$

For a specific turbine design, the values of C_p (α, β) are usually presented as a function of the pitch angle (β) and the tip speed ratio (α). The tip speed ratio is given by:

$$\alpha = \frac{\omega_{tur} R}{V_w} \quad (2.5)$$

Where R: the radius of the turbine blades.

ω_{tur}: the turbine angular speed.

The aerodynamic efficiency C_p (α, β) is usually defined as a form of a two-dimensional lookup characteristic (for different values of α and β) by actual measurement. The variation of the power coefficient C_p with variation of the tip speed ratio is shown in Fig. 2.2.

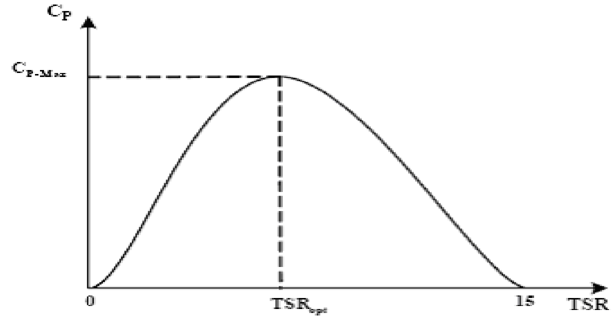

Fig. 2.2 power Coefficient Versus Tip Speed Ratio

A two dimensional, cubic line-interpolation method is used for calculating points between measured values. The high accuracy of the interpolation method avoids the need of entering a large number of points. Alternatively, analytical approaches for approximating the aerodynamic efficiency C_p (α, β) characteristic could be used. Finally, the mechanical power extracted from the wind is calculated using:

$$P_{mech} = \frac{\square}{2}\Pi R^2.C_P(\alpha,\beta).V_w^2 \quad .6)$$

The aerodynamic efficiency C_p (α, β) characteristic can be calculated using special software for aerodynamic designs that is usually based on blade-iteration techniques or it can be obtained from actual measurements. The power coefficient of wind turbine can be expressed by:

$$C_p(\alpha,\beta) = c_1\left(\frac{c_2}{\alpha_i} - c_3\beta - c_4\right)e^{-\frac{c_5}{\alpha_i}} + c_6\alpha \quad (2.7)$$

c_2, c_2, c_3, c_2, c_5 and c_6 are the constants they depend on mechanical characteristics of the wind turbine.

Types of Wind Generators

Various types of generators that are used for wind power generation are induction generators and synchronous generators. In this section a brief review of different types of generators including their advantages and disadvantages are presented.

Generators suitable for Constant speed turbines:

- ❖ Squirrel Cage Induction Generator (SCIG)

Generators suitable for variable speed turbines:

- ❖ Doubly Fed Induction Generator (DFIG)
- ❖ Permanent Magnet synchronous Generator (PMSG).

Induction Generators

The induction machine is a well-established technology, as its application as a wind generator, using a gear drive to a generator with a low number of poles. In general, because of its small air-gap, the induction machine leakage flux increases to an unacceptable limit for machines with many poles. This causes difficulty, in which the machine cannot use the available current flow to generate torque. Induction machines with a large number of poles must be large enough to accommodate a sufficient number of slots per pole per phase, in order to prevent this situation from taking the upper hand. This means that induction machines with many poles will inevitably be oversized in relation to the rated output. The induction generator applied to conventional wind power generation has advantages like low maintenance, robustness, and low cost, asynchronous operation, which allow some flexibility when the wind speed is fluctuating. These advantages make the induction machine very attractive for wind power application, for both fixed and variable speed operation. However, a major disadvantage is the need for excitation of the magnetic field through the supply terminal, which results in relatively low power factor for full load operation. For power factor compensation of the reactive power in the generator, ac-capacitor banks are used. The generators are normally compensated over the whole power range. The switching of capacitors is done as a function of average value of measured reactive power during a certain period. The capacitors may be heavy loaded and damaged in case of over-voltages to the grid. Therefore, they may increase

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the maintenance cost. Another solution to improve the power factor is to insert a power converter in series with the armature circuit. In this way, full control is obtained over the induction generator performance, but at the cost of a converter capable of handling the full power of the generator.

Squirrel Cage Induction Generator

A squirrel cage induction generator is an asynchronous machine, with a squirrel cage rotor and stator, which is directly connected to the grid. The wind turbine rotor will be directly coupled to the generator through a gearbox, which matches the rotational speed of blades with that of the generator. Essentially this is a constant speed wind turbine because the power converted from the wind is limited by designing the turbine rotor in such a way that its efficiency decreases under high wind speeds.

Induction generator is the most common generator in wind energy systems because of its simplicity, ruggedness, low maintenance and low cost. The main drawback in induction generator is its consumption of reactive power for producing the real power. The VAR compensation can be done with the help of fixed capacitance connected near the Induction generator. The fixed capacitance method of VAR compensation is generally done when the torque applied to the induction generator is constant.

In practice, most wind farms have fixed capacitor banks installed to fulfill reactive power compensation requirement at rated output level. Using a fixed capacitor to supply reactive power may lead to voltage fluctuation and wear out the turbine's gearboxes.

Doubly Fed Induction Generator

The doubly fed induction generator is an induction machine with wound rotor and a four-quadrant ac-to-ac converter setup connected to the rotor winding. The doubly fed induction generator (DFIG) wind turbines are nowadays more widely used especially in large wind farms. These are generally used in the variable speed applications. The main reason for the popularity of the doubly fed wind induction generators is their ability to supply power at constant voltage and frequency while the rotor speed varies. The DFIG concept also provides a possibility to control the overall system power factor. DFIG wind turbine utilizes a wound rotor induction machine while the rotor winding is supplied from frequency converter providing speed control, together with terminal voltage and power factor control for the overall system.

SOLAR SYSTEM

The continuous increase in the electrical energy with the clean environment needs the decentralized renewable energy production. The increasing energy consumption may overload the distribution grid as well as power station and may cause the negative impact on power availability, security and quality. The only solution to overcome this problem is integrating the utility grid with the renewable energy systems like solar, wind or hydro. The grid can be connected to the renewable energy system as per the availability of renewable energy sources. Recently the solar power generation systems are getting more attention because solar energy is abundantly available, more efficient and more environment friendly as compared to the conventional power generation systems such as fossil fuel, coal or nuclear. The PV systems are still very expensive because of higher manufacturing cost of the PV panels, but the energy that drives them -the light from the sun- is free, available almost everywhere and will still be present for millions of years, even all non-renewable energy sources might be depleted. One of the major advantages of PV technology is that it has no movin parts. Therefore, the PV system is very robust, it has a long lifetime and low maintenance requirements. And, most importantly, it is one solution that offers environmentally friendly power generation.

Why Is Solar Energy

The most important issue of all is probably why solar energy is important to you, personally.

Fossil fuels, like gas and oil, are not renewable energy. Once they are gone they can't be replenished. Someday these fuels will run out and then mankind will either need to come up with a new way to provide power or go back to life as it was prior to man's use of these things.

Fossil fuels create massive pollution in the environment. This pollution affects waterways, the air you breathe, and even the meat and vegetables that you eat.

These fuels are expensive to retrieve from the earth and they are expensive to use. Other, more Eco-friendly energy sources like wind and solar energies are relatively inexpensive and easy to produce.

