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A Project Report on

"Design and performance analysis of LCL filter with active damping in grid connected inverter based systems"

Project Report submitted in partial fulfillment of the requirement for the award of the degree of

Bachelor of Engineering

In

Electrical & Electronics Engineering

Submitted by

SHALETTA ELIAS 1CR16EE073

SUPRITHA.S 1CR16EE084

Under the Guidance of

Dr.Hemachandra.G

Assistant Professor, Department of Electrical & Electronics Engineering

CMR Institute of Technology

CMR Institute of Technology, Bengaluru-560 037

Department of Electrical & Electronics Engineering

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CMR INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
AECS Layout, Bengaluru-560 037

Certificate

Certified that the project work entitled **"Design and performance analysis of LCL filter with active damping in grid connected inverter based systems"** carried out by Ms.Shaletta Elias, USN:1CR16EE073; Ms.Supritha.S, USN:1CR16EE084 are bonafied students of CMR Institute of Technology, Bengaluru, in partial fulfillment for the award of Bachelor of Engineering in Electrical & Electronics Engineering of the Visvesvaraya Technological University, Belgaum, during the year 2019-2020. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library.

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Dr. Hemachandra.G, Assistant Professor EEE Department CMRIT, Bengaluru	Dr. K. Chitra Professor & HOD EEE Department CMRIT, Bengaluru	Dr. Sanjay Jain Principal, CMRIT, Bengaluru

External Viva

Name of the Examiners   Signature & Date

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DECLARATION

We, [Ms. **Shaletta Elias (1CR16EE073), Supritha.S (1CR16EE084),** hereby declare that the report entitled **"Design and performance analysis of LCL filter with active damping in grid connected inverter based systems"** has been carried out by us under the guidance of **Dr. Hemachandra.G,** Assistant Professor, Department of Electrical & Electronics Engineering, CMR Institute of Technology, Bengaluru, in partial fulfillment of the requirement for the degree of **BACHELOR OF ENGINEERING in ELECTRICAL & ELECTRONICS ENGINEERING**, of Visveswaraya Technological University, Belagaum during the academic year 2019-20. The work done in this report is original and it has not been submitted for any other degree in any university.

Place: Bengaluru

Date:30/05/20

Shaletta Elias(1CR16EE073)

Supritha.S (1CR16EE084)

Abstract

The active damping of the LCL filter and the interjected grid current regulator are vital to control the LCL type grid connected inverters. The active damping suppresses the resonance peak caused by the LCL filter and the current regulator gives a very good quality of interjected grid current, all of this make it easy to stabilize the whole system. Based on the proportional integral (PI) and proportional resonant (PR) compensator together with the capacitor current feedback active damping, which are used because of their efficiency, effectiveness and simple methods of use, this report elaborates on a simple step by step controller design method for the LCL type grid connected inverter. The interactions between the current regulator and active damping are observed to complete satisfactory regions of the controller parameters for meeting the system specifications, the controller parameters can be easily obtained .Based on these satisfactory regions, it is more convenient to optimize the system performance. The insight of tuning the controller parameters from these satisfactory regions is also obtained. Simulation and experimental results verify the proposed step by step design method.

Acknowledgement

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LIST OF ABBREVIATIONS AND SYMBOLS

DPGS	Distributed power generation
PWM	Pulse width modulation
PM	Phase margin
GM	Gain margin
fc	Cross over frequency
PI	Proportional integral
PR	Proportional resonant
SO	Symmetrical optimum
VSI	Voltage source inverter
PLL	Phase locked loop
IGBT	Insulated gate bipolar transistor
MOS	Metal oxide semi conductor
PDM	Pulse duration modulation

CHAPTER 1

INTRODUCTION

1.1 BRIEF BACKGROUND OF THE RESEARCH

Distributed power generation system (DPGS) based on renewable energy, such as wind energy and solar energy, has been drawing more and more attentions, for its environmental friendly features. As the interface between the DPGS and power grid, grid-connected inverter plays an important role

in injecting high-quality power into the grid . An L filter or LCL filter is usually placed between the inverter and the grid to attenuate the switching frequency harmonics produced by the grid-connected inverter. Compared with L filter, LCL filter has better attenuation of the switching frequency harmonics, which usually yields lower volume and costs. However, the inherent resonance of the LCL filter requires proper damping methods to avoid the possible instability of the system. A direct way to damp the resonance of the LCL filter is introducing a passive resistor to be in series or parallel with the filter inductors or filter capacitor, which is called passive-damping method. Among which, adding a resistor in series with the filter capacitor has been widely adopted for its simplicity and relatively low power loss. However, it will weaken the switching harmonic attenuation ability . Adding a resistor in parallel with the filter capacitor will not impair the low-and high-frequency characteristics of the LCL filter, but the power loss brought by this resistor is too large to be accepted. In order to avoid the power loss resulted from the passive resistor, the concept of virtual resistor was proposed in place of the passive resistor, and the virtual resistor can be realized through proper control schemes.

Such methods are called active damping methods .

to a resistor in parallel with the filter capacitor. Besides, multiple state feedback can also be used to achieve LCL resonance damping, fast dynamic response, and reasonable robustness. Multiple-state feedback can be formalized within general theoretical frameworks of state-space control by properly specified pole placements , predictive control by proper deadbeat control laws and observers, or h-infinity control by solving one single optimization problem with specified control constraints, etc. In this paper, the capacitor– current-feedback active-damping is studied due to its effectiveness, simple implementation, and wide application. The capacitor–current feedback coefficient should be selected with great caution, since a too small one cannot damp the resonance effectively, and a too large one may result in system instability. Besides the system stability, high-quality injected power is another essential object in the control of the grid-connected inverter. Therefore, the design of the injected grid current regulator is very important. The primary goals of the injected grid current regulator are to minimize the steady-state error, achieve the best possible dynamic performance, minimize the harmonics in the

injected grid current, and so on . Generally, these system performance and stability margin can be specified by steady state error, crossover frequency (fc), phase margin (PM), and gain margin (GM) of the system. As a consequence, these terms will be frequently referred during the design of the current regulator and capacitor–current-feedback active-damping in this paper. In recent years, the design of current regulator and capacitor– current-feedback active-damping for LCL-type grid-connected inverter has been extensively discussed. The root-locus design method was used in, but the controller parameters were partially tuned according to the simulations and experiments. Both proportional-integral (PI) and proportional-resonant (PR) current regulators were investigated in , and pole-zero cancellation along with pole placement method was introduced.

current and injected grid current (only two state variables) could notprovide complete information of the three-order LCL filter to assign all the poles in the optimal positions. Therefore, parameter adjustments were necessary to obtain an optimized result. Symmetrical optimum (SO) was used to design the current regulator whereas the LCL filter was approximated to the L filter, and then the capacitor–current feedback coefficient could be determined easily using root-locus method . SO mainly focused on the PM, and did not pay enough attention to the specifications of steady-state error, fc , and GM. The active-damping method of capacitor–current feedback would deteriorate the PM to obtain sufficient GM, thus the controller parameters designed by SO may not be good enough, some further work was needed to obtain an optimized result. Besides, technical optimum was also widely used in designing controller parameters especially for second-order systems, but it was not convenient for designing the controller parameters of high-order systems such as LCL-type grid-connected inverters, and may lead to a poor disturbance rejection system. In fact, the frequency responses of the current regulator and capacitor– current-feedback active-damping interact with each other on the PM and GM of the system, thus the design and optimization of the current regulator and capacitor–current feedback coefficient are coupled. This paper analyzes the characteristics of the controller parameters of PI and PR regulators for the injected grid current closed-loop together with capacitor–current-feedback active damping in detail and proposes a simple step-by step design and optimized method of the current regulator and capacitor–current feedback coefficient for the LCL-type grid connected inverter. Performance improvements over state-space control, predictive control, h-infinity, etc., are beyond the scope of this paper and might be discussed in future work. By carefully dealing with the interaction between the current regulator and active-damping, the satisfactory regions of the controller parameters can be obtained with the given

specifications of the system performance and stability margin, which reveal the boundaries of the controller parameters and make the choices and optimizations of these parameters more convenient and explicit. This paper is organized as follows. The mathematical model of the LCL-type grid-connected inverter using averaged switch model (ASM) is derived. Based on the derived ASM, the relationship between the controller parameters and the system loop gain is analyzed preliminarily . A step-by-step design method of the PI injected grid current regulator and capacitor–current-feedback active-damping is presented in detail. The proposed method is extended to design the controllers based on PI current regulator plus grid voltage feed forward scheme, and PR current regulator, respectively. Design examples and simulation results of an LCL-type single-phase grid-connected inverter are presented. The experimental results are presented and the conclusion is given

1.2 CONTRIBUTION

PR compensator and PI compensator are widely used to control the injected grid current in single-phase grid-connected inverters. PR compensator can provide infinite gain at the selected resonant frequency to eliminate steady-state error or to suppress unwanted harmonics. Compared with PR compensator, PI compensator suppresses the dc injected grid current, but the zero steady-state error of the injected grid current can not be achieved . When the grid voltage feed-forward scheme is adopted, PI compensator is competent for the regulation of the injected grid current . Design method based on PI compensator is discussed for instance in this paper. Traditionally, root locus, dominate poles placement and bode diagram are introduced to design the injected grid current regulator together with the capacitor-current-feedback active-damping in the LCL-type grid-connected inverter. Massive trial-and-error procedures are usually necessary to get proper controller parameters with the aforementioned design methods. And there is little literature mentioning the effects and optimal choices of the current regulator

together with capacitor current feedback coefficient considering the interaction of the controller parameters.

