

**NEUTRAL POINT INVERTER CONTROLLER USING H INFINITY  
TECHNIQUES**

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## ABSTRACT

For applications in renewable energy and distributed generation, there is often a need to have a neutral line to provide a current path. This can be achieved by using a neutral-point circuit that consists of a conventional neutral leg and a split dc link. In this project, a H infinity ( $H^\infty$ ) current controller is proposed to force the current flowing through the split dc link to be nearly zero so that the neutral-point current is stable, and then, a current control loop is added to eliminate the imbalance of the current so that the neutral-point current is balanced with respect to the dc terminals. This leads to very small deviations of the neutral point from the mid-point of the DC source, in spite of the possibly large neutral current. Simulation of inverter circuit, neutral-point and H infinity ( $H^\infty$ ) has been performed using MATLAB/SIMULINK software. The simulation results confirm the validity of the proposed method.

## ABSTRAK

Aplikasi dalam tenaga yang boleh diperbaharui dan agihan penjaanaan sering memerlukan talian neutral untuk menghasilkan laluan arus. Ini boleh dicapai dengan menggunakan titik neutral pada litar yang terdiri daripada kaki neutral konvensional dan pecahan pautan arus terus (AT). Dalam projek ini, pengawal arus infiniti H ( $H^\infty$ ) dicadangkan untuk memaksa arus yang mengalir melalui perpecahan pautan AT menghampiri sifar supaya arus pada titik neutral- adalah stabil. Kemudian, gelung kawalan arus ditambah untuk menghapuskan ketidakseimbangan arus supaya arus pada titik neutral- seimbang berkadar dengan terminal AT. Ini membawa kepada pengurangan yang sangat kecil pada titik neutral daripada titik pertengahan sumber DC, walaupun arus neutral yang tinggi. Simulasi litar penyongsang, titik neutral dan infiniti H telah dihsilkan dengan menggunakan perisian MATLAB / SIMULINK. Keputusan simulasi mengesahkan kesahihan kaedah yang telah dicadangkan.

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**PTTA UTHM**  
PERPUSTAKAAN TUNKU TUN AMINAH

## CHAPTER I

### INTRODUCTION

#### 1.1 Project Background

A power inverter, or inverter, is an electrical power converter that changes direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits [1].

A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3<sup>rd</sup> harmonic and its multiples are cancelled [2].

Inverters can be broadly classified into two types, voltage source and current source inverters. A voltage fed inverter (VFI) or more generally a voltage–source inverter (VSI) is one in which the DC source has small or negligible impedance. The voltage at the input terminals is constant. A current–source inverter (CSI) is fed with adjustable current from the DC source of high impedance that is from a constant DC source. A voltage source inverter employing thyristors as switches, some type of forced commutation is required, while the (VSI) made up of using GTOs, power transistors, power MOSFETs or IGBTs, self-commutation with base or gate drive signals for their controlled turn-on and turn-off.

Since the neutral point of an electrical supply system is often connected to neutral, under certain conditions, a conductor used to connect to a system neutral is also used for grounding of equipment and structures. Current carried on a grounding conductor can result in objectionable or dangerous voltages appearing on equipment enclosures, so the installation of grounding conductors and neutral conductors is carefully defined in electrical regulations. Where a neutral conductor is used also to connect equipment enclosures to earth, care must be taken that the neutral conductor never rises to a high voltage with respect to local ground.

For a three-phase three-wire system, due to the topology, the sum of the three phase currents are zero and the voltage in the neutral point is floating. During balanced load condition this is not a problem. Since the potential in the neutral point during balance always will be zero, the load voltages can be correctly controlled. During unbalanced load conditions however, the line to neutral output voltages will unavoidable become unbalanced as well since the voltage in the neutral point cannot be controlled separately. The control target of balanced three-phase voltages contradicts with the fact that the zero-sequence current cannot exist only the positive and negative sequence current exists in the system. In order to make the control target possible, a neutral conductor must be provided so that the zero sequence current can flow through. For a three-phase four wire system there is a neutral connection that provides current to flow from the neutral point of the load [3].

## 1.2 Problem Statements

The neutral line is usually needed to provide a current path for possible balanced loads and the traditional six-switch inverter must be supplemented with a neutral connection. If the neutral point of a four-wire system is not well balanced, then the neutral-point voltage may deviate severely from the real midpoint of the DC source. This deviation of the neutral point may result in an unbalanced or variable output voltage, the presence of the DC component, larger neutral current or even more serious problems. Thus, the generation of a balanced neutral point in a simple and effective manner has become an important issue. These issues are mainly due to the lack of control and feedback.

## 1.3 Project Objectives

The objectives of this study are formulated as follows:

- 1) To design the  $H^\infty$  control strategy that is suitable for neutral point inverter.
- 2) To analyse the output from the inverter with and without the controller.
- 3) To maintain a stable and balanced neutral point, which makes  $I_C$  as small as possible while maintaining the stability of the system.

## 1.4 Project Scopes

This project based on the following scopes:

- 1) Modelling of three phase DC-AC inverter with neutral point connection and  $H^\infty$  controller strategy is simulated using MATLAB Simulink software.
- 2) Using  $H^\infty$  intelligent technique as controller to improve power inverter for system.
- 3) The zero current flows at the capacitor link at neutral point

## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Introduction

In this chapter generally given introduction about some of types of controls and neutral point of three phase inverter and it also focus on  $H^\infty$  controller. The basic components and their detailed functions will be introduced and discussed.

#### 2.2 Three-Phase Inverter

Inverters can be found in a variety of forms, including half bridge or full bridge, single phase or three phases. In pulse width modulated (PWM) inverters the input DC voltage is essentially constant in magnitude and the AC output voltage has controlled magnitude and frequency. Therefore the inverter must control the magnitude and the frequency of the output voltage. This is achieved by PWM of the converter switches and hence such converters are called PWM converters.

The principles for the physical layout of three phase inverters, also known as voltage-source converters (VSC:s) are shown in Figure 2.1 The bridge is connected to the DC link, whose voltage is raw material in the creation of the three phase output voltage. The link voltage is from now on called DC link. The mid potential of the DC-link is defined as neutral.