The disadvantage of the PV system is that it can supply the load only in sunny days. Therefore, for improving the performance and supplying the power in all day, it is necessary to hybrid the PV system into another power generation systems or to integrate with the utility grid. The integration of the PV system with the utility grid requires the PWM voltage source converter for interfacing the utility grid and results some interface issues. A prototype current- controlled power conditioning system has been developed and tested. This prototype sources 20 kW of power from a photovoltaic array with a maximum power point tracking control. The disadvantage of this system is the need of high bandwidth current measurement transducers (dc to several times the switching frequency), and the need for relatively high precision in the reference signal generation. Hence, this increases the cost of the system. The inverters suitable for the PV system are central inverters, string inverters, Module integrated or module oriented inverters, multi string PV inverter with new trends has been described . If these solar inverters are connected with the grid, the control of these

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inverters can be provided using the phase locked loop. The need and benefits of the distribution technology has been presented.Single-phase Grid connected PV inverters with the control has been described with its advantages and disadvantages. The three-phase Photovoltaic power conditioning system with line connection has been proposed with the disturbance of the line voltage which is detected using a fast sensing technique. The control of the system is provided through the microcontroller. Power electronic systems can also be used for controlling the solar inverter for interfacing the Solar Power Generation system with the grid.The complete design and modeling of the grid connected PV system has been developed to supply the local loads

Background

World is moving towards the greener sources of energy to make the planet pollution free and environment friendly. The major utilization of these sources with grid integration is the challenging task. It is therefore Distribution Generation (DGs) particularly single phase rooftop PV system are major research area for grid integration, since these sources have huge opportunity of generation near load terminal. The rooftop application involving single phase DG's fed with PV source can be not only utilized for household use but the excess energy can be transferred to the grid through proper control scheme and adequate hardware. Control scheme based on instantaneous PQ theory has been presented in some literatures for single phase system.

Other control scheme such as synchronous reference frame (SRF) is mainly used with three phase system in which sinusoidal varying quantities are being transferred to dc quantities that provides better and precise control than PQ based control even under distorted condition of mains. But SRF based control scheme can be customized for single phase which can't be utilized to get the desired dc quantity to generate required reference command. PV sources are interfaced with the grid through voltage source converters (VSC's). VSC's can be controlled either in PWM based voltage control method or hysteresis based current controlled method (HCC). HCC based controller gives fast response and better regulation but its major drawback lies with Variable frequency. On the other hand the PWM based control gives fixed switching frequency that could be utilized easily for proper design of LC or LCL filters. With PV sources connected at the DC side of the inverter, it is utmost essential to fetch maximum power from the source to make the system efficient. Out of different algorithm to track maximum power point (MPP) such as perturb and observe (P&O), Incremental Conductance (IC) etc., IC based method provides fast dynamics and control over fast changing insolation condition. In this paper new control scheme based on SRF theory has been proposed for single phase rooftop PV grid connected system. The VSC controller is designed in taking the advantage of both current and voltage controller which is called current driven PWM based voltage controller. Through the VSC the maximum tracked power is pumped into the grid through proper control on DC link voltage. By maintaining the DC link voltage constant during operation, is ensured the total power being generated by PV transferred across the DC bus by the inverter to the grid. Apart from active power transfer the system could be well utilized for providing limited reactive power compensation based on available capacity of the VSC. The detailed system configuration and various control schemes are briefly discussed and explained. The rooftop PV system with proposed scheme is simulated under the MATLAB simulink environment for grid connection to push real power into the grid along with limited power conditioning. The contents are dealt in the following sections: (II) System Configuration (III) PV array modeling and IC MPPT techniques, (IV) Control, (V) MATLAB Simulation, (VI) Performance evaluation.

The photovoltaic effect was experimentally demonstrated first by French physicist Edmond Becquerel. In 1839, at age 19, he built the world's first photovoltaic cell in his father's laboratory. Willoughby Smith first described the "Effect of Light on Selenium during the passage of an Electric Current" in a 20 February 1873 issue of Nature. In 1883 Charles Fritts built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions; the device was only around 1% efficient. In 1888 Russian physicist Aleksandr Stoletov built the first cell based on the outer photoelectric effect discovered by Heinrich Hertz in 1887.

Albert Einstein explained the underlying mechanism of light instigated carrier excitation—the photoelectric effect—in 1905, for which he received the Nobel Prize in Physics in 1921. Russell Ohl patented the modern junction semiconductor solar cell in 1946 while working on the series of advances that would lead to the transistor.

The first practical photovoltaic cell was publicly demonstrated on 25 April 1954 at Bell Laboratories. The inventors were Daryl Chapin, Calvin Souther Fuller and Gerald Pearson.

Solar cells gained prominence when they were proposed as an addition to the 1958 Vanguard I satellite. By adding cells to the outside of the body, the mission time could be extended with no major changes to the spacecraft or its power systems. In 1959 the United States launched Explorer 6, featuring large wing-shaped solar arrays, which became a common feature in satellites. These arrays consisted of 9600 Hoffman solar cells.

Improvements were gradual over the next two decades. The only significant use was in space applications where they offered the best power-to-weight ratio. However, this success was also the reason that costs remained high, because space users were willing to pay for the best possible cells, leaving no reason to invest in lower-cost, less-efficient solutions. The price was determined largely by the semiconductor industry;

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their move to integrated circuits in the 1960s led to the availability of larger boules at lower relative prices. As their price fell, the price of the resulting cells did as well. These effects lowered 1971 cell costs to some $100 per watt.

In late 1969, Elliot Berman was investigating organic solar cells, when he joined a team at Exxon SPC who were looking for projects 30 years in the future. The group had concluded that electrical power would be much more expensive by 2000, and felt that this increase in price would make alternative energy sources more attractive, finding solar the most interesting. He conducted a market study and concluded that a price per watt of about $20/watt would create significant demand.

The first improvement was the realization that the standard semiconductor manufacturing process was not ideal. The team eliminated the steps of polishing the wafers and coating them with an anti-reflective layer, relying on the rough-sawn wafer surface. The team also replaced the expensive materials and hand wiring used in space applications with a printed circuit board on the back, acrylic plastic on the front, and silicone glue between the two, "potting" the cells. Solar cells could be made using cast-off material from the electronics market.

Navigation market

SPC convinced Tideland Signal to use its panels to power navigational buoys, after finding that Automatic Power, the market leader, had purchased and shelved a solar navigation aid prototype from Hoffman Electronics to protect its battery business. Tideland's solar-powered buoy quickly overtook Automatic.

The rapidly increasing number of offshore oil platforms and loading facilities led Arco to buy Solar Power International (SPI), forming ARCO Solar. ARCO Solar's factory in Camarillo, California was the first dedicated to building solar panels, and was in continual operation from its purchase by ARCO in 1977 until 2011 when it was closed by Solar World.

Following the 1973 oil crisis oil companies used their higher profits to start solar firms, and were for decades the largest producers. Exxon, ARCO, Shell, Amoco (later purchased by BP) and Mobil all had major solar divisions during the 1970s and 1980s. Technology companies also participated, including General Electric, Motorola, IBM, Tyco and RCA.

5. Proposed Dvr Simulation Result

INTRODUCTION

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Models are hierarchical, so we can build models using both top-down and bottom-up approaches. We can view the system at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After we define a model, we can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens, for "what if" exploration.

The simulation results can be put in the MATLAB workspace for post processing and visualization. Simulink can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems.

