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Faculty of Electrical Engineering

TEMPERATURE CONTROL AND INVESTIGATION of PARABOLIC DISH BASED CONCENTRATING SOLAR POWER (CSP) IN MALAYSIA ENVIRONMENT

Liaw Geok Pheng

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TEMPERATURE CONTROL AND INVESTIGATION OF PARABOLIC DISH BASED CONCENTRATING SOLAR POWER (CSP) IN MALAYSIA ENVIRONMENT

LIAW GEOK PHENG

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Temperature Control and Investigation of Parabolic Dish Based Concentrating Solar Power (CSP) In Malaysia Environment" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Liaw Geok Pheng
Date	:	....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature : ....

Name : Datuk Professor Dr. Mohd Ruddin Bin Ab Ghani

Date : ....

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DEDICATION

To my beloved husband, mother and father

for their enduring love, encouragement, motivation, and support

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ABSTRACT

In the Renewable Energy Act 2011, the focus is on solar energy particularly the solar Photovoltaic, whereby the solar thermal, such as the Parabolic Dish Concentrating Solar Power (CSP) is not given enough attention. This could be due to the lack of a thorough investigation of implementing solar CSP in the Malaysia environment. Nowadays, even though many researchers continue to investigate and study about Parabolic Dish based on Concentration Solar Power (CSP), the findings are not conclusive and do not provide accurate evidence and proof on the potential of CSP development in Malaysia. The missing link in the Parabolic Dish Stirling Engine system model is the control systems, which vary the amount of working gas in the Stirling engine. The temperature of the heater in PD system which has been modelled is easily overheated that which will cause damage to the heater material that will lead to low output efficiency, high thermal losses and effect to the lifespan of the PD system. Therefore, the primary aim of this project was to design a control system to maximize output efficiency during a normal operation by maintaining the heater/absorber temperature at the highest safe operating point to prevent excessive range of threshold to avoid damage to the heater material besides carry out a fundamental investigation on solar CSP, by focusing on Parabolic Dish type in the Malaysia environment. Recent literatures which address the CSP were reviewed. The preliminary considerations and basic thermodynamics of the Stirling engine were to derive a model of dish and Stirling engine. According to literature, the PD system achieves the highest solar for electric efficiency and it is small and modular among CSP technologies. The proposed model showed the idea of PD systems with control system model which vary the amount of working gas in the Stirling engine. The control systems were designed using Matlab /Simulink 2012a. Based on the developed linearized model, an improved temperature controller with transient droop characteristic and Mean Pressure Control (MPC) has been proposed. This temperature controller is effective in reducing the temperature that will improve the performance of the PD system. The overall performance of the system improved more than 78% in output power and energy. Besides, the system can improve in term of sensitivity compare with the PD system without compensate. In addition, the system also reduce thermal losses up to 97.6% which shows significant improvement for the output efficiency to the system. The analysis shows that the PD system is feasible in term of technical but not economically feasible. Unless, when levelised tariff of solar thermal is increase more than RM20.2499/kWh by electrical policy similar as photovoltaic, then the PD system is economic feasible in the Malaysia environment at the moment.