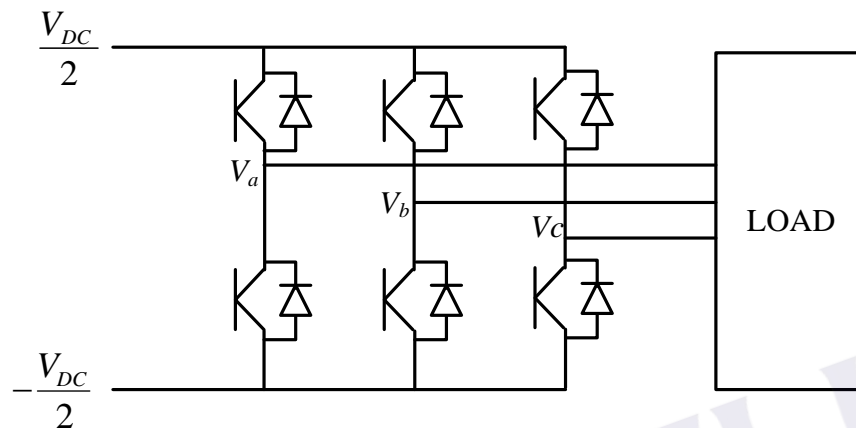


Figure 2.1: Three-phase inverter network.

Between the two poles of the DC link, the three half-bridges are connected. Each half bridge has two power electronic switches. By switching them, between fully conducting and fully blocking, the potentials of each half-bridge ( $V_a, V_b, V_c$ ), with respect to the mid potential of the DC link, can attain  $\pm V_{DC} / 2$ .

The neutral current usually makes the neutral point shift. The shift of the neutral point may result in unbalanced variable output voltage, DC component in the output, larger neutral current or even more serious problems. The neutral line is usually needed on the AC side of the converter to provide a current path for the zero-sequence current components.

If the neutral line is not well controlled and the neutral current has strong low-frequency components, then the neutral current causes the neutral point to deviate severely from the mid-point of the DC source. This deviation of the neutral point may result in an unbalanced or modulated output voltage, the presence of zero-sequence voltage components, and hence an even larger neutral current. Thus, the generation of a balanced neutral point efficiently and simply has now become an important problem.

A straightforward way to provide the neutral point is to use two capacitors shown in Figure (2.2a), in parallel with large balancing resistors. Such a configuration is called a split DC link. Since the neutral current flows through the capacitors, very high capacitance is needed to make the voltage ripple on the capacitors small. Another drawback is that the neutral point usually drifts and becomes non-balanced, in particular, when the neutral current has a DC component. Hence, this topology is not suitable for DC-AC converters which supply power to possibly unbalanced consumers or to the grid. Since the neutral current in Active power filters does not have a DC component and the fundamental component is relatively small, the split DC link is widely used in Active power filters. There are three different circuit topologies have been widely used to generate a neutral point. The most popular topology is a split DC link, shown in Figure (2.2a), with the neutral point clamped at half of the DC link voltage. Since the neutral current flows through capacitors, high capacitance is necessary. Moreover, the neutral point usually shifts following capacitors and switches differences. To improve performance of the split DC link topology, different neutral point balancing strategies are reported, usually using redundant states of the Space Vector Pulse Width Modulation (SVPWM).

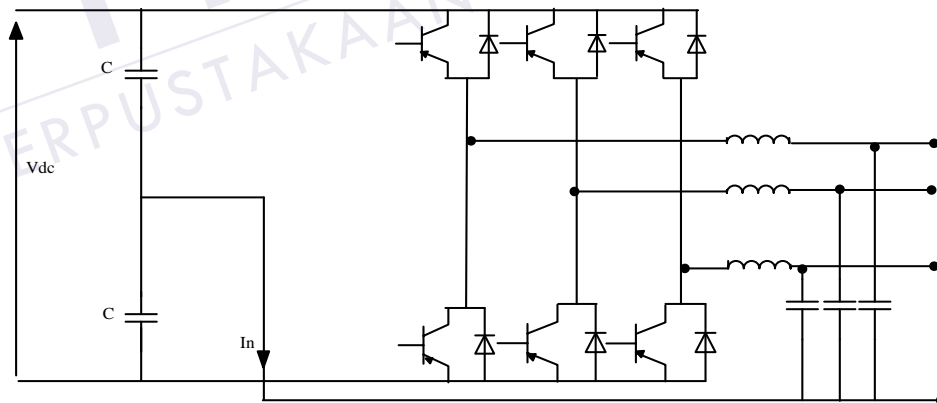


Figure 2.2a: Split DC link neutral connection.



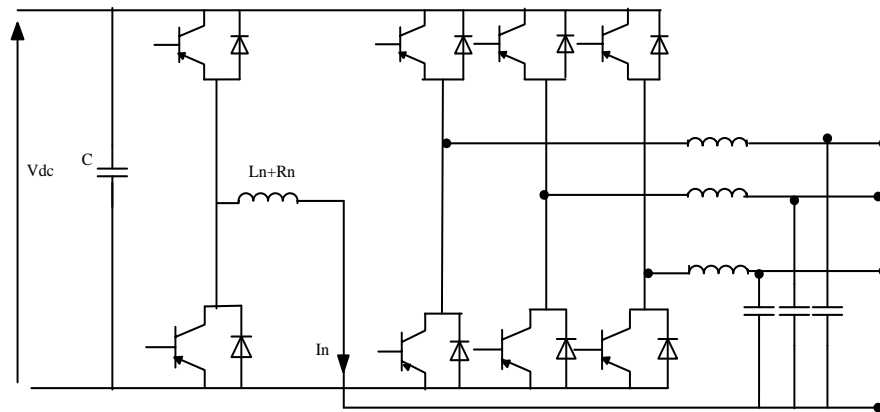


Figure 2.2b: A fourth-leg neutral connection used with three dimensional space-vector modulations [4].

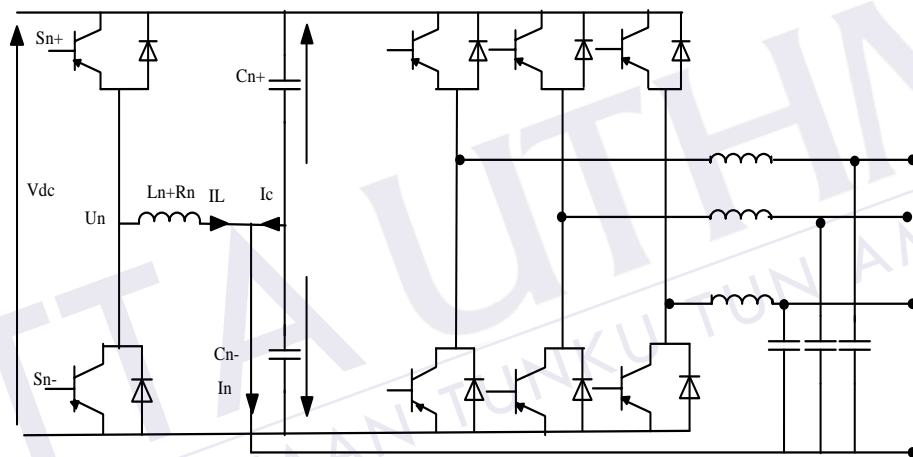


Figure 2.2c: The combination of Fig (2.2a and 2.2b), The Actively balanced split DC link [4].