Simulating a dynamic system is a two-step process with Simulink. First, we create a graphical model of the system to be simulated, using Simulink's model editor. The model depicts the time-dependent mathematical relationships among the system's inputs, states, and outputs. Then, we use Simulink to simulate the behavior of the system over a specified time span. Simulink uses information that you entered into the model to perform the simulation.

BLOCK DIAGRAM

A Simulink block diagram is a pictorial model of a dynamic system. It consists of a set of symbols, called blocks, interconnected by lines. Each block represents an elementary dynamic system that produces an output either continuously (a continuous block) or at specific points in time (a discrete block). The lines represent connections of block inputs to block outputs. Every block in a block diagram is an instance of a specific type of block. The type of the block determines the relationship between a block's outputs and its inputs, states, and time. A block diagram can contain any number of instances of any type of block needed to model a system. Blocks represent elementary dynamic systems that Simulink knows how to simulate. A block comprises one or more of the following:

1) A set of inputs,
2) A set of states, and
3) A set of outputs.

A block's output is a function of time and the block's inputs and states (if any). The specific function that relates a block's output to its inputs, states, and time depends on the type of block of which the block is an instance. Continuous Versus discrete Blocks Simulink's standard block set includes continuous blocks and discrete blocks. Continuous blocks respond continuously to continuously changing input. Discrete blocks, by contrast, respond to changes in input only at integral multiples of a fixed interval called the block's sample time. Discrete blocks hold their output constant between

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successive sample time hits. Each discrete block includes a sample time parameter that allows you to specify its sample rate. The Simulink blocks can be either continuous or discrete, depending on whether they are driven by continuous or discrete blocks. A block that can be either discrete or continuous is said to have an implicit sample rate. The implicit sample time is continuous if any of the block's inputs are continuous. The implicit sample time is equal to the shortest input sample time if all the input sample times are integral multiples of the shortest time. Otherwise, the input sample time is equal to the fundamental sample time of the inputs, where the fundamental sample time of a set of sample times is defined as the greatest integer divisor of the set of sample times.

Simulink can optionally color code a block diagram to indicate the sample times of the blocks it contains, e.g., black (continuous), magenta (constant), yellow (hybrid), red (fastest discrete), and so on. The block contains block name, icon, and block library that contain the block, the purpose of the block

Simulink Block Libraries

Simulink organizes its blocks into block libraries according to their behavior.

1) The Sources library contains blocks that generate signals.

2) The Sinks library contains blocks that display or write block output.

3) The Discrete library contains blocks that describe discrete-time components.

4) The Continuous library contains blocks that describe linear functions.

5) The Math library contains blocks that describe general mathematics functions.

6) The Functions & Tables library contains blocks that describe general functions and table look-up operations.

7) The Nonlinear library contains blocks that describe nonlinear functions.

8) The Signal & Systems library contains blocks that allow multiplexing and demultiplexing, implement external input/output, pass data to other parts of the model, and perform other functions.

9) The Subsystems library contains blocks for creating various types of subsystems.

10) The Block sets and Toolboxes library contains the Extras block library of specialized blocks.

Sub Systems

Simulink allows to model a complex system as a set of interconnected subsystems each of which is represented by a block diagram. We create a subsystem using Simulink's Subsystem block and the Simulink model editor. We can embed subsystems with subsystems to any depth to create hierarchical models. We can create conditionally executed subsystems that are executed only when a transition occurs on a triggering or enabling input.

Solvers

Simulink simulates a dynamic system by computing its states at successive time step solver a specified time span, using information provided by the model. The process of computing the successive states of a system from its model is known as solving the model. No single method of solving a model suffices for all systems. Accordingly, Simulink provides a set of programs, known as solvers, that each embody a particular approach to solving a model. The Simulation Parameters dialog box allows us to choose the solver most suitable for our model.

Fixed-Step and Variable-Step Solvers

Fixed-step solvers solve the model at regular time intervals from the beginning to the end of the simulation. The size of the interval is known as the step-size. We can specify the step size or let the solver choose the step size. Generally decreasing the step size increases the accuracy of the results while increasing the time required to simulate the system.

Variable-step solvers vary the step size during the simulation, reducing the step size to increase accuracy when a model's states are changing rapidly and increasing the step size to avoid taking unnecessary steps when the model's states are changing slowly. Computing the step size adds to the computational overhead at each step but can reduce the total number of steps, and hence simulation time, required to maintain a specified level of accuracy for models with rapidly changing or piecewise continuous states.

Continuous and Discrete Solvers

Continuous solvers use numerical integration to compute a model's continuous states at the current time step from the states at previous time steps and the state derivatives. Continuous solvers rely on the model's blocks to compute the values of the model's discrete states at each time step. Mathematicians have developed a wide variety of numerical integration techniques for solving the ordinary differential equations (ODEs) that represent the continuous states of dynamic systems. Simulink provides an extensive set of fixed-step and variable-step continuous solvers, each implementing a specific ODE solution method. Some continuous solvers subdivide the simulation time span into major and minor steps, where a minor time step represents a subdivision of the major time step. The solver produces a result at each major time step. It use results at the minor time steps to improve the accuracy of the result at the major time step.

Discrete solvers exist primarily to solve purely discrete models. They compute the next simulation time-step for a model and nothing else. They do not compute continuous states and they rely on the model's blocks to update the model's discrete states. We can use a continuous solver, but not a discrete solver, to solve a model that contains both continuous and discrete states. This is because a discrete

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solver does not handle continuous states. If you select a discrete solver for a continuous model, Simulink disregards your selection and uses a continuous solver instead when solving the model.

Simulink provides two discrete solvers, a fixed-step discrete solver and a variable-step discrete solver. The fixed-step solver by default chooses a step size and hence simulation rate fast enough to track state changes in the fastest block in our model. The variable-step solver adjusts the simulation step size to keep pace with the actual rate of discrete state changes in our model. This can avoid unnecessary steps and hence shorten simulation time for multirate models.

MODEL EXECUTION PHASE

In the simulation model execution phase, Simulink successively computes the states and outputs of the system at intervals from the simulation start time to the finish time, using information provided by the model. The successive time points at which the states and outputs are computed are called time steps. The length of time between steps is called the step size. The step size depends on the type of solver used to compute the system's continuous states, the system's fundamental sample time, and whether the system's continuous states have discontinuities (Zero Crossing Detection). At the start of the simulation, the model specifies the initial states and outputs of the system to be simulated. At each step, Simulink computes new values for the system's inputs, states, and outputs and updates the model to reflect the computed values. At the end of the simulation, the model reflects the final values of the system's inputs, states, and outputs. At each time step:

1) Simulink Updates the outputs of the models' blocks in sorted order. Simulink computes a block's outputs by invoking the block's output function. Simulink passes the current time and the block's inputs and states to the output function as it may require these arguments to compute the block's output. Simulink updates the output of a discrete block only if the current step is an integral multiple of the block's sample time.
2) Updates the states of the model's blocks in sorted order. Simulink computes a block's discrete states by invoking its discrete state update function. Simulink computes a block's continuous states by numerically integrating the time derivatives of the continuous states. It computes the time derivatives of the states by invoking the block's continuous derivatives function.
3) Optionally checks for discontinuities in the continuous states of blocks. Simulink uses a technique called zero crossing detection to detect discontinuities in continuous states.
4) Computes the time for the next time step.

Simulink repeats steps 1 through 4 until the simulation stop time is reached.

