"I hereby declare that I have read through this report entitle "Study of DC Bus Instability With Constant Power Load" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic And Drive)"

Signature : .....

Supervisor's Name : ENCIK MOHAMAD NA'IM BIN MOHD NASIR

Date : 28/6/2012

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STUDY OF DC BUS INSTABILITY WITH CONSTANT POWER LOAD

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A report submitted in partial fulfillment of the requirement for the degree of Power Electronic And Drive

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2012

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I declare that this report entitle "Study of DC Bus Instability With Constant Power Load" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : MOHD. FAQRUL LAZIM B. JARIN

Date : 28/06/2012

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To my beloved mother and father

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ABTRACT

Many applications of DC supply have been used in Distributed Power system. For instance aircraft, spacecraft and electric vehicle were using this kind of system. Unfortunately, this system has instability effect on the DC bus because of interconnection of DC bus and converters such as DC-DC converter with constant power load (CPL). The project is to study about CPL that make instability effect to the system and one method to eliminate or reduce it by using damping network. This project is limited by using the DC supply as a source and damping network as a method to eliminate or reduce the instability. Pspice software will be used to modeling the CPL and MATLAB software use to know the stability condition of RC passive damping and to simulate close loop buck converter. Then, hardware development will be build according to the calculation design. The performances from simulation and hardware will be analyzed. Result shows with addition of damping network DC bus will stable.

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ABSTRAK

Banyak applikasi dari bekalan kuasa Arus Terus (AT) telah digunakan dalam Sistem Pengagihan Kuasa. Untuk contoh, pesawat, kapal angkasa dan kenderaan elektrik telah menggunakan sistem seperti ini. Walaubagaimanapun, sistem ini mempunyai kesan ketidakstabilan pada bas Arus Terus kerana sambungan antara bas Arus Terus dan penukar seperti Arus Terus ke Arus Terus dengan kuasa beban malar. Di dalam projek ini, kuasa beban malar dipelajari yang membuat kesan ketidakstabilan kepada sistem dan satu kaedah untuk menghapuskan atau mengurangkannya ia dengan menggunakan rangkain redaman. Projek ini terhad dengan menggunakan bekalan arus terus sebagai sumber bekalan dan rangkaian redaman sebagai satu kaedah untuk mengurangkan ketidakstabilan. Perisian Pspice akan digunakan untuk modelkan kuasa beban malar dan perisian MATLAB untuk mengetahui keadaan kestabilan redaman RC pasif dan membuat simulasi litar "close loop buck converter". Kemudian, perkakasan untuk litar dijalankan mengikut kiraan yang telah dilakukan ketika reka bentuk litar. Hasil dari simulasi dan perkakasan litar akan dianalisis. Keputusan menunjukkan dengan penambahan rangkaian redaman dapat menstabilkan bas arus terus.

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LIST OF SYMBOLS AND ABBREVIATIONS

CPL	-	Constant Power Load
R_L	-	Negative Input resistance
Δv	-	Interval of voltage value
Δi	-	Interval of current value
Z_{od}	-	Output impedance of the damped filter with any of damping circuit
Z_I	-	The small signal incremental impedance of CPL
p(s)	-	polynomial expression
v_o	-	Nominal output voltage
V_o	-	Constant voltage load
C_2,C_d	-	Damping capacitor
C_p	-	combined capacitance of the filter and damping capacitors
P_{CPL}	-	Power of constant power load
P_{CVL}	-	Power of Constant Voltage load
R	-	Damping Resistor
V_{in}	-	Voltage input
V_o	-	Voltage output
H(s)	-	Small signal transfer function
$H_1(s)$	-	Transfer function close loop buck converter 1
$H_2(s)$	-	Transfer function close loop buck converter 2
P_{min}	-	Minimum Power
P_{max}	-	Maximum Power

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f_s	-	Switching frequency
D	-	Duty Cycle
R_T	-	Timing resistor
C_T	-	Timing capacitor
C_{rss}	-	Reverse Transfer Capacitance
C_{iss}	-	Input Capacitance
I_{gate}	-	Gate current
R_{gate}	-	Gate resistor

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Direct Current (DC) has long been known as a medium that offers efficient and effective power transmission and it also has significant advantages over its counterpart of Alternating Current (AC) electricity. Because of that advantage, distributed power system or DPS is designed to distribute the power among converter at the point needed. Applications such as aircraft, spacecraft, hybrid-electric, ships and electrical vehicle are recently used this system.

Although it has been recognized as a perfect system, it still has one common problem such as sub-system interaction and instability phenomena. This problem arises because of converter function that is to regulate output voltage and intends to sustain the power. This behavior called constant power load (CPL). Each one of the converter has an internal control function for instance to regulate their output voltage or motor speed. When the converter intends to draw a constant power, one characteristic has been occur and it is the negative incremental input, $-R_L$.

