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CONSTANT LOCK CIRCUIT FOR DC MICRO-GRID SYSTEM

ASAAD ABDULJABBAR MOHAMMED

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By

ASAAD ABDULJABBAR MOHAMMED

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

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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ASAAD ABDULJABBAR MOHAMMED

May 2017

Chairman : Associate Professor Wan Zuha bin Wan Hasan, PhD
Faculty : Engineering

The escalating rates of fossil fuels have enforced researchers to seek renewable energy systems. Power generation from fossil fuels may not be possible for very long as they are depleting. Recently, the researchers have been interested in the techniques of exploiting renewable energy sources such as solar, hydro, wind, etc. The energy conversion from water flow streams to electrical energy via Pico turbine generator is the only solution. The only disadvantage of hydro energy is the seasonal variations when it cannot generate enough power to meet the load demand. Also, the changing of water flow rates causes a variable output voltage. In this renewable system, continuous power flow to meet load demand is not possible. For integration of REs to optimal results, an excellent option for energy production can be obtained by using a micro-grid system by combining the renewable energy source with a backup source such as a utility grid.

Therefore, this thesis develops DC micro-grid control strategies based on providing continuous load power regardless of the generated power and load demand. The comparison between generated power and load consumption leads the monitoring system to determine the proper mode that the system should follow. Three modes come into view during DC micro-grid operations. These operational scenarios are the stand-alone scenario, grid scenario, and feedback scenario.

A simulation of the DC micro-grid in order to provide a continuous load demand based on using a CLC which is keeping the DC link at a 24v constant value is designed. Due to the ongoing interaction between the fluctuating weather conditions and load demands in a DC micro-grid, each source needs to be in a highly precise control regulation to link with the DC link node. So,it requires voltage compatibility of all sources associated with the DC link bus for keeping the stability of the DC link at a constant value, Moreover, parallel sources connection for sharing power at a DC

micro-grid have problems such as reverse current, and degradation of power conversion efficiency, due to a slight difference between output voltages. For all the above, there is a need for a new interface block control to deal with these problems.

For this, an algorithm system strategy for utilizing a Constant Lock Circuit in the DC micro-grid aims at maintaining a constant DC link voltage at the desired constant value of 24v to ensure high stability voltage and current without any ripple. Furthermore, it is deemed relevant to give priority to the renewable energy production for supplying load extracting maximum power from the REs. Moreover, it is also necessary to provide an adequate load demand regardless the power generation amount for satisfying an easy connection between two parallel sources for sharing power. On top of that, the power that the load needs from the backup source to meet load demand should be compensated to export the surplus RE power to the backup source.

The models of the DC micro-grid with CLC system are simulated in Proteus8 Professional. Results obtained from simulations have proven that the proposed algorithm system strategy have achieved its aims through keeping constant 24v with percentage error 0.059%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

KAWALAN BEBAN KUASA SISTEM MIKRO-GRID DC MENGGUNAKAN TEKNIK LITAR KUNCI BERTERUSAN

Oleh

ASAAD ABDULJABBAR MOHAMMED

Mei 2017

Pengerusi : Profesor Madya Wan Zuha bin Wan Hasan, PhD
Fakulti : Kejuruteraan

Kenaikan kadar bahan api fosil telah menyebabkan para penyelidik mencari sistem tenaga yang boleh diperbaharui. Penjanaan tenaga daripada bahan api fosil mungkin tidak boleh dilakukan buat masa yang lama kerana ia semakin berkurangan. Baru-baru ini, para penyelidik telah berminat dalam teknik mengeksploitasi sumber-sumber tenaga boleh diperbaharui seperti solar, hidro, angin dan lain-lain. Penukaran tenaga daripada aliran air kepada tenaga elektrik melalui penjana turbin Pico adalah satu-satunya penyelesaian. Kelemahan tunggal tenaga hidro adalah variasi bermusim, apabila ia tidak boleh menjana kuasa yang mencukupi untuk memenuhi permintaan beban. Juga, perubahan kadar aliran air menyebabkan voltan keluaran berubah-ubah. Di dalam sistem yang boleh diperbaharui ini, aliran kuasa yang berterusan untuk memenuhi permintaan beban adalah tidak mungkin. Untuk integrasi tenaga yang boleh diperbaharui ke arah hasil yang optimum, pilihan yang sangat baik untuk pengeluaran tenaga boleh diperolehi dengan menggunakan sistem mikro-grid secara menggabungkan tenaga boleh diperbaharui dengan sumber sandaran seperti grid utiliti. Oleh itu, tesis ini membangunkan strategi kawalan mikro-grid Arus terus berasaskan kepada penyediaan kuasa beban berterusan tanpa mengira kuasa yang dijanakan dan permintaan beban. Perbandingan antara kuasa yang dijanakan dan penggunaan beban membawa sistem pemantauan itu ke arah menentukan mod yang betul yang sistem tersebut perlu ikuti. Tiga mod diperlihatkan semasa operasi mikro-grid Arus terus. Senario-senario operasi ini adalah senario berdiri sendiri, senario grid, dan senario maklum balas.

