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# ANALYSIS OF DC-DC MODULAR STRUCTURE CONVERTERS FOR VOLTAGE TRANSIENTS MITIGATION

BY

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A dissertation submitted in partial fulfilment of the requirement for the degree of Master of Science (Electronics Engineering)

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# ABSTRACT

One module of back converter is simulated using a forward quad-transistor topology. The 1: N stepping-down transformer is an effective component with galvanizing performance. Transistors are fitted with a diode while keeping the coil protected from spikes and fly-back issues. These configurations can be used in a modular structure, thereby reducing power losses of electronic components of the circuit, thus ensuring better analysis while enhancing efficiency and performance, thereby reducing design cost as well as being an integral part of hot swap features. Modules are stacked in parallel at the output for applications that increase the power rating. The proposed model structure of the Input Series Output Parallel (ISOP) module is selected for analysis under both steady and dynamic performance. The areas concentrated and explored in this research of the proposed configuration topology with considering voltage transient spikes and power loses. The circuit is simulated using PSIM Powersimtech with clearly state and emphasizing the modularity and transistors switching. The experiment has been conducted using Arduino Mega board to generate PWM and reduce the cost of the module. The result obtained from the two module using four transistor forward configuration shows the output voltage levels for different duty cycle values. Three value of duty cycle are determined by setting the duty cycle to be at 40% as the benchmark. Then, the duty cycle is set to 30%, 50% and 75%, which is later compared to the benchmark duty cycle, giving the output as expected accordingly. Depending on the switching frequency, the duty cycle and the input voltage, the output voltage will be valid as long as the duty cycle is set exactly at 50%. The current spikes and the output voltage stability are investigated by first determining the full bridge DC-DC converter topology. It shows that by increasing the switching frequency to 10 kHz and keeping the duty cycle to be at 50%, will produce less overshoot and system efficiency of 95% based on the simulation and measurement of the time taken for the output voltage to be at 30% overshot voltage. The input voltage is set to be at 48 V resulting best stability of the two modules connecting in series at the input. The effect of the switching frequency on the output will be optimized as long as the value of the duty cycle is set at 50% which then will reduce the spikes and hence achieving the objectives of this research, but however at the same time increasing the frequency at high level will reduce the output voltage and hence it need control strategy to get maximum power efficiency.

# خلاصة البحث


لقد تمت محاكاة نوذج واحد من وحدات المحول الخلفي back converter باستخدام بنية رباعية الترانزستور. المحول المخفض للجهد بخطوة ١: N هو مكون أساسي يعمل على عزل وحماية المكونات بين المدخل والمخرج. ركبت الترانزستورات مع الصمام الثنائي مع المحافظة على الملف محميا من الشرارات الكهربائية و فقدان الطاقة المرتفع. هذا التصميم يمكن استخدامه في بناء النوذج لتقليل فقدان الطاقة من المكونات الإلكترونية للدائرة، وبالتالي ضمان تحليل أفضل مع تعزيز الكفاءة والأداء، وكذا تقليل تكلفة التصميم. بالإضافة إلى كونها جزءًا لا يتجزأ من ميزات المبادلة الساخنة.

في هذا البحث يتم تكديس الوحدات بشكل متوازٍ عند المخرج و ذلك للتطبيقات التي تتطلب طاقة عالية. تم اختيار النموذج ISOP للتحليل، تحت كل من الأداء الثابت والديناميكي. في النموذج المقترح، تركب الوحدات بشكل متتالٍ عند المدخل، متوازٍ عند المخرج. في هذه الدراسة، تمّ التركيز على النموذج البنائي المقترح مع الأخذ في الأعتبار فقدان الجهد العابر وفقدان الطاقة. تمت محاكاة الدائرة باستخدام PSIM Powersimtech مع التأكيد على البناء الهيكلي المكون من وحدات بنيوية، و تبديل الترانزستورات. تم إجراء التجربة باستخدام لوحة Arduino Mega لإنشاء PWM وتقليل تكلفة الوحدة.

