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Optimized Controller Design for LCL-Type Grid-Connected Inverter for Improved Quality against Variations in Grid Impedance

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Abstract:

Feedback active damping grid inverters connected to the current- capacitor the LCL filters is a powerful method to suppress resonance. However, due to the diversity of the grid impedance, LCL filter coefficient of resonant frequency the capacitor-current-feedback design challenges, which vary in a wide range. Moreover, the resonance frequency of the sampling frequency (f s / 6) equal to one- sixth, digitally-controlled inverter connected to the grid is hardly consistent with the type of LCL- capacitor current- no matter how much is the feedback coefficient. In this paper, capacitor current- feedback coefficient of variation of the model to deal with a wide range of impedance is displayed in the grid.

First, gain margin requirements for the stability of the system in response to different resonant frequencies. By evaluating the effect of the edges of the grid impedance gain, you can get a proper capacitor current- feedback coefficient. This view is consistent with the activities, except for the multiplier will be held for all the resonance frequencies (f s / 6). Secondly, a resonance frequency (f s / 6) to improve system stability, the loop gain and phase lag compensation is proposed for.

1. INTRODUCTION

And the greenhouse gas emissions of increasing concern to the rising cost of traditional energy Resources, such as wind, solar, etc, renewable, distributed power generation systems have attracted more and more attention. Grid connected power generation unit is usually active and reactive power injected into the grid, which is controlled by a pulse width modulation (PWM) -controlled voltage source inverter is [1], [2]. Inverter output current balance, to reduce the need for output filters often. LCL- type filter switching frequencies, especially in the high-energy systems more affordable, due to the decrease in becoming better adapted to its harmonics.

Despite the known advantage, LCL filter Challenges to the stability of the whole system, control system, the open loop transfer function introduced in the echo. [3] LCL- inherent damping characteristic of the type of grid-connected inverter analyzed. The damping characteristic of the current control loop, which is embedded in the word grid side of the inverter-side current feedback control is found to be used for implementation. As for the damping characteristic of the current side of the grid inverter-side current loop is no dumping. [4] and [5], a detailed theoretical analysis

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of the ratio of the resonance frequency specific to soak up the sampling frequency of the LCL, at the margin of a digital single-loop controller, which shows the importance of the stability of the grid to control the current, the range is presented. In practice, the grid impedance will always exist, and [6] is the motivating factor - [9], potentially resulting in instability, in which case it is to reduce the proportion of a volatile range.

Therefore, control solutions are needed to stabilize the system. A straightforward way to add resistors in series or in parallel with the filter capacitors [2], [10], [11]. However, the circuit can lead to huge losses inevitably introduce additional resistors and filter [12] reduces the ability to hear high-frequency balance. An alternative solution, such as the filter capacitor voltage [13] In terms of control, the current control loop feedback to the principle that additional variable active damping (ed) to be used [14], the filter capacitor current [15] - [18], or on the side of the grid, such as the current [19], only the current feedback control, to. Due to its flexible and effective implementation of the AD And widely used. [23] - In this paper, the capacitor current feedback capacitor [20] In parallel with the variable resonance as the control that acts as a virtual resistor selection.

AD-current feedback capacitor LCL is used for resonance damping stability analysis of literature, despite the very low [27] - [30], very little research has investigated how to extend beyond the complex resonance frequency FS / 6 grid to improve robustness against the variation in impedance. A recent literature [20] (0 FS / 6) will be found to be an effective control of the area only received feedback capacitor is proportional to the current in amperes. The method of calculating the delay, the more the control of the reduction [20] proposed increase. However, the sample frequency is four times the frequency of exchange, and the immediate implementation of the capacitor increases the complexity of the current of the sample is different from the others.

Improved capacitor-current feedback AD In order to damp the resonance of all possible method to FS / 4 to increase the area of control is proposed in this paper. First, the system is described and presented in Section II mathematical model of discrete-time domain. Division III, the study of the system without any control system, and will be given a detailed stability analysis. The method is proposed to extend the control area. Moreover, in order to obtain an optimal damping performance, regulatory multiplier effect on the performance of the regulatory investigation. In Section VI, the experimental results of the proposed AD the method was performed to verify.

2. MODEL OF THE LCL-TYPE THREE-PHASE GRID-CONNECTED INVERTER

Fig. 1 is a three-phase grid-connected inverter type LCL- shows the topology of the circuit. L1 is inverter-side inductor. Inductor L2 is on the side of the grid. Filter capacitor Cf, and C on the DC side of the capacitor. Is equal to the parasitic resistance of the inductors and capacitors are relatively small, and therefore would be ignored here. vgk (K = a, b, c s) for the purpose of controlling and synchronizing i2k i1k and measured, it refers to the grid voltage (K = a, b, c's) side of the inverter and the grid-side current, respectively.

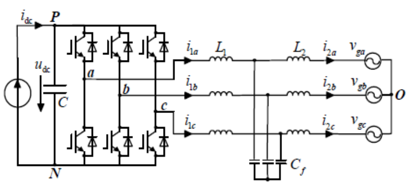

Fig. 1. Circuit topology of an *LCL*-type three-phase grid-connected inverter.