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ABSTRAK

Akta Tenaga Baharu 2011, tumpuan kepada tenaga solar adalah terutamanya kepada Photovoltaic solar, di mana haba suria, seperti Dish Parabolic Concentrating Solar Power (CSP) tidak diberi perhatian yang cukup. Ini boleh disebabkan oleh kekurangan penyiasatan secara menyeluruh terhadap pelaksanaan CSP solar dalam persekitaran Malaysia. Pada masa kini, walaupun ramai pengkaji berterusan untuk menyiasat dan mengkaji tentang Dish Parabolic Concentrating Solar Power (CSP), tetapi dapatan kajian ini tidak membuat kesimpulan dan menyediakan tepat jelas dan membuktikan bahawa potensi pembangunan CSP di Malaysia. Walau bagaimanapun, pautan yang hilang dalam Dish Parabolic yang sudah dimodelkan adalah sistem kawalan, dengan mengubah jumlah gas bekerja dalam enjin Stirling ini. Suhu pemanas dalam sistem PD yang dimodelkan adalah terlalu panas dan akan menyebabkan kerosakan kepada bahan pemanas, kecekapan output yang rendah, kehilangan haba yang tinggi dan memberi kesan jangka hayat sistem PD. Oleh itu, yang terutamanya bertujuan projek ini adalah untuk mereka bentuk sistem kawalan untuk memaksimumkan kecekapan pengeluaran semasa operasi biasa dengan mengekalkan pemanas / suhu penyerap di tertinggi titik operasi yang selamat dan mencegah melebihi julat ambang untuk mengelakkan kerosakan kepada bahan pemanas dan juga untuk menjalankan siasatan asas kepada solar CSP, memberi tumpuan kepada Dish Parabolic dalam suasana Malaysia. Sesetengah penulisan yang alamat dikaitkan kerja-kerja penyelidikan dengan karya ini dikaji. Pertimbangan awal dan termodinamik asas enjin Stirling yang dibentangkan untuk terbitan model hidangan dan enjin Stirling kajian. Walau bagaimanapun, juga mengkaji teknologi CSP dan pembangunan CSP. Dari kajian literatur, ia dapat disimpulkan bahawa dari beberapa jenis teknologi CSP, sistem PD mencapai solar tertinggi kepada kecekapan elektrik, kecil dan modular. Model yang dicadangkan menunjukkan idea sistem PD dengan model sistem kawalan dengan mengubah jumlah gas bekerja dalam enjin Stirling ini. Sistem kawalan direka dengan menggunakan Matlab / Simulink 2012 a. Berdasarkan model lelurus maju, pengawal suhu yang lebih baik dengan transient droop characteristic dan Mean Pressure Control (MPC) telah dicadangkan. Ini pengawal suhu amat berkesan dalam mengurangkan suhu dan prestasi yang lebih baik sistem PD. Prestasi keseluruhan sistem ini meningkatkan lebih daripada 78% pada output kuasa dan tenaga yang dihasilkan. Selain itu, ada yang sangat jelas lebih baik dalam sistem apabila sensitiviti berbanding sistem PD tanpa pampasan, dan penurunan haba kehilangan sehingga 97.6% yang secara langsung mempunyai peningkatan yang ketara untuk kecekapan output kepada sistem. Walau bagaimanapun, kajian ini mempunyai mendedahkan analisis teknikal dan ekonomi sistem PD di bawah persekitaran Malaysia. Daripada analisis ini menunjukkan bahawa sistem PD boleh dilaksanakan dari segi teknikal tetapi tidak boleh dilaksanakan dari segi ekonomi. Kecuali, apabila tarif levelised solar haba adalah peningkatan lebih daripada RM20.2499 / kWh oleh dasar elektrik sama seperti photovoltaic, maka sistem PD adalah ekonomi boleh dilaksanakan dalam persekitaran Malaysia.

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LIST OF ABBREVIATIONS

DSSPG	Dish Stirling Solar Power Generation
HTS	High Temperature Superconducting
SPTR	Stirling Pulse Tube Refrigerator
LSG	Linear Synchronous Generator
PWM	Pulse-Width Modulated
CF	Capacity factor
CSP	Concentrating Solar Power
DNI	Direct Normal Irradiation
TCS	Temperature Control System
PCS	Pressure Control System
MPC	Mean Pressure Control
LCOE	Levelised Cost of Electricity
NREL	National Renewable Energy Laboratory

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NPV	Net Present Value
O&M	Operating and Management
PD	Parabolic Dish
PV	Photovoltaic
PCU	Power Conversion Unit
RE	Renewable Energy
R&D	Research and Development
SBP	Schlaich-Bergermann and Partner
SAIC	Science Applications International Corp.
SES	Stirling Energy Systems Inc.

