

# UNIVERSITI PUTRA MALAYSIA

# SIMULATION, DESIGN AND CONSTRUCTION OF A 15 KV DC POWER SUPPLY USING VOLTAGE MULTIPLIER CIRCUITS

ANAYET KARIM.

FK 2005 21



## SIMULATION, DESIGN AND CONSTRUCTION OF A 15 KV DC POWER SUPPLY USING VOLTAGE MULTIPLIER CIRCUITS

By

## ANAYET KARIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of the Requirements for the Degree of Master of Science.

September 2005



Dedicated to Allah S.W. T (Most Gracious, Most Merciful)



Abstract of thesis is presented to the Senate of Universiti Putra Malaysia in Partial fulfilment of the requirements for the Degree of Master of Science.

# SIMULATION, DESIGN AND CONSTRUCTION OF A 15 KV DC POWER SUPPLY USING VOLTAGE MULTIPLIER CIRCUITS

By

#### ANAYET KARIM

September 2005

#### Chairman: Associate Professor Nasrullah Khan, PhD

#### Faculty: Engineering

This thesis describes a PSpice and PSCAD based design and implementation of high voltage DC power supply at 15 kV output. It presents the detail description of the simulation, design, development and implementation of hardware for high voltage DC power supply in the laboratory. The conventional technique is used because the designed DC power supply is intended to be applied either for impulse generator charging units or laser excitation. The main components of a DC power supply are rectifier diodes and capacitors. The output of the power supply is a fairly smooth DC voltage. The simplest unregulated power supply consists of three parts namely, the transformer unit, the rectifiers unit and the capacitors unit. The main emphasis of this project is on the simulation, and design by using two different software (mentioned earlier) to compare simulation results as well as experimental results of the high voltage DC power supply. The economic feasibility of designing doubler or tripler based high voltage DC power supply and observation of the fact that



simulated and experimental values are different. A piece of high voltage generator is made available to the department. Simulation and experimental results are presented. It has been observed that the results are in agreement except due to the tolerances of the capacitor. The system hardware has been implemented and tested in the laboratory.

**KEYWORDS:** Power Supply, High Voltage, Regulator



Abstrak tesis yang dikemukakan kepada Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains.

# REKABENTUK PENYELAKUAN DAN PEMBINAAN SUMBER KUASA DC 15 KV MENGGUNAKAN LITAR PENDARAB

#### OLEH -

#### ANAYET KARIM

September 2005

#### Pengerusi: Profesor Madya Nasrullah Khan, PhD

Fakulti: Kejuruteraan

Penulisan ini menerangkan rekabentuk berasaskan perisian PSpice dan PSCAD untuk membina sumber votan tinggi DC pada keluaran 15 kV. Ia membentangkan penerangan terperinci tentang penyelakuan, rekabentuk dan perlaksanaan kerja perkakasan untuk membina sumber kuasa voltan DC dalam makmal dan kerja penyelakuan yang telah dijalankan dengan menggunakan perisian PSpice. Teknik lazim digunakan kerana sumber kuasa DC yang direkabentuk bertujuan untuk digunakan bagi unit pengecasan penjana dedenyut atau pengujaan laser. Komponen utama sumber kuasa DC adalah penerus dan pemuat. Keluaran sumber kuasa adalah voltan DC yang agak licin. Sumber kuasa yang teringkas mengandungi tiga bahagian yang dinamakan sebagai unit pengubah, unit penerus dan unit pemuat. Projek ini lebih menekankan tentang penyelakuan, rekabentuk dengan menggunakan dua jenis perisian ( telah dijelaskan sebelum ini) untuk membandingkan keputusan simulasi dan keputusan dari eksperimen sumber bekalan kuasa voltan tinggi DC.



Selain dari itu, kajian dari segi ekonomi dalam merekabentuk pekali dua dan pekali tiga berasaskan bekalan kuasa voltan tinggi DC.Didapati bahawa keputusan dari penyelakuan dan eksperimen adalah berbeza. Sebuah alat penjana voltan tinggi diserahkan kepada jabatan. Keputusan penyelakuan dan amali dibentangkan. Ia didapati seperti yang dipersetujui melainkan kerana had-terima pemuat. Perkakasan sistem telah dilaksanakan dan diuji dalam makmal.

KATA KUNCI: Sumber Kuasa, Voltan Tinggi, Pengatur



#### **ACKNOWLEDGEMENTS**

#### In the Name of Allah, Most Gracious, Most Merciful

First of all my thanks and gratitude to Allah S.W.T for the successful completion of this project. The author would also like to express his heart-felt thanks and deep gratitude to his supervisor Dr. Nasrullah Khan and his supervisory committee Deputy Dean/Associate Professor Ir. Dr. Norman bin Mariun and En. Mohd Amran Mohd. Radzi for their valuable advice, guidance and willingness to share their expertise.