The DC-AC inverters usually operate on Pulse Width Modulation (PWM) technique. The PWM is a very advance and useful technique in which width of the gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user's choice) irrespective of the output load. In a conventional inverter the output voltage changes According to the changes in the load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC depends on the switching frequency and pulse width which is adjusted

According to the value of the load connected at the output so as to provide constant rated output.

The DC to AC converters more often known as inverters, depending on the kind of the source of feeding and the related topology of the power circuit, are classified as voltage source inverters (VSI) and current source inverters (CSI). The following Figure (2.4) and Figure (2.5) illustrates the types of inverter.

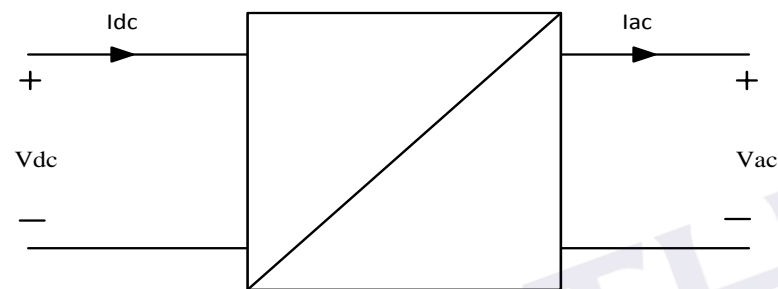


Figure 2.3: General block diagram

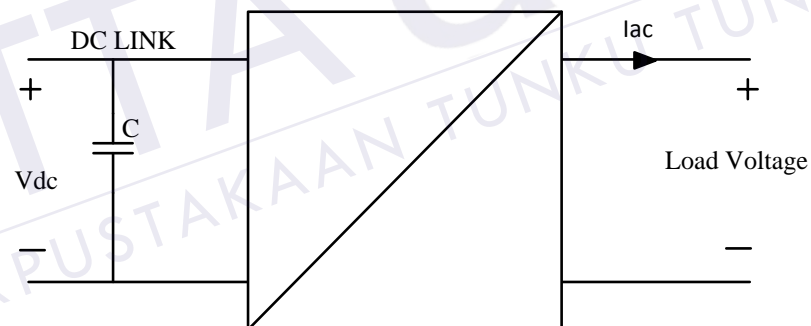


Figure 2.4: Voltage Source Inverter (VSI)

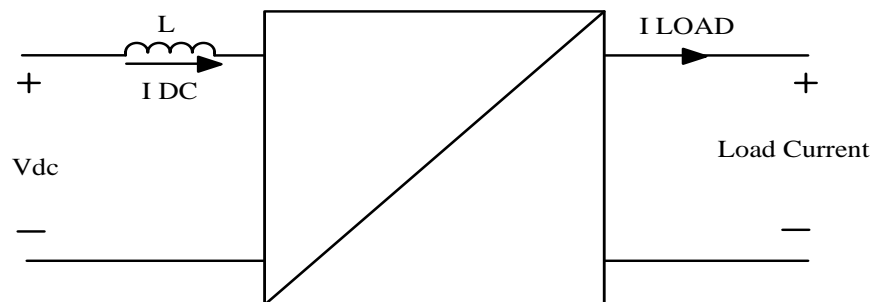


Figure 2.5: Current Source Inverter (CSI)

The three-phase counterparts of the single-phase half and the full bridge voltage source inverters are shown in Figures 2.6 and 2.7, Single-phase (VSI) covered low-range power applications and three-phase (VSI) covered medium to high power applications. The main purpose of these topologies is to provide a three-phase voltage supply, where the can be controlled amplitude, phase and frequency of the voltages can be controlled. The three-phase DC-AC voltage source inverters are widely used in motor drives, Active filters and unified power flow controllers in power systems and uninterruptured power supplies to generate controllable frequency. AC voltage magnitudes using various pulse width modulation (PWM) strategies. Standard of three-phase inverter shown in Figure 2.7 has six switches the switching of that depends on the scheme of modulation. Usually the input DC is obtained from a single-phase or three phase utility power supply through a diode-bridge rectifier and LC or C filter.

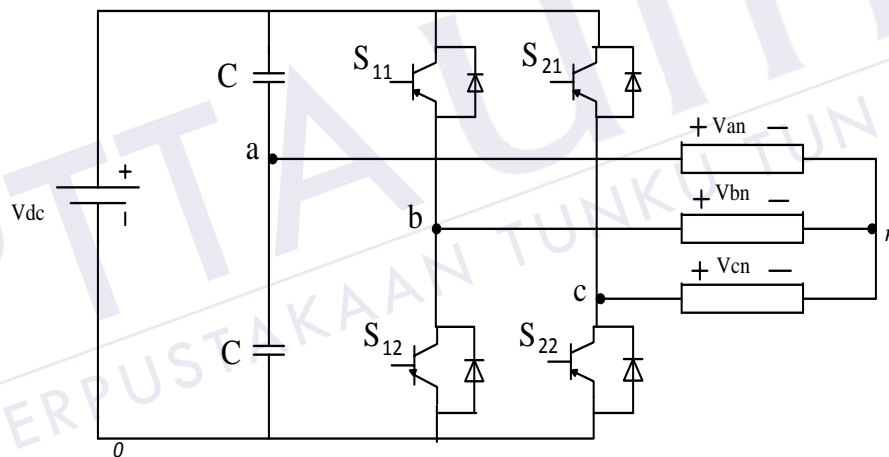


Figure 2.6: Three-Phase Half-Bridge Inverter

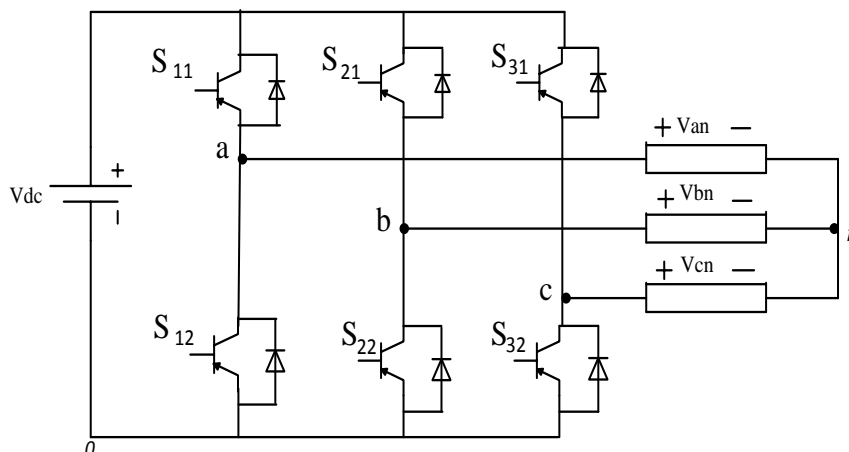


Figure 2.7: Three-phase Full-Bridge Inverter

Three-Phase DC-AC inverter is commonly used in industry. There are many applications in industry that used this type of DC-AC conversion in order to operate. The types of inverters that are used to make sure all those applications operate have different types. Here are several types of three-phase inverter that are used in industry. Figure 2.8 shows a conventional three-phase voltage-source inverter VSI [9].

