DYNAMIC TIME-OF-USE SCHEME IMPLEMENTATION IN A STAND-ALONE MICROGRID SYSTEM

JAWAD NAZAR

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Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

This project report is dedicated to my father, Nazar Hussain, 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, Musarrat Naureen, who taught me that even the largest task can be accomplished if it is done one step at a time with prayers and dedication.

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ABSTRACT

The purpose of this study is to develop a dynamic time-of-use (d-TOU) tariff scheme for microgrid (MG) systems in islanded mode. A MG system consists of renewable energy sources (RES) which generate limited energy with certain degree of uncertainty. Thus, energy consumption can be controlled effectively by the implementation of d-TOU tariff. For this purpose, a MG system was designed using HOMER simulation tool to fulfil residential load demand from RES and battery storage as a backup. The average cost of energy (COE) was obtained from the HOMER's optimized net present cost (NPC) of the system. Then, a day was divided into three time-zones, i.e. peak hours, mid-peak hours, and off-peak hours based on the generation profile. Considering the generation cost in each time-zone, the average COE was transformed into a d-TOU tariff structure with distinct electricity price for each time-zone. The results showed that electricity price in each time-zone was higher than conventional electricity prices, but greenhouse gas (GHG) emission from the designed MG system was found 85% lesser than conventional electricity generation. Finally, the impact of demand response (DR) was evaluated, which showed that only 10% load-shift from peak hours to off-peak hours saved consumers' annual electricity bills by 3.46%, and increased utility's annual profit by 57.89% at the same time. Similarly, shifting 20% load from peak hours to off-peak hours resulted in 10.58% reduction in consumers' electricity bills annually along with 105.26% increase in the utility's annual profit. The results validated that efficient implementation of d-TOU tariff and DR in a MG system, result in the peak load shaving, reduction in consumers' electricity bills, increased utility's profit, and reduction in GHG emissions.

ABSTRAK

Tujuan kajian ini adalah untuk membangunkan skim tarif masa dinamik yang diniagakan (d-TOU) untuk sistem microgrid (MG) dalam mod terasing. Sistem MG terdiri daripada sumber tenaga boleh diperbaharui (RES) yang menjana tenaga terhad dengan tahap ketidakpastian tertentu. Oleh itu, penggunaan tenaga boleh dikawal dengan berkesan melalui pelaksanaan tarif d-TOU. Untuk tujuan ini, sistem MG direka menggunakan alat simulasi HOMER untuk memenuhi permintaan beban kediaman dari RES dan bateri digunakan sebagai kelengkapan sokongan. Kos purata tenaga (COE) diperoleh daripada nilai kini bersih (NPC) yang dioptimumkan oleh HOMER. Seterusnya, sehari dibahagikan kepada tiga zon waktu, iaitu waktu puncak, waktu pertengahan puncak, dan waktu luar puncak berdasarkan profil penghasilan tenaga. Berdasarkan kos penghasilan tenaga di setiap zon waktu, COE purata diubah menjadi struktur tarif d-TOU dengan harga elektrik yang berbeza bagi setiap zon masa. Keputusan menunjukkan bahawa harga elektrik di setiap zon masa lebih tinggi daripada harga elektrik konvensional, tetapi pelepasan gas rumah hijau (GHG) dari sistem MG direka mempunyai 85% lebih rendah daripada penjanaan elektrik konvensional. Akhir sekali, kesan tindak balas permintaan (DR) turut diuji, dimana ianya menunjukkan bahawa 10% beban beralih dari waktu puncak ke waktu pertengahan puncak mampu menjimatkan bil elektrik tahunan pengguna sebanyak 3.46%, dan pada masa yang sama, peningkatan keuntungan tahunan utiliti sebanyak 57.89%. Selain itu, peralihan 20% beban dari waktu puncak ke waktu pertengahan puncak menyebabkan pengurangan 10.58% dalam bil elektrik pengguna setiap tahun dengan kenaikan keuntungan utiliti tahunan sebanyak 105.26%. Ini membuktikan pelaksanaan tarif d-TOU yang dicadangkan adalah efisien dan DR dalam sistem MG mampu mengakibatkan pencukuran beban puncak, pengurangan bil elektrik pengguna, peningkatan keuntungan utiliti, dan pengurangan pelepasan GRG.

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LIST OF ABBREVIATIONS

TOU	-	Time-of-Use
DR	-	Demand Response
d-TOU	-	Dynamic Time-of-Use
MG	-	Microgrid
DG	-	Distributed Generation
RES	-	Renewable Energy Sources
BESS	-	Battery Energy Storage System
COE	-	Cost of Energy
PV	-	Photovoltaic
WT	-	Wind Turbine
LCOE	-	Levelized Cost of Energy
NPC	-	Net Present Cost
GHG	-	Greenhouse Gas
RTP	-	Real Time Pricing
AC	-	Alternating Current
DC	-	Direct Current
IEA	-	International Energy Agency
FiT	-	Feed-in Tariff
NEM	-	Net Energy Metering
CPP	-	Critical Peak Pricing
NREL	-	National Renewable Energy Laboratory
HOMER	-	Hybrid Optimization Model for Electric Renewables
LCC	-	Lifecycle Cost
AET	-	Alternative Energy Technology
NASA	-	National Aeronautics and Space Administration
DoD	-	Depth of Discharge
O&M	-	Operation and Maintenance
CRF	-	Capital Recovery Factor
SOC	-	State of Charge
TNB	-	Tenaga Nasional Berhad

