DESIGN OF A PHASE SYNCHRONOUS INVERTER FOR MICRO-GRID SYSTEMS

BY

TAWFIKUR RAHMAN

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

Kulliyyah of Engineering
International Islamic University Malaysia

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ABSTRACT

Nowadays, micro-grid power system is becoming popular for utilizing renewable energy. Generally, electronic inverter and switching system are used to convert the source's DC supply into the AC supply for the micro-grid line. However, the converted AC supply suffers many problems such as, poor quality of waveform, synchronization problem, high unexpected voltage, etc. The power quality is a significant concern in all sectors that are utilizing electrical power. Therefore, the challenges are to make the AC waveform free from higher harmonic distortion and synchronized with the grid line frequency to improve the power quality and efficiency of the inverter. A three phase, phase synchronous inverter (PSI) circuit has been designed for the micro-grid system. Lowpass LC filters are utilized to reduce the higher harmonic in both input and output sides in the design. Switching and logic networks have generated the pulse width modulation (PWM) signal and a zero crossing sampling is used to precisely synchronize with grid line frequency. A balanced resistive load of star configuration (RL = 40 Ω), and also the input DC voltage ± 35V are considered in this design. The overall conversion efficiency of the PSI is 96.1% and phase synchronization error for each phase is about 0.50 degrees. The results show that the design has better performance and can be utilized efficiently in the micro-grid system.

ملخص

صار استخدام الشبكة الصغرى لنظام الطاقة "Microgrid Power System" بهدف استغلال الطاقة المتجددة، رائجا في الوقت الحاضر. عادة ما يستخدم العاكس الإلكتروني ونظام التبديل لتحويل الإمداد الثابت DC من المصدر إلى تيار متردد AC لامداد خط الشبكة الصغرى. إلا أن إمدادات التيار المتردد AC المتحول تعاني العديد من المشاكل، مثل تدني جودة شكل الموجة، مشاكل في التزامن و الجهد الكهربائي العالي غير المتوقع وغيرها. إن نوعية الطاقة المنتجة من الاهمية بمكان لدى جميع القطاعات التي تستخدم الطاقة الكهربائية. ولذلك، فإن التحدي هو محاولة جعل الموجة AC خالية من التشوه التوافقي العالي وتزامن ذلك مع تردد خط الشبكة لتحسين نوعية الطاقة وكفاءة العاكس. في هذا البحث، تمّ تصميم عاكس طوري متزامن ثلاثي الطور "Three phase, Phase Synchronous Inverter"، لنظام الشبكة الصغرى. في التصميم، أستخدم فلتر الترددات المتخفضة LC "LC low Pass Filter" للتقليل من التوافق العالي في كل من المدخلات والمخرجات. كما قد ولّد نظام العاكس الإلكتروني ومنطقية الشبكة تحويرا في عرض نبض الذبذبات "Pulse Width Modulation PWM", واستخدم معبر عينة صفري "Zero crossing sampling" لقياس ضبط دقة التزامن مع تردد خط الشبكة. كما أستخدم في هذا التصميم مقاومة حمل التوازن لترتيب النجمة Star Configuration(RL = 40 Ω)، وكذلك الجهد الثابت 35V DC ±. أظهرت النتائج أنّ كفاءة التحويل ل PSI هي 96.1% , و درجة الخطأ لكل مرحلة من مراحل التزامن حوالي 0.50 درجة. أكدت هذه النتائج أن للتصميم أداء جيد ويمكن استخدامه بكفاءة في نظام الشبكة الصغرى.

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 thesis for the degree of Master of Science (Electronics Engineering).

....
Muhammad Ibn Ibrahimy
Supervisor

....
S.M.A Motakabber
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 thesis for the degree of Master of Science (Electronics Engineering).

....
A. H. M. Zahirul Alam
Internal Examiner

....
Musse Mohamud Ahmed
Internal Examiner

This thesis has submitted to the Department of Electrical and Computer Engineering and is accepted as a fulfillment of the requirement for the degree of Master of Science (Electronics Engineering).

....
Teddy Surya Gunawan
Head, Department of Electrical and Computer Engineering

This thesis has submitted to the Kulliyyah of Engineering and is accepted as a fulfillment of the requirement for the degree of Master of Science (Electronics Engineering).