1.3 OBJECTIVES OF THE THESIS

1. To design and analyse a robust controller for grid connected inverter using active damping method in LCL filter
3. To design a H- bridge inverter
4. To design a LCL filter
5. To study PI and PR controller characteristics
6. To obtain experimental waveforms of PI compensator
7. To obtain experimental waveforms of PR compensator

1.4 Layout of the Thesis

An improved single-phase inverter topology is presented to eliminate the common mode leakage current in the grid connected system. Active damping of the LCL filter and the injected grid current regulator are vital for the control of the LCL type grid connected inverters. The active damping suppresses the resonance peak caused by the LCL filter and the current regulator gives a very good quality of injected grid current, all of this makes it easy to stabilize the whole system. With the help of the proportional integral (PI) and proportional resonant (PR) compensator together with the capacitor current feedback active damping, which are used because of their efficiency, effectiveness and simple methods of use, a simple step by step controller design method for the LCL type grid connected inverter is proposed. The interactions between the current regulator and active damping are observed to complete satisfactory regions of the controller parameters for meeting the system specifications, the controller parameters can be easily obtained, based on these satisfactory regions it is more convenient to optimize the system performance. The insight of tuning the controller parameters from these satisfactory regions is also obtained. Simulation and experimental results verify the proposed step by step design method.

CHAPTER 2

LITERATURE REVIEW

2.1 Initial works

- By referring to the paper “Step-by-step Controller Design for LCL-Type Grid connected inverter with Capacitor-Current-Feedback Active-Damping” proposed by Chenlei Bao,Xinbo Ruan,Senior Member, Xuehua Wang,Weiwei Li,Donghua Pan and Kailei Weng,Members and student of IEEE,we found the work performed by them and studied the characteristics of LCL filter and Respective PI and PR compensated system.

- A Distributed Power Generation System (DPGS) based on renewable energy, such as wind energy and solar energy, has been attracting more interests due to its environmental friendly features. The interface between the DPGS and power grid, grid-connected inverter plays a vital role in injecting high-quality power into the grid.Furthermore,there was a need for improvisation of existing system. Hence, the system was modified by introducing an L filter or LC filter or LCL filter into the grid connected-inverter system.

- An L filter or LC filter or LCL filter is usually placed between the inverter and the grid to attenuate the switching frequency harmonics produced by the grid-connected inverter. Among L, LC and LCL filters LCL filter has better attenuation of the switching frequency harmonics, which usually yields lower volume and costs. Hence, LCL filter is used in the Grid connected-Inverter.

- However, the inherent resonance of the LCL filter requires to be damped and this lead to further improvisation of LCL-Filter based Grid Connected-Inverter.

2.2 Damping of LCL Filter based Grid Connected-Inverter.

- To eliminate the problem of inherent resonance of LCL Filter a suitable damping method among Passive Damping and Active Damping is to be adopted.
- Passive Damping is a direct way to damp the resonance of the LCL filter by introducing a passive resistor in series or parallel with the filter inductors or filter capacitor. However, by adding a resistor in series will weaken the switching harmonic attenuation and by adding a resistor in parallel, the power loss brought by the resistor will be too large to be accepted. Due to the drawbacks posed by passive damping an alternate method called Active Damping is used.
- Active Damping uses the concept of virtual resistor in place of the passive resistor, and the virtual resistor can be realized through proper control schemes. A current-feedback active-damping is studied due to its effectiveness, simple implementation, and wide application . The capacitor–current feedback coefficient should be selected with great caution, since a too small one cannot damp the resonance effectively, and a too large one may result in system instability.

R-Ld PARALLEL DAMPING:

The disadvantage of this approach is the fact that the high frequency attenuation of the filter is degraded, the high frequency asymptote of the filter transfer function is increased from 1/ω2 LC to 1/ω2 (L||Ld)C. Furthermore, since the need for damping limits the maximum value of Ld, significant loss of high frequency filter attenuation is unavoidable. A tradeoff occurs between damping and degradation of high frequency attenuation, limiting the degradation of high frequency attenuation to 6 dB leads to an optimum peak filter output impedance of 6 times the original characteristic impedance.

R-Ld SERIES DAMPING

Inductor Ld provides a dc bypass, to avoid significant power dissipation in R. To allow R to damp the filter, inductor Ld should have an impedance magnitude that is sufficiently greater that R at the filter resonant frequency. Although this circuit is theoretically equivalent to the Parallel damping R-Ld case, several differences are observed in practical design. Both inductors must carry the full dc current, and hence both have significant size. The filter high frequency attenuation is not affected by the choice of Ld, and the high-frequency asymptote is identical to that of the original undamped filter. The tradeoff in design of this filter does not involve high-frequency attenuation; rather, the issue is damping vs. bypass inductor size.

R-Cd PARALLEL DAMPING

Capacitor Cd blocks dc current, to avoid significant power dissipation in R. To allow R to damp the filter, capacitor Cd should have an impedance magnitude that is sufficiently less that R at the filter resonant frequency. The filter high frequency attenuation is not affected by the choice of Cd, and the high-frequency asymptote is identical to that of the original undamped filter. The trade off in design of this filter is damping vs blocking capacitor size.

2.3 Injected Grid Current Regulator

- To acquire high-quality injected power is another essential object in the control of the grid-connected inverter. Therefore, the design of the injected grid current regulator is very important. Therefore the control technique employed here is the Injected grid current regulator.
- The primary goals of the injected grid current regulator are to minimize the steady-state error, achieve the best possible dynamic performance, minimize the harmonics in the injected grid current.
- The control parameters and behavior of both Proportional-Integral (PI) and Proportional-Resonant (PR) controllers are studied.
- In recent years, the design of current regulator and capacitor–current-feedback active-damping for LCL-type grid-connected inverter has attracted great interests. Hence, by carefully dealing with the interaction between the current regulator and active-damping, the satisfactory regions of the controller parameters can be obtained with the given specifications of the system performance and stability margin.

CHAPTER 3

Proposed Model With Theoretical Background

3.1 Proposed Model

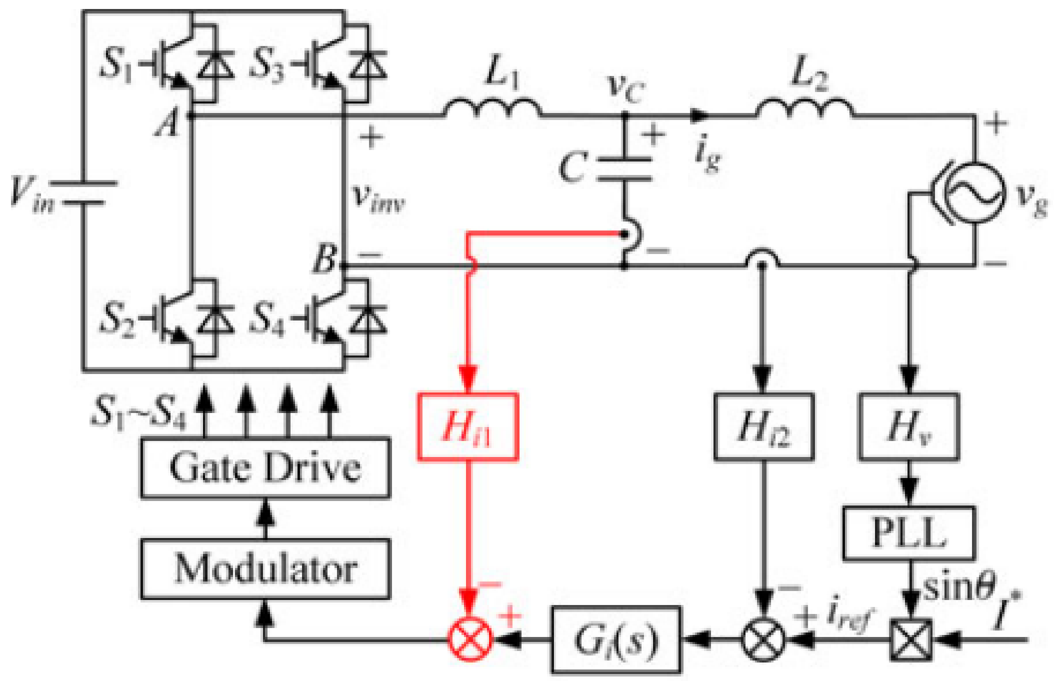


Figure 01-Schematic diagram of LCL-type single-phase grid-connected inverter Based on capacitor–current-feedback active-damping.

Figure.01 shows the topology and the control scheme of an LCL-type single-phase grid-connected inverter.

- A typical single phase voltage-source inverter (VSI) is connected to the grid through an LCL filter with one inductor L_1 placed on the inverter side and the other inductor L_2 placed on the grid side of the system.
- The equivalent series resistors of L_1, C and L_2 are relatively small and ignored here.