Suatu simulasi mikro-grid Arus terus untuk menyediakan permintaan beban yang berterusan berasaskan penggunaan litar kunci berterusan yang mengekalkan pautan Arus terus pada nilai yang tetap direka. Oleh kerana interaksi yang sentiasa berlaku antara keadaan cuaca yang berubah-ubah dan permintaan beban di dalam sesuatu

mikro-grid Arus terus, setiap sumber perlu berada dalam pengaturan kawalan yang sangat tepat untuk dihubungkan dengan nod pautan Arus terus tersebut.

Dengan itu, untuk mengekalkan kestabilan pautan Arus terus pada nilai yang malar, adalah diperlukan keserasian voltan semua sumber yang berkaitan dengan bas pautan Arus terus itu. Selain itu, sambungan sumber selari untuk berkongsi kuasa di mikro-grid Arus terus mempunyai masalah seperti arus balikan, dan degradasi kecekapan penukaran kuasa, oleh kerana sedikit perbezaan antara voltan-voltan output. Untuk semua di atas, terdapat keperluan untuk kawalan blok antara muka baru bagi menangani masalah-masalah ini.

Untuk itu, strategi sistem algoritma untuk menggunakan suatu litar kunci berterusan di mikro-grid Arus terus bertujuan untuk mengekalkan secara berterusan voltan pautan Arus terus malar pada nilai 24v yang dikehendaki untuk memastikan kestabilan voltan dan arus yang tinggi tanpa sebarang ombak kecil, mengekstrak kuasa maksimum dari RE apa juga kuasa tersebut, dan memberi keutamaan kepada pengeluaran tenaga boleh diperbaharui untuk membekalkan beban. Ia juga menyediakan permintaan beban yang mencukupi tanpa mengira jumlah penjanaan kuasa, mengadakan sambungan mudah antara dua sumber selari untuk berkongsi kuasa, mengganti kuasa yang beban itu perlukan dari sumber sandaran untuk memenuhi permintaan beban, dan mengeksport kuasa RE lebihan ke sumber sandaran.

Model mikro-grid Arus terus dengan sistem litar kunci berterusan disimulasi melalui Proteus 8 Profesional. Keputusan yang diperolehi daripada simulasi telah membuktikan bahawa strategi sistem algoritma yang dicadangkan telah mencapai matlamat melalui 24v yang malar dengan peratusan ralat 0.059%.

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I certify that a Thesis Examination Committee has met on 26 May 2017 to conduct the final examination of Asaad Abduljabbar Mohammed on his thesis entitled "Constant Lock Circuit for DC Micro-Grid System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Nasri bin Sulaiman, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Amran bin Mohd Radzi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nowshad Amin, PhD
Professor
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 August 2017

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Wan Zuha bin Wan Hasan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Suhaidi B. Shafie, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Hashim b. Hizam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
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Name and Matric No.: Asaad Abduljabbar Mohammed , GS42336

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________
Name of Chairman of Supervisory Committee: Associate Professor Dr. Wan Zuha bin Wan Hasan

Signature: ______________________
Name of Member of Supervisory Committee: Associate Professor Dr. Suhaidi B. Shafie

Signature: ______________________
Name of Member of Supervisory Committee: Associate Professor Dr. Hashim b. Hizam

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LIST OF ABBREVATIONS

EPS	Electric Power System
MGPs	Micro-Grid Power System
MG	Micro-grid
RE	Renewable Energy
PE	Power Electronic
CLC	Constant Lock Circuit
PTG	Pico turbine generator
CLCC	Constant Lock Control Circuit
CSVC1	Current Source Voltage Control
CSVC2	Current Source Voltage Control
SOC	State of Charge
CAN	Controller Area Network
MPPT	Maximum Power Point Tracking
MCC	Magnetically Coupled Converters
ECC	Electrically Coupled Converters
MAS	Multi-Agent Systems