....
Md Noor Bin Salleh
Dean, Kulliyyah of Engineering

DECLARATION

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LIST OF ABBREVIATIONS

AC	Alternating Current
ASCI	Auto-Sequential Commutated Inverter
CSI	Current Source Inverters
DC	Direct Current
DR	Demand Response
DCMLI	Diode Clamped Multilevel Inverter
DTSRE-PLL	Decoupled Twice Synchronous Reference Edifice PLL
FFT	Fast Fourier Transform
GTO	Gate Turn-Off Thyristor
IGBT	Insulated-Gate Bipolar Transistor
IEEE	Institute of Electrical and Electronics Engineers
L	Inductance
LC	Inductance Capacitance
LCL	Inductance Capacitance Inductance
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
PSI	Phase Synchronous Inverters
PWM	Pulse-Width-Modulated
PFC	Power Factor Correction
PLL	Phase-Locked-Loop
PI	Proportional-Integral
PV	Photovoltaic
RE	Renewable Energy

SE	Sustainable Energy
STPWM	Sine-Triangle Pulse Width Modulation
SRE-PLL	Synchronous Reference Edifice PLL
THD	Total Harmonic Distortion
VSI	Voltage Source Inverters
ZCS	Zero-Current Switching
SRS	Synchronous Reference Structure
NRS	Natural Reference Structure
WT	Wind Turbine
TWT	Tidal Wave Turbine
UTS	Uninterruptible Power Supply
TLI	Transformer Less Inverter
SRS	Stationary Reference Structure

LIST OF SYMBOLS

A	Amp
a_0	Amplitude of the n^{th} Harmonic Component
a_n	Amplitude of the Cosine Wave
b_n	Amplitude of the Sine Wave
C	Capacitor
D	Diode
V_r	Regulation Voltage
f	Micro-grid Frequency
f_s	Switching Frequency of the Inverter
f_{res}	Resonance Frequency
$f(v)$	DC Voltage Function
G	Gate
H	Henry
Hz	Hertz
I	Current
I_a	Line Current
$I_{ab(p-p)}$	Peak to Peak Current
I_{abc}	Three Phase Current
ΔI_{max}	Estimated Inductor Ripple Current
I_{out}	Output Current
kHz	Kilohertz
L	Inductor
m	Modulation Index
n	Harmonic Number (Only Odd Values of n are Required)
N	Neutral Point
0	Mutual Point
P	Power
P	Actual Power
Q	Reactive Power
R	Resistance

S	Switch
μH	Microhenry
μF	Microfarads
V	Voltage
V_a	Line Voltage
V_c	Carrier Signal
V_r	Reference Signal
V_n	Magnitude of the Nth Harmonic
V_i	Major Harmonic
V_{DC}	DC Voltage
V_{in}	Input Voltage
V_{out}	Output Voltage
$V_{ab(p-p)}$	Peak to Peak Voltage
V_{abc}	Three Phase Voltage
V_{AC}	AC Voltage
ΔV_{out}	Desired Output Voltage Ripple
V_{out}	Desired Average Output Voltage
V_a	Line Voltage
V_{oa}	Micro-grid Voltage
W	Watt
Ω	Ohm
3φ	Three Phase

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

With the world energy demand increasing at an exponential rate, the search for energy sources other than fossil fuels and gases is no more an extravagance. In spite of the fact that the fossil fuels and gases offer a short-term solution for this energy crisis, but they contribute CO_2 and other greenhouse gases, which are not environmentally friendly. Renewable energy can be a long term solution. However, sometimes a loss is involved in conversion into electric energy from renewable energy makes it useless. This makes a scope of research in power electronics and relevant engineering sectors by utilizing the renewable energy properly and efficiently.

The renewable energy, solar, wind, tidal wave, etc., are used as input sources for phase synchronous inverter (PSI) to be converted into AC electric energy for micro-grid systems. The sun is an unlimited energy source for renewable energy; the photovoltaic (PV) cell can be used to convert the solar energy into electrical energy directly. However the energy generates by PV cell must use instantly otherwise there is needed storage battery systems which are expensive, bulky, and also need regularly maintains. To overcome the battery storage systems complicity, nowadays many PV systems are connected through common local networks which are known as a micro-grid system. Before connecting the micro-grid system, DC generated by PV cell is converted into AC using electric switching and inverter system. The efficiency and usefulness of the micro-grid most depend on electric switching and inverter system. There are still some problems in this system due to high frequency switching, higher harmonic distortion, and phase matching etc. which makes the system performance poor. Many researchers are trying to improve the system efficiency by introducing new switching technologies and algorithms.