- A phase-locked loop (PLL) is used to synchronize the reference of the injected grid current i_{ref} with the grid voltage V_g.
- H_v and H_{i2} are the gains of the grid voltage and injected grid current sensors, respectively. $G_i(s)$ is the injected grid current regulator.
- The feedback of the filter capacitor current is adopted to damp the resonance peak caused by the LCL filter, and H_{i1} is the feedback coefficient.
- Unipolar Sinusoidal Pulse Width Modulation (SPWM) is used for the grid-connected inverter. An outer-loop power control is usually introduced to automatically adjust the current reference amplitude I∗.
- A gate drive with necessary Modulation circuit is used.

3.1.1 Gate drive

A gate drive circuit is an integrated circuit that accepts a low power input from a controller IC and produces the appropriate voltage and current for a power semiconductor switch. Here IGBTs are used as a power semiconductor switch.

Gate drive circuits for IGBTs have evolved from simple choice of the resistance in the gate drive circuit to more sophisticated dynamic variation of the gate drive resistance during the switching event. These improved methods allow reduction of collector current and voltage overshoots during the IGBT switching events while allowing minimizing the switching power loss. This allows improving the efficiency of the IGBT-based inverter circuits.

3.1.2 IGBT-Insulated Gate Bipolar Transistor

An insulated-gate bipolar transistor (IGBT) is a three-terminal power semiconductor device primarily used as an electronic switch. It is widely used due to it’s high efficiency and fast switching. It consists of four alternating layers (P-N-P-N) that are controlled by a metal–oxide–semiconductor (MOS) gate structure without regenerative action. Since it is designed to turn on and off rapidly, the IGBT can synthesize complex waveforms with pulse-width modulation and low-pass filters, so it is also used in switching amplifiers in sound systems and industrial control systems.

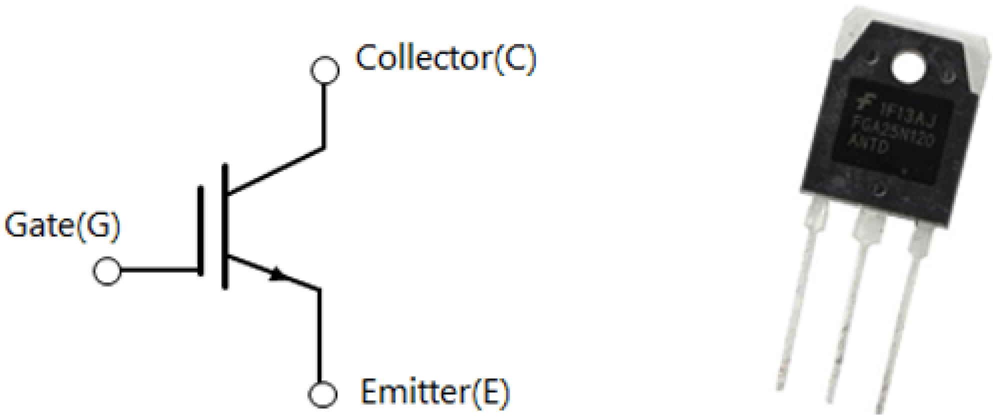


Figure2: IGBT symbol

Internal Structure of IGBT

IGBT can be constructed with the equivalent circuit that consists of two transistors and MOSFET, as the IGBT posses the output of the below combination of the PNP transistor, NPN transistor, and MOSFET. IGBT combines the low saturation voltage of a transistor with the high input impedance and switching speed of a MOSFET. The outcome obtained from this combination delivers the output switching and conduction characteristics of a bipolar transistor, but the voltage is controlled like a MOSFET.

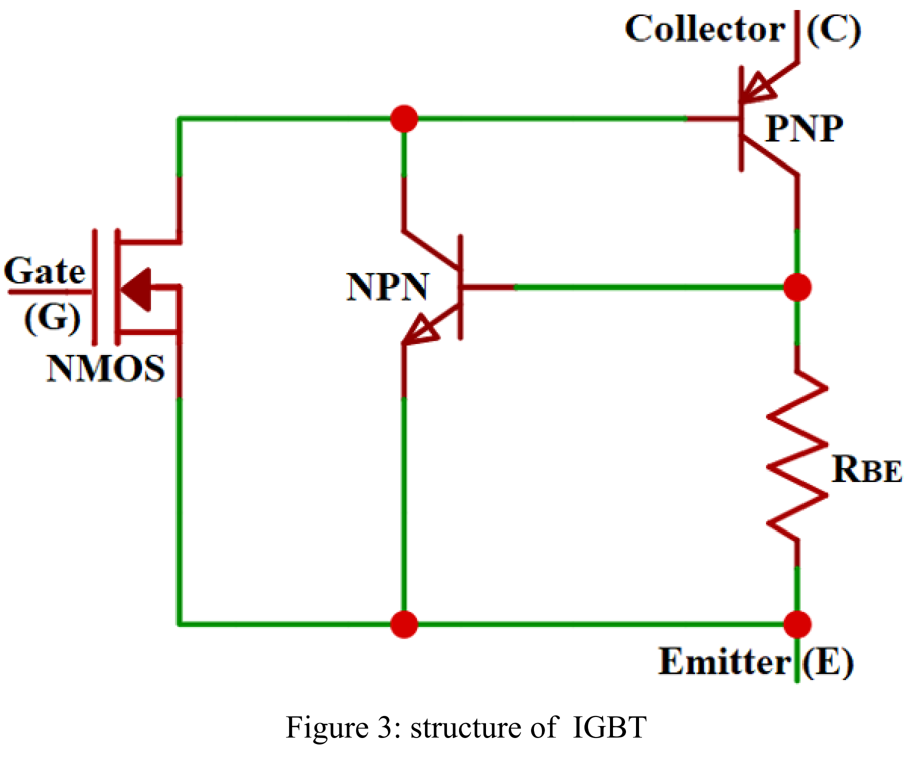
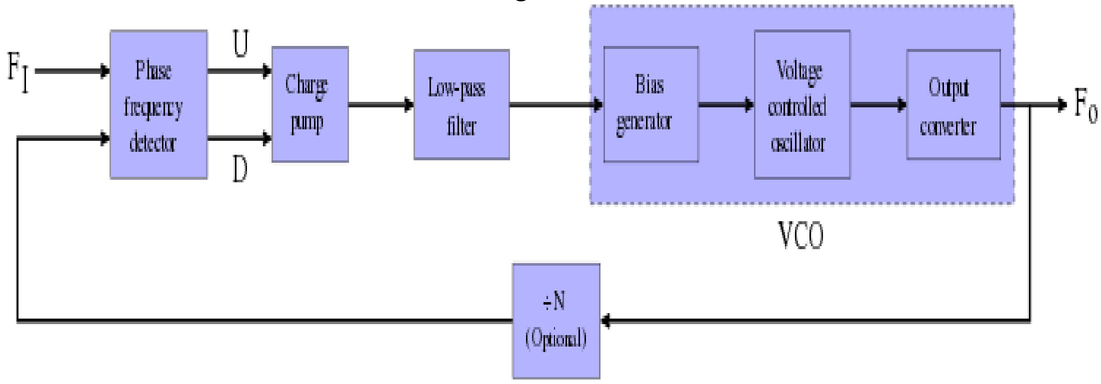


Figure 3: structure of IGBT

3.1.3 Phase Locked Loop

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal.

Figure 4:PLL



Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same. Consequently, in addition to synchronizing signals, a phase-locked loop can track an input frequency, or it can generate a frequency that is a multiple of the input frequency.

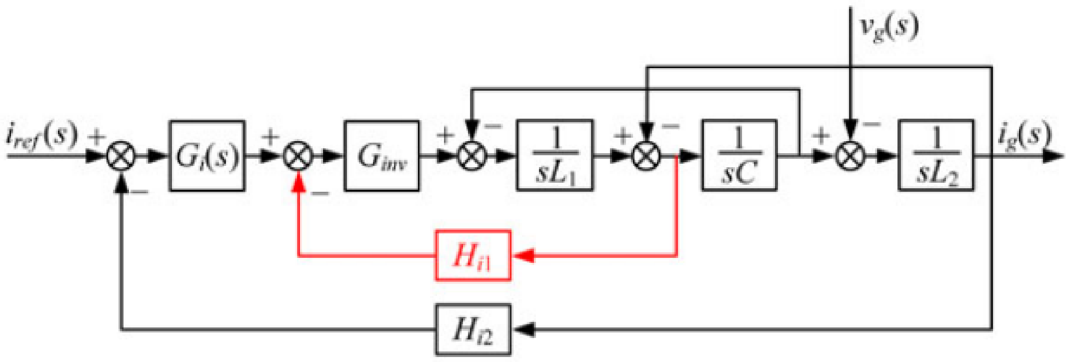
Here, the Phase Locked Loop is used to synchronize the reference of the injected grid current i_{ref} with the grid voltage V_g.

3.1.4 Pulse Width Modulation

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch.

Unipolar Sinusoidal Pulse Width Modulation is used here for the Grid-connected Inverter.

3.2 Mathematical Model



Mathematical Model of LCL Grid-connected Inverter.

Figure 5: shows the Mathematical Model of the LCL-type grid-connected inverter.