Block Sorting Rules

Simulink uses the following basic update rules to sort the blocks:

1) Each block must be updated before any of the direct-feed through blocks that it drives. This rule ensures that the inputs to direct-feed through blocks will be valid when they are updated.
2) Non direct-feed through blocks can be updated in any order as long as they are updated before any direct-feed through blocks that they drive. This rule can be met by putting all non direct-feed through blocks at the head of the update list in any order. It thus allows Simulink to ignore non direct-feed through blocks during the sorting process.

The result of applying these rules is an update list in which non direct-feed through blocks appear at the head of the list in no particular order followed by direct-feed through blocks in the order required to supply valid inputs to the blocks they drive. During the sorting process, Simulink checks for and flags the occurrence of algebraic loops, that is, signal loops in which an output of a direct-feed through block is connected directly or indirectly to one of the block's inputs. Such loops seemingly create a deadlock condition since Simulink needs the input of a direct-feed through block in order to compute its output. However, an algebraic loop can represent a set of simultaneous algebraic equations (hence the name) where the block's input and output are the unknowns. Further, these equations can have valid solutions at each time step. Accordingly, Simulink assumes that loops involving direct-feed through blocks do, in fact, represent a solvable set of algebraic equations and attempts to solve them each time the block is updated during a simulation.

Determining Block Update Order

During a simulation, Simulink updates the states and outputs of a model's blocks once per time step. The order in which the blocks are updated is therefore critical to the validity of the results. In particular, if a block's outputs are a function of its inputs at the current time step, the block must be updated after the blocks that drive its inputs. Otherwise, the block's outputs will be invalid. The order in which blocks are stored in a model file is not necessarily the order in which they need to be updated during a simulation. Consequently, Simulink sorts the blocks into the correct order during the model initialization phase.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include-

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows

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solving many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or FORTRAN.

The MATLAB system consists of six main parts:

(a) Development Environment

This is the set of tools and facilities that help to use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files and the search path.

(b) The MATLAB Mathematical Function Library

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix Eigen values, Bessel functions, and fast Fourier transforms.

(c) The MATLAB Language

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create large and complex application programs.

(d) Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow to fully customize the appearance of graphics as well as to build complete graphical user interfaces on MATLAB applications.

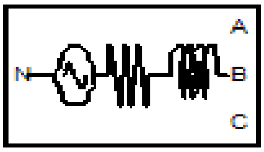
(e) The MATLAB Application Program Interface (API)

This is a library that allows writing in C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

(f) MATLAB Documentation

MATLAB provides extensive documentation, in both printed and online format, to help to learn about and use all of its features. It covers all the primary MATLAB features at a high level, including many examples. The MATLAB online help provides task-oriented and reference information about MATLAB features. MATLAB documentation is also available in printed form and in PDF format.

(1) Three phase source block

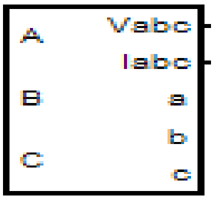


Three Phase Source Block

The Three-Phase Source block implements a balanced three-phase voltage source with internal R-L impedance. The three voltage sources are connected in Y with a neutral connection that can be internally ground.

(2) VI measurement block

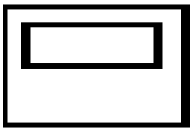
The Three-Phase V-I Measurement block is used to measure three-phase voltages and currents in a circuit. When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase voltages and the three line currents



Three Phase V-I Measurement

(3) Scope

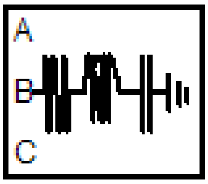
Display signals generated during a simulation. The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes. The Scope allows you to adjust the amount of time and the range of input values displayed. You can move and resize the Scope window and you can modify the Scope's parameter values during the simulation



Scope

(4) Three-Phase Series RLC Load

The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.



Three-Phase Series RLC Load

(5) Three-Phase Breaker block

The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal or from an internal control signal.

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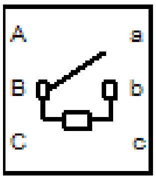
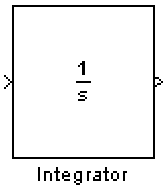


Three-Phase Breaker Block

(6) Integrator

Library: Continuous



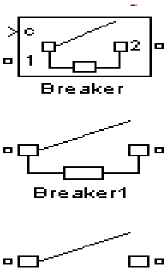
Integrator

The integrator block outputs the integral of its input at the current time step. The following equation represents the output of the block y as a function of its input u and an initial condition y_0, where y and u are vector functions of the current simulation time t.

(7) Breaker

Implement circuit breaker opening at current zero crossing.

Library: Elements



Circuit Breaker

Purpose: The Breaker block implements a circuit breaker where the opening and closing times can be controlled either from an external SIMULINK signal (external control mode), or from an internal control timer (internal control mode).

A series R_s-C_s snubber circuit is included in the model. It can be connected to the circuit breaker. If the Breaker block happens to be in series with an inductive circuit, an open circuit or a current source, you must use a snubber.

When the breaker block is set in external control mode, a SIMULINK input appears on the block icon. The control signal connected to the SIMULINK input must be either 0 or 1 (0 to open the breaker, 1 to close it).

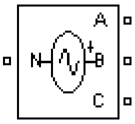
When the Breaker block is set in internal control mode, the switching times are specified in the dialog box of the block.

When the breaker is closed, it is represented by a resistance R_{on}. The Ron value can be set as small as necessary in order to be negligible compared with external components (a typical value is 10 m ohms). When the breaker is open, it has an infinite resistance.

(8) Three-Phase Programmable Voltage Source

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics

Library: Electrical Sources



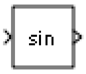
Three Phase Voltage Sources

Purpose: This block is used to generate a three-phase sinusoidal voltage with time-varying parameters. It can be programmed with the time variation for the amplitude, phase or frequency of the fundamental component of the source. In addition, two harmonics can be programmed and superimposed on the fundamental signal.

(9) Trigonometric Function

Specified trigonometric function on input

Library: Math Operations



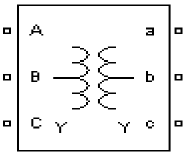
Trigonometric Function

Purpose: The Trigonometric Function block performs common trigonometric functions

(10) Three-Phase Transformer (Two Windings)

Implement three-phase transformer with configurable winding connections

Library: **Elements**



Three Phase Transformer

Purpose:

The Three-Phase Transformer (Two Windings) block implements a three-phase transformer using three single-phase transformers. The saturation characteristic, when activated, is the same as the one described for the saturable Transformer block, and the icon of the block is automatically updated. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

(11) Three-Phase Transformer 12 Terminals

Implement three single-phase, two-winding transformers where all terminals are accessible

Library: Elements

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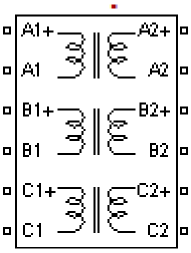


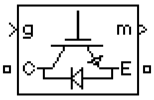
Two winding Transformer

Purpose: The Three-Phase Transformer 12 Terminals block implements three single-phase, two-winding linear transformers where all the twelve winding connectors are accessible. The block can be used in place of the Three-Phase Transformer (Two Windings) block to implement a three-phase transformer when primary and secondary are not necessarily connected in Star or Delta.