1.2 PROBLEM STATEMENT

Micro-grid PSI generates a small amount of output power. Several losses in the power inverting process are not desirable whereas powering to the load circuit. There are many problems in the power inversion by inverter; the main problems are focused as:

- High switching frequency losses in the inverter circuit.
- Switching controller losses in the inverter.
- Higher frequency harmonic distortions.
- Phase synchronous problem during feeding the micro-grid system.

1.3 RESEARCH OBJECTIVES

The objective of the research is to improve the efficiency of the micro-grid system by improving switching mechanism in the inverter for PV cell. To achieve the final goal, following objectives are considered in this research work:

1. To design a low frequency switching inverter circuit system for the micro-grid system.
2. To optimize the switching parameters of the inverter through simulation.
3. To minimize the higher order harmonic frequency distortion of the inverter.
4. To improve the phase synchronization between inverter and micro-grid system.
5. To assess the effectiveness of the inverter by comparing with others works.

1.4 RESEARCH METHODOLOGY

Figure 1.1 shows the flow diagram of the methodology used for this research. In the literature review, previously existing methods are illustrated to analyze and investigate the conversion systems to be utilized. A low frequency switching system inverter circuit has been designed for micro-grid system using MATLAB2014a. The switching parameters have been optimized and verified the performance of the inverter through simulation. A lowpass filter has been used as both input and the output sides of the inverter for minimizing the higher order harmonic frequencies of the system. The zero-crossing switching method has been used for the improvement of phase synchronization between inverter and micro-grid systems. The simulated results of the proposed PSI design have been compared with other research.