تمّ تسجيل مستويات جهد الإخراج من وحدتين بنيويتين باستخدام أربعة ترانزستورات ذات التكوين الأمامي، لقيم دورة العمل المختلفة. وقد تمّ تحديد ثلاثة قيم مختلفة لدورة العمل، ٣٠٪، ٥٠٪ و ٧٥٪ ، بالاضافة الى القيمة المرجعية لها، ألا وهي ٤٠٪.

أظهرت النتائج أنه واعتمادًا على تردد التحويل ودورة التشغيل وفرق الجهد في المدخل، سيكون جهد الخرج ساريًا طالما كانت دورة التشغيل تمامًا عند ٥٠٪. سجلت النتائج أولا بتحديد بناء هيكلي ذا تحويل لتيار مستمر بالكامل. في هذا النوذج الهيكلي، تبين أنه بزيادة تردد التحويل إلى ١٠ كيلوهرتز والحفاظ على دورة التشغيل بنسبة ٥٠٪ يؤدي إلى تقليل فقدان الجهد ورفع كفاءة النظام الى ٩٥٪. وذلك بناءً على المحاكاة وقياس الوقت المستغرق في جهد الخرج ليكون ٣٠٪ من الجهد الزائد.

ضبط جهد المدخل ليكون عند ٤٨ فولت، مما أدى الى استقرار أفضل للوحدتين المتصلتين بالتتالي عند المدخل. لوحظ تحسن تأثير تردد التحويل على المخرج طالما كانت قيمة دورة التشغيل عند ٥٠٪، مما أدى الى التقليل من القوس الكهربائي. لكن في نفس الوقت زيادة التردد زيادة كبيرة يؤدي الى التخفيض من جهد الخرج، وبالتالي فالأمر يحتاج إلى إستراتيجية للتحكم لضمان الحصول على أقصى كفاءة للطاقة.

# APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Electronics Engineering).

…………………………………..
Sheroz Khan
Supervisor

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Mohd Shahrin Bin Abu Hanifah
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Electronics Engineering).

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Erry Yulian Triblas Adesta
Dean, Kulliyyah of Engineering

# DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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*I dedicate this research work to my beloved parents, wife, kids, siblings and the ummah…*

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In the Name of Allah, The Most Beneficent, The Most Merciful

The most important acknowledge is to our Lord Most Merciful Most Wise by whose mercy we were able to begin this project, His Mercy is such that unworthy slaves like ourselves are given the ability to work in His cause through which we can remember Him and be grateful towards all He has given us. May Allah accept our humble project as an effort to remember and thank him.

It is my utmost pleasure to dedicate this work to my dear parents, Mr. Guerras Mohammed and Mrs. Aouchett Ziloukha, my wife Bahaz Aicha, my kids Rihane and Abderrahim, and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| EV | Electric Vehicle |
| RES | Renewable Energy System |
| DG | Distributed Generation |
| IPOS | Input Parallel Output Series |
| IPOP | Input Parallel Output Parallel |
| ISOS | Input Series Output Series |
| ISOP | Input Series Output Parallel |
| FTF | Four Transistors Forward |
| DC-DC | Direct Current to Direct Current |
| AC | Alternating Current |
| PWM | Pulse Width Modulation |
| IGBT | Integrated Gate Bi-polar Transistor |
| CAD | Computer Aided Design |
| IVS | Input Voltage Sharing |
| ICS | Input Current Sharing |
| OVS | Output Voltage Sharing |
| OCS | Output Current Sharing |
| FB | Full Bridge |

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND

Researchers had been focusing for decades to get clean (green) energy from renewable sources such as: solar, wind and vibration; thus leading to decrease of energy cost and minimizes the side effects of conventional energy to the environment. Electricity in conventional form is mostly produced from fossil fuel, hydro or nuclear, and in most of the cases the sources are far away from consumption places where this energy is consumed. Then, transmission lines carry the electricity over long distances utilizing high voltage (132 kV, 33 kV, 11 kV) cables. Finally, substation step down the voltage through transformers before the energy ultimately reaches the actual consumers as shown in Figure 1-1.