The author would also like to acknowledge the help of Associate Professor Dr. Senan Mahmod Abdullah, from the department of Electrical and Electronic Engineering, Faculty of Engineering, UPM, for his valuable ideas and verbal suggestions.

In addition, the author would like to extend his sincere appreciation to his family and all the relatives, friends for making this project a success and special thanks given to his wife Mrs. Hasina Momtaz for her typing the whole thesis.

Last but not least, the author would like to thank his lab partner, Mohd Rizal Bin Ahmad, for his moral and physical support in the entire study period.



# **TABLE OF CONTENTS**

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	$\mathbf{v}$
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	Х
LIST OF TABLES	xiv
LIST OF FIGURES	XV
LIST OF ABBREVIATIONS	xvii

## CHAPTER

#### **1 INTRODUCTION**

1.1	Research Background	1.1
1.2	Project Overview and Problem Statement	1.2
1.3	Aims and Objectives	1.5
1.4	Scope of the Work	1.5
1.5	Structure of the Thesis	1.6

#### 2 LITERATURE REVIEW

2.1	Introduction	2.1
2.2	High Voltage Historical Development	2.3
2.3	High Voltage Design Guidelines	2.4
2.4	Quality of High-Voltage Research	2.6
2.5	High Voltage Power System	2.8
2.6	Critical Review of Previous Works	2.9
2.7	High Voltage Generation	2.15
2.8	DC High Voltage Generation	2.16
2.9	Voltage Multipliers	2.17
2.10	Voltage Doubling Principle	2.18
2.11	Voltage Tripling Principle	2.20
2.12	Definition of Ripple Factor	2.22
2.13	Ripple in Voltage-Doubler Circuit	2.22
2.14	Ripple in Voltage-Tripler Circuit	2.23
2.15	Ripple in Cascaded Voltage Multiplier Circuits	2.25
2.16	Voltage drops on Load and Regulation	2.28
2.17	High Voltage DC Application	2.30
2.18	Summary	2.31



# 3 METHODOLOGY

3.1	Introduction	3.1
3.2	Brief Description on DC Power Supply	3.1
3.3	Simulation	3.2
3.3.1	Design Criterion	3.2
3.3.2	Capacitor Selection	3.2
3.3.3	Diode Selection	3.3
3.4	Simulation of High Voltage DC Power Supply Circuit	3.4
3.5	Number of Stages	3.7
3.6	Hardware	3.8
3.7	Selecting Components	3.8
3.8	Selecting Other Devices	3.9
3.9	High Voltage Measuring Tools	3.9
3.10	Testing of Voltage Doubler Circuit	3.10
3.11	Testing of Voltage Tripler Circuit	3.10
3.12	Testing of Voltage Quadrupler Circuit	3.11
3.13	C-W Voltage Multiplier Circuits	3.11
3.14	Development of DC Power Supply (15 kV)	3.12
3.15	Block Diagram of the Project	3.13
3.16	Input and Output of DC Power Supply	3.14
3.17	Summary	3.14

## 4 **RESULTS AND DISCUSSION**

4.1	Introd	luction	4.1
4.2	Simul	ation result	4.1
	4.2.1	Simulation Result for Voltage Doubler Circuit using PSpice	4.1
	4.2.2	Simulation Result for Voltage Doubler Circuit using PSCAD	4.2
	4.2.3	Simulation Result for Voltage Tripler Circuit using PSpice	4.2
	4.2.4	Simulation Result for Voltage Tripler Circuit using PSCAD	4.3
	4.2.5	Simulation Result for Voltage Quadrupler Circuit using PSpice	4.3
	4.2.6	Simulation Result for Voltage Quadrupler Circuit using PSCAD	4.4
	4.2.7	Discussion between Voltage Doubler and Tripler Circuit	44
	4.2.8	Simulation Circuit for 15 kV DC Power Supply	4.5
	4.2.9	Simulation Voltage for 15 kV DC Power Supply	4.3 4.8
4.3	Hardw	vare result	4.10

		1.10
4.3.1	Test on Voltage Doubler Circuit	4.10
4.3.2	Test on Voltage Tripler Circuit	4.12



		<ul><li>4.3.3 Test on Voltage Quadrupler Circuit</li><li>4.3.4 Test on Developed DC Power Supply</li></ul>	4.13 4.14
	4.4	Cost of the Project	4.17
	4.5	Summary	4.18
5	CON	<b>ICLUSION AND RECOMMENDATION</b>	
	5.1 5.2	Conclusion Recommendation for Future Work	5.1 5.2
REF	EREN	CES/BIBLIOGRAPHY	R1
APP	ENDIC	CES	A1

