MODELING AND FEASIBILITY STUDY OF A DISH-MICRO GAS TURBINE SYSTEM IN DIFFERENT REGIONS OF MALAYSIA

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A thesis submitted
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DECLARATION

I declare that this thesis entitled “Modeling And Feasibility Study Of A Dish-Micro Gas Turbine System In Different Regions Of Malaysia” 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.

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Date	:	31 January 2022

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 Doctor of Philosophy.

Signature	:	………………………………………
Supervisor Name	:	Emeritus Professor Datuk Dr.Mohd Ruddin Bin Ab Ghani FASc
Date	:	31 January 2022

DEDICATION

To my beloved late father, mother, children, family and friends.

For their endless love, support and encouragement.

ABSTRACT

Concentrated solar power (CSP) systems are a renewable energy source that can help decouple the energy mix from fossil fuel combustion and its associated environmental effects. Due to high costs, complexity, and poor dependability, existing small-scale CSP solutions (Dish-Stirling) have not entered the market. These projects intended to address the drawbacks of small-scale CSP by combining a solar dish with the compact and relatively inexpensive micro gas turbine (MGT) technology. The study's objective is to investigate the performance and viability of a 30kW dish-MGT in Malaysia. In this study, a hybrid system of solar micro gas turbine with a combustion chamber was investigated. A dish-MGT system with three main components: a concentrator, a receiver, and a micro gas turbine was the subject of this study. Matlab Simulink is used to simulate the background of the dish-MGT system and its components model. Meanwhile, the performance of the three major components was tested under three different solar irradiation conditions: low, medium, and high. Thus, five sites or locations have been chosen for this study by considering the highest Direct Solar Irradiance (DNI) and based on regions. In the northern part of Peninsular Malaysia, George Town has the highest DNI. Besides that, Subang, in the middle part of Peninsular Malaysia, Kuantan, on the east coast of Peninsular Malaysia, Senai, in the southern part of Peninsular Malaysia, and Kuching, in East Malaysia. To investigate the impact of climatic conditions on system performance and electricity generation, a thermodynamic model was built. The highest daily solar irradiation cycle outlet power for 81 m^2 dish collector aperture area was 30 kW, with a solar-to-electric efficiency of 36%. Dish-MGT has a higher total yearly energy, Levelized Cost Of Energy (LCOE), and capacity factor of 87 kWh, MYR 1.01/kWh, and 33%, respectively, than a traditional dish system such as dish-Stirling. The developed model of the dish-MGT system shows that the system is technically feasible but not economically feasible and not environmentally sustainable. In conclusion, the study's findings showed that Malaysia's dish-MGT system is capable of serving local demand reliably. However, in order to improve the LCOE and reduce CO_2 emissions, more work is required. The findings of this study can assist policymakers and regulators in better understanding the potential for CSP development in this country and other equatorial countries.

PEMODELAN DAN KAJIAN KEBOLEHLAKSANAAN SISTEM PIRING-MIKRO GAS TURBIN DI PELBAGAI WILAYAH DI MALAYSIA

ABSTRAK

Concentrator Solar Power (CSP) merupakan sumber tenaga boleh diperbaharui yang boleh membantu memisahkan campuran tenaga daripada pembakaran bahan api dan kesan alam sekitar yang berkaitan. Disebabkan