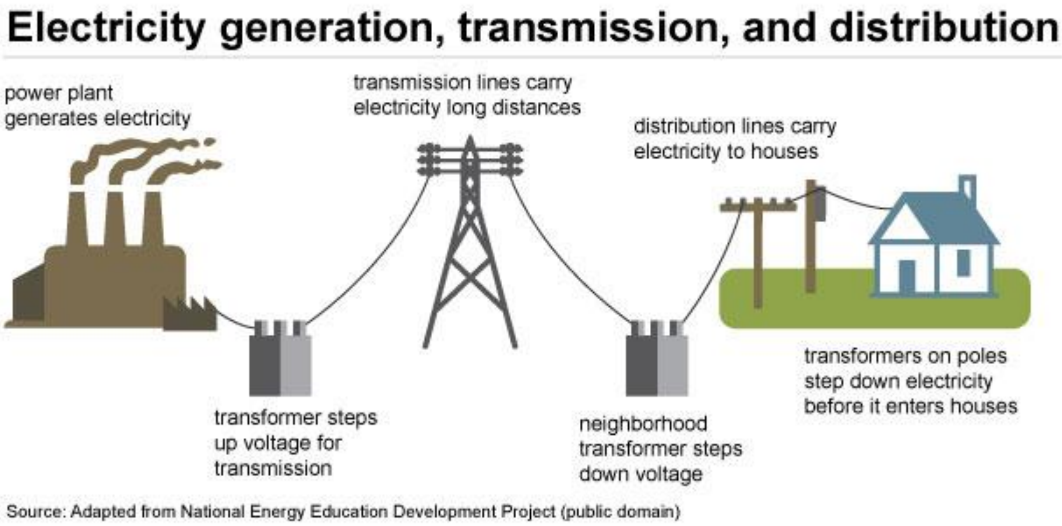


Figure 1-1 Conventional Power Production, Transmission and Distribution
Source (*https://www.eia.gov/Energyexplained/index.cfm?page=electricity_delivery*)

The electric energy needed in Zone A (for example, urban area) is related to the generating station that located in another Zone B (let's call it, area B), which is far away by hundreds of kilometers, named top-down centralized technique—most of the time is costly and with complicated operational inflexibility. This has resulted into having a network composed of pylons for transporting the energy over long distances passing sometimes over crowded urban cities populated by distribution substations, producing many reasons of public concern. In addition, it results into great power losses in transmission cables due to current and wire resistivity, or due to environmental contamination in the form of dust, moisture and so on and thermal radiation. In reality, with the aging of actual energy system from source to substations, natural disasters such as storms, thunderbolts, floods and hurricanes are affecting the whole system of power generation, transmission and distribution - all those evidence are strong factor facing electricity to be solved. When it comes to talk about the alternative renewable energy, the conventional grid of top-down becoming a bottleneck for further development.

In the developing countries, providing electricity to the rural areas is one of the priorities from enterprising projects viewpoint. (When it comes to the cost as the main reason to determine what type of sources to use, using solar panels as alternative sources of energy at homes with electric cars in the future to lower the energy consumption especially in the peak hours, thus leading us to create micro-grid network in the rural areas or in far off places). However, the general trend in the developed countries is moving toward systems that are more flexible in time and distribution, thus conduct to decrease the total peak consumption and hence leading to more permanent energy resource.

In fact, adding generators and new units is supported by newly developed technologies of those systems such as solar panel, fuel cell and wind turbine, etc. Those alternative resources are becoming attractive research areas these days especially in form of Distributed Generation (DG) to produce electricity in areas close to where energy is needed for consumption, and hence to make it available to the distribution system. The deployment of renewable energy based Distributed Generation systems on wide scale can contribute to improve and reliable energy supply, increases in the energy supply diversity, reducing fuel associated pollution risks and long distance electrical transmission losses.

