POWER FLUCTUATION CONTROL ON A DC-RESIDENTIAL NETWORK USING TANAKA'S OPTIMIZATION AND TABU SEARCH APPROACH

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DEDICATION

This thesis is dedicated to my lovely husband, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

The power fluctuation problem of renewable energy sources, frequency and voltage deviations are usually occurred in the isolated power systems, in which the ability to maintain stable supply-demand balance is low. Smart grid system is a solution to this problem and because of that the idea of smart grid concept is proposed which cooperatively could balance the supply-demand between power supply side and power demand side. The installation of photovoltaic (PV) system is proposed in a residential building which can be straight forwardly connected to DC sources. DC systems are required to bring lower costs by elimination of inverter and rectifier circuits and it may be possible to operate the PV system with high efficiency. Therefore, this study presents a DC smart grid system for a small residential network that sourced by solar energy which consist of a PV generator, a solar collector (SC), a heat pump (HP) and a battery. Battery and heat pump are used as controllable loads. Then, in order to minimize the interconnection, point power flow fluctuations and its operational cost, Tanaka's Optimization and Tabu Search Approach is employed. Tanaka's Optimization is used to obtain the optimal operation of thermal unit and controllable loads. Meanwhile, Tabu Search approach helps to control the power consumption of controllable load and discharge and/or charge output of the battery. From the results it has been found that the interconnection point power flow in the smart house could be controlled within the given bandwidth from the power reference. By smoothing the interconnection point of power flow, the electricity cost could be reduced due to reduction of contract fee with the electricity power company. Consequently, we can expect high quality power supply, higher efficiency of power transfer and lower CO_2 emissions.

ABSTRAK

Masalah kuasa elektrik yang tidak stabil daripada sumber tenaga yang boleh diperbaharui, voltan dan penyimpangan frekuensi biasanya terjadi pada sistem tenaga terpencil, di mana kemampuan untuk mengekalkan keseimbangan penawaran-permintaan adalah rendah. Sistem grid pintar adalah penyelesaian untuk masalah ini dan oleh kerana itu konsep grid pintar dicadangkan dapat menyeimbangkan permintaan-penawaran antara bekalan kuasa dan permintaan tenaga. Pemasangan sistem fotovoltaik (PV) dicadangkan di bangunan kediaman yang boleh dihubungkan terus ke sumber DC. Sistem DC diharapkan dapat membawa biaya yang lebih rendah dengan kerana litar penyongsang dan penyearah tidak digunakan dan juga untuk mengoperasikan sistem PV dengan kecekapan tinggi. Oleh itu, kajian ini membentangkan sistem grid pintar DC untuk jaringan kediaman kecil yang bersumberkan tenaga suria yang terdiri daripada pengumpul suria (SC), penjana PV, pam haba (HP) dan bateri. HP dan bateri digunakan sebagai beban terkawal. Kemudian, untuk mengurangkan turun naik aliran kuasa titik penyambungan dan kos operasinya, *Tanaka's Optimization* dan pendekatan *Tabu Search* digunakan. T*anaka's Optimization* digunakan untuk mendapatkan operasi optimum unit termal dan beban terkawal. Sementara itu, pendekatan *Tabu Search* membantu mengawal penggunaan kuasa beban dan pelepasan terkawal dan / atau mengecas bateri. Diharapkan, aliran daya titik penyanbungan di rumah pintar dapat dikendalikan dalam had yang diberikan rujukan. Dengan melancarkan titik sambungan aliran kuasa, kos elektrik dapat dikurangkan kerana pengurangan yuran kontrak dengan syarikat tenaga elektrik. Oleh itu, kita dapat menjangkakan bekalan kuasa berkualiti tinggi, kecekapan pemindahan kuasa yang lebih tinggi dan pelepasan CO_2 yang lebih rendah.

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LIST OF ABBREVIATIONS

PV	-	Photovoltaic
SC	-	Solar Collector
HP	-	Heat Pump
TS	-	Tabu Search
RE	-	Renewable Energy
DG	-	Distribution Grid
UTM	-	Universiti Teknologi Malaysia
AC	-	Alternating Current
DC	-	Direct Current
PV	-	Photovoltaic
SC	-	Solar Collector

LIST OF SYMBOLS

T	-	All time section
I	-	Smart house i group
B_{Icen}	-	Interconnection point power flow reference
P_{It}	-	Interconnection point power flow from power system to grid
P_{Imin}	-	Interconnection point power flow bandwidth minimum value
P_{Imax}	-	Interconnection point power flow bandwidth maximum value
P_{Bit}	-	Charge/discharge power of battery
P_{Bmax}	-	Charge/discharge power maximum value of battery

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CHAPTER 1

INTRODUCTION

1.1 Introduction

From the outlook of worsening global warming and exhaustion of fossil fuels, strategies on the reduction of CO_2 emissions and energy consumptions are very important to be implemented globally. As has been proved by the world's top countries in solar and wind energies capacity such as China, USA, Germany, and UK, these renewable energy sources have shown great success in addressing the aforementioned issues. However, because of the power fluctuation problem of renewable energy sources, voltage and frequency deviations are usually occurred in the isolated power systems, in which the capacity to maintain stable supply-demand balance is low [1]. Instead, electricity cost is determined by maximum electric power consumption for the year [1]. Because of that, idea on smart grid concept is proposed which cooperatively could balance the supply-demand between power supply side and power demand side. By applying the smart grid concept, it is projected that higher efficiency of power transfer, better energy management & conservation, and lower carbon culture can be realized [1,2].