(12) IGBT/Diode

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

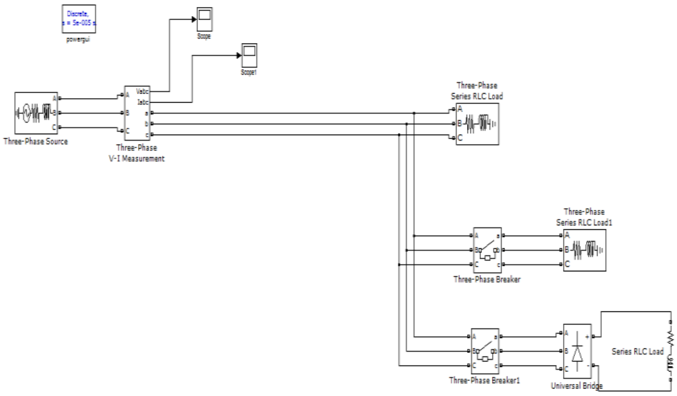
Library: **Power Electronics**



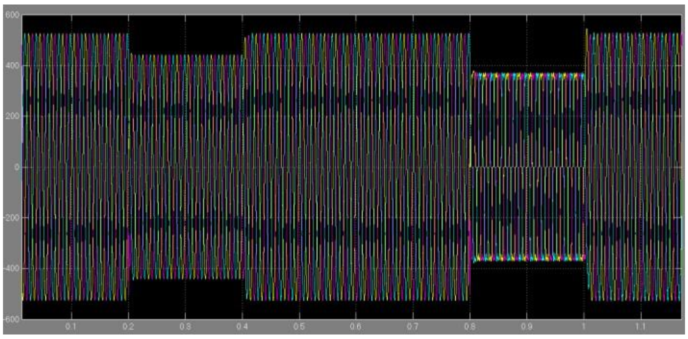
IGBT

Purpose: The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.

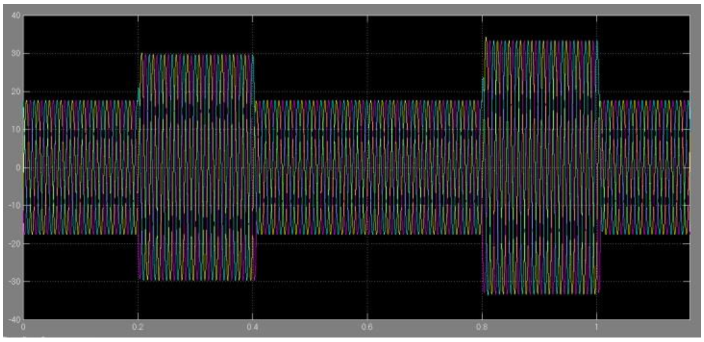
4.11 SIMULATION CIRCUIT WITHOUT NOVEL DVR



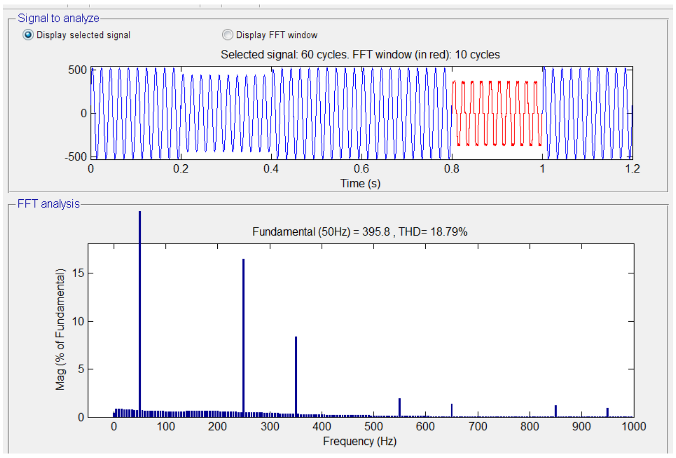
Circuit without DVR



Voltage profile without DVR



Current profile without DVR



Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 60 cycles. FFT window (in red): 10 cycles

FFT analysis

Fundamental (50Hz) = 395.8 , THD= 18.79%

Total harmonic distortion

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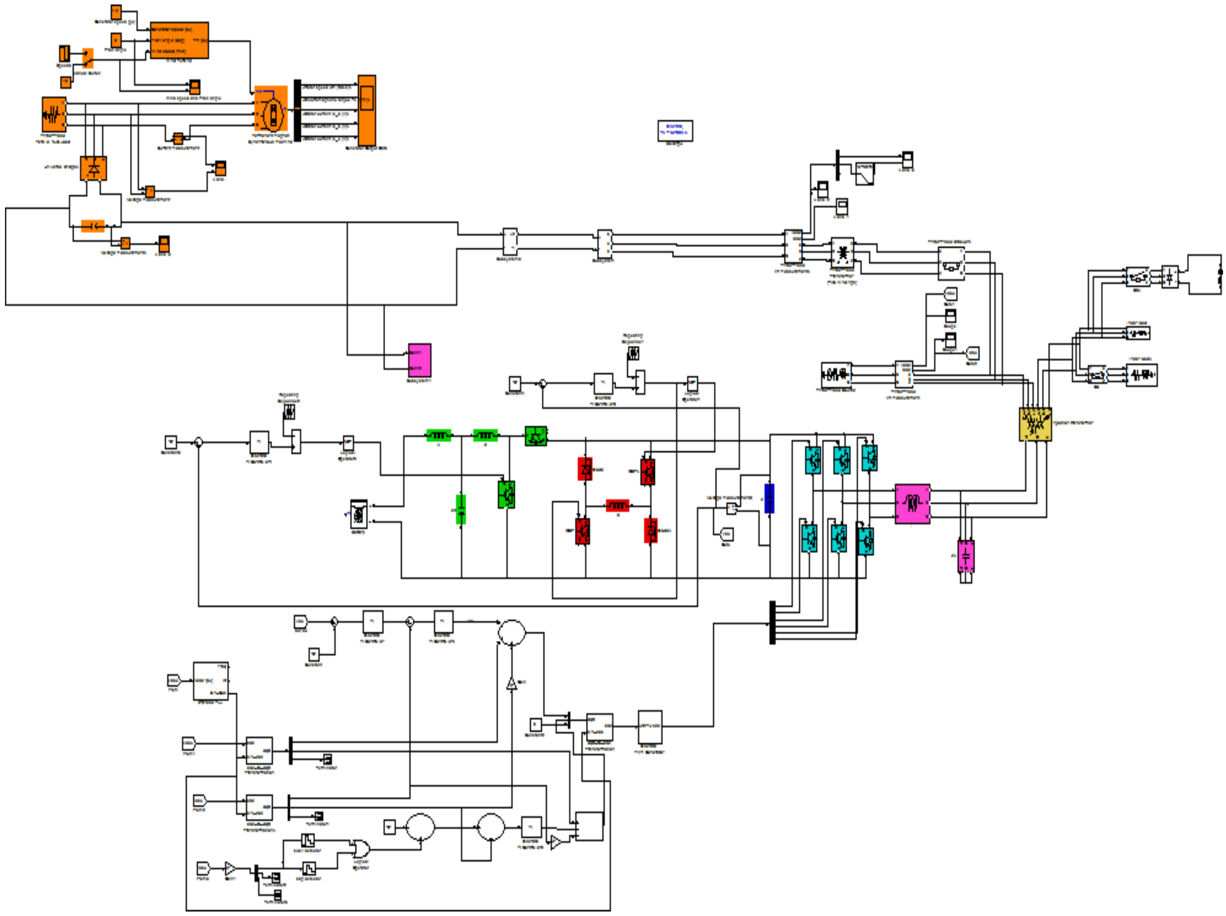
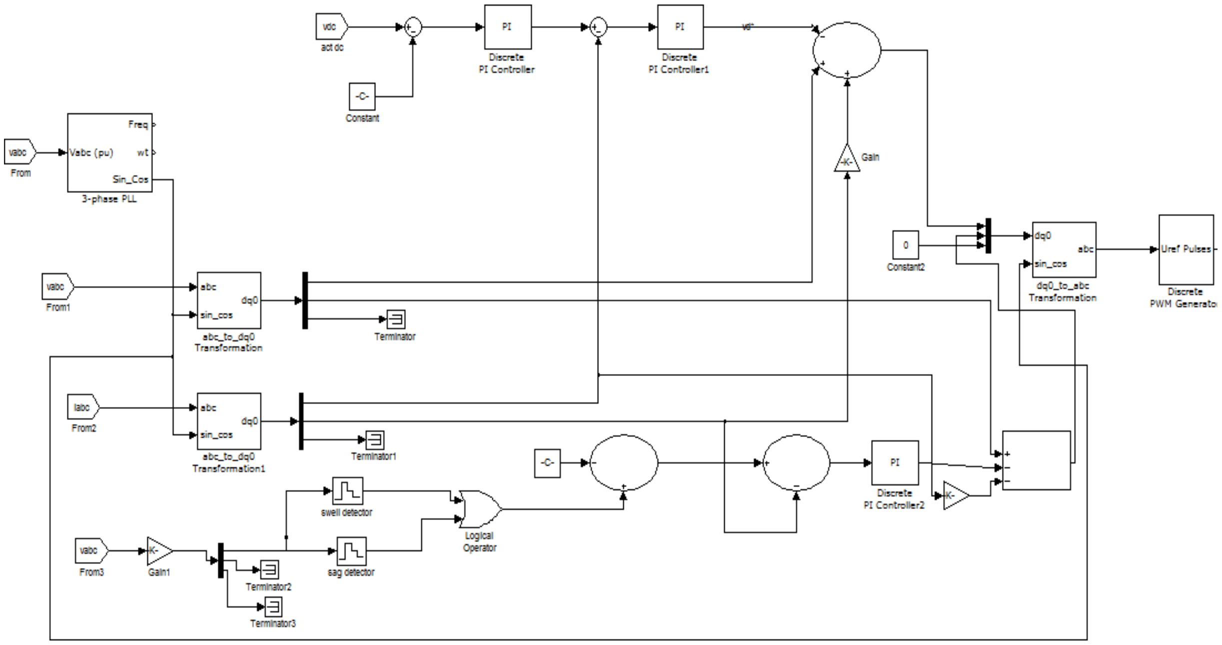