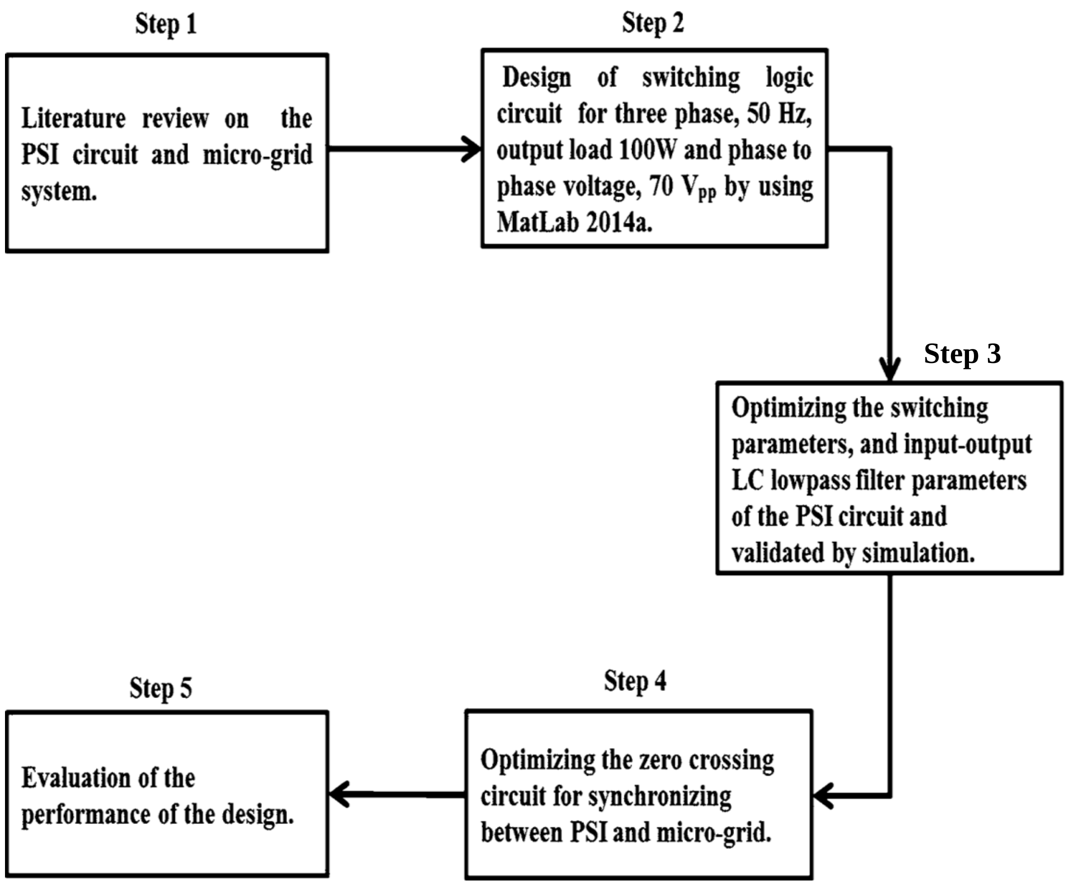

Figure 1.1: Research Methodology Flow Chart

1.5 RESEARCH SCOPE

The phase synchronous inverter design is composed of duel DC supply source, electronic switching circuit and controller, lowpass filters and synchronization control circuit. There are many challenges involved in DC to AC inverter, micro-grid and coupling between them. However, the scope of the research work is limited as follows:

- The research work includes designing of low frequency switching logic circuit of the inverter.
- Design of lowpass filters for the systems to reduce the higher order harmonic frequency distortion.
- Design of zero crossing circuit for phase synchronization between inverter and micro-grid system.
- The simulation results have been compared with other relevant works.

1.6 THESIS ORGANIZATION

The thesis paper has been organized as follows:

Chapter one: Introductory of the PSI design that follows the sequence of overview, problem statement, research objectives, and thesis outline are described.

Chapter Two: A PSI basic and therefore the theoretical related to the inverting method have been studied here in chapter. Literature view has introduced in this chapter, which is concerning diverse PSI circuit phenomena. At the ends of this chapter, it has presented different technique of the PSI system in the tabular form to bring the justification of the research study.

Chapter Three: In this chapter includes, it presents a research methodology in where describes the development of the proposed design. The following step is to simulate

PSI parameters. Simulate the proposed outline utilizing MATLAB2014a. Finally, the proposed streamlined configuration has executed in fittings to check with the simulation result.

Chapter Four: Simulated and analytical results have been presented in this chapter.

Chapter Five: This chapter has concluded the analysis related to the findings of this research work and also by recommendation for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter begins with a brief definition of inverter and micro-grid system. A detailed description of inverters and brief history of the techniques of micro-grid systems around the word has been discussed. Interfacing circuits of the inverter devices have been reviewed. A number of PSI developed by other researchers are also analyzed and discussed thoroughly. The advantages and limitations of different techniques are carefully evaluated to strengthen the understanding about the topic. A tabular presentation of the literature review is also highlighted at the end of the chapter to justify the features of the PSIs.

2.2 DC AND AC TRANSFORMATION

Nowadays, there are two types of transmission, which are formerly used in the micro-grid system, DC and AC. Each of them has its own advantages and particular preferences. Basically the DC power is used in a steady voltage across a load. A common source of storage battery is used in DC transmission to deliver the electrical power from one end to the other end. It has the capability to provide both low and high constant voltage.

Traditionally, the DC power line was the basic form of electricity to be commercially transmitted by Thomas Alva Edison. Nevertheless, this electricity had low voltage, because of the incapability to boost DC voltage at the time, and thus it had unable to transmit power terminated long distances (Rudervall et al., 2000). On the other hand, electricity had generated from power plants and distributed to the domestic users through AC voltage. AC, dissimilar DC, oscillates between two voltage values at a stated frequency, and it's continually altering. This altering in the voltage and current makes it simple to step up or step down transmission process. Transformers are used to step up or step down for long distance and high voltage transmission conditions are essential. Electrical DC to AC inverters and AC to DC converters countenance people this freedom in transferring electrical power between the two.

2.3 MICRO-GRID SYSTEM

A micro-grid is confined as an open system which interconnects between transmission and distribution electrical energy systems, such as wind power, fuel generator set and solar energy with storage strategy like flywheels, batteries and electric capacitors rely on both high and low voltages (Hatziargyriou et al., 2006). An electrical distribution energy system consists of energy storage systems, local loads and distributed generators that can work on building or main grid-connected modes. A simple micro-grid design is shown in Figure 2.2. This micro-grid consists of a group of radial feeders is generally used in the transmission and distribution electrical energy into domestic and small cottage industries in a rural area and the island. There are sensitive-load feeders and non-sensitive-load feeder in a micro-grid system. The sensitive-load feeders have to continuously supply the energy in grid line; therefore every feeder connected with the system should have a minimum number of micro sources to fulfil the inner feeder load. On the other hand, the non-sensitive-load feeder is used to shut down if there is a power quality problem on the micro-grid, utility or a disturbance (Lasseter, 2002) and (Robert Lasseter et al., 2002).