CHAPTER 1

INTRODUCTION

1.1 Research Overview

The global resources of nuclear fuel and fossil are limitated due to the global warming caused by the abundance of CO2 in the atmosphere [1]. Not only that, it is also expensive to carry out the linking of remote areas with master electric grid, especially when the utility national network is not suitably designed for the growing needs of the population and some of them may be damaged by new consumers [95]. For all these reasons, it is necessary to conduct an imperative study for alternative sources of energy to meet any future demands. Renewable energy system (REs) is one of these energies which meets the continuously increasing demands. The REs is connected differently to the electric power system (EPS) depending upon the overall system structures. One of the these structures is a micro-grid power system (MGPs). The MGPs has a fantastic prospect for supplying higher quality and more trustworthy power to end users [96]. The REs can be operated either off-grid style or an on-grid connected style. An off-grid system is defined as standalone power system, which operates independently without a grid support. For providing continuous power to the load, a standalone RES cannot be operated effectively and efficiently in the off-grid system; thus, it is always operated in a grid connected mode to maximize its optimal use and credentials. The fluctuating weather condition, on the other hand, also impacts on the REs output power. So, the mismatch between the RE power and variation in load demands is compensated by a grid. The major important renewable sources are hydropower, sola, biomass, wind, and geothermal.

Hydropower energy is considered as promising power sources which not polluted, free in terms of their availability and is renewable as well. Hydropower plant is classified according to its capacity to large, medium, small, mini, micro, and Pico. Pico power deals with the lower-level production of energy production under a few kilowatts only. It can be made at a relatively cheap cost and applied to small streams. A Pico hydro energy is specified to the process of taking out the potential capacity from water flow. However, due to their unpredictability and weather dependency, the integration of REs to form a hybrid system is an excellent option for energy production [97].

Since a hybrid power system augments the renewable energy sources in DC MG by a grid network or saving system as energy storage, the overall power system can overcome the power load demands. The chief advantage of this architecture is that the power capacity rating of the hybrid system is required to meet load consumption. Major problems of the hybrid methods are concerning to the management and control of the power flow. An uninterrupted dynamic interaction between the load demand consumption and the renewable energy generation can be pushed to enhance the power quality and stability of critical troubles that are not very concerted in traditional power systems. Thus, managing outflow power during the hybrid style is fundamental to guarantee the supplying load demand continuously.

This thesis presents an optimized management strategy for providing continuous power load demand in DC micro-grid DC (MG) power systems by using constant lock circuit (CLC) which keeps the DC link at a constant value. The importance of this study lies in the hybrid system which deals with low RE voltage systems and provides continuous load demand. The DC micro-grid system consists of Pico turbine generator (PTG) to convert the kinetic energy from the hydro flow into electrical energy. The DC –DC also boosts the converter to increase the output voltage to a higher value than input voltage, constant lock circuit CLC holds the DC link node or load voltage at a constant value, CLC controls (CLCC) to ensure fixing a CLC output voltage. The AC-DC converter, on the other hand, converts AC grid voltage to DC required voltage. Current source voltage control (CSVC1) controls the injected power to DC link for meeting load demand. Current source control circuit (CSCC) sets the injected current to meet the load demand at shortage RE generation mode. Moreover, Current source control circuit (CSVC2) and its control for exporting power at generation power is more than the load demand mode.

1.2 Problem Statement

Linking the main electric power system grid to remote areas is very uneconomical to carry out. Moreover, the utility network is not designed to achieve the fast growth of the population needs and may be damaged by new users. Thus, it is not expensive to electrify those areas with a MG by methods of existing RE sources which are available locally. Due to the fast growth of renewable energy and PE technologies, different control strategies and power management systems have been proposed to ensure balancing systems. Therefore, there are many drowbacks such as: fluctuations Voltage which are caused by natural variability of renewable energy resources, and harmonics which are caused by power electronic devices used in renewable energy generation become an important aspect of renewable energy integration. So, these significant technical challenges need to solve for increasing contribution to our modern society [103].

Likewise, the ongoing interaction between fluctuating weather conditions and load demands in DC micro-grid causes instability DC link voltage on constant value. So, it requires an interface unit to face this problem in DC link node for keeping the stability of the DC link at constant value [98].

Similarly, providing continuous power from a RE source which has low electricity generation or operating limits to the load, cannot operate satisfactorily to meet the load demand. Therefore, some additional source or sources are required to compensate this shortage of power [104].

1.3 Research Objectives

Management control system for power flow is an essential part of developing any hybrid power system. The ultimate aim of this investigation is to develop a more robust control algorithm for providing continuous load power. In addition, depending on the new management criteria, a constant lock circuit CLC is used with a control circuit which deals with a change in both power generation and load demand as a major part for fixing DC link to manage and control system with an ability to overcome various changes. The advanced algorithm is designed to optimize the power flow between the renewable power system and local grid as a backup source to satisfy the load requirements by providing with continuous power using a constant lock circuit CLC. Thus, the thesis objectives are:

1. To investigate design and simulate a CLC circuit with stabilized constant voltage.
2. To install the DC link voltage at a constant value to ensure stability and accurate higher flow of energy.
3. To provide sufficient power for loads connected with renewable energy sources in the DC micro-grid system.