Total circuit configuration with existing controller



Simulink diagram for existing controller

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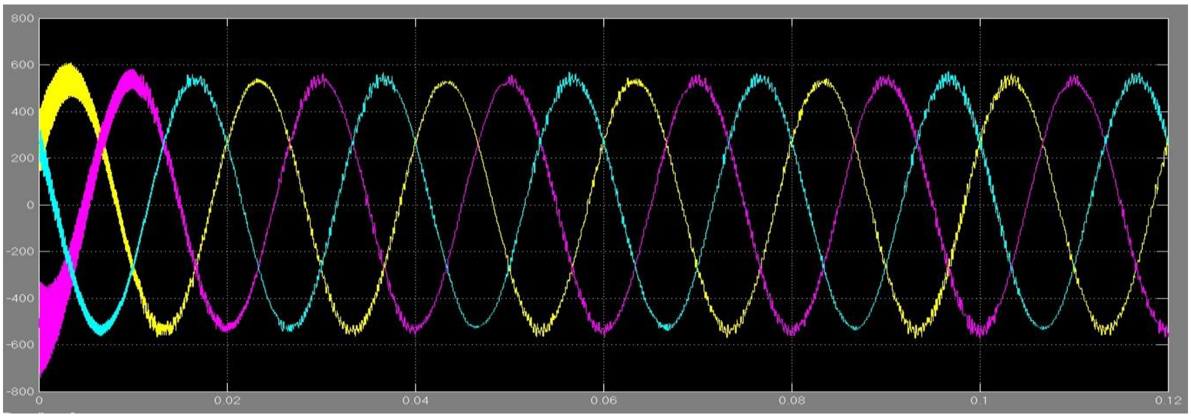
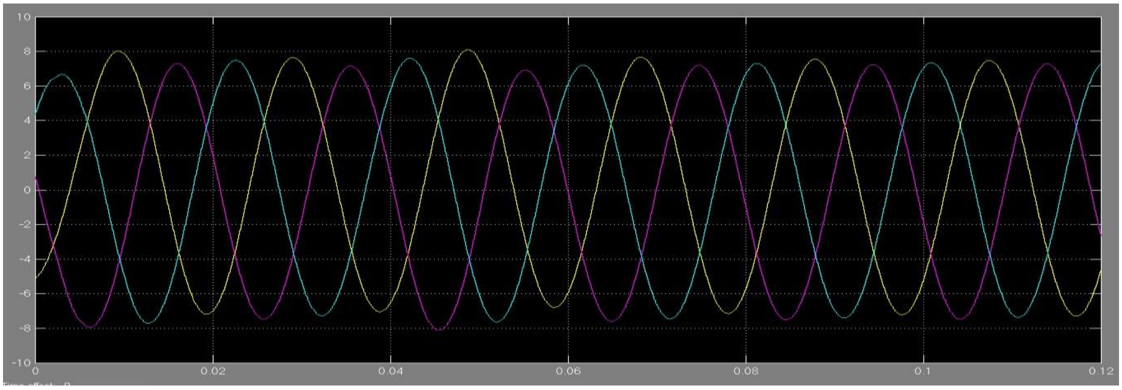
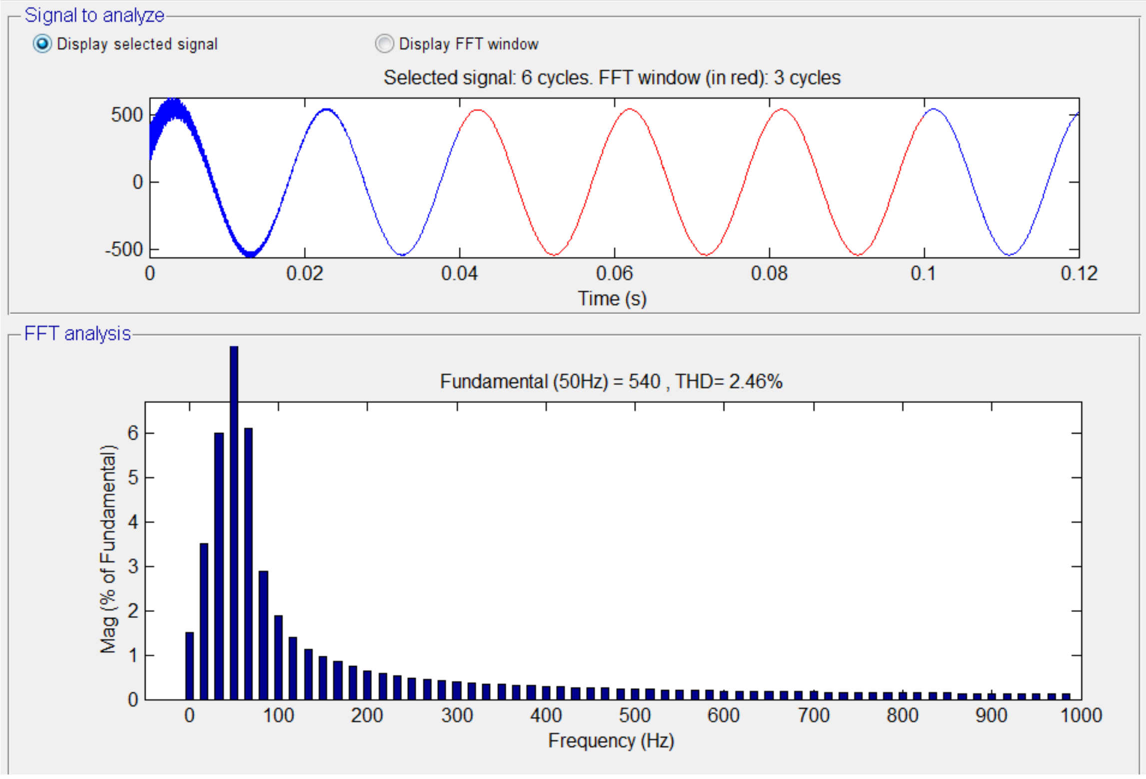