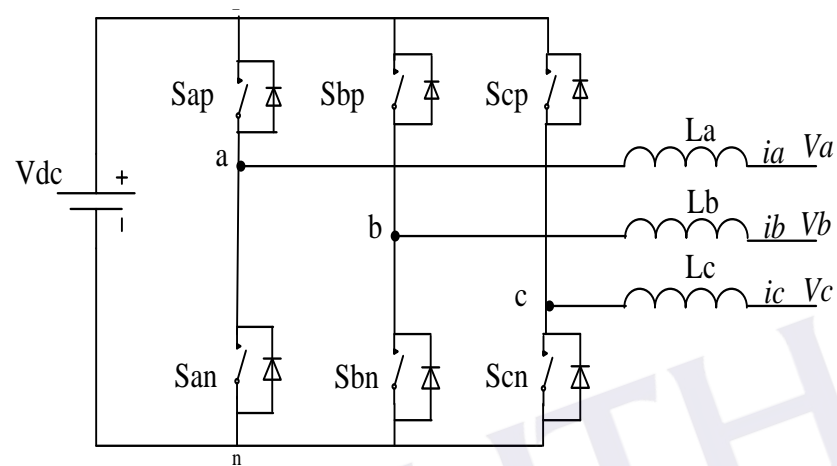


Figure 2.8: Conventional three-phase Voltage Source Inverter

### 2.2.1 Pulse Width Modulation

In electronic power converters and motors, PWM is used extensively as a means of powering alternating current (AC) devices with an available direct current (DC) source or for advanced DC-AC conversion. Variation of duty cycle in the PWM signal to provide a DC voltage across the load in a specific pattern will appear to the load as an AC signal, or can control the speed of motors that would otherwise run only at full speed or off. The pattern at which the duty cycle of a PWM signal varies can be created through simple analog components, a digital microcontroller, or specific PWM integrated circuits.

Analog PWM control requires the generation of both reference and carrier signals that feed into a comparator which creates output signals based on the difference between the signals. The reference signal is sinusoidal and at the frequency of the desired output signal, while the carrier signal is often either a saw

tooth or triangular wave at a frequency significantly greater than the reference. When the carrier signal exceeds the reference, the comparator output signal is at one state, and when the reference is at a higher voltage, the output is at its second state. This process is shown in Figure 2.9 with the triangular carrier wave in red, sinusoidal reference wave in blue, and modulated and unmodulated sine pulses [20].

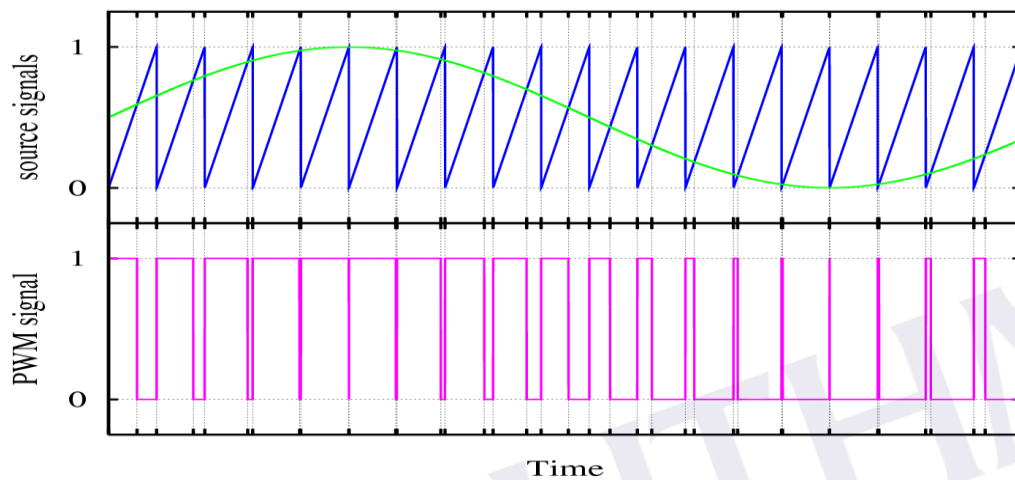


Figure 2.9: Pulse Width Modulation

### 2.3 Three-level Neutral-point Inverter

In order to provide the data base to modulation strategy proposed for the three-level-output-stage matrix converter, the three-level neutral point-clamped voltage source inverter technology from the operating principles to the related modulation diagram. The neutral-point balancing problem of the three-level neutral-point-clamped voltage supply inverter and associated control methods are also discussed.

#### 2.3.1 Circuit Topology

The three-level neutral-point-clamped voltage source inverter (NPC-VSI) was Introduced by Nabae in 1981 [10]. And is probably the most popular among the multilevel converter topologies for high voltage, high power applications. As shown

in Figure 2.10, the NPC VSI is supplied by two series-connected capacitors ( $C1$  and  $C2$ ), where both capacitors are charged to an equal potential of  $V_{DC}$ , with the DC-link middle point ' $i_c$ ' as a zero DC voltage neutral point. Each phase leg of the NPC VSI consists of four series-connected switching devices and two clamping diodes. These diodes clamp the middle switches' potential to the DC-link point ' $i_c$ ' [11].