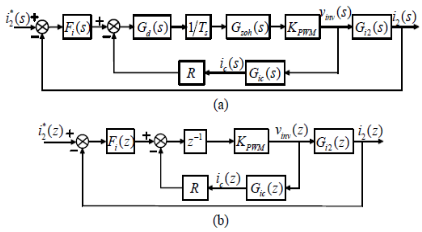

Fig. 2. Control models of the grid-side current with proportional capacitor-current-feedback AD. (a) In continuous-time domain. (b) In discrete-time domain.

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In general, the inner current loop control strategy is used in grid-connected inverters, grid controls, where the current of a cascaded loop control, and the external voltage loop controls the voltage on the DC side. In this paper, the stability of the inner current loop and voltage-controlled DC- side to be investigated here. Fig. 2 (a) fixed αβ- proportional to the capacitor-current feedback in the framework of current continues to be on the side of the grid with AD shows the time domain model. Phi (s) of the current controller. KPWM of the PWM inverter is profit, and KPWM space vector PWM (SVPWM) = 1. HR for AD is the coefficient of damping. 1 / Ts and Ts is a sampling period is the transfer function of the model. GD (s) cannot be neglected due to the fact that the computation time of the microprocessor, DSP, a sample collection is delayed for a long time.

AC L-C-L converter

The resonance properties of the zero-current switching converters (ZCS), zero voltage switching (ZVS), and the capacity is greater, will be small in size, and EMI problems. Resonant converters successfully in domestic and industrial applications [10, 11 and 12] and heating for the power factor, DC Power Supplies AC power supply will improve. There are two types of series and parallel RC Primary resonant converters. RC RC series connected capacitor series, because a good part of it is the lack of the ability to load and voltage transformer DC blocking. But, the load regulation is poor and output voltage control cannot be
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No-load condition. But, PRC provides better control of the no-load and load capacity of the poor and the lack of blocking DC transformer.

AC converter, the benefits of L-C-L

- Parallel operation is very simple and there is less circulating currents at light load conditions.
- AC power supply to improve the power factor.
- Peak-peak output current ripple is reduced.
- Resonance frequency can be increased and reducing the need for filters requirements.
- Total harmonic distortion (THD) reduced.
- There are no problems with EMI.

Furthermore, AC converter, the output of L-C-L echo planar transformers connected to the primary winding. The planar transformer connected to the current levels shown in the Fig. For that purpose alone, the top center of the primary side and secondary side of the series connected in parallel, which means that there are eight transformers.

MODELING AND CONTROL OF INVERTER INTERFACED DG UNITS

Each DG is mainly connected to the unit load or utility rectified for the DC type or generation unit (fuel cell, solar cell, wind turbine, micro turbine ...), storage devices, DC-DC converters, DC-AC inverter, filter, and power transformer in order to be to exchange. Each of the model and this is part of a dynamic system that may have an effect on the operation. But here it is the liberalization and consider whether there is sufficient storage units on the DC side may also be a source of constant DC. Only DC-AC inverter modeling and control of the investigated in this paper. LC output filter is a three-phase DC, AC inverter, as shown in the figure, a circuit model is described in more figure, the system is a DC voltage source (Vdc), a three-phase PWM inverter, there is an output filter (LF and parasite resistance FILTER- Rf considering c). Sometimes the output voltage of a transformer LF transformer inductance and hence can be used for the foundation.

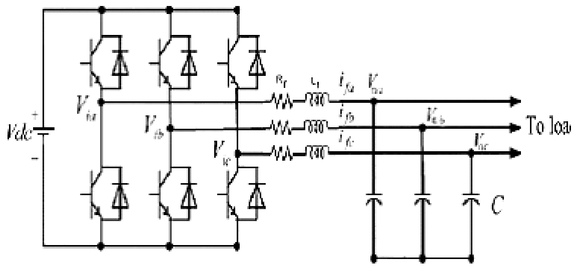

Figure: 2.6 PWM inverter diagram

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There are two ways for controlling an inverter in a distributed generation system,

2.5.1. PQ Inverter Control

DG unit system or load external to the grid, and the type of control when connected to an island received more generators. In this situation, preferences and inverter control variables set points respectively Qref, follow the grid, are injected into the active and reactive power. The set points can be selected by the customer or by a central controller. PQ of an inverter to control the inverter current active and reactive power is controlled in amplitude and phase to meet the desired set points QD reference frame is performed using the current control method.

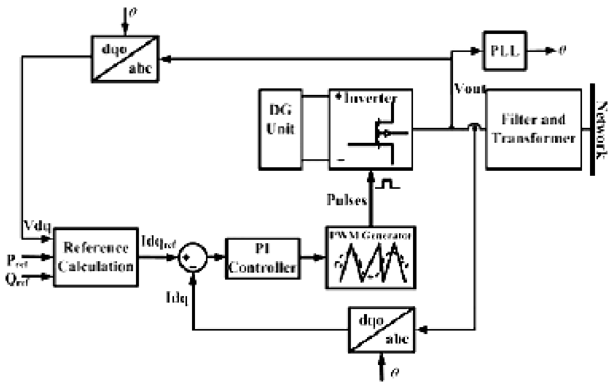

Fig: 2.7 PQ control scheme of inverter

The current controller, two proportional-integral (PI) regulators in accordance with the requirements of the stability of the system and the option to have a steady state error to zero. In this control scheme, the other part of it into a stand-alone network preferences, Qref sent to the reference value in such a way that it is possible to control the inverter. When the output voltage is regulated, Qref PQ mode is used to adjust the voltage feedback control scheme that is similar to PV.