1.4 Scope of Research

The focus of this thesis is on developing a power administration of monitoring strategies at a DC micro-grid hybrid system by using a CLC in different modes. The hybrid power system consists of PTG as a REs and utility grid as a non-REs. So, this thesis develops DC micro-grid control strategies for a hybrid system to provide continuous load power regardless of the consumption of power and generation of power. A comparison between load consumption and RE generation power leads the system to monitor and determine the proper mode that the system should follow. Three modes come into view during DC micro-grid operation. These operational scenarios are the stand-alone scenario, grid scenario, and feedback scenario. Thus, a DC micro-grid control strategy is implemented to achieve: fixing DC link voltage despite variable input voltage or changing in load consumption. Furthermore, extracting maximum power from REs, compensating the shortage power from non-REs to meet load demand, exporting the excess power generated from REs to the grid, and protecting the REs from any overload due to load consumption. In order to achieve our aims in this thesis, it will use the following tool: PROTEUS8 professional software which is a tool for simulating, modeling and analyzing electronic control systems.

1.5 Research Contributions

The major contributions of the dissertation can be summarized as:

1. Fixing the DC link node in DC MG system by constant lock circuit CLC which is proposed. The CLC control strategy fixes the DC link voltage at required value without battery or dummy load. The objective of this integrated strategy is to fix the DC link voltage to the specified voltage value

so as to make the power flow process smoothe irrespective of the fluctuating in the generation of power and varying load demand. It also equips DC load with a current which is free of any ripple.

2. The CLC control in a DC MG system is suggested. The CLCC functions to generate a control voltage to CLC to hold the DC link node voltage at a required voltage. Therefore, the target of a CLCC is to monitor the DC link voltage permanently to generate an appropriate control voltage which is applied to CLC for getting the required voltage 24v.
3. The organized control for DC micro-grid system consists of PTG as REs, utility grid, CLC, CLCC, CS, and CSC is proposed for providing enough load demand on the system regardless of the oscillation in odd weather conditions and load demand.
4. Ease of connecting the parallel sources for sharing power in DC micro-grid at grid scenario whatever their voltage is. Therefore, it does not need the precise voltage converter for matching with their voltage. Consequently, consumption power is less.

The notable features of the proposed control strategy are:

- Its provides adequate load power regardless the power generation amount.
- It ensures comfortable design for selecting DC link voltage for any desired value.
- It requires no real time communication link which takes no delay time within the control process.
- It is possible to plug and play.
- It is easy to connect parallel source whatever their voltage is because of the constancy of the DC link node.

1.6 Organization of Thesis

This thesis is structured into the following chapters:

Chapter 1 begins with the research overview which is followed by the problem statement. Scope of research is discussed after that. Research contributions are highlighted before the chapter finsihes in giving the organizational scheme of the thesis.

Chapter 2 focuses on the micro-grid power system concept, micro-grid operation overview. Then it introduces hydropower generation, power electronic system, and DC microgrid strategies developed for this scientific study.

Chapter 3 describes the overall methodology for DC micro-grid system that includes a brief introduction to the power management algorithm, Pico turbine generator system which consists of energy conversion and regulation system. In addition, discussion is made on the DC-DC boost converter scheme and the appropriate methodology applied to develop the system. It offers the constant lock circuit CLC and its CLCC control methodology and describes its work strategy. Furthermore, power management algorithm with control system strategies is discussed. It covers methods like standalone scenario, grid scenario, and feedback scenario which are applied to develop the DC micro-grid system. It marks out to backup source stages which consist of a current source CS stage design. Besides these, it also provides exporting power stages and its current source design to enhance DC micro-grid system.

In chapter 4, the results and discussion are discussed. The DC-DC boost converter simulation with constant duty cycle is presented next. A CLC output voltage simulation under variable test is performed. It also provides the results obtained from the simulation study. Integration of operation modes strategy is developed with CLC in DC MG system. This chapter offers standalone scenario and its configuration. The results of this scenario are also presented. The grid scenarios are well brought in this chapter. It also displays the results obtained from simulation study in two cases. Moreover, feedback scenario with its two cases is simulated. The third scenario results are discussed in the end.

Chapter 5 concludes the contributions of this study and provides an overview of the development of CLC with DC micro-grid system. It also recommends the future research scopes to improve the power management control strategy in DC micro-grid system for the electrical market.

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