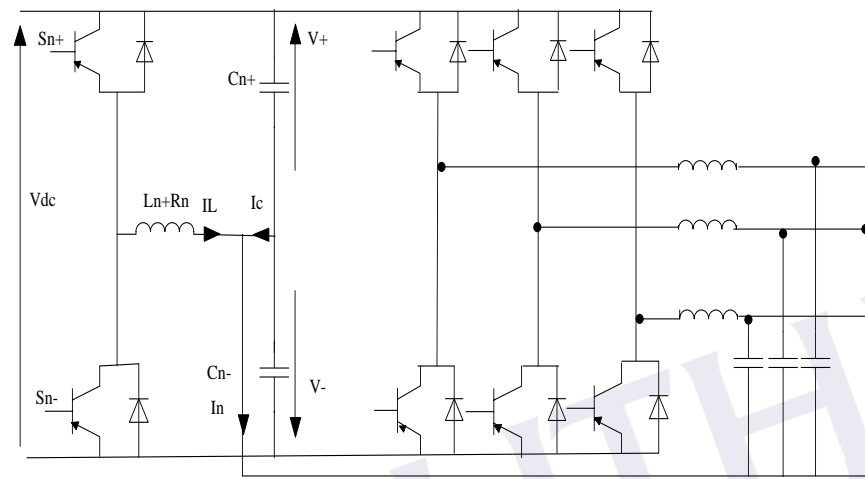


Figure 2.10: The schematic diagram of a conventional three-level neutral-point clamped voltage source inverter using the IGBT switches

## 2.4 Controller

There are essentially two categories of control systems: open-loop and closed-loop. Both maintain a chosen variable at a selected level with different levels of success.

### 2.4.1 Open-loop control systems

An open-loop control system is designed to meet the desired goals by using a reference signal that drives the Actuators that directly control the process output. Output feedback is not present in this type of system. Figure 2.11 shows the general

structure of an open-loop control system. A few examples of open-loop control systems are bread toasters, ovens, washing machines and water sprinkler systems.

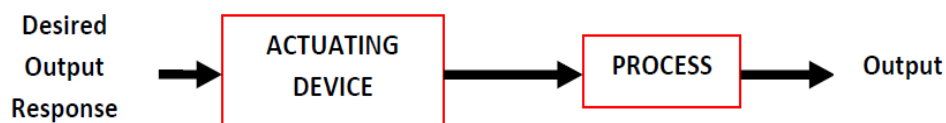


Figure 2.11: Open loop control system [13].

Open-loop control systems are in general relatively simple in design and inexpensive. However, require frequent operator intervention. Under many circumstances pre-set values become incorrect due to the parameter they are controlling changing in some way, and so they need resetting. The pre-set value often needs a high level of skill or judgement to set it correctly. In cases where the consequences of the system not controlling the parameter as desired are serious, such as the level of a hazardous liquid in a tank overflowing, open-loop systems are not suitable[19].

#### 2.4.2 Closed-loop control systems

In a closed-loop control system, the state of the output directly affects the input condition. A closed-loop control system measures the value of the parameter being controlled at the output of the system and compares this to the desired value. Sometimes, and use the output of the control system to adjust the input signal. This is called feedback. Feedback is a special feature of a closed loop control system. A closed loop control system compares the output with the expected result or command status, and then it takes appropriate control Actions to adjust the input signal. Therefore, a closed loop system is always equipped with a sensor. Figure 2.12 shows a simple closed loop system. The output signal is feedback to the input to produce a new output. A well-designed feedback system can often increase the accuracy of the output [17].

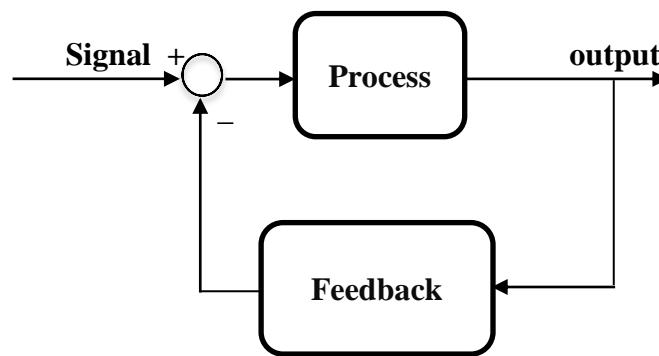


Figure 2.12: Block diagram of a closed loop control system

Feedback can be divided into positive feedback and negative feedback. Positive feedback causes the new output to deviate from the present command status. For example, an amplifier is put next to a microphone, so the input volume will keep increasing, resulting in a very high output volume. Negative feedback directs the new output towards the present command status, so as to allow more sophisticated control. For example, a driver has to steer continuously to keep his car on the right track. Most modern appliances and machinery are equipped with closed loop control systems.

An advantage of the closed-loop control system is the fact that the use of feedback makes the system response relatively insensitive to external disturbances (e.g. temperature and pressure) and internal variations in system parameters (e.g. Component tolerances) which are not known or predicted [18].

In closed-loop control systems the difference between the actual output and the desired output is feedback to the controller to meet desired system output. Often this difference, known as the error signal is amplified and fed into the controller. Figure 2.13 shows the general structure of a closed-loop feedback control system. A few examples of feedback control systems are elevators, thermostats, and the cruise control in automobiles.



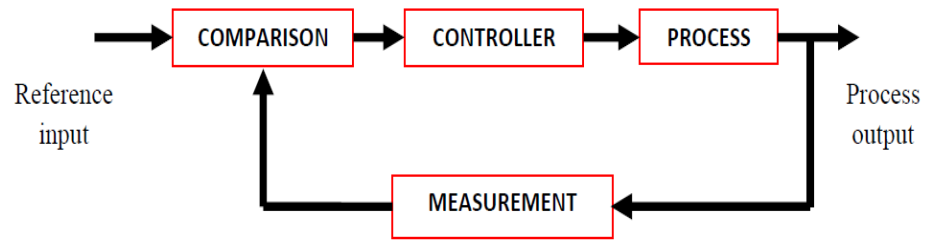


Figure 2.13: Closed loop process control system [13].

## 2.5 Controllers for neutral point application

Control systems are basically based on the feedback information from the main system. These systems are usually required to regulate and rectify the input of the system with respect to the desired output. The fundamental control system setup is depicted in Figure 2.14.

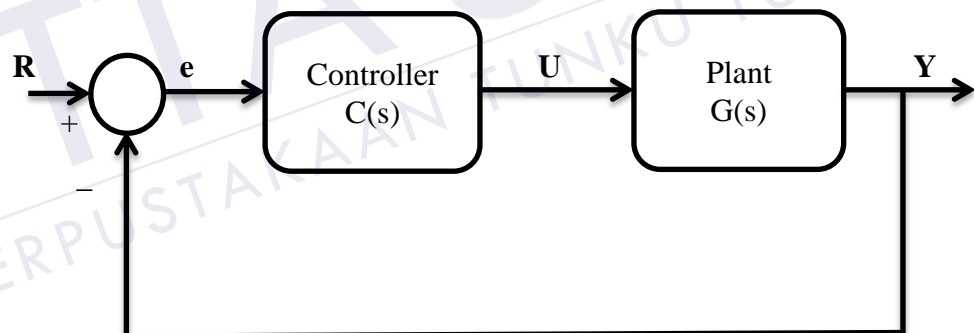


Figure 2.14: basic control systems

### 2.5.1 P Controller

In general it can be said that P controller cannot stabilize higher order processes. For 1<sup>st</sup> order processes, the meaning of processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1<sup>st</sup> order unstable process. Changing controller gain  $K$  can change closed loop system. A large

gain controller will result in control system with small steady state error, faster dynamics, phase margin and smaller amplitude.