2.5.2. VF Control option

When the system is in a stand-alone operation, the inverter controller has to work. In this case it is a reference to the fact that the value of the voltage at the bus bar, and the need to regulate the grid frequency. In order to measure the voltage regulators are working on a set of points. Moreover, the frequency of an oscillator PWM control of the inverter by the average charge by sorting signals. With a simple PI controller actual bus voltage reference value in order to get feedback can regulate the voltage on the bus. Figure outlines the control strategy. DG Energy and voltage control unit in this case it is obvious that in order to be stored in the device.

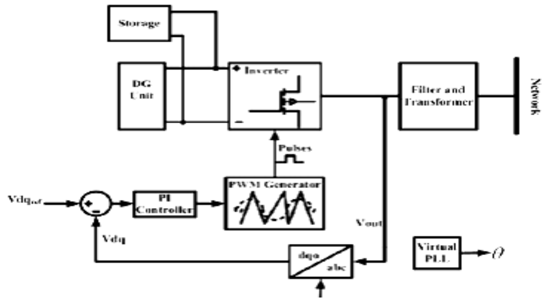

Fig: 2.8 V_f control scheme of inverter

2.6 .Summary:

This chapter summarizes the importance of distributed generation as the focus on the DG's are increasing day by day due to huge demand and power quality problems mainly at distribution side and also configuration of distribution energy systems modeling and control of inverter which are interfaced with DG units have also been explained.

HARMONICS

3.1 Introduction

Ideally, each customer is seated at a power supply voltage with a perfect sinusoidal signal to the show. However, for many reasons, such as utilities often hard to find the necessary conditions to preserve. Sinusoidal deviation waveform distortion of the voltage and current waveforms, are often described in terms of harmonic distortion. When it comes to FACTS devices, due to their switching outputs are presented in the balance of activities. The balance of this chapter and the harmonic distortion, the harmonic content of the device, which is performed for the measure. The balance also depends on the type and weight. Already presented in this chapter the different types of loads.

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3.2 Harmonics

Increased burdens on the industry, but is placing increasing harmonic distortion in the distribution networks. Perhaps the most widely-used linear device in the steel, paper, and textile industries, the exchange of static electricity is used in industrial applications. Other multipurpose motor speed control, and electro domestic appliances are electric transportation systems. The power used by utilities. As a result, the balance of the reactive impedance of the load is likely to coincide with a certain frequency, inductive reactance system forms a tank circuit.

3.3 Harmonics Content

In the presence of harmonics of the fundamental frequency wave measurement expressed as a percentage. The amplitude of each of the square root of the sum of the balance of the total harmonic content is expressed as expressed as a percentage of the infrastructure.

3.4 Harmonic Distortion

Other than the basic part of the balance of the output when the input sinusoidal wave characterized by the appearance of a nonlinear distortion of the wave form.

3.5 Total Harmonic Distortion

Total harmonic distortion (THD) is widely used to describe the transmission and distribution systems, power quality issues is an important indicator. It is assumed that the signal contribution of each individual harmonic component. THD is defined for voltage and current signals, respectively, the balance of this account only the fundamental frequency and RMS values of signals, including signals that define the meaning of the ratio of the total harmonic distortion. (THD)

THD mathematical electromagnetic interference (EMI) and AC motor drives is given by the pulsating torque. Any periodic waveform and harmonic superposition of a basic set of components shown. By applying the Fourier transformation, the components can be collected. The frequency of each harmonic component of a comprehensive multi-is its primary. There are many ways to refer to the size of the balance. The most widely used measure in North America is the total harmonics distortion (THD), which is defined in terms of the amplitudes of the harmonics, *Hn*, at frequency nw_0, 2 where $w_0$is frequency of the fundamental

$$THD_v = \frac{\sqrt{\sum_{h=2}^{\infty} {V_h}^2}}{V_1} \quad \text{………………..(3.1)}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} {I_h}^2}}{I_1} \quad \text{…………………(3.2)}$$

Load balancing can cause overheating of the transformer and motors, magnetic cores. On the other hand, the balance of non-sinusoidal voltage waveform, the power supply generated by the source. Voltage and current source, the balance of power losses, H1 indicate that the prevalence and n is an integer. The above equations (3.1) and (3.2), total harmonic distortion (THD) of voltage and currents refers to equations.

3.6 Linear and non-linear loads

The aim of the electric utility voltage supply of sinusoidal magnitude is consistent throughout the system. The goal is complicated by the fact that there are loads on the system can generate harmonic currents. The currents that can affect the performance of the system in negative ways, as a result of distorted voltages and currents. There is a growing number of harmonic loads, it's an installation of any additional or when making changes to their influence has become increasingly necessary. To appreciate the full effect of these matters, in relation to the balance of the power system to bear in mind that there are two important elements.