3.2.1 Grid parameters

The resonance frequency of the LCL filter f_r is derived as :

$$f_r = \frac{1}{2\pi}\sqrt{\frac{L_1+L_2}{L_1L_2C}} \text{ .... } equation(3.1)$$

G_{inv} is the transfer function of the inverter bridge. The switching frequency of VSI is assumed to be sufficiently high, thus

$$G_{inv} = \frac{V_{in}}{V_{tri}} \text{ ......} equation(3.2)$$

Where, V_{in} is the Dc-link voltage and V_{tri} is the amplitude of the triangular carrier wave.

The loop gain of the system is expressed as:

$$T_s = \frac{H_{i2}G_{inv}G_i(s)}{s^3L_1L_2C+s^2L_2CH_{i1}G_{inv}+s(L_1+L_2)} \text{ .... } equation(3.3)$$

The Transfer Function of the system is expressed as:

$$G_g(s) = \frac{s^2L_1C+sCG_{inv}H_{inv}+1}{s^3L_1L_2C+s^2L_2CH_{i1}G_{inv}+s(L_1+L_2)} \text{ .... } equation(3.4)$$

The crossover frequency f_c is typically restricted lower than f_s considering the effect of attenuating high-frequency noise, where f_s is the switching frequency of the inverter, and the resonance frequency of the LCL filter f_r is usually constrained between 1/4 and 1/2 of

the equivalent switching frequency of the inverter, for unipolar SPWM is adopted, the equivalent switching frequency is $2f_s$. Therefore, for a properly designed LCL-type grid-connected inverter, the crossover frequency f_c will be lower than the resonance frequency f_r thus the influence of the filter capacitor can be ignored when calculating the magnitude

Of the loop gain at f_c and the frequencies lower than f_c, therefore the magnitude of T_s Can be approximated as:

$$T_s \approx \frac{H_{i2}G_{inv}G_i(s)}{s\left(L_{1+}L_2\right)} \quad \text{.........}equation\ (3.5)$$

3.3 PI controller Parameters

PI compensator is adopted as the injected grid current regulator and the transfer function of $G_i(s)$ is given by:

$$G_i(s) = K_p + \frac{K_i}{s} \quad \text{........} \quad equation(3.6)$$

Where the proportional constant K_p is given as:

$$K_p = \frac{2\pi f_c(L_1+L_2)}{H_{i2}G_{inv}} \quad \text{........} \quad equation(3.7)$$

The magnitude of the loop gain at f_o is T_{fo} and is expressed as:

$$T_{fo} = 20log_{10}\left|T(j2\pi f_o)\right| \approx 20log_{10}\frac{V_g}{2\pi f_o\left(L_1+L_2\right)I_{g2}} \quad \text{......}equation(3.8)$$

Where the unit of T_{fo} is dB .

According to equations (3.5) and (3.6), T_{fo} is expressed as:

$$T_{fo} = 20log_{10}\left|T(j2\pi f_o)\right| \approx 20log_{10}\frac{H_{i2}G_{inv}\left(K_p+\frac{K_i}{j2\pi f_o}\right)}{j2\pi f_o\left(L_1+L_2\right)} \quad \text{.....} \quad equation(3.9)$$

On substituting equation(3.7) in equation(3.9) we get the Integral constant K_i

$$K_i = \frac{4\pi^2 f_o (L_1 + L_2)}{H_{i2} G_{inv}} \sqrt{(10^{\frac{T_{fo}}{20}} f_o)^2 - f_c^2} \quad ......equation(3.10)$$

According to equation (3.3) the PM of the system can be expressed as:

$$PM = arctan\frac{2\pi L_1 (f_r^2 - f_c^2)}{H_{i1} G_{inv}} - arctan\frac{K_i}{2\pi f_c K_p} \quad .... equation(3.11)$$

Equation (3.11) can be written as:

$$K_i = 2\pi f_c K_p \frac{2\pi L_1 \left(f_r^2 - f_c^2\right) - G_{inv} f_c H_{i1} tanPM}{2\pi L_1 \left(f_r^2 - f_c^2\right) \tan tan\, PM + G_{inv} f_c H_{i1}} \quad .... equation(3.12)$$

Substituting equations (3.7) and (3.10) into (3.12) leads to:

$$H_{i1} = \frac{2\pi L_1 (f_r^2 - f_c^2)(f_c^2 - f_o \sqrt{(10^{\frac{T_{fo}}{20}} f_o)^2 - f_c^2} \tan tan\, PM}{G_{inv} f_c (f_c^2 \tan tan\, PM + f_o \sqrt{(10^{\frac{T_{fo}}{20}} f_o)^2 - f_c^2})} \quad .... equation(3.13)$$

The GM of the system is given as:

$$GM = - 20log_{10}\left|T\left(j2\pi f_r\right)\right| \quad .... equation(3.14)$$

Where the unit of GM is dB.

The magnitude of the loop gain T_s shown in (3.5) is not accurate at f_r. Therefore, substituting (3.3) the expression of the loop gain without approximation and (3.7) into (3.14) yields

$$H_{i1} = 10^{\frac{GM}{20}} \cdot \frac{2\pi f_c L_1}{G_{inv}} \quad ......equation(3.15)$$

3.3.1 PR Controller Parameters

A practical transfer function of PR compensator is given by:

$$G_i(s) = K_p + \frac{2K_r \omega_i s}{s^2 + 2\omega_i s + \omega_o^2} \quad .... equation(3.16)$$

Where, $\omega_o = 2\pi f_o$ and ω_i is the bandwidth of the resonant part concerning −3 dB cutoff frequency to reduce the sensitivity of the compensator to variations at the fundamental frequency.

The Resonant Constant of PR controller is derived by:

Considering equations(3.5),(3.7) and (3.16) K_r can be derived as follows:

$$K_r = \left(\sqrt{210}^{\frac{T_{fo}}{20}} f_o - f_c\right)\frac{2\pi(L_1+L_2)}{H_{i2}G_{inv}} \text{.....} equation(3.17)$$

According to equations(3.11) and (3.16), the PM can be written as:

$$PM = arctan\frac{2\pi L_1(f_r^2-f_c^2)}{H_{i1}G_{inv}f_c} - arctan\frac{K_r\omega_i}{\pi f_c K_p} \text{.........} equation(3.18)$$

According to equation(3.18), K_r can be expressed as:

$$K_r = \frac{\pi f_c K_p}{\omega_i}\frac{2\pi L_1\left(f_r^2-f_c^2\right)-H_{i1}G_{inv}f_c tanPM}{H_{i1}G_{inv}f_c+\pi L_1\left(f_r^2-f_c^2\right)\tan tan\, PM} \text{.....} equation(3.19)$$

Substituting equations(3.7) and (3.17) into (3.19) leads to expression of H_{i1} , given by:

$$H_{i1} = \frac{2\pi L_1\left(f_r^2-f_c^2\right)}{G_{inv}f_c}\frac{\pi f_c^2-\left(\sqrt{210}^{\frac{T_{fo}}{20}} f_o-f_c\right)\omega_i\tan tan\, PM}{\left(\sqrt{210}^{\frac{T_{fo}}{20}} f_o-f_c\right)\omega_i+\pi f_c^2\tan tan\, PM} \text{.......} equation(3.20)$$

Furthermore, with the regions of H_{i1} and K_i obtained from the aforementioned design procedure, once f_c is determined, the controller parameters can be further optimized according to different requirements:

- a larger K_i can be chosen to get a smaller steady-state error
- a larger H_{i1} can be chosen for a larger gain margin
- a smaller K_i and H_{i1} can be chosen for a larger phase margin.

CHAPTER 4
DESIGN PROCESS

The design process for LCL type Grid-Connected Inverter with Capacitor-Current Feedback Active damping comprises of the following steps:

- Design of Inverter and Grid Parameters
- Design of LCL filter Parameters.
- Design of PI and PR compensator Parameters.

4.1 Design of Inverter and Grid parameters

The specifications required for calculation of Grid parameters are

$V_{in} = 360$ V

$V_{tri} = 3.05$ V

$V_g = 220$ V

$P_o = 6$ KW

- The Transfer Function of Inverter given by G_{inv} is obtained

$$G_{inv} = \frac{V_{in}}{V_{tri}}$$

$$G_{inv} = \frac{360}{3.05} = 118.0327$$

$G_{inv} = 118.0327$

- The Grid current I_1 is obtained by:

$$I_1 = \frac{P_o}{V_g}$$

$$I_1 = \frac{6000}{220} = 27.27 \text{ A}$$

$$I_1 = 27.27 \text{ A}$$

4.2 Design of LCL Parameters

The specifications required for the calculations of LCL filter Parameters are as follows:

- The resonance frequency is in the range of 1/4 and 1/2 of the equivalent switching frequency
- and the switching harmonics are less than 0.3% of the fundamental current at rated power
- the reactive power is less than 5% of the rated power
- the converter-side current ripple is less than 20% of the rms value of the injected grid current at rated power

Therefore;

Switching Frequency f_s =10 KHz

Fundamental/System Frequency =50 Hz

DC-Link voltage V_{dc}= 360 V

λ_{iL1}= The ratio of RMS values of current of the inductor to the capacitor current =30%

λ_{vL1} = The ratio of RMS values of voltages of the inductor to the capacitor voltage=5%

δ_c = The ratio of reactive power to the rated output active power = 2%

ω_o= Angular system frequency = $2\pi f_o$=314.159 rad/sec

4.2.1 Calculation of Inductor parameters

Inductor on Inverter side L_1:

- $L_{1min} = \frac{V_{dc}}{8\lambda_{cL1} I_1 f_s}$

$$= \frac{360*220}{8*0.3*6000*10,000} = 0.00055 \text{ H}$$

$$L_{1min} = 0.55\text{mH} \cong 550\mu\text{H}$$

- $L_{1max} = \frac{\lambda_{vL1} V_g}{2\pi f I_1}$

$= \frac{5*220*220}{100*2\pi*50*6000}$ =1.28mH ≅1283. 1μH

L_{1max}= 1283. 1μH

- Since $L_{1min} \leq L_1 \leq L_{1max}$

  550μH≤L_1≤1283.1μH

  Therefore, L_1 =600μH

Inductor on Grid side L_2:

- $L_{2min} = 0.2 * L_{1min}$

  = 0.2*550 μH

  = 110 μH

  L_{2min}=110 μH

- $L_{2max} = 0.2 * L_{1max}$

  = 0.2*1283.1 μH

  = 256.62 μH

  L_{2max}=256.62 μH

- Since $L_{2min} \leq L_2 \leq L_{2max}$

  110 μH≤L_2 ≤256.62 μH

  Therefore, L_2=150 μH

4.2.2 Calculation of Capacitor Parameters

$$C = \delta_c \frac{P_o}{w_o V_g^2}$$

$$= \frac{2*6000}{100*2\pi*50*220*220}$$

$$= 7.8919\mu F \approx 8\mu F$$

Since C lies in the limit 8μF <C<12μF

C = 10μF

4.3 Design of PI Compensator

The specifications of the loop gain are given as follows:

- PM ≥ 45◦ and GM ≥ 5 dB, which ensure good dynamic performance and enough stability margin
- T_{fo} ≥ 52 dB, which ensures PF greater than 0.98 when the output power of the inverter is larger than 50% of the rated power.
- The crossover frequency f_c is set at 2 kHz (1/5 switching frequency of the inverter) here to ensure that the system has fast dynamic response and good ability of attenuating high frequency noise.

- System frequency $f_{o=}$50Hz
- Cross over/Cut-off frequency$f_c = 2$KHz
- Resonance frequency $f_r = 4$KHz

4.3.1 Calculation of Integral constant K_i

Using equation (3.10) we calculate the value of K_i

$$K_i = \frac{4\pi^2 f_o(L_1+L_2)}{H_{inv}G_{inv}}\sqrt{\left(10^{\frac{T_{fo}}{20}}f_o\right)^2 - f_c^2} =$$

$$= \frac{4\pi^2 * 50(550*10^{-6}+150*10^{-6})}{0.12*118.0327}\sqrt{\left(10^{\frac{52}{20}} * 50\right)^2 - 2 * 10^{3^2}}$$

K_i = 2200

4.3.2 Calculation of Proportional constant K_p

Using equation (3.7) we calculate the value of K_p

$$K_p = \frac{2\pi f_c(L_1+L_2)}{H_{i2}G_{inv}}$$

$$= \frac{2\pi * 2 * 10^3(550*10^{-6}+150*10^{-6})}{0.15*118.0327}$$

K_p = 0.45

The feedback gain H_{i1} is calculated using equation (3.15)

$$H_{i1} = 10^{\frac{GM}{20}} . \frac{2\pi f_c L_1}{G_{inv}}$$

$$=10^{\frac{5}{20}} * \frac{2\pi*2*10^3*550*10^3}{118.0327}$$

$$= 0.126 \approx 0.12$$

$$H_{i1} = 0.12$$

The Transfer Function of PI Controller is given by equation (3.6)

$$G_i(s) = K_p + \frac{K_i}{s}$$

On further simplification we get,

$$G_i(s) = \frac{K_p s + K_i}{s}$$

$$G_i(s) = \frac{0.45s+2200}{s}$$

4.4 Design of PR Controller

The specifications of loop gain for PR compensator are given as follows:

- $T_{fo} \geq$ 75 dB ensuring the amplitude error less than 1% at the rated power.
- PM ≥ 45◦, GM ≥ 5 dB
- System frequency $f_{o=}$50Hz
- Cross over/Cut-off frequency $f_c =$ 2KHz
- Resonance frequency $f_r =$ 4KHz

4.4.1 Calculation of Resonant Constant of PR controller

The resonant Constant K_r is calculated by using the equation(3.17)

$$K_r = \left(\sqrt{210}^{\frac{T_{fo}}{20}} f_o - f_c\right)\frac{2\pi(L_1+L_2)}{H_{i2}G_{inv}}$$

$$=(\sqrt{210}^{\frac{75}{20}} * 50 - 2 * 10^3)\frac{2\pi*(600*10^{-6}+150*10^{-6})}{0.15*118.0327}$$

$$K_r = 346.46$$

The feedback loop gain of H_{i2} is calculated using equation (3.20)

$$H_{i1} = \frac{2\pi L_1\left(f_r^{\,2}-f_c^{\,2}\right)}{G_{inv}f_c}\frac{\pi f_c^{\,2}-\left(\sqrt{210^{\frac{T_{fo}}{20}}}\,f_o-f_c\right)\omega_i \tan tan\,PM}{\left(\sqrt{210^{\frac{T_{fo}}{20}}}\,f_o-f_c\right)\omega_i+\pi f_c^{\,2}\tan tan\,PM}$$

$$= \frac{12566370.61-1128137.23*\pi*0.1916}{1128137.23*\pi+12566370.61}$$ since tan(45°)=1

$$H_{i1} = 0.126 \approx 0.12$$

4.4.2 Calculation of Proportional constant of PR Controller

The proportional constant K_p is calculated using equation (3.7)

$$K_p = \frac{2\pi f_c(L_1+L_2)}{H_{i2}G_{inv}}$$

$$= \frac{2\pi*2*10^3(500*10^3+150*10^3)}{0.15*118.0327}$$

$$K_p = 0.45$$

4.4.3 Transfer Function of PR Controller

The Transfer Function of PR Controller is given by the equation (3.16)

$$G_i(s) = K_p + \frac{2K_r\omega_i s}{s^2+2\omega_i s+\omega_o^{\,2}}$$

On further simplification we get,

$$G_i(s)= \frac{K_p^{\,2}+2K_p w_i s+2K_r w_i s+K_p w_o^{\,2}}{s^2+2w_i s+w_o^{\,2}}$$

$$G_i(s)= \frac{0.45s^2+2179.69s+44413.14}{s^2+6.28s+98695.87}$$

4.5 SOFTWARE USED

What is MATLAB?
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
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve 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 name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to *learn* and *apply* specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

The MATLAB System

The MATLAB system consists of five main parts:

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 complete large and complex application programs.

The MATLAB working environment.

This is the set of tools and facilities that you work with as the MATLAB user or programmer. It includes facilities for managing the variables in your workspace and importing and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

Handle Graphics.

This is the MATLAB graphics system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete Graphical User Interfaces on your MATLAB applications.

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 eigenvalues, Bessel functions, and fast Fourier transforms.

The MATLAB Application Program Interface (API).

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

Simulink

Is a MATLAB based graphical programming environment for modeling, simulating and analyzing multi domain dynamical systems. Its primary interface is a graphical bloc diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in automatic control and digital signal processing for multi domain simulation and model-based design