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LIST OF SYMBOLS

$A_{aperture}$	Aperture area for the concentrator
$A_{aperture}$	The concentrator aperture area
A_r	Receiver aperture area
C	Geometric concentration ratio
CC	Total capital cost
C	Commanded mass flow rate
c_p	The absorber material specific heat capacity
d	Focal point diameter
D_{con}	Diameter for the concentrator
dm_c	The change of mass for working gas in the compression space
dm_e	The change of mass for working gas in the expansion space
dm_h	The change of mass for working gas in heater
dm_k	The change of mass for working gas in cooler
dm_r	The change of mass for working gas in regenarator
DQ_h	The rate of heat transfer in heater
DQ_I	Rate of heat transfer to the receiver
DQ_k	The rate of heat transfer in cooler
DQ_r	The rate of heat transfer in regenerator
dv_c	Dead space volumes compression
dv_e	The dead space volumes of expansion

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D_p	Permanent droop
Ɛ	Effective emissivity of the cavity aperture
E	The net amount of energy produced over a year
E	Unshaded aperture area
f	Focal length
gA_{SV}	Mass flow in the solenoid valve
G_p	Mean Pressure Regulator
h	Convection coefficient
I	Interest rate on capital
I_{DNI}	Direct Normal Irradiation
K_c	Concentrator Gain
K_R	Receiver Gain
K_L	Receiver Loss Gain
Kv	Gain constant and of the valve
K_p	Total Mass Relationship
M	Total Mass
m_h	Mass for working gas in heater
m_k	Mass for working gas in cooler
m_r	Mass for working gas in regenerator
n	Life of the system.
$\emptyset$	Crankshaft angle
$\emptyset$	Intercept factor
$\overline{P}_{mean}$	Mean Pressure
$\overline{P}_{max}$	Maximum Mean Pressure
$\overline{P}_{min}$	Minimum Mean Pressure

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P_{gross}	Power gross
P_{heat}	Power Heat
$P_{in,rec}$	Solar power intercepted by the receiver
P_{net}	Net power output
$P_{parasitic}$	Parasitic power
q_{conv}	Convection losses
pst	High pressure storage tank pressure
Q_h	Heat transfer to the Stirling engine
Q_L	Heat loss of the absorber
q_{rad}	Radiation losses
Q_{total}	Receiver thermal losses
R	Gas Constant
T_{amb}	Ambient temperature
T_c	Compression temperature
T_e	Expansion temperature
T_r	Regenerator temperature
T_h / $\overline{T}_h$	Heater temperature
T_{set}	Temperature Set Point
$\overline{T}_{h,max}$	Maximum Heater Temperature
$\overline{T}_{h,min}$	Minimum Heater Temperature
T_k	Cooler temperature
Tv	Time constant of the valve
V	Heater material volume
v_c	Compression space volumes
v_e	Expansion space volumes

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v_r	Regenerator space volumes
V_{de}	Dead Space Volume (Expansion Space)
V_{dc}	Dead Space Volume (Compression Space)
V_s	Cylinder swept volume
α_c	Displacement angle of the compression space
α_e	Displacement angle of the expansion space
γ	Ratio of specific heats
$\eta conc$	Concentrator efficiency
ηo	Optical efficiency
θi	Incident angle cos
ρ	Density material for heater
ρ	Reflectivity of the concentrator
σ	Stefan Boltzmann's constant
$\emptyset_{rim}$	Concentrator rim angle
$\Delta\overline{T}_h$	Different of the Maximum and Minimum Temperature
$\Delta\overline{P}_{mean}$	Different of the Maximum and Minimum Pressure

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LIST OF PUBLICATION

The following publications have been achieved by this research work

Journals:

1) ***Liaw Geok Pheng****, Rosnani Affandi, Mohd Ruddin Ab Ghani, Chin Kim Gan, Zanariah Jano, Tole Sutikno* (2014), "A Review of Parabolic Dish-Stirling Engine System Based on Concentrating Solar Power". TELKOMNIKA (Telecommunication Computing Electronics and Control), 12(4), pp. 1142-1152. **(Scopus)**

2) ***Liaw Geok Pheng****, Rosnani Affandi, Mohd Ruddin Ab Ghani, Chin Kim Gan, Jano, Zanariah* (2015), "Stirling Engine Technology for Parabolic Dish-Stirling System Based on Concentrating Solar Power (CSP)". Applied Mechanics and Materials, 785, pp. 576–580. http://doi.org/10.4028/www.scientific.net/AMM.785.576. **(Scopus)**

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