On the other hand, a non-linear load current wave shape of the voltage (Figure3.2 see) is not the same. Typical examples of non-linear loads, rectifiers (power supplies, UPS units, discharge lighting), adjustable speed motor drive, ferromagnetic equipment, DC motor drives and discharge devices. Where the voltage and current waveforms are sinusoidal AC electrical

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load. The current is proportional to the voltage at any time. Linear Loads are: the improvement of power factor capacitors, vulgar, lights, heaters, etc.

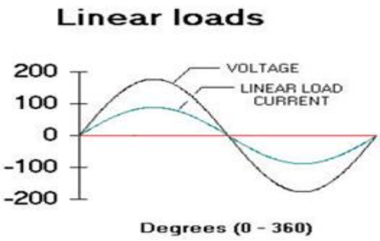

Fig.3.1.voltage and current wave form for linear

The current drawn by non-linear loads is not sinusoidal but it is periodic, meaning that the current wave looks the same from cycle to cycle. Periodic waveforms can be described mathematically as a series of sinusoidal waveforms that have been summed together. The only way to measure a voltage or current that contains harmonics.

Fig 3.2. Non linear wave form

An average meter is used, the most common type of fault it is important, in the current-voltage ratio is not applicable here, for AC load. Their definition, combined with loads of saturated ballast coils and between the first thyristor (SCR) controlled gas discharge lighting loads. The balance of the current waveform to generate non-linear nature of the load. Waveform. Under this distortion of the current wave form distortion of the conditions that can lead to voltage; The current is no longer proportional to the voltage waveform. Non Linear Loads are: computer, laser printers, Smps, rectifier, PLC, electronic ballast, refrigerator, TV, etc.

Each word is referred to as basic a harmonic series. Three times in the third harmonic frequency is 60 Hz or 180 Hz between. Waves of symmetrical balance is just odd and un-even and odd symmetrical waves have to have balance. The positive part of the wave to the negative part of the wave of the wave of a symmetrical one. A DC component of an un-symmetrical wave (or offset) or the load is such that the positive portion of the wave is different than the negative part. An example of a half-wave rectifier is a symmetrical wave. The most symmetrical power system elements. They are just the odd balance of product and DC offset.

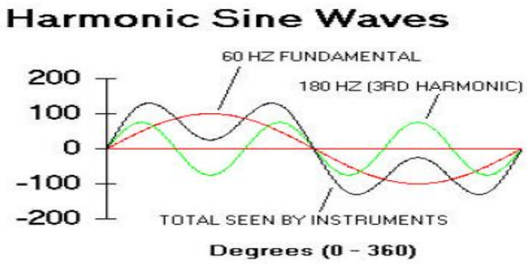

Fig.3.3 wave form with symmetrical harmonic components

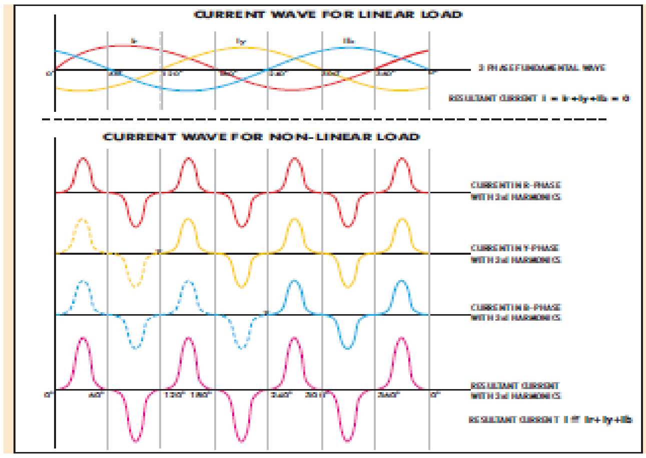

Fig 3.4 current wave for linear and non linear loads

DEFFERANCE BETWEEN LINEAR LOADS AND NON-LINEAR LOADS

S.NO.	LINEAR LOADS	S.NO.	NON-LINER LOADS
1.	Ohms law is applicable	1.	Ohms law is not applicable
2.	Crest Factor= $\frac{\text{I Peak}}{\text{I RMS}} = \sqrt{2} = 1.41$	2.	Crest Factor could be 3 to 4
3.	Power factor= $\frac{\text{Watts}}{\text{V X I}}$ =Cos Ø	3.	Power factor= $\frac{\text{Watts}}{\text{V X I}} \neq$ Cos Ø = Displacement factor X Distortion Factor
4.	Load current does not contain harmonics.	4.	Load current contains all ODD harmonics.
5.	Could be inductive or capactive.	5.	Can't be categorized. As leading or lagging Loads.
6.	Resistive, Inductive or capacitive	6.	Usually an equipment with Diode and Capacitor
7.	Zero neutral current if 1 Ph. loads are equally balanced on 3Ph. Mains (Vector sum of line current)	7.	Neutral current could be 2.7 times the line current even if 1Ph. loads are equally balanced on 3 Ph. Mains
8.	May not demand high inrush currents while starting.	8.	Essentially very high inrush current (20 time of I Normal) is drawn while starting for approx. One cycle.