In that situation, the converters try to draw more current while the voltage is decrease. This means, the negative incremental input impedance has a hyperbolic characteristic between voltages and current. However, this instability can be overcome by adding one damping system or network into the system such as RC damping.

DC-DC converters such as buck converters will behave like a constant power load because of their function to regulate the output voltage. The characteristic of constant power

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load is same with the negative incremental input impedance phenomenon at the DC bus. However, there is stability condition that must be satisfied by the converter that involved Constant Power and Constant Voltage Load. Thus, this project is all about the study of DC instability criteria with constant power load.

1.2 Problem Statement

Distributed Power System (DPS) is recently used widely in many electrical applications such as aircraft, spacecraft, hybrid-electric and electric car. DPS is a system that distributes power among a lot of power processing unit or DC to DC converters at the point needed. The benefit using this system, it is capable to integrate a large variety of loads and it can control more easily the quality of power reaching each separate board. In addition, advantages in weight, size, isolation, voltage regulation and flexibility are the characteristic why this system is widely used.

Although, this can be said a perfect system to use, it still has a problem such as instability phenomena. This problem occurs because of interaction between converters and bus instability that takes leads of imbalance in power distribution between the parallel converters. Each one of converter has internal control functions to regulate the output voltage. Due to the regulated output, the converter needs to draw a constant power and as a result, it has negative incremental input impedance.

Negative incremental input impedance characteristic means it has a hyperbolic graph relationship between voltage and currents. This characteristic becomes the main characteristic of the constant power load (CPL). This means, the current in the converter will increase when the voltage supply falls in order to draw constant power. As a result, the system will be unstable which it may effect to the unequal distribution of output current. So this project focuses on the instability of DC bus that cause of constant power load. The method that has been choose in this project to overcome it is passive damping network.

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1.3 Objectives

From the problem statement that has been stated before, this project is about to study the DC bus instability because the presence of constant power load. So, the project objectives that are to be achieved regarding to the problem occurs in the DC instability and the method to overcome it. These are the objectives of the project:

1. To modeling the constant power load (CPL).
2. To study and design the damping network to reduce the instability of DC Bus.
3. To develop hardware from simulation design.
4. To analyze the performances from simulation and hardware results.

1.4 Scope

This project is focused and limit on:

1. The instability effect of constant power load to the DC bus system using DC as a source.
2. Passive damping method was chosen as a damping network in the design.
3. PSpice and MATLAB software will be used in order to implement the project in term of modeling and design.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This part discusses about the Distribution Power System (DPS) problem phenomenon such as instability effect. This problem came out because of negative incremental input impedance characteristic from the behavior converter that intends to regulate output or can be called constant power load. One simple Constant power load model circuit that consists of DC supply and LC filter is discussing first that related to the instability effect. Then, it follows by method to reduce the instability of constant power load. The behavior of DC-DC converter such as buck converter that behaves like constant power load also will be defined.

2.2 Distributed Power System (DPS)

Generally, in power system, the power can be constructed in one centralized unit. The power then will be delivered to the customers by use a network of cables and buses. This system can be called as a centralized power system. But, in Distributed Power system or DPS, the power is processed in a number of different processing units that can convert the voltage to different levels [1]. By comparing to the centralized power system, this DPS system has a power processing units (PPUs) that are connected to the loads by different ways. There are five basic distributed power system structures are founded. They are paralleling, cascading, source splitting, load splitting, the sum stacking module and the different stacking module. DPS is mostly constructed in combination of paralleling, cascading and load splitting.

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This DPS can be either Direct current (DC) or Alternating current (AC) system. Recently, DC Distributed Power System or DC DPS has take more attention and widely use especially in Distributed Generations (DGs) for renewable generations because of its cost, safety and good efficiency. Some applications of this system are such as aircraft, spacecraft and electric vehicle. Figure 2.1 shows the example of DC distribution system with renewable sources generation. Renewable sources such as Wind power and photovoltaic (PV) are used to give power to the load.