Voltage profile with existing controller



Current profile with existing controller



Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 6 cycles. FFT window (in red): 3 cycles

FFT analysis

Fundamental (50Hz) = 540 , THD= 2.46%

Total harmonic distortion existing controller

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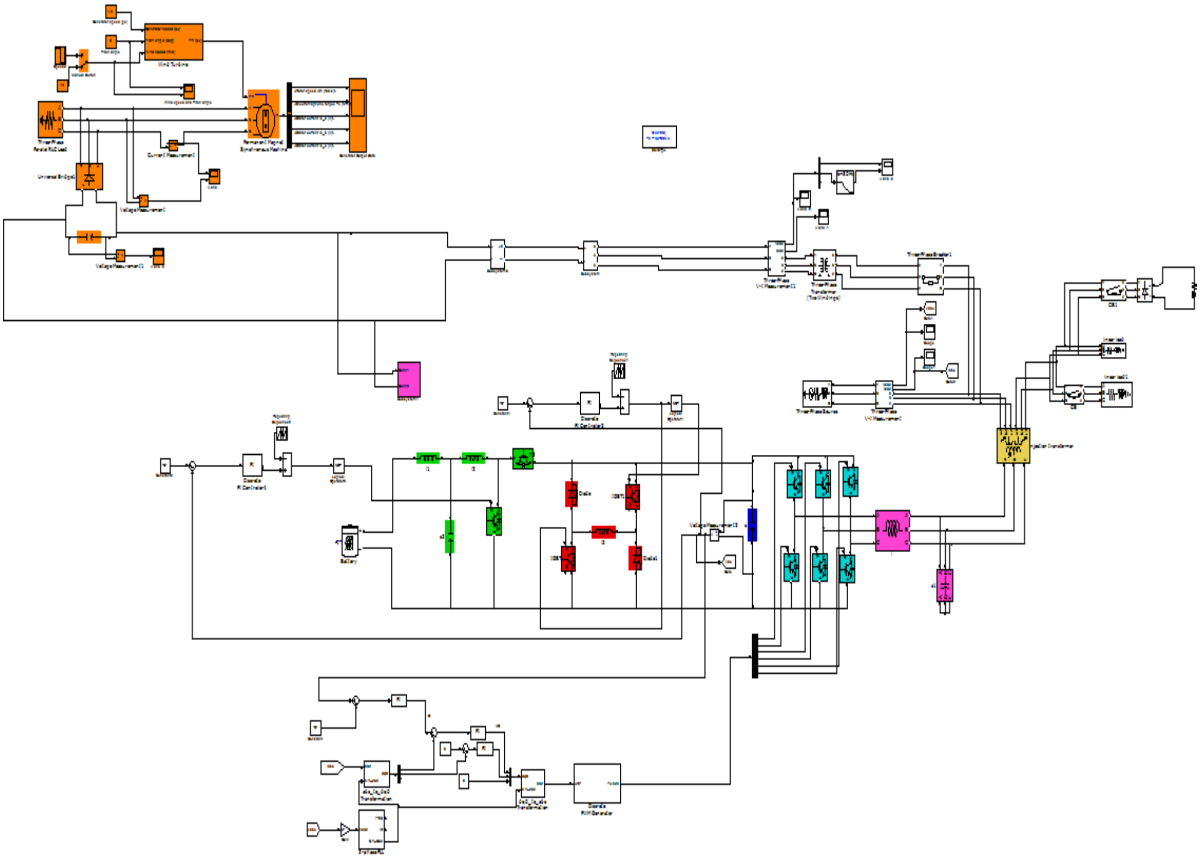
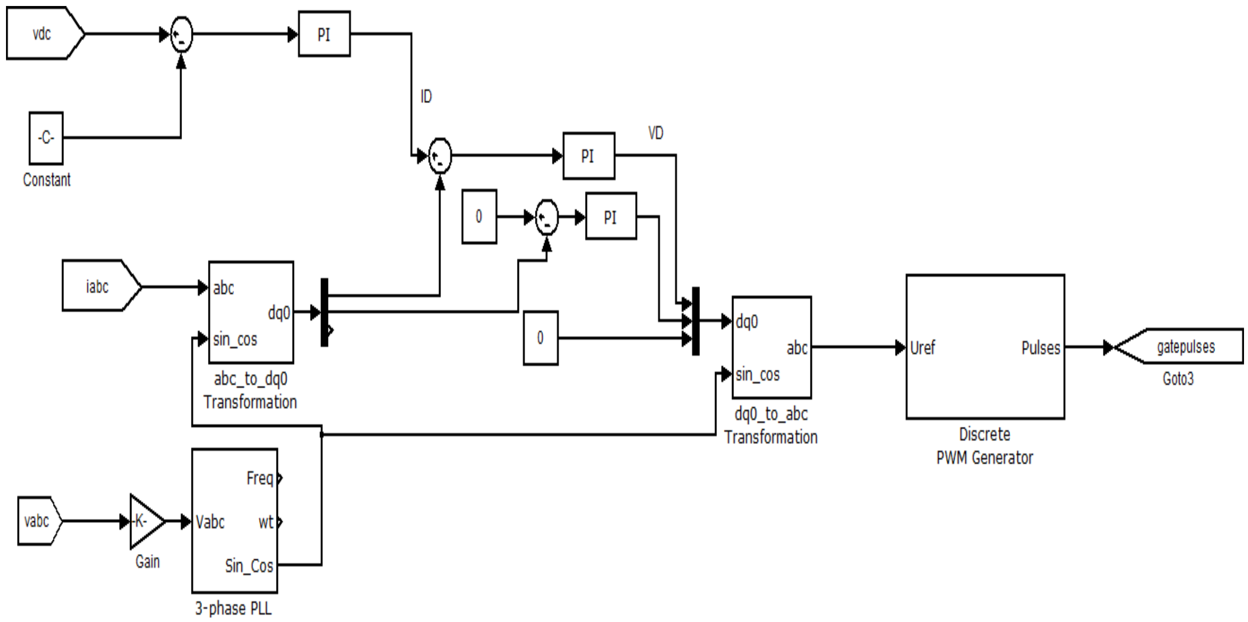