## **BIODATA OF THE AUTHOR**



Table

4.1 Cost of the project

Page

4.18



Figure	Page
1.1: The overview of the project	1.3
2.1: Historical development of transmission AC & DC voltages	2.3
2.2: World electricity consumption	2.9
2.3: Connection diagram half-wave voltage doubler	2.18
2.4: Voltage doubler in positive alternation	2.19
2.5: Voltage doubler in negative alternation	2.20
2.6: Connection diagram half-wave voltage Tripler	2.20
2.7: Voltage tripler in positive alternation	2.21
2.8: Voltage tripler in negative alternation	2.21
2.9: Voltage doubler circuit	2.23
2.10: Voltage tripler circuit	2.24
2.11: C-W voltage multiplier circuit	2.27
3.1: Connection diagram of voltage doubler circuit using PSpice	3.2
3.2: Connection diagram of voltage doubler circuit using PSCAD	3.3
3.3: DC power supply simulation circuit using PSpice	3.5
3.4: DC power supply simulation circuit using PSCAD	3.6
3.5: High voltage measuring tools	3.9
3.6: Testing of voltage doubler circuit	3.10
3.7: Testing of voltage tripler circuit	3.10
3.8: Testing of voltage quadrupler circuit	3.11
3.9: C-W voltage multiplier circuits	3.12
3.10: Fabricated DC power supply in the laboratory	3.13
3.11: Block diagram of the project	3.13

# LIST OF FIGURES



3.12: Input and output of the DC power supply	3.14
4.1: Simulation result of the voltage doubler circuit by PSpice	4.1
4.2: Simulation result of the voltage doubler circuit by PSCAD	4.2
4.3: Simulation result of the voltage tripler circuit by PSpice	4.2
4.4: Simulation result of the voltage tripler circuit by PSCAD	4.3
4.5: Simulation result of the voltage quadrupler circuit by PSpice	4.3
4.6: Simulation result of the voltage quadrupler circuit by PSCAD	4.4
4.7: Simulation of DC power supply circuit by PSpice	4.6
4.8: Simulation of DC power supply circuit by PSCAD	4.6
4.9: Simulation output voltages for DC power supply by PSpice	4.8
4.10 Simulation output voltages for DC power supply by PSCAD	4.8
4.11: Simulation output current of DC power supply by PSpice	4.9
4.12: Stray capacitance effect using PSpice	4.9
4.13 Stray capacitance effect using PSCAD	4.9
4.14 Distorted output using PSCAD	4.10
4.15 Experimental output of the voltage doubler circuit	4.11
4.16: Ripple output of the voltage doubler circuit	4.11
4.17: Experimental output of the voltage tripler circuit	4.12
4.18: Ripple output of the voltage tripler circuit	4.13
4.19 Experimental output of the voltage quadrupler circuit	4.14
4.20: Ripple output of the voltage quadrupler circuit	4.14
4.21: Constructed DC power supply in the laboratory	4.15
4.22: Experimental output voltage of the DC power supply	4.16
4.23: Ripple output of 15 kV design circuit	4.16
4.24: Experimental output current of the DC power supply	4.17



# LIST OF ABBREVIATIONS

AC	Alternating current
APU	Auxiliary power unit
AIS	Air insulated system
BTOE	Billions tons oil equivalent
СВ	Circuit breaker
CT	Current transformer
C1, C2, C3	Capacitors
CVT	Capacitor Voltage Transformer
CRT	Cathode-ray tubes
C-W	Cockcroft - Walton
D1, D2, D3	Diodes
DC	Direct current
EHV	Extra high voltage
EAPU	Electric auxiliary power unit
FFOV	Fast-front over voltages
GIS	Gas insulated system
Hz	Hertz
HV	High voltage
HVDC	High voltage direct current
HVAC	High voltage alternating current
HVPS	High voltage power supply
HVDCPS	High voltage direct current power supply
IEC	International electro technical commission



KA	Kilo ampere
KV	Kilovolts
KV/CM	Kilovolts per centimeter
KJ	Kilojoules
KW	Kilo watt
KM	Kilo meter
KHz	Kilo hertz
LV	Low voltage
mA	Miliampere
MS	Millisecond
MV	Mega volt
MW	Mega watt
MSFC	Marshall space flight center
NS	Nanosecond
OV	Operating voltages
PU	Per unit
PMT	Photo multiplier tube
PWM	Pulse width modulation
RF	Ripple factor
R1, R2	Resistors
SEI	Sumitomo Electric Industries
STD-531	Standard module
Trr	Reverse Recovery time
TOV	Temporary over voltages
TV	Television