Table 3.1 Difference between Linear Loads and Non Linear Loads

Each word is referred to as basic a harmonic series. Three times in the third harmonic frequency is 60 Hz or 180 Hz between. Waves of symmetrical balance is just odd and un-even and odd symmetrical waves have to have balance. The positive part of the wave to the

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negative part of the wave of the wave of a symmetrical one. A DC component of an un-symmetrical wave (or offset) or the load is such that the positive portion of the wave is different than the negative part. An example of a half-wave rectifier is a symmetrical wave. The most symmetrical power system elements. They are just the odd balance of product and DC offset.

The nominal voltage of the voltage and the output voltage distortion is added to the album. The size of the source impedance and output voltages of harmonic voltage distortion is based.

If the source impedance is low, then the voltage distortion is very low.

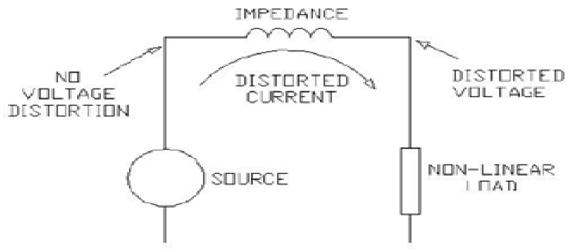

Fig.3.5 Distorted-current induced voltage distortion

Most of the non-linear load (harmonic currents increase) and / or runs a resonance condition (impedance increases system) can be obtained, the voltage increases dramatically. Power Systems are able to absorb a considerable amount of distortion without the problems of the current recommended levels of distortion produced by the facility may be the following.

Harmonic currents issues, they can produce many:

- Equipment Heat
- Equipment Malfunction
- Equipment failure
- Communications intervention
- Fuse and breaker miss-operation
- Process issues
- Conductor of heat

3.7 Effects on neutral Harmonics

A 4-wire three-phase system, in any case, the basic channels will always be neutral to zero. However, the other two phases, with each phase of the third harmonic is at the stage. As a result, the cancellation of themselves (basic as is the case), than they are additive and may lead to more serious problems neutral load. As an example, a three-phase system has a load of 100 amperes and the third harmonic of each phase consisting of 30%. Harmonic is three times the current flowing through the neutral. Fundamental frequency (50 150 Hz Hz systems) Ref 100, or 90 amperes to 30% at three times. The current wave diagram.

3.8 Conclusion:

This chapter briefly voltage that affects the balance and the current balance of the linear and nonlinear loads, total harmonic distortion, as we discussed .And also talked about the different types of harmonics. The first electric power systems, harmonic distortion, mainly transformers, industrial arc furnace, and large electric arc welders and other such devices, causing saturation.

PHASE LOCKED LOOP (PLL)

4.1. Introduction

The purpose of this application note for the design and phase-locked loops (PLL) integrated circuits configured with the necessary tools to analyze the electronic system that provides the designer. The majority of problems in the design of the PLL can be reached by using the Laplace transform technique. Therefore, a brief review of Laplace to establish a common reference included with the reader. Scope of this article is not practical in nature, because all the theoretical derivations hoping to simplify and clarify the content, have been omitted. A bibliography is included for those who desire to pursue the theoretical aspect.

4.2. Parameter Definition

Laplace complex domain F (s) in response to the time allowed to F (T) are transformed into a system of

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representation. This response includes both the transient and steady state solutions is twofold in nature. Therefore, considered and evaluated all operating conditions. Laplace transform linear parameters are only valid for the positive in real time; therefore, its use must be justified for both linear and non-linear functions, PLL had. The justification Gardner1, presented in chapter three phase locked Techniques

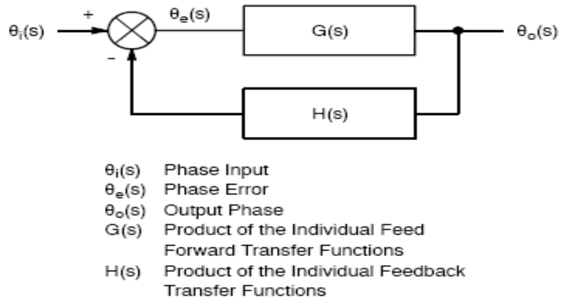

Fig 4.1. Feedback System

Using servo theory, the following relationships can be obtained.

$$\theta_e(s) = \frac{1}{1+G(s)H(s)} = \theta_i(s) \quad \textit{Eqn. 1}$$

$$\theta_o(s) = \frac{G(s)}{1+G(s)H(s)} = \theta_i(s) \quad \textit{Eqn. 2}$$

These parameters relate to the functions of a PLL as shown in Figure 4.2.

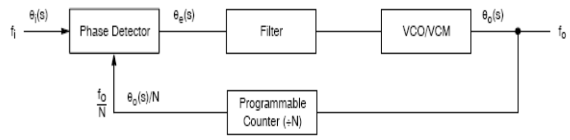

Fig.4.2 Phase Locked Loop

The phase detector produces a voltage proportional to the phase difference between the signals θi and θo/N. This voltage upon filtering is used as the control signal for the VCO/VCM (VCM. Voltage Controlled Multi-vibrator).