LIST OF SYMBOLS

ŋ	-	Efficiency
ρ	-	Air density

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

The unpredictable use of electrical energy by the consumers has rendered challenge for the utilities to determine optimal energy generation, because any instantaneous energy consumption doesn't truly reflect the actual energy demand. In some parts of the day, the energy consumption hits its peak, and failure to match supply and demand at these times may result in extreme abnormalities, including blackouts [1]. So, to meet this supplementary demand, as a way of convention, more generation units are linked into the network whose operational cost is relatively higher and consume fossil fuels as well, thereby resulting in environmental pollution [2]. In order words, the generation cost of electricity doesn't remain constant throughout the day. Hence, volumetric tariff, also called as flat-rate tariff, as prevalent in the past, cannot be an appropriate method to charge for electricity prices because it doesn't accommodate the impact of changing generation cost [3]. Therefore, instead of increasing the unneeded generation capacity, time-varying pricing schemes are deployed to control peak energy consumption [4]. Under this approach, a day is divided into different time-zones with distinct electricity prices. In conventional systems, electricity prices are kept higher when consumption is higher, and kept lower when consumption drops down. Thus, by doing so, to gain monetary advantages, customers are encouraged to shift their consumption to low-priced hours of the day, called as demand response (DR) [5].

The formulation a tariff scheme is a challenge in microgrid (MG) systems, especially in islanded or off-grid configuration. Unlike conventional large-scale generating stations, MG system contains distributed generation units (DGs), mainly renewable energy sources (RES), which generate time-limited energy with certain degree of uncertainty [6]. On the other hand, the load profile may be continuous which needs to be fulfilled through limited generation. Thus, development of a dynamic tariff scheme is necessitated for islanded MG systems, which can accommodate the stochastic nature of renewable generation in its consideration.

1.2 Problem Statement

The main feature that discriminates a MG system, consisting of RES, from a conventional grid system is its sporadic, intermittent and uncertain nature of energy generation [7]. The energy production is enough and, sometimes, even surplus during the availability of the resources. On the other hand, during the unavailability of the resources, the energy is supplied through energy storage systems [8], which is relatively costlier entity. To ensure the system balancing without any external assistance, time varying pricing schemes are needed to be introduced, so that users minimize and/or shift their load from peak hours to off-peak hours to shave the load curve [9]. The real challenge with the current pricing strategies in MG systems is that, so far, they have been deployed only in grid-tied systems. In grid-tied mode, the large-scale main grid is the dominant factor affecting the prices, as energy supply can be made continuous by linking-up additional generators at the time of need [2]. Furthermore, the current strategies are inclined towards consumer side for the calculation of net pricing [10]. In case of MG in islanded mode, due to its stochastic nature, generation profile becomes the main factor affecting the electricity prices. The purpose of this research is to make a dynamic time-of-use (d-TOU) pricing scheme for islanded MG systems which is flexible, comprehensive, and accommodates both the generation side and load side for the final version of a dynamic energy tariff.

1.3 Research Objective

The objectives of this research work are:

i. To design a MG system on HOMER with RES along with batteries as storage element to fulfil a residential load demand.

ii. To develop time-zones (peak hours, mid-peak hours and off-peak hours) based on electricity generation profile from RES.

iii. To formulate a d-TOU tariff, and to evaluate the impact of DR on system economics.

1.4 Research Scope

i. The DGs to be used in this work are solar photovoltaic (PV) system, wind turbines (WT), and battery energy storage system (BESS).

ii. HOMER simulation tool is used for modelling and analysis of the proposed MG system.

iii. The levelized cost of energy (LCOE), and d-TOU tariff structure is developed based on the net present cost (NPC) optimized by HOMER.

iv. Estimation of greenhouse gas (GHG) emissions from the designed MG, and comparison with GHG emission rate from conventional electricity.

1.5 Significance of the Study

The successful simulations and results of the proposed system will prove the effectiveness of d-TOU tariff scheme on a MG in islanded configuration. The stochastic generation profile in islanded MG systems is a challenge, and an efficient implementation of d-TOU tariff and dynamic DR ensures optimal balancing between continuous load consumption and limited generation. Furthermore, the deployment of RES in the design render lesser consumption of fossil fuels, thus guarantee the reduction in GHG emissions to the atmosphere. Due to higher capital cost of renewable energy products used in RES, the electricity prices of the designed MG system are, of course, higher than conventional electricity tariff, but this is justifiable by the gain of immensely reduced carbon prints in the atmosphere.

1.6 Report Structure

In the following thesis sections, Chapter 2 discusses and compares the literature review carried out for this work. The proposed research methodology is explained in Chapter 3. The simulation results and detailed discussions in presented Chapter 4. Finally, Chapter 5 draws the conclusion and recommendations.

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