UHV	Ultra high voltage
UK	United Kingdom
UPM	University Putra Malaysia
VT	Voltage transformer
V1	Input Voltage
VRRM	Repetitive Peak Reverse Voltage
VFFOV	Very fast-front over voltages
VMD	Voltage multiplier designer
$\Delta V$	Ripple voltage
q	Charge
μF	Micro farad
μsec	Micro second
f	Supply frequency
I	Load current
<i>t</i> <sub>1</sub>	Conduction period of the rectifiers
<i>t</i> <sub>2</sub>	Non-conduction period of rectifiers



#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Research Background

High voltage testing equipment is generally used in mostly two places, in the research laboratories and routine testing laboratories. Besides the above places, it can be used to the industry and agricultural application also. The work carried out in research laboratories varies considerably from one establishment to the other and the type of equipment needed varies accordingly. A general high voltage laboratory may include equipment for all classes of tests. The routine testing is concerned with testing equipment such as transformer, switchgear, bushings as well as cables etc. It is sometimes carried out in the factory premises.

The high voltage equipment is required to study the insulation behavior under all conditions, which the apparatus is likely to encounter. Tests are also made with voltages higher than the normal working voltage to determine the safety factor over the working conditions and to ensure that the working margin is neither too high nor too low.

The conventional forms of high voltage in use can be divided into the following classes:

- a) Alternating current voltages
- b) Direct current voltages
- c) Transient voltages



In the industry the main application of the DC high voltage is to test on cables with a relatively large capacitance, which takes a very large current if it is tested with AC voltages. The simplest unregulated power supply consists of three parts namely, the transformer unit, the rectifiers unit and the capacitors unit.

#### 1.2 **Project Overview and Problem Statement**

This project is divided into two main parts, the circuit design and the hardware development part as shown in Figure 1.1. The first part concentrates on the design aspect, simulation of its circuits using PSpice software, version 6.3 and also using PSCAD 3.8, and selecting its components for the high voltage DC power supply. The maximum output of the power supply will be 15 kV. The second part of the work is the construction of DC power supply in the laboratory. The DC power supply takes AC input voltage from 180 volt to 240 volt.

To develop high voltage DC, it is noted that there are several techniques used such as voltage multipliers circuits, cascaded rectifier circuits with transformers, electrostatic HVDC generators (Van de Graaff Generators) and using induction coils [1]. Cascaded rectifier circuits with transformer multipliers needs excessive insulation for DC power supply, so it is very large arrangements and its range normally starts in MV capacity and it is expensive [2].





Figure 1.1: The overview of the project



1.3

On the other hand, electrostatic HVDC generators (Van de Graaff Generators) technique is mainly for very high voltage of 5-6 MV with output current of microamperes and used for particle accelerators and it is very much expensive [1, 2, 4]. Another idea is using induction coils which generate the high voltages required to create a spark [1].

Therefore it is noted that this project has been developed using voltage multipliers circuits instead of other techniques because below 100 kV, this is most suitable technique for generating high voltage DC. Voltage multiplier circuits are diode circuits that function as power supplies for special applications. They have the advantages of being simple solid state circuits with fairly low parts count and being able to produce output voltages much higher than the input voltage according to project demand.

Most DC test sets are done at lower frequency instead of high frequency [3]. It is less expensive, less insulation is required and its range can start from even 1 kV instead of MV capacity compare to the other methods [1, 2, 3, 4]. This is one of the methods for increasing voltages known as voltage multiplication or voltage multipliers.



#### 1.3 Aims and Objectives

The aim of this project is to design a single phase high voltage DC power supply and the range of the power supply will be a maximum of 15 kV. The objectives of this project are -

- 1. To make a simulation study on various types of voltage multiplier circuits such as voltage doubler, voltage tripler and voltage quadrupler circuits.
- To design and develop high voltage DC power supply (maximum 15 kV) using voltage multiplier circuits based on PSpice simulation and to construct/fabricate in the laboratory.

The contributions of this work are as follows,

- The main emphasis of this project is on the simulation, design by using two different software (mentioned earlier) to compare simulation results and hardware development of the high voltage DC power supply.
- 2. The economic feasibility of designing doubler or tripler based high voltage DC power supply.
- Observation of the fact that simulated and experimental values are different.
- 4. A piece of high voltage generator is made available to department. It can be used for multiple purposes such as excitation of laser, test on cables in industrial application, insulation testing and lightning impulse testing.