Since the VCO/VCM produces a frequency proportional to its input voltage, any time variant signal appearing on the control signal will frequency modulate the VCO/VCM. The output frequency is

$$f_o = Nfi \quad \textit{Eqn. 3}$$

During phase lock. The phase detector, filter, and VCO/VCM compose the feed forward path with the feedback path containing the programmable divider. Removal of the programmable counter produces unity gain in the feedback path (N = 1). As a result, the output frequency is then equal to that of the input. Various types and orders of loops can be constructed depending upon the configuration of the overall loop transfer function. Identification and examples of these loops are contained in the following two sections.

4.3. Type – Order

These two terms are used somewhat indiscriminately in published literature, and to date there has not been an established standard. However, the most common usage will be identified and used in this article.

The **type** of a system refers to the number of poles of the loop transfer function G(s) H(s) located at the origin.

For example:

Let

$$G(s)H(s) = \frac{10}{s(s+10)} \quad \textit{Eqn. 4}$$

This is a *type one* system since there is only one pole at the origin.

The **order** of a system refers to the highest degree of the polynomial expression

$$1+G(s)H(s) = 0 \triangleq C.E. \quad \textit{Eqn. 5}$$

Which is termed the **Characteristic Equation** (C.E.)? The roots of the characteristic equation become the closed loop poles of the overall transfer function.

For example:

$$G(s)H(s) = \frac{10}{s(s+10)} \quad \textit{Eqn. 6}$$

Then

$$1+G(s)H(s) = 1+\frac{10}{s(s+10)} = 0 \quad \textit{Eqn. 7}$$

Therefore

$$C.E. = s(s+10)+10 \quad \textit{Eqn. 8}$$

$$C.E. = s^2+10s+10 \quad \textit{Eqn. 9}$$

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Which is a *second order* polynomial. Thus, for the given G(s) H(s), we obtain a type 1 second order system.

4.4. Error Constants

The system can be applied to different inputs. Usually, at this stage, position, velocity, and acceleration are. Type 1, 2, and 3 systems, the response will be examined with different inputs. θe (s), the incoming reference signal θi (s) and feedback θo (s) / N is in the middle stage of the phase error detector. A systems analysis, θe (s), steady state and transient characteristics of the optimum and / or must be examined in order to determine if satisfactory. Action loop stability and transient response is covered in the next section. The final value of the steady state theory of the research associated with the use of Laplace can be simplified. Back to the time domain to the principle of changing the steady state of a system error θe (s) input θi (s) resulting from the permits to discover.

Simply stated

$$\lim_{t \to \infty}[\theta(t)] = \lim_{s \to 0}[s\theta_e(s)] \qquad \textit{Eqn. 10}$$

Where

$$\theta_e(s) = \frac{1}{1 + G(s)H(s)}\theta_i(s) \qquad \textit{Eqn. 11}$$

The input signal θi(s) is characterized as follows:

Step position:

$$\theta_i(t) = C_p \qquad t \geq 0 \qquad \textit{Eqn. 12}$$

or, in Laplace notation:

$$\theta_i(s) = \frac{C_p}{s} \qquad \textit{Eqn. 13}$$

WhereCp is the magnitude of the phase step in radians. This corresponds to shifting the phase of the incoming reference signal by Cp radians:

Step velocity:

$$\theta_i(t) = C_v t \qquad t \geq 0 \qquad \textit{Eqn. 14}$$

Or, in Laplace notation:

$$\theta_i(s) = \frac{C_v}{s^2} \qquad \textit{Eqn. 15}$$

Where, Cv is the magnitude of the rate of change of phase in radians per second. This corresponds to inputting a frequency that is different than the feedback portion of the VCO frequency. Thus, Cv is the frequency difference in radians per second seen at the phase detector.

Step acceleration:

$$\theta_i(t) = C_a t^2 \qquad t \geq 0 \qquad \textit{Eqn. 16}$$

or, in Laplace notation:

$$\theta_i(s) = \frac{2C_a}{s^3} \qquad \textit{Eqn. 17}$$

Ca is the magnitude of the frequency rate of change in radians per second per second. This is characterized by a time variant frequency input.

Typical loop G(s) H(s) transfer functions for types 1, 2, and 3 are:

Type 1

$$G(s)H(s) = \frac{K}{s(s+a)} \qquad \textit{Eqn. 18}$$

Type 2

$$G(s)H(s) = \frac{K(s+a)}{s^2} \qquad \textit{Eqn. 19}$$

Type 3

$$G(s)H(s) = \frac{K(s+a)(s+b)}{s^3} \qquad \textit{Eqn. 20}$$

The final value of the phase error for a type 1 system with a step phase input is found by using Equation 11 and Equation 13.

$$\theta_e(s) = \left(\frac{1}{1 + \frac{K}{s(s+a)}}\right)\left(\frac{C_p}{s}\right) = \frac{(s+a)C_p}{(s^2 + as + K)} \qquad \textit{Eqn. 21}$$

$$\theta_e(t = \infty) = \lim_{s \to 0}\left[s\left(\frac{s+a}{s^2 + as + K}\right)C_p\right] = 0 \qquad \textit{Eqn. 22}$$

A foot position (phase) when applied in such a way that, in the final value of the zero phase error. Similarly, type 1, 2, and 3 may be applied to the three inputs and the final value of the theory laid out by using the following table showing the relative steady phase errors.