Numbers of paper have been published on the ideas and the implementations of smart grid systems. Smart grid systems may relate to grid connected, islanded connection, AC or DC connection systems [3], solely sourced by renewable energy (RE) or combined with conventional grid systems [3], and etc. Presently, transmission and distribution infrastructure of Malaysia is based on AC connection system. AC smart grid system could be implemented over the current infrastructure. However, AC smart grid system offers challenges regarding power stability, dynamics, power quality, safety and protection because it is usually unidirectional from generation to transmission then to distribution and lastly to the consumer. Smart grid should be capable of bidirectional power flow thus if numerous Distribution

Grid (DG) units are associated to the similar AC bus, then different protection scheme are needed at both voltage levels [4]. Besides, existing AC grid has centralized control but because of bi-directional micro-generators, a decentralized control of MV and LV distribution network is required [5]. Subsequently, highly stable network structure, communication and planning is needed so as to operate and maintain the equilibrium of this confounded AC power system [4]. On other hand, as load demand increases may change frequency. Hence, presentation of the DG also presents a complexity in system frequency control since the relationship between required demand load and frequency is not proportional [6]. Table 1.1 shows the details of the AC and DC smart grid connection system.

Table 1.1: Comparison on AC and DC Smart Grid System

	AC Smart Grid System	**DC Smart Grid System**
System Complexity	The system complexity of the AC system is much higher than DC system.	The DC system has complexity in terms of voltage step up or step down. [4]
Reliability	The AC systems require rectification and then again, a DC/DC conversion or a DC/AC inversion.	DC systems are more reliable because of lesser conversions at the loads decreasing the points of failures. Dc system bypass the rectification. [4]
Efficiency	AC system need to be oversized to increases the power capacity of existing infrastructure.	DC system no need to be oversized to increases the power capacity of existing infrastructure. [5]
Cost	AC system using existing infrastructure but have to added FACT devices, control switchgear and communication.	DC system need to replace transformer to DC-DC converters and change the loads designed. The cost will be more effective as it replaces the bulky low frequency equipment with comparatively smaller high frequency equipment [5]

As observed in Table 1.1, it then can be summarized that DC smart grid has a great potential to be used in home or residential building, as a DC smart grid system allows easier integration of renewable energy sources of variable voltage levels and frequency compared to AC. The higher number of variables to control being the major drawback for AC and the reliability for the DC smart grid is more because of lesser point of failures and can be easily increased by integrating unconventional and/or intermittent the sources. The DC power quality is better and easier to control than AC. Even though the investment in a DC smart grid will be higher than AC smart grid because of the existing AC infrastructure but the running cost of a DC smart grid will be lesser than AC. The cost further decreases when reliability, complexity, efficiency and power are translated into their respective costs. A DC smart grid clearly supersedes the AC smart grid in its feasibility. The only disadvantage for the DC smart grid is the initial investment cost required by it, which can be recovered later by the distribution company and the consumers. Table 1.2 shows the advantages of DC compared to AC smart grid system.

Table 1.2: Advantages of DC Compared to AC Smart Grid System [7]

No	Details
1	All power generators that connected to DC grid can be cooperated or controlled easier due to single dc bus voltage.
2	In hybrid AC and DC system, when grid experiences abnormal or fault conditions, DC grid can be disconnected from the AC system and then can work independently under islanded mode, whereby the loads will be supplied by the DC generators.
3	The losses and cost of DC system can be lowered since only one inverter will be required for the ac-grid-connected side.
4	In DC system, distributed generators are supplied by DC power. No phase detection is needed as in AC grid system.
5	The performance cost for DC houses, hospitals and information centres are satisfactory.

a) Problem Statement

In a micro or smart DC grid system, the fluctuating power from renewable energy sources and also the variation from demand response side could cause the DC bus voltage fluctuations of the DC grid system [1]. The problematic of the supply-load mismatch will cause to voltage and frequency deviations. As consequence, the interconnection point power flow is fluctuated due to the supply-load mismatch. Furthermore, there has been an increase in electrification house or residence in recent years. Thus, energy control ability has also been increasing when the loads are used as controllable loads. For instance, to reduce energy consumption at the residence, load usage needs to be controlled and managed due to the set or pre-determined priority.

1.1 Research Aims and Objectives

The aim of this study is to reduce the supply-demand balancing of power system that happens due to voltage and frequency deviations because of the power fluctuation of renewable energy source. Therefore, the objectives of this study are as the followings:

(a) To minimize interconnection point power flow fluctuation and the operational cost of DC smart home, using Tanaka's Optimization and Tabu Search Approach.

1.2 Research Scopes

The scopes of this study can be explained as listed below:

(a) Small Residential DC network consist of six DC smart homes which connected to power system and control system communications infrastructures and through transmission line.

(b) Solar collector (SC) and PV generator will be used as renewable energy (RE) source.

(c) Battery and heat pump (HP) are used as controllable loads.

(d) Modelling will be done using Matlab/Simulink Software.

1.3 Research Contributions

The major contribution of this study is to build a small residential DC network which consist of six DC smart homes using Matlab Simulink software. In this system, the PV generator and solar collector will be used as RE sources and battery and HP are used as controllable loads. The usage of controllable loads in each smart home will be monitored closely in order to investigate the voltage profile pattern in a small-residential DC network.

1.4 Report Outlines

The thesis is content five major part of chapters. The first chapter describes the issues related to the thesis which are the introduction, problem statement, objectives, scopes, research contributions as well as the structure of the thesis. The second chapter deals with an elementary view and an overview of previous study about smart grid system and small DC residential network. The third chapter describes the proposed research methodology and basic techniques related to the thesis. The fourth chapter deals with the simulation results and discussion. The simulation results of the DC smart grid system will be discussed and analyze in this chapter. Finally, the fifth chapter deals with conclusion and recommendations for future improvement. Lastly, references have been given a place in the thesis.

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