When P controller is used, there will be a need to have a large gain to improve steady state error. Stable systems do not have problems when the gain is large; such systems are energy storage (1<sup>st</sup> order capacitive systems) systems. Constant steady state error can be accepted with such processes, and then P control can be used. Small steady state errors can be accepted if sensor will give measured value with error or if importance of measured value is not significant.

### 2.5.2 PD Controller

PD mode is used when prediction of the error can improve control or when it is necessary to stabilize the system.

To avoid effects of the sudden change of the reference input that will cause sudden change in the value of error signal. Sudden change in error signal will cause sudden change in control output. To avoid that it is suitable to design D mode to be proportional to the change of the output variable.

PD controller is often used in control of moving objects such as flying and underwater vehicles, ships, rockets etc.

$$k(S) = k_p + k_d s \quad (2.1)$$

### 2.5.3 PI Controller

PI controller will reduce force of oscillations and steady state error resulting in operation of on-off controller and P controller respectively.

However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, the PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue.

A control without D mode is used when fast response of the system is not required, large disturbances and noise are present during operation of the process, there is only one energy storage in process (capacitive or inductive), and there are large transport delays in the system.

$$k(S) = k_p + \frac{k_i}{s} \quad (2.2)$$

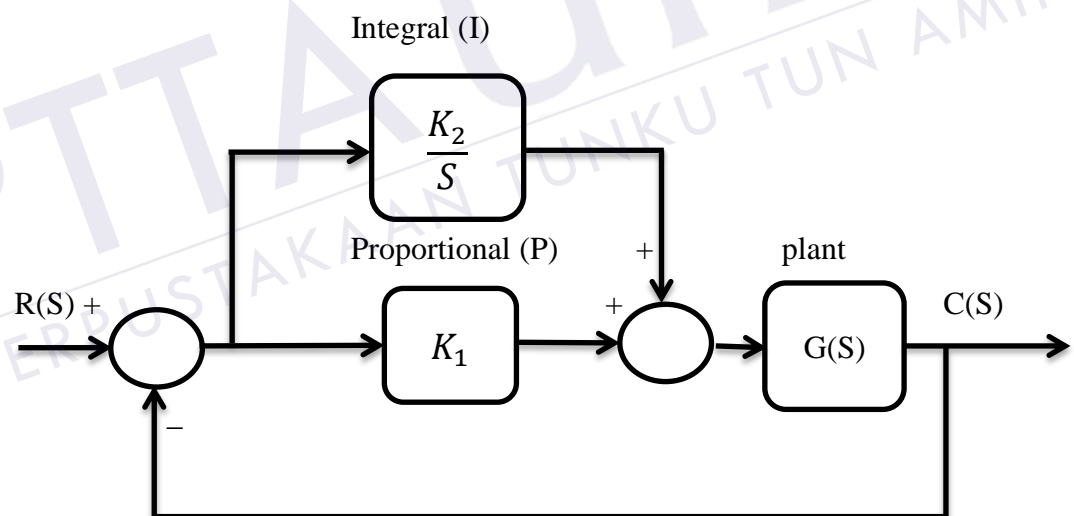


Figure 2.15: PI controller block diagram

#### 2.5.4 PID Controller

This control theory is one of the classic controls, which is simple, easy to implement, and cheap. If assumed that the Actual velocity of the car can be measured, the error

can be calculated easily by targeting actual velocity. Most control theories use the error to track the reference, especially PID control uses this error multiplied by proportional, derivative, and integral gain to track the target. In this case, proportional gain is P, derivative gain is D, and integral gain is I, called "PID controller". P gain usually influences how fast the systems can response, D is used to reduce the magnitude of the overshoot, and I-controller used to eliminate the steady-state error. But there is no optimal solution in this controller. For example, if PID is combined together, the combination of PID gains affects the system response not affect independently. Thus there is no solution to find the optimal gain so usually PID gains are specified by tuning. As a result of this feature, PID controller is mostly used in Linear-Time Invariant (LTI) system and Single-Input Single-Output (SISO) system not in non-linear and complex Multi-Input Multi-Output (MIMO) system. To tune the system response, usually the system specification is set at the first. Then each gain is tuned to satisfy the system response specification defined such as per cent overshoot, rising time, settling time, and so on.

A PID controller has proportional, integral and derivative terms that can be represented in transfer function form as [12].

$$k(S) = k_p + \frac{k_i}{s} + k_d s \quad (2.3)$$

PID controller has all the necessary dynamics: fast reaction with any change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to delete oscillations (P mode). The control PID is used when dealing with higher order capacitive processes when their dynamic is not similar to the dynamics of an integrator.

PID controller is often used in industry, but also in the control of mobile objects when stability and precise reference following are required.

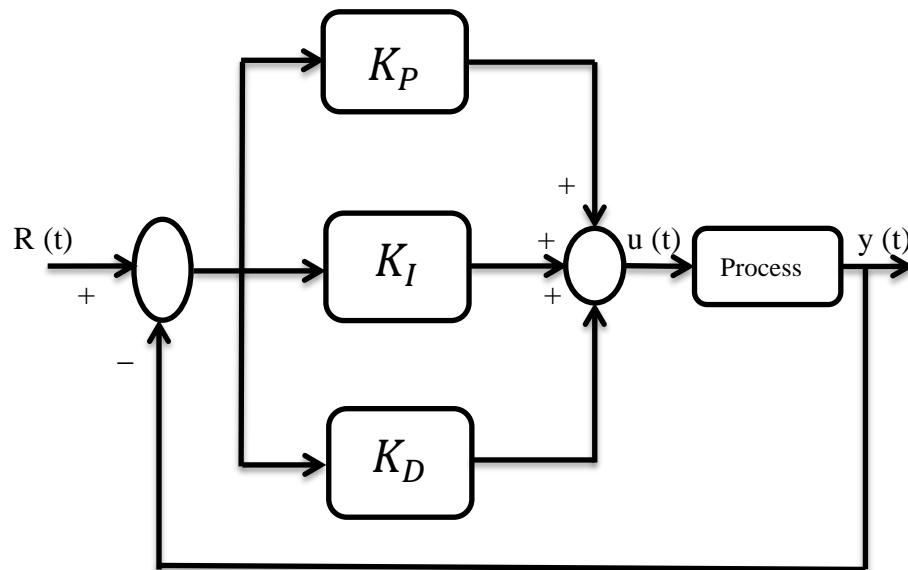


Figure 2.16: PID control logic [12].