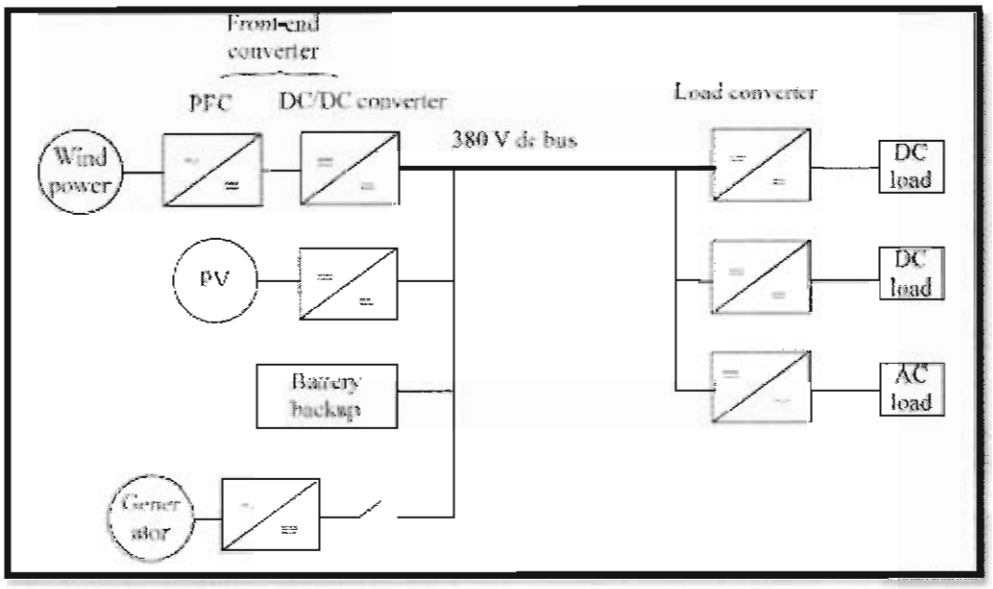

Figure 2.1: DC Distributed Power System with renewable sources [1].

Normally, each of this system or power modules are designed with stand-alone operation. As a result, the converters intend to draw a constant power to regulate the power modules. Because of this constant power, the systems stability is decrease and become unstable. The negative impedance characteristic in constant power and interaction among the power modules make the voltage of the system unstable. If two stable sub-systems are combined or integrated, there is no confidently this combined system will be in stable [2]. Interaction between two or more subsystems can be the main cause of this instability.

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2.3 Negative Incremental Impedance

The instability effect of Constant Power Load has become the main concern in the Distributed Power System analysis. The interaction load-source has caused the instability. This has shown that the interaction arises because each individual converter has internal control functions, such as the regulation of the converter output voltage or motor speed [2]. Then, a negative incremental input resistance occurs because of converter that desired to draw constant power. If this phenomenon happens, the internal controller in converter makes more current while the source voltage is drop.

The input resistance, R_L is given by the ratio of small signal changes in input voltage over the small signal input current [2], which is can be expressed in equation,

$$\text{Negative Input resistance, } R_L = \frac{\Delta v}{\Delta i} \tag{2.1}$$

This value will depend on the converter operating point [2]. The value of input power and output power is exactly same. Then, in a result, negative input resistance can be known by using this equation [2],

$$\frac{\partial v}{\partial i} = -i^{-2} P = -\left|\frac{P}{i^2}\right| = -\left|\frac{v^2}{P}\right| = -R_l \tag{2.2}$$

This equation is provided for small signal input resistance in constant power load. The resistance has been proving to be negative value that causes the system in unstable.

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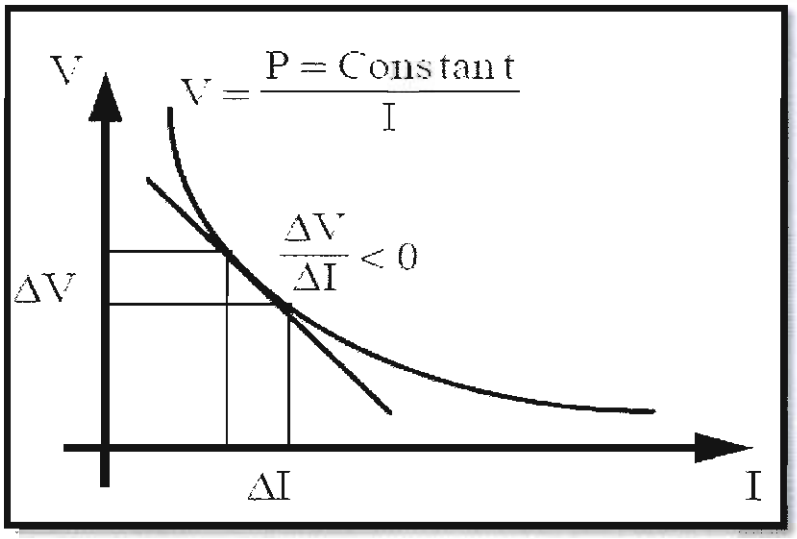

Figure 2.2: The negative incremental impedance characteristic graph [3].

Figure 2.2 shows the negative impedance or resistance characteristic graph between voltage and current. In this case, the value of power is constant while for voltage and current is varies. As a result, the graph is plotted in a hyperbola with in a negative slope. That's mean, in any increment, the voltage will be decrease and current will be increase.

2.4 Constant Power Load Model

The major characteristic of CPL is negative incremental impedance o resistance. In [4], has state that the negative resistance reduces system damping and can lead to instability or unacceptable oscillatory responses when a significant portion of system power is consumed by CPL. In practically, load will show the constant-power behavior only within their control bandwidth [4]. But, for general application, assume an ideal CPL with show the negative incremental resistance over infinite frequency range. The power is delivered from voltage source through single-stage LC filter. The LC filter of the circuit can be function as typical source output impedance or the input filter of CPL.

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