Total circuit with proposed controller



Simulink diagram for proposed controller

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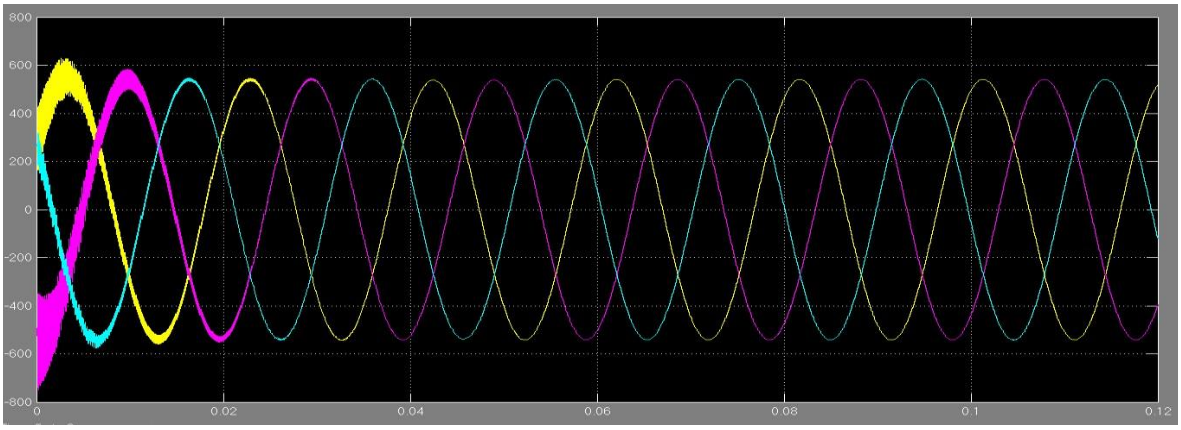
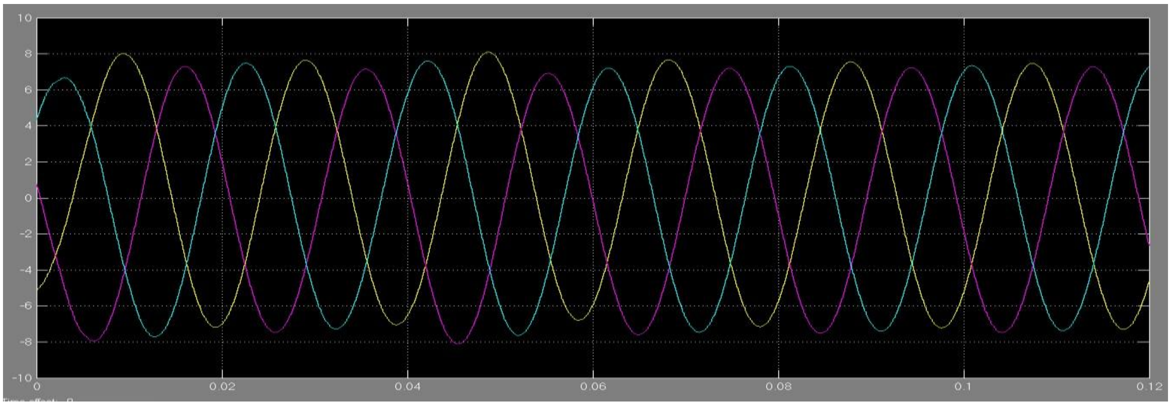
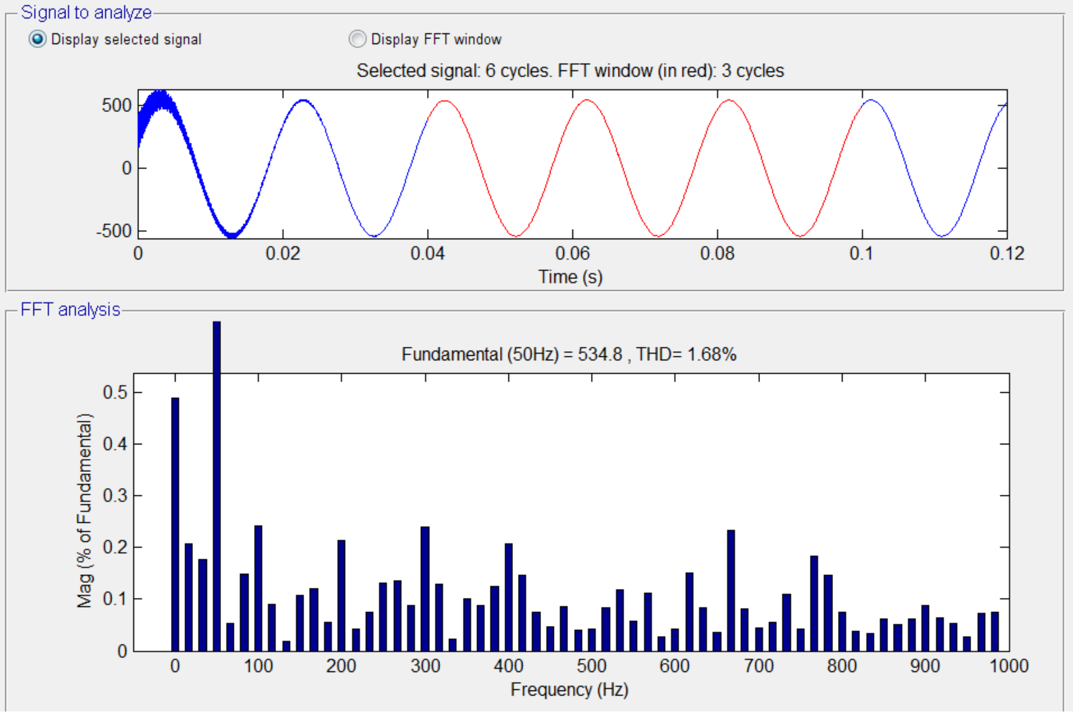


Voltage profile with proposed controller



Current profile with proposed controller



Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 6 cycles. FFT window (in red): 3 cycles

FFT analysis

Fundamental (50Hz) = 534.8 , THD= 1.68%

Total harmonic distortion proposed controller

6. Conclusion

The simulation results show that the proposed DVR is capable of repairing power quality interference. The DVR control block will detect the disturbance of voltage that occurs and the DVR functions as a compensator. phase injection transformer or three single-phase injection transformers with the main supply. The filtered VSI output voltage is boosted to the desired level with the injection transformer. The transformer also isolates the DVR circuit from the distribution system. The capacity of the voltage source inverter (VSI) and the values for the link filter connected between the injection transformer and the inverter play a crucial in the design of the DVR. In this

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research project, new Dynamic Voltage Restorer (DVR) topology has been proposed. The capacity of the voltage source inverter (VSI) and values of the link filter is small that will improve the compensation capabilities for voltage harmonic, swell and voltage sag mitigation under various fault conditions. The new RLC filter is able to eliminate the switching harmonics. The capacity of the dc supply voltage is reduced when the value of inductance is small. The new DVR topology has high efficiency and the ability to improve the quality of voltage. An outline architecture of the RLC filter parameters for the specific model has been presented. The new DVR with proposed controlled Dynamic Voltage Restorer topology is modeled and simulated using the MATLAB. The control scheme has good control dynamics with minimum transient current overshoot. The simulation results under transient performance are good.

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