	Type 1	Type 2	Type 3
Step Position	Zero	Zero	Zero
Step Velocity	Constant	Zero	Zero
Step Acceleration	Continually increasing	Constant	Zero

Table 4.1 steady state phase errors for various system types

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Zero at the two input signals to the phase error between the phase detector detects the phase coherence. At a static phase error phase detector determines the differential phase between the two input signals. The size of the loop gain and the input of the differential phase error is proportional to the size of the foot.

Recognizes that the time rate of change of the phase error is one that is constantly growing stage. This phase of the loop to an unlocked state.

Using Table 4.1, the system type is specified for the specific inputs. For example, the zero phase error, a reference frequency (speed step) If you want to keep track of it for a PLL, Type 2 requires a minimum.

4.5. Stability

S-plane root locus of the system to determine the position of the poles and zeroes of the technique is often used to visualize graphically the stability of the system. The closed loop poles (the roots of the characteristic equation) used for the loop gain will change the graph or plot. For consistency, all columns must have the left half of the aircraft. Poles and zeroes of the system is determined by the relationship of the degree of stability. Root locus structure can be determined using the following guidelines.

Rule 1 - the root locus G (s) H (s) (k = 0, starting at the poles of G (s) H (s) (K = ∞), K loop gain of zeroes at the end.

Rule 2 - What is the root loci of the number of branches the number of columns or the number of zeroes, is equal. A limited number of zeroes at infinity, the poles and G (s) H (s) is the difference between a limited numbers of zeroes.

Rule 3 - The root locus contour is bounded by asymptotes whose angular position is given by:

$$\frac{(2n+1)}{\#P-\#Z}\pi; \qquad n = 0, 1, 2... \qquad \text{Eqn. 23}$$

Where#P (#Z) is the number of poles (zeroes).

Rule 4 - The intersection of the asymptotes is positioned at the center of gravity C.G.:

$$C.G. = \frac{\Sigma P - \Sigma Z}{\#P - \#Z} \qquad \text{Eqn. 24}$$

WhereΣP (ΣZ) denotes the summation of the poles (zeroes).

Rule 5 - On a given section of the real axis, root loci may be found in the section only if the #P + #Z to the right is odd.

Rule 6 - Breakaway points from negative real axis is given by:

$$\frac{dK}{ds} = 0 \qquad \text{Eqn. 25}$$

Again, where K is the loop gain variable factored from the characteristic equation.

Example: The root locus for a typical loop transfer function is found as follows:

$$G(s)H(s) = \frac{K}{s(s+4)} \qquad \text{Eqn. 26}$$

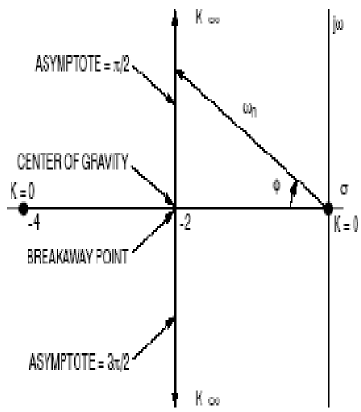

Fig.4.3. Type 1 Second Order Root Locus Contour

1 of this type of response to a step input of a second order system, is shown in Fig 4.3. This is a step in the curvature of the different damping ratios (phase) correspond to the input phase of the response. A step in the speed (frequency) frequency response of the input to the output as a function of time is identical to the set.

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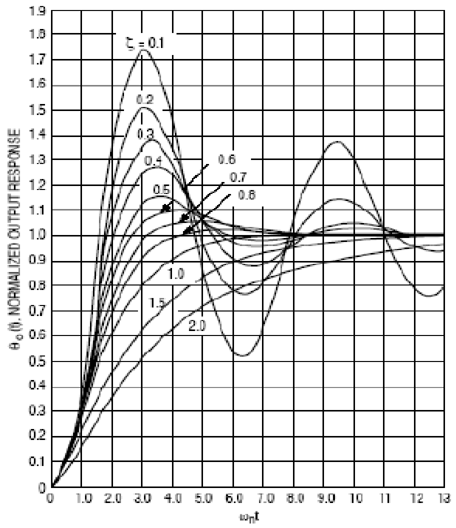
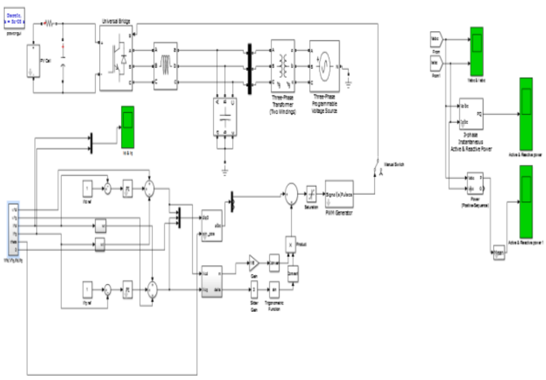
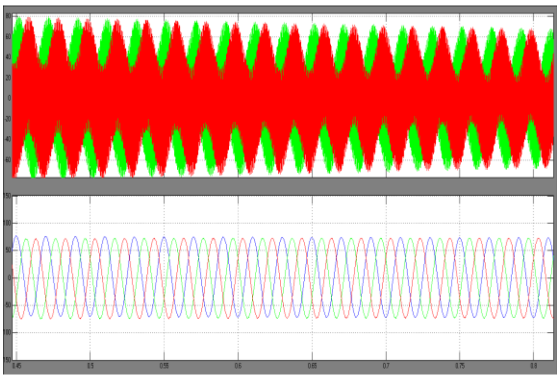