Table 2.1: Effects of coefficients

parameter	Speed of response	stability	Accuracy
Increasing K	Increases	Deteriorate	Improves
Increasing KI	Decreases	Deteriorate	Improves
Increasing KD	Increases	Improves	No impact

Table 2.2: Advantages of PID

Response	Rise time	Overshoot	Settling time	S-S error
$k_p$	Decrease	Increase	NT	Decrease
$k_i$	Decrease	Increase	Increase	Eliminate
$k_d$	NT	Decrease	Decrease	NT

### 2.5.5 P-Resonant controller

This controller aims to get a good reference tracking and to reduce the output voltage harmonic distortion when the inverter feeds linear and nonlinear loads. The

resonant controller is a generalized PI controller that is able to control not only DC but also AC variables, Figure 2.17 shows the structure of the resonant controller [15].

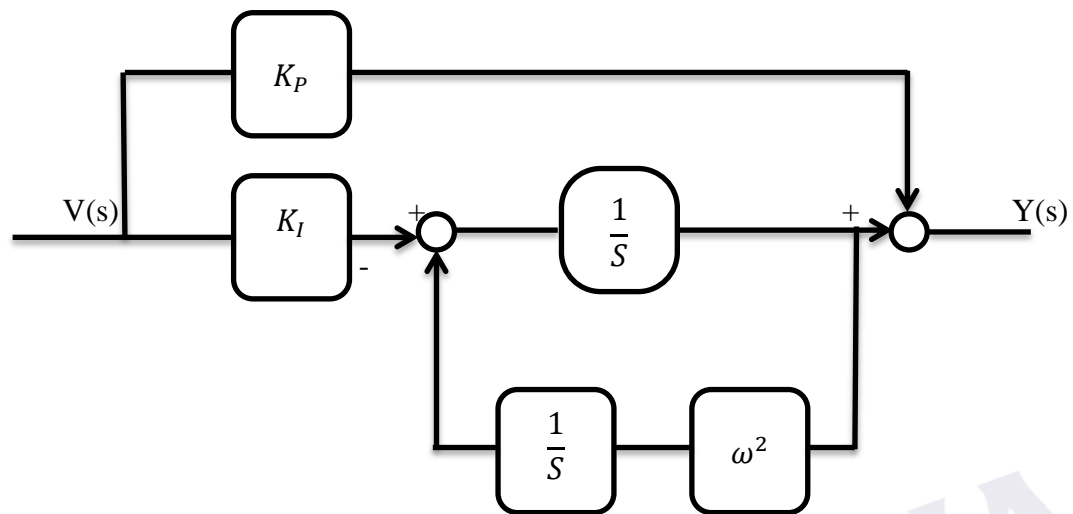


Figure 2.17: P-Resonant controllers

In addition to a forward integrator there is another integrator in the feedback loop. The transfer function is given by

$$G_{PR} = K_P + K_I \cdot \frac{s}{s^2 + \omega_0^2} \quad (2.4)$$

Figure 2.18 shows bode diagram of the resonant at a resonance frequency of 50Hz. At 50Hz there is an infinite open loop gain and thus it is able to eliminate the steady state error at this frequency. If  $\omega$  would be zero the resonant controller has the same structure as the well-known PI controller [16].

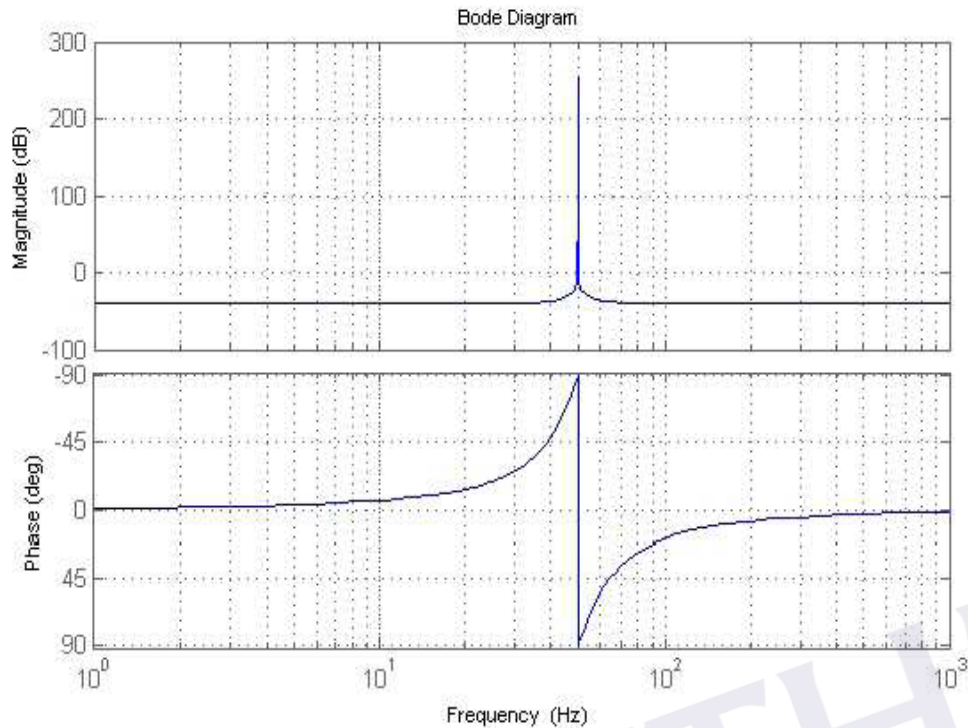


Figure 2.18: Frequency response characteristic of the open loop P+ resonant Controller

## 2.6 $H^\infty$ control

$H^\infty$  is used in control theory to synthesize controllers, achieving stabilization with guaranteed performance. To use  $H^\infty$  methods, a control designer expresses the control problem as a mathematical optimization problem and then finds the controller that solves this.  $H^\infty$  techniques have the advantage over classical control techniques in that they are readily applicable to problems involving multivariable systems with cross-coupling between channels.

The mathematical symbol  $H^\infty$  comes from the name of the mathematical space over which the optimisation takes place. The  $H^\infty$  is the space of matrix-valued functions that are analytic and bounded in the open right-half of the complex plane. The standard  $H^\infty$  optimal control problem is shown in Figure 2.19 where  $W$  represents an external disturbance,  $y$  is the measurement available to the controller,  $U$  is the output from the controller, and  $Z$  is an error signal that it is desired to keep small.