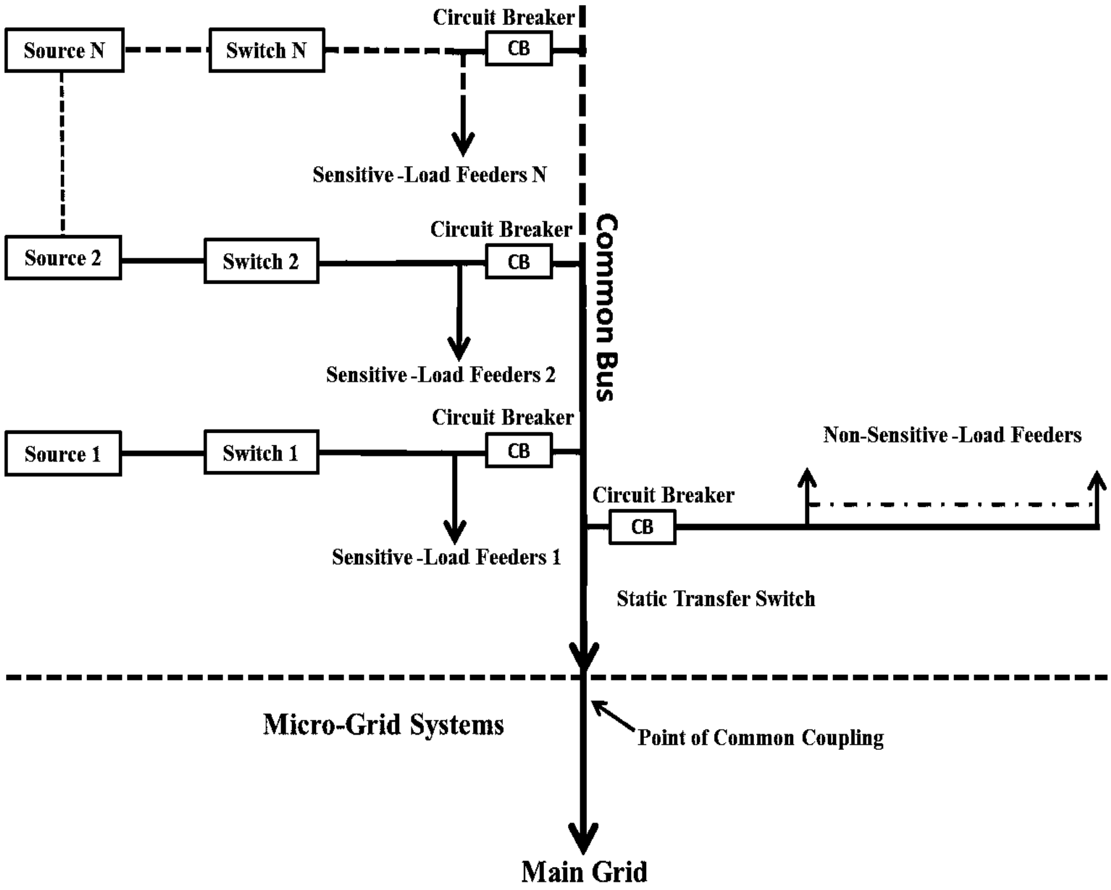

Figure 2.2: A Simple Microgrid Design

A controller is used to monitor and insure the connectivity of the sensitive and non-sensitive load feeders and the operating points after the processes are satisfied (Zamora et al., 2010). Finally the micro-grid system connects to main grid via the static transfer switch and the point of common coupling (PCC).

2.3.1 MICRO-GRID SOURCES

Generally, renewable energy systems such as solar cell, wind turbine, tidal energy converter, etc. are connected with the micro-grid system. Micro-grid source, then again gradually substitutes itself and is normally available throughout an unremitting source (Boyle, 2004). Renewable energy source, sunlight can be directly converted into DC electrical power by using solar panel or somehow collect the solar energy to convert it into heat and generate steam to operate an electrical generator (Hassaine et