Fig.4.4. Type 1 Second

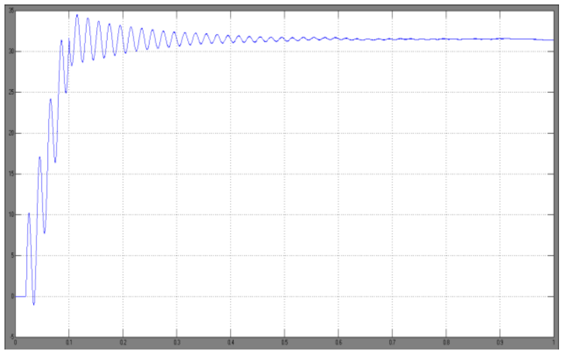
SIMULATION RESULTS



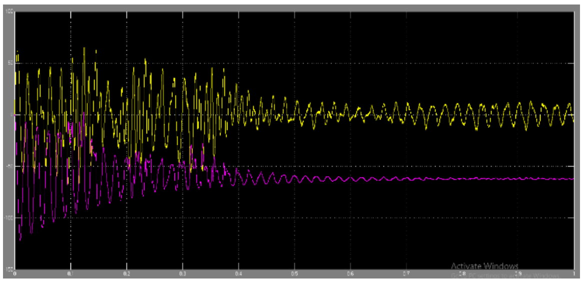
Simulation Circuit



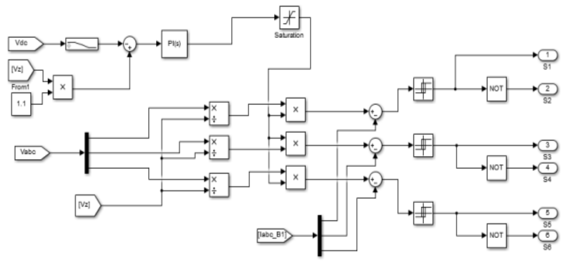
Grid Voltages and Currents with Conventional System



Active Power of Grid with Conventional System

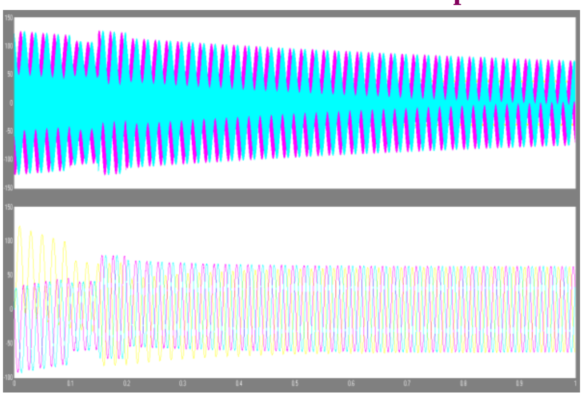


Results: Active and reactive power



Proposed Control Structure

Extension Results: Active and reactive power



Extension Results: a) Grid Voltages b) Grid Currents

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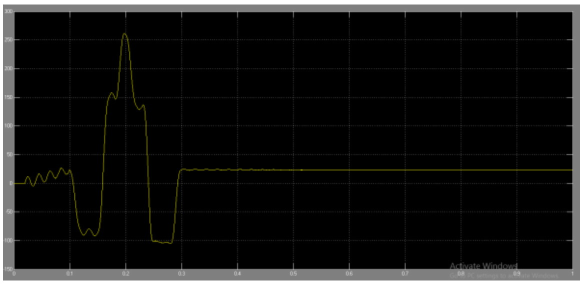

Extension: Active power of grid with conventional system

CONCLUSION

This paper presents a comprehensive investigation of the digitally controlledLCL-type grid-connected inverter with capacitor-current-feedback active damping. Based on the Nyquist stability criterion, the gain margin requirements for system stability are derived under various resonance frequencies. Through evaluating the effect of grid impedance on the gain margins, the optimal design of capacitor-current-feedback coefficient is proposed to deal with the wide range variation of grid impedance: for fr_0≥ fs/6, the optimal capacitor-current- feedback coefficient is the one which yields critically stable for fr= fs/6. With this feedback coefficient, stable operations are retained for all resonance frequencies except fs/6. And for fr_0<fs/6, the capacitor-current-feedback coefficient should be tuned under zero grid impedance. Further, in order to improve system stability for fr= fs/6, a lag element is incorporated into the current regulator to achieve phase-lag compensation for the loop gain.

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