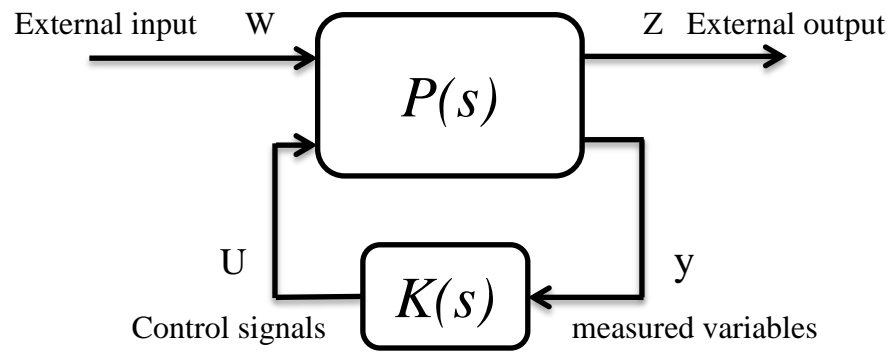


Figure 2.19: The standard  $H^\infty$  optimal control problem

From the Figure 2.19,

$$\begin{bmatrix} Z \\ y \end{bmatrix} = P(s) * \begin{bmatrix} W \\ u \end{bmatrix} \quad (2.5)$$

Suppose  $P(s)$  can be partitioned as follows

$$P(s) = \begin{bmatrix} P_{11}(s) & P_{12}(s) \\ P_{21}(s) & P_{22}(s) \end{bmatrix} \quad (2.6)$$

From equation (2.5) and (2.6),

$$Z = P_{11}w + P_{12}u \quad (2.7)$$

$$y = P_{21}w + P_{22}u \quad (2.8)$$

Then with the feedback law  $u = K(s)y$  can eliminate  $u$  and  $y$

$$Z = [P_{11} + P_{12}K(I - P_{22}K)^{-1} P_{21}]w \quad (2.9)$$

$$= F_1(P, K)w \quad (2.10)$$



## 2.7 $H^\infty$ controller and Its Operational Methodology

From Figure 2.20,  $G$  is the DC-AC inverter,  $K$  is the transfer function of  $H^\infty$  controller,  $\omega$  is a stable weight function, the vector  $d$  represents references current and  $y$  represents output voltage.

The standard problem of  $H^\infty$  controller is to find  $K$  that stabilizes the plant  $P$  minimizing the infinity norm of the close-loop transfer function

By using MIXSYN- Mixed-Sensitivity-Loop-Shaping. This MATLAB function computes a controller  $K$  that minimizes the  $H^\infty$  norm of the closed-loop transfer function.

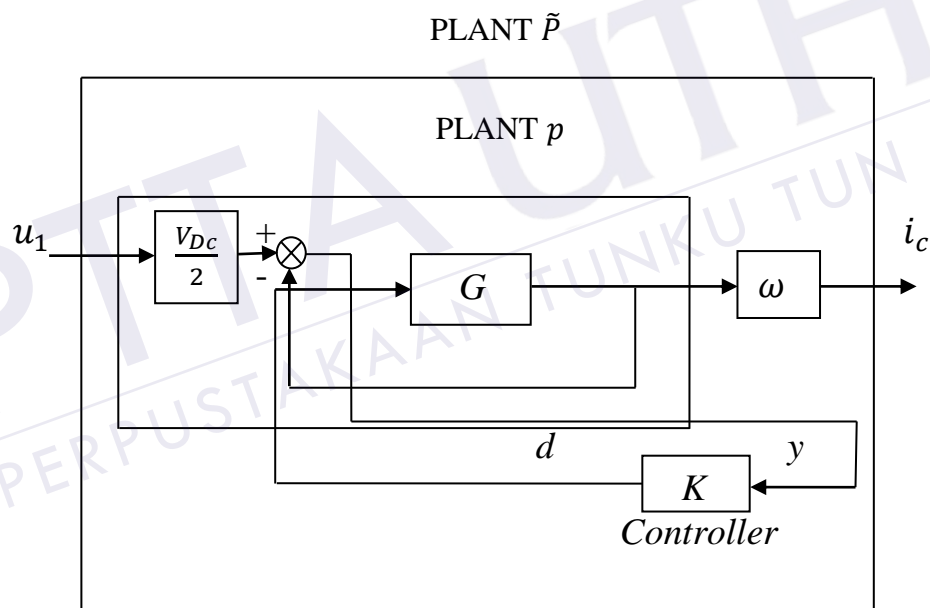


Figure 2.20: Standard  $H^\infty$  control problem for DC-AC inverter.

## CHAPTER III

### METHODOLOGY

#### 3.1 Introduction

The chapter describes about the methodological procedures which have been followed during the implication of this study. It familiarises about the introduction of the topology of the basic simulative setup. The fundamental system design is represented in terms of block diagrams and the systematic procedure of the project implementation is presented. The chapter concludes by illustrating the modelling of neutral point circuitry as it has been simulated using MATLAB/Simulink.

#### 3.2 System block diagram

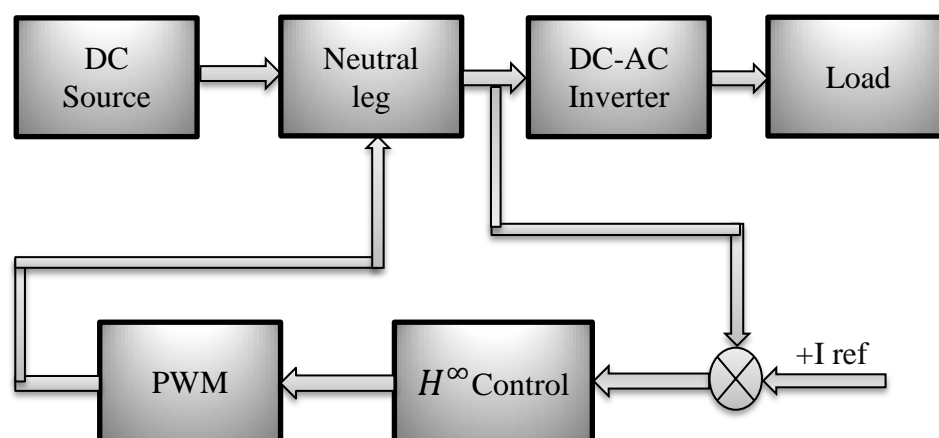


Figure 3.1: System block diagram.

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