Generally, DG system is a small-scale generator, which is located in a place of source for supplying an existing network near where to exploit. Basically, there are two types of sources used for DG purpose: wind and solar. These sources are using their technologies, which are related to the conventional and non-conventional generator (Ackermann et al, 2001; Gudimetla et al, 2012; Lopes et al, 2007; Yadav & Srivastava, 2014). DG Renewable energy sources capacity-wise are listed in Table 1-1. (Mahmoud et al, 2015).

Table 1-1 Technologies for DG

| **Technology** | **Typical available size per module** |
|---|---|
| Wind turbine | 200 Watt – 3 MW |
| Micro-Turbines | 35 kW – 1 MW |
| Combined cycle gas T. | 35 – 400 MW |
| Internal combustion engines | 5 kW – 10 MW |
| Combustion turbine | 1 – 250 MW |
| Small hydro | 1 – 100 MW |
| Micro hydro | 25 kW – 1 MW |
| Photovoltaic arrays | 20 Watt – 100kW |
| Solar thermal, central receive | 1 - 10 MW |
| Solar thermal, Lutz system | 10 – 80 MW |
| Biomass, e.g. based on gasification | 100 kW – 20 MW |
| Fuel cells, acid | 200 kW – 2 MW |
| Fuel cells, molten carbonate | 250 kW – 2 MW |
| Fuel cells, solid oxide | 250 kW – 5 MW |
| Geothermal | 5 – 100 MW |
| Ocean energy | 100 kW – 1 MW |
| Battery storage | 500 kW – 5 MW |

Using DG System for power generation has many advantages, such as: reducing power losses occurring in the transportation lines, better stability and reliability of the output power energy (Yadav & Srivastava, 2014).

The energy extracted from the sun is one of the competitor next to wind energy. Based on research works, it is expected that usage of photovoltaic (PV) energy will increase up to 20-30% by the end of 2050 (Beetz, 2015).

Photovoltaic panels produce DC energy, which does not remain ideally constant from hour to hour of the day, depending on the sunshine or other reasons, and hence it needs some conditioning before storage in order to connect to main AC supply network distribution system. For both situations, the energy has to be regulated to avoid any possible battery over-charging. Similarly, the DC source has to be good DC (100%) before converting it into AC for grid-connected system, requiring synchronization in terms of frequency, amplitude and phase. Moreover, transferring power into sine wave of 50 Hz (or 60 Hz) is an important conversion phase, thus needing Renewable Energy Sources (RES) to use multi-level inverters operated by PWM of required switching frequency approach. Every task requires series of equipment and material linked to each other before PV-panels can be connected to the network. The worldwide energy demand is increasing dramatically facing environmental pollution, renewable or clean energy attract researchers recently, among which, solar power is extraordinary promising as it is featured with purity, nature friendly and sustainability. However, the solar panels still suffer the drawback of low conversion efficiency. Therefore, it is of importance to figure out solutions as to improving the whole system efficiency.

## 1.2 PROBLEM STATEMENT AND DEFINITIONS

DC-DC converters are widely demanded for electrical applications requiring isolation between the input and the output such as photovoltaic applications. A general modular structure for the Input-Series Output-Parallel (ISOP) design is composed of DC–DC converters connected in a modular structure. High frequency strategy integrated with convenient electronic design has the ability to mitigate current spike among the cells. This study is necessary to increase the power efficiency and the reliability of DC-DC converters in high-input voltage/low output-voltage applications such as photovoltaic applications and feeding with electric supply appliances and equipment for use on ships

However, power loses among the modules, unit instability and limited power delivery is a big challenge facing DC-DC converters, due to high switching frequency producing current spikes, affecting the total power efficiency. The simulation for the ISOP by using the CAD Tools (i.e. National Instrument Multisim, Powersimtech PSIM and OrCAD Pspice) will state clearly and emphasizing on the modularity and the switching transistor. The results obtained will be compared to the benchmarking paper, which then later the investigation on the voltage spike and the effect of switching frequency on the output waveform will be carried out in order to mitigate the spike and energy loss.