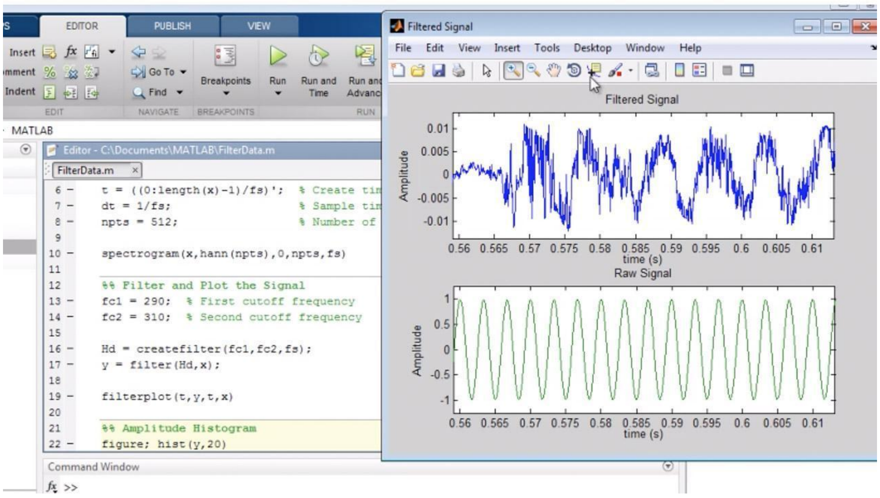


Figure 6: MATLAB

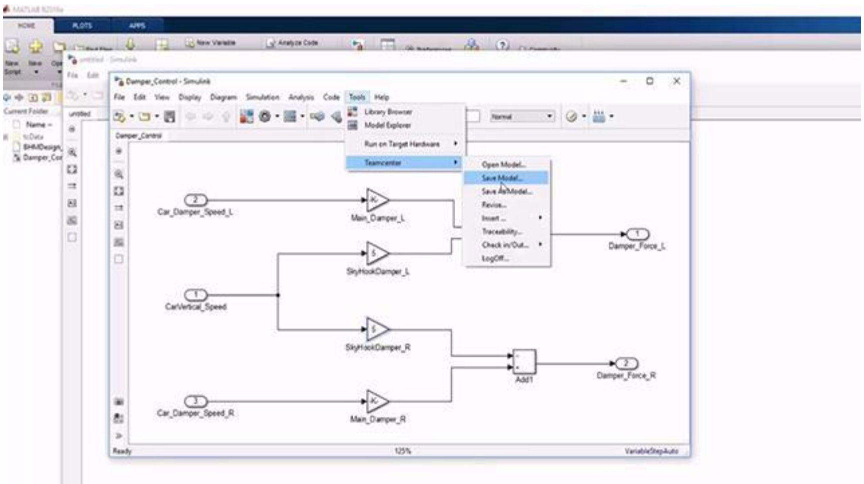


Figure 7: Simulink

4.6 SIMULATION MODEL

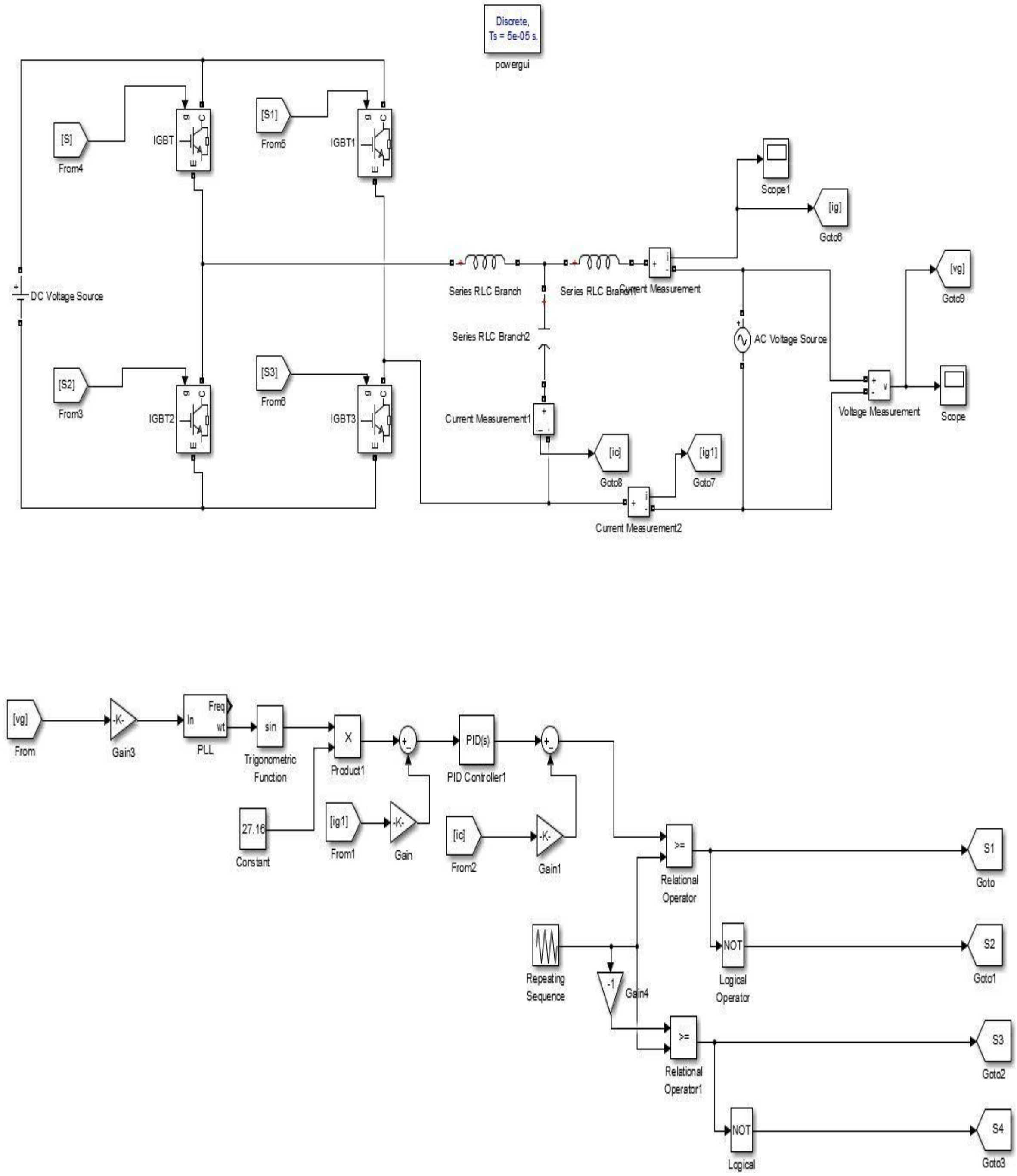


Figure 8: Simulation model

CHAPTER 5

RESULTS AND DISCUSSIONS

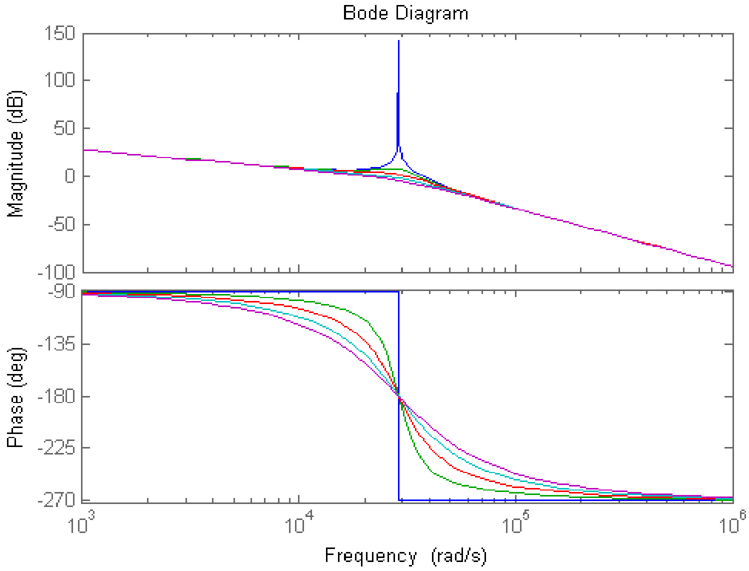


Figure9: Bode of loop gain without compensation

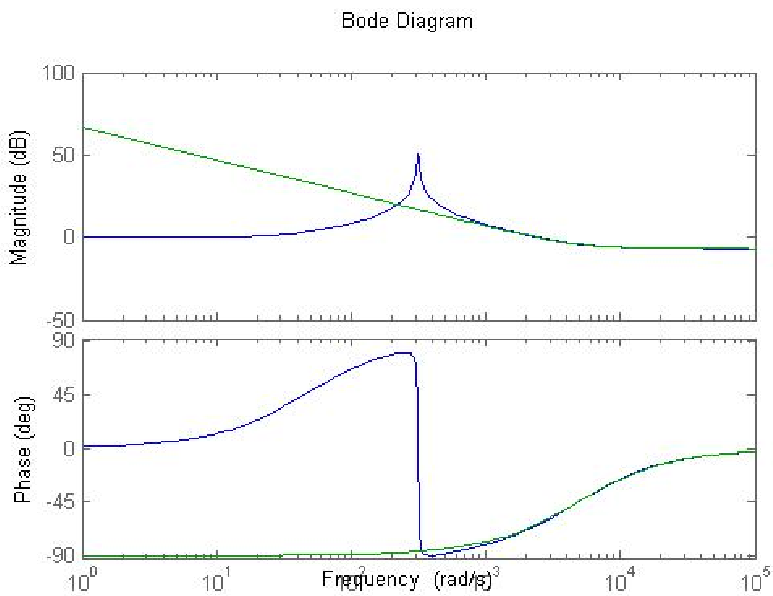


Figure 10: Bode of PI and PR compensators

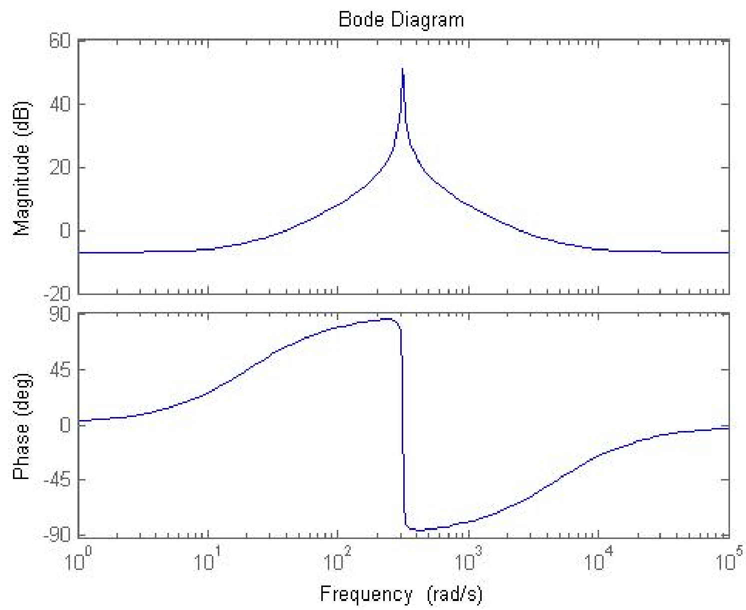


Figure 11:Transfer function of PR controller

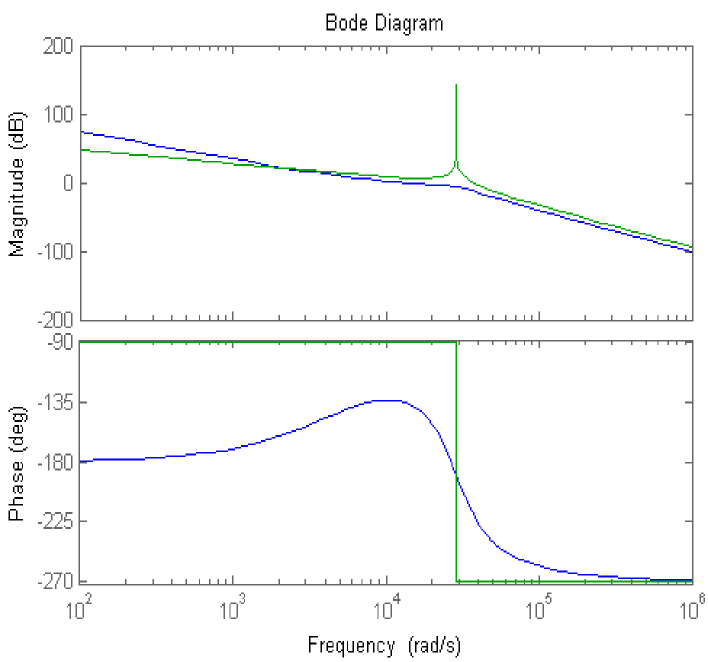


Figure 12: Bode of compensated system with PI compensator

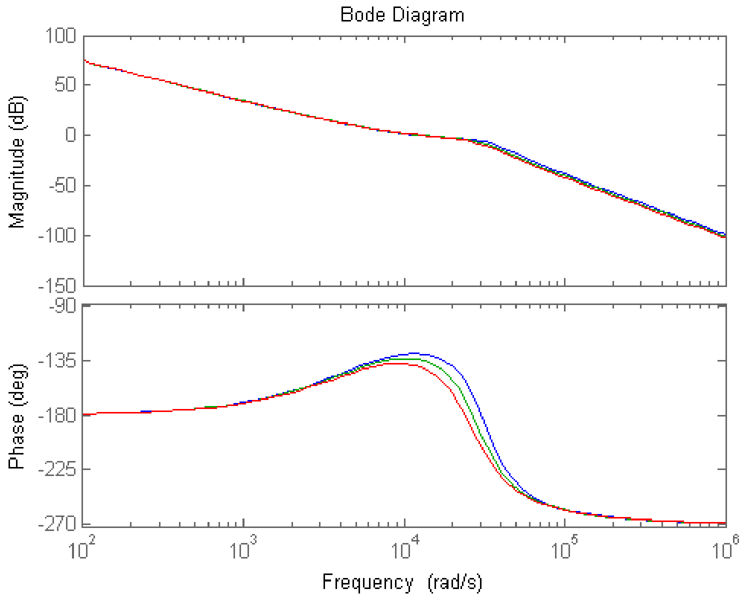


Figure 13:Variations of LCL filter parameters, C=8-12uF

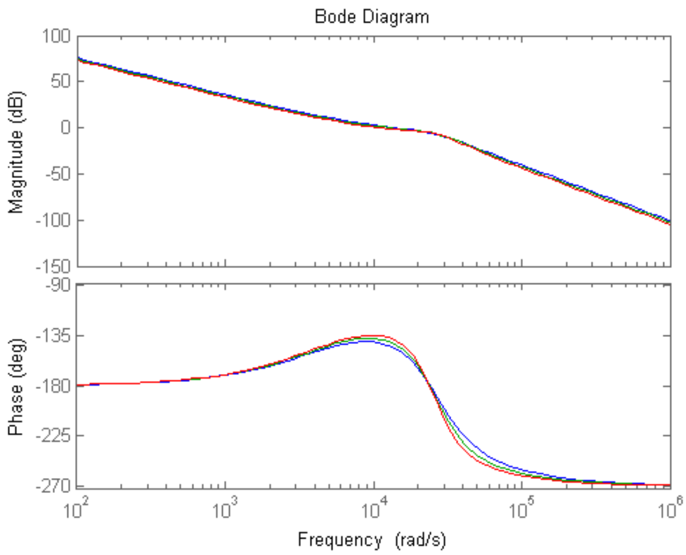


Figure 14: L1=480 to 720uF

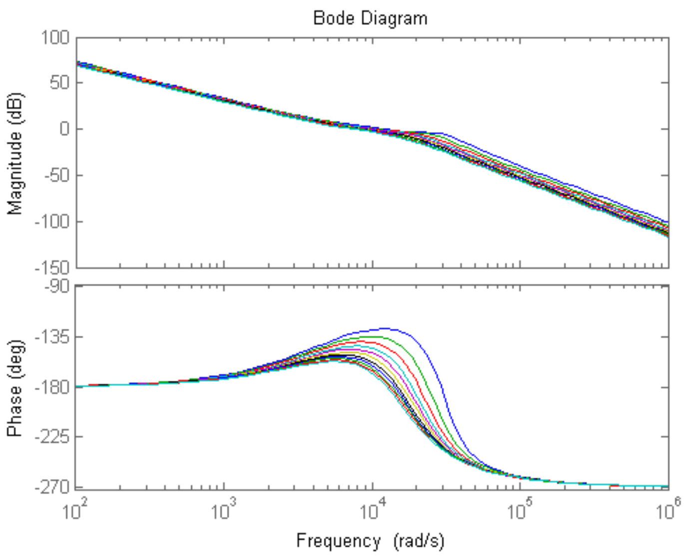


Figure15: L2=100 to 600uF

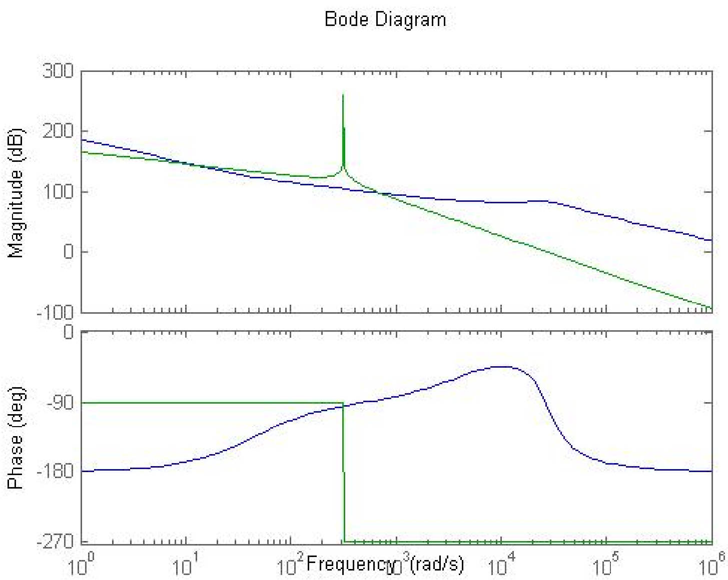


Figure 16: Bode of compensated system with PR compensator

Chapter 6

CONCLUSIONS AND FUTURE DIRECTIONS

The characteristics and design method of the injected grid current regulator and capacitor current feedback active-damping for the LCL-type grid-connected inverter have been modeled. The relationship between the controller parameters and the system loop gain has been investigated: active-damping method based on the feedback of the filter capacitor current can damp the resonance peak caused by the LCL filter effectively, but it impairs the PM of the system; the injected grid current regulator determines the crossover frequency and steady-state error of the system, but the negative phase shift of the regulator impairs the phase margin. A proper simple step-by-step interactive and optimized controller design method is proposed. The satisfactory regions of the controller parameters constrained by the specifications of the phase margin, gain margin, and steady-state error, are calculated and drawn to assist in determining and optimizing the controller parameters. Thus the compensated system can satisfy all the aforementioned specifications. Experimental results of a 6-kW prototype verify the effectiveness of the proposed design method and validity of the analysis. This idea has been investigated based on PI current regulator in detail, and extended to the controller design based on PI current regulator plus grid voltage feed forward scheme, PR current regulator, and also can be applied to the controller design of LCL-type three-phase grid-connected inverters.

References

1. J. Dannehl, M. Liserre, and F. W Fuchs, “Filter-based active damping of voltage source converters with LCL-filter,” IEEE Trans. Ind. Electron., vol. 58, no. 8, pp. 3623–3633, Aug. 2011. [1]

2. M. Lindgren and J. Svensson, “Control of a voltage-source converter connected to the grid through an LCL-filter-application to active filtering,” in Proc. IEEE Power Electron. Spec. Conf., 1998, pp. 229–235.[2]

3. J. M. Esp´ı, J. Castell´o, R. Garc´ıa-Gil, G. Garcer´a, and E. Figueres, “An adaptive robust predictive current control for three-phase grid-connected inverters, ” IEEE Trans.Ind.Electron., vol.58,no.8,pp.3537–3546,Aug. 2011.[3]
4. K.JaliliandS.Bernet,“DesignofLCLfiltersofactive-front-endtwo-level voltage-source converters,” IEEE Trans. Ind. Electron., vol. 56, no. 5, pp. 1674–1689, May 2009[4]
5. G. Willmann, D. F. Coutinho, L. F. A. Pereira, and F. B. L´ıbano, “Multiple-loop h-infinity control design for uninterruptible power supplies,” IEEE Trans. Ind. Electron., vol. 54, no. 3, pp. 1591–1602, Jun. 2007. [5]
6. R. Pe˜na-Alzola, M. Liserre, F. Blaabjerg, R. Sebasti´an, J. Dannehl, and F. W. Fuchs, “Analysis of the passive damping losses in *LCL*-filter-based grid converters,” *IEEE Trans. Power Electron.*, vol. 28, no. 6, pp. 2642–2646, Jun. 2013[6]
7. M.Liserre,R.Teodorescu,and F.Blaabjerg,’’Stability of photovoltaic and wind turbine grid connected inverters for a large set of grid impedance values,’’IEEE trans.powerelectron,vol.21,no.1,pp.263-272,Jan.2006.[7]

APPENDIX

```
clc
close all
clear all
fo=50*(180/pi);% System frequency
fs=10e3*(180/pi);% Switching frequency
Hi2=0.15;% Grid current sensor gain
Vin=360; % DC-Link voltage
Vtri=3.05;% Carrier signal amplitude
L1=600e-6;%Inverter side Inductor
C=10e-6;% Filter Capacitor
L2=150e-6; % Grid sideInductor
Ginv=Vin/Vtri;
wres=sqrt(L1+L2/(L1*L2*C))
fres=wres/2/pi
figure
for Hi1=0:0.05:0.2%4*Vtri*fs*L1/Vin;
Num=Hi2*Ginv;
Den=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0];
TT_uncomp=tf(Num,Den);%Eq...3 and Fig....2
bode(TT_uncomp)
hold on
end
%Controller Design%
% Vg=220;
Fc=2e3;
Pm=45*pi/180;
Gm=5;
fr=4.6e38*(180/pi);
```

Hi1=0.12;

```
kp=0.5
Tfo=52; %magnitude of loop gain at fo
Kp_Max=(2*pi*Fc*(L1+L2))/(Hi2*Ginv)
Kp=0.85*Kp_Max
Ki_Min=4*pi*pi*fo*(L1+L2)/(Hi2*Ginv)*sqrt((10^(Tfo/20)*fo)^2+Fc^2)
Ki_Max=2*pi*Fc*Kp*((2*pi*L1*(fr^2-Fc^2)-Ginv*Fc*Hi1*tan(Pm))/(2*pi*L1*(fr^2-F
c^2)*tan(Pm)+Ginv*Fc*Hi1))
Ki=2200;
Gi=tf([Kp Ki],[1 0])
figure
bode(Gi)

figure
Hi1=0
Gi1=([Kp Ki])
Num1=Hi2*Ginv;
Den1=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0];
TT_unc=tf(Num1,Den1)
Hi1=0.12;
Num2=Hi2*Ginv*Gi1;
Den2=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0 0];
TT_compen=tf(Num2,Den2);%Eq...3
bode(TT_compen)
hold on
bode(TT_unc)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 figure
 for C=8e-6:2e-6:12e-6
Hi1=0.12;
Gi1=([Kp Ki])
Num2=Hi2*Ginv*Gi1;
Den2=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0 0];
```

```
TT_compen=tf(Num2,Den2);%Eq...3
bode(TT_compen)
hold on
 end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 figure
 for L1=480e-6:120e-6:720e-6
Hi1=0.12;
Gi1=([Kp Ki])
Num2=Hi2*Ginv*Gi1;
Den2=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0 0];
TT_compen=tf(Num2,Den2);%Eq...3
bode(TT_compen)
hold on
 end
 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 figure
 for L2=100e-6:50e-6:600e-6
Hi1=0.12;
Gi1=([Kp Ki])
Num2=Hi2*Ginv*Gi1;
Den2=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0 0];
TT_compen=tf(Num2,Den2);%Eq...3
bode(TT_compen)
hold on
 end

% Num1=[L1*C C*Ginv*Hi1 1]
% Den1=[L1*L2*C L2*C*Hi1*Ginv L1+L2 0]
% G=tf(Num1,Den1)
```

```
% figure
% bode(G)
 % T1=tf([3895.079],[9*10^-3 2.011*10^-8 7.5*10^-4])
% figure(1)
% bode(T1)
%
% T2=tf([3895.079],[9*10^-3 2.655*10^-8 7.5*10^-4])
% figure(2)
% bode(T2)
%
% T3=tf([3895.079],[9*10^-3 3.54*10^-8 7.5*10^-4])
% figure(3)
% bode(T3)

%design of pr controller
fc=2e3;
fo=50;
Pm=45*pi/180;
Gm=5
fr=4e3;
Hil=0.12;
Kp=0.450
Tfo=75;
Kr=346.46;
wi=pi;
wo=2*pi*fo;
Gi_pr=tf([Kp (2*wi*kp)+(2*Kr*wi) Kp*wo*wo],[1 2*wi wo*wo])
figure
bode(Gi_pr)

%bode for PI and PR controller
```

```
fc=2e3;
fo=50;
Pm=45*pi/180;
Gm=5;
fr=4e3;
Hi1=0.12;
Kp=0.5;
Tfo=52;
l1=600e-6;
l2=150e-6;
c=10e-6;
Hi2=0.15;
Kp_max=(2*pi*fc*(l1+l2))/(Hi2*Ginv)
Kp=0.85*Kp_max
Ki_min=4*pi*fo*(l1+l2)/(Hi2*Ginv)*sqrt((10^(Tfo/20)*fo)^2+fc^2)
Ki_max=2*pi*fc*Kp*((2*pi*l1*(fr^2-fc^2)-Ginv*fc*Hi1*tan(Pm))/(2*pi*l1*(fr^2-fc^2)
*tan(Pm)+Ginv*fc*Hi1))
Ki=2200;
Gi=tf([Kp  Ki],[1 0])
Kp=0.45;
Tfo=75;
Kr=346.46;
wi=pi;
wo=2*pi*fo;
Gi_pr=tf([Kp  (2*wi*Kp)+(2*Kr*wi)  Kp+wo^2],[1 2*wi wo^2])
figure
bode(Gi_pr)
hold on
bode(Gi)
figure
Hi1=0
Gi1=1
num1=Hi2*Ginv;
```

```
den1=[l1*l2*c  l2*c*Hi1*Ginv  l1*l2  0];
TT_uncomp_pr=tf(num1,den1);
Hi1=0.12
Gi1=([Kp  (2*wi*Kp)+(2*Kr*wi)  Kp+wo^2])

num2=Hi2*Ginv*Gi1;
den2=[l1*l2*c  l2*c*Hi1*Ginv  l1+l2  0  0];
TT_comp_pr=tf(num2,den2)%eqn...3
bode(TT_comp_pr)
hold on
bode(TT_uncomp_pr)
```

BIO DATA

NAME – SHALETTA ELIAS

FATHERS NAME – ELIAS JACOB

MOTHERS NAME – JILU ELIAS

DOB - 11ST FEBRUARY 1998

PERMANENT ADDRESS - NO 109, 2nd F CROSS , RAMIAH LAYOUT ,
KAMANAHALLI, BANGALORE-560084

CONTACT NUMBER - +91 8105607170

EMAIL ID – shaletta98elias@gmail.com

GENDER - FEMALE

NATIONALITY - INDIAN

RELIGION - CHRISTIAN

QUALIFICATION

- PASSED ICSE CLASS 10 EXAMINATION FROM ST.FRANCIS XAVIER GIRL'S HIGH SCHOOL , FRAZER TOWN, BANGALORE-560005

- PASSED 2ND PUC BOARD EXAMINATION FROM CMR PU COLLAGE , KAMANAHALLI ,BANGALORE 5600084

- FINAL YEAR IN B.TECH ENGINEEERING IN ELECTRICAL AND ELECTRONICS (EEE) DEPT FROM CMR INSTITUTE OF TECHNOLOGY , AECS LAYOUT , WHITEFIELD , BANGALORE.

BIO DATA

NAME - SUPRITHA .S

FATHERS NAME - SRIDHARAN . D

MOTHERS NAME - KOKILA B

DOB - 31ST OCTOBER 1998

PERMANENT ADDRESS - NO 48 , 8TH CROSS , 2ND MAIN , SG PALYA CV RAMAN NAGAR POST , BANGALORE -560093

CONTACT NUMBER - +91 95356 29369

EMAIL ID - suas16ee@cmrit.ac.in

GENDER - FEMALE

NATIONALITY - INDIAN

RELIGION - HINDU

QUALIFICATION

- PASSED ICSE CLASS 10 EXAMINATION FROM SACRED HEARTS GIRLS HIGH SCHOOL & GOOD SHEPHERD COVENT RESIDENCY ROAD , BANGALORE

- PASSED 2ND PUC BOARD EXAMINATION FROM DEEKSHA INTEGRATED , MIRANDA COMPOSITE PU COLLEGE , KODIAHLLI , BANGALORE 560008

- FINAL YEAR IN B.TECH ENGINEEERING IN ELECTRICAL AND ELECTRONICS (EEE) DEPT FROM CMR INSTITUTE OF TECHNOLOGY , AECS LAYOUT , WHITEFIELD , BANGALORE.