## 1.3 RESEARCH OBJECTIVES

Having considered the open research issues, the research objectives are listed as below:

1. To design a block diagram of the DC-DC Converter highlighting module structure and the switching transistor.
2. To simulate using CAD tools and realize the circuit experimentally comparing the resulting plots to results in the reported benchmark paper.

3. To investigate the effect of changing duty cycle, voltage transient spike and switching frequency on the output of DC-DC converter.

## 1.4 RESEARCH METHODOLOGY

A general review on DC-DC converter for Input Series Output Parallel connected in modular configuration is conducted. The acquisition of materials, which are related to ISOP Configuration, is important. (By utilizing some CAD software such as National Instrument Multisim, OrCAD Pspice and Powersimtech PSIM for development of simulation is done). The realization of ISOP DC-DC converter with suitable electronic components is carried in an experiment as same with configuration of the simulation. Comparison and study of the voltage spikes, the effect of changing the duty cycle and the switching frequency, is conducted.

Design to simulate an ultra-low power DC-DC converter, employment of suitable component circuit, eliminating unwanted high current pin. Examine the performance of the proposed prototype and the total module: study the power balance in order to address the power loses. Design and simulate the conditioning circuit to balance the power. Test the performance of the total prototype by connecting the modules in input-series output-parallel and optimize the area of the circuit. Implement the designed circuit and analyzing the experimental results. The sequential design will follow the block diagram as shown in Figure 1-2.

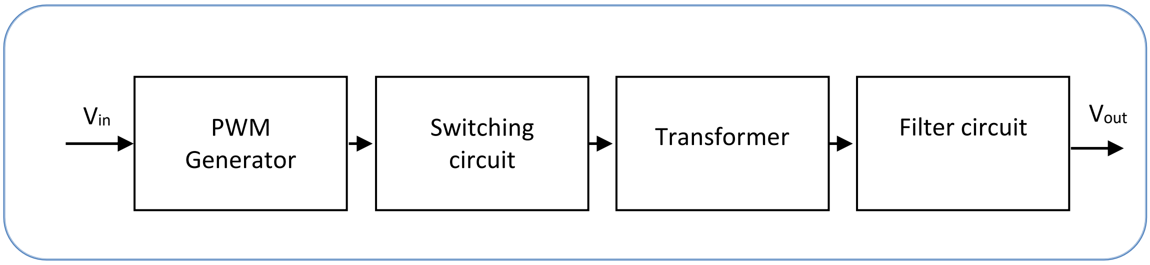


Figure 1-2: Block diagram of the DC-DC converter

The DC-DC converter is composed of four main elements: Pulse Width Modulation (PWM), switching circuit, transformer and filter/rectification circuit. Our principal focus on design methodology that can be implemented to obtain the lowest power loses under different input voltage and output voltage by varying switching frequency controlled by PWM Generator from Arduino Mega.

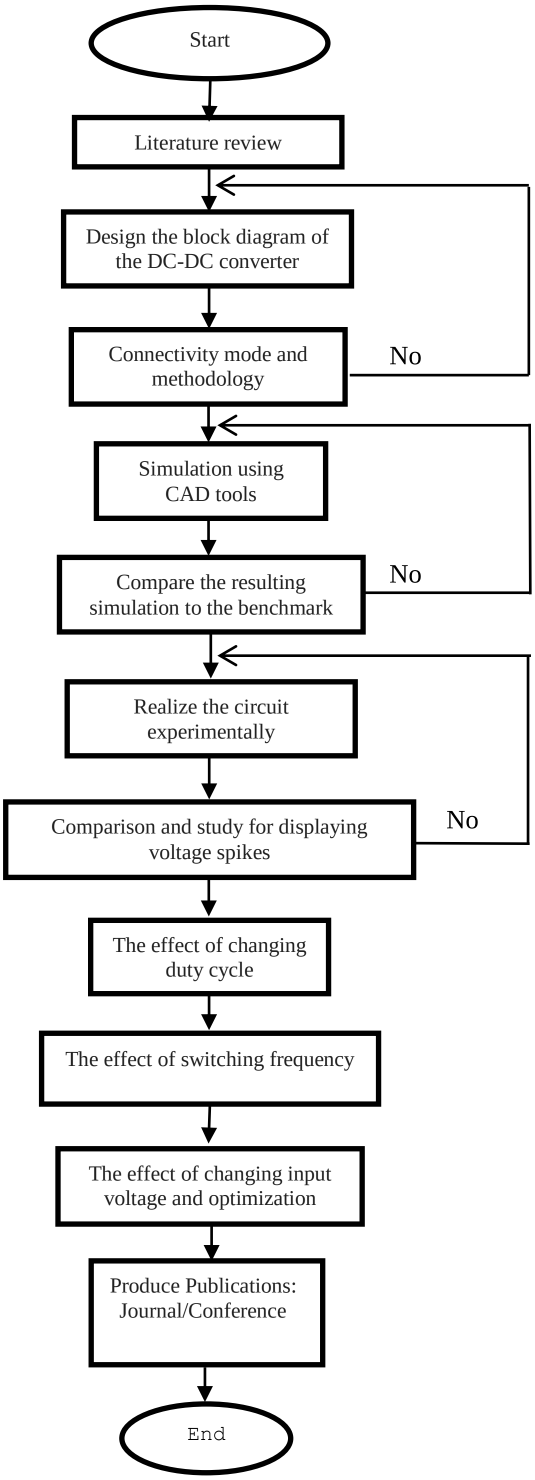


Figure 1-3 The process flow chart of Research methodology showing research activities

### 1.5 DISSERTATION OUTLINE

Chapter 1 is an introductory part of the whole work, which has discussed the background and basic review of latest methods in distributed grids and multi-level grid-tied inverters. Hence, preparing a solid base of this study is essential for describing the problems, its statement, definition and objectives of the work.

Chapter 2 presents detailed literature review of DC-DC converters, modular connectivity, various techniques utilized in modular configuration for utility of network connectivity, focusing on ISOP configuration, including, spikes mitigation, response of converter to unusual conditions.

Chapter 3 concentrates on the methodology used, showing simulation of DC-DC converter in a modular structure ISOP configuration for utility application. Simulation results are shown to mention how effectively ISOP works for getting stable DC output voltage. Experiment has been conducted in order to experimentally validate the simulation results.

Chapter 4 gives an elaborated analysis and discussion result of the simulation and experiment, the creation and minimization of spikes, and resulting power loss.

Chapter 5 concludes thesis to giving conclusion and future recommendations of this research thesis by highlighting the outcome of this research. This chapter also discusses the limitations faced by giving recommendation for future work.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter presents an overview of how multiple-output DC levels can be made available. This is done through the use of connecting in different combination such as series or parallel DC-DC converters. A background of such converters is followed by a critical review of the articles consisting of series connections at the inputs for intended applications. This is sequenced by a similar review of the articles reporting research on such connectivity. Preparing a base for our work on the phenomenon of spikes generation and control strategy for mitigating such spikes.

## 2.2 MODULAR DC-DC CONVERTERS

At present, fabrication industry of power and Renewable Energy System (RES) demand multi-level DC-DC converters for output utilization in inverters. It consists of connecting number of DC-DC converters in modular structure (series or parallel). In instrumentation electronic systems, power-transformers are widely used in power equipment especially in instrumentation electronic systems, requiring the uses of converting voltage from one level to another level using DC-to-DC and AC-to-AC converters. Their applications available in instrumentation electronics and renewable energy system. The area of converters has been attracting the attention of researchers in variety of applications recently. It depends on the application of the converter that determines which type to use. Some of the application need low output voltage high current while others require high output voltage low current. (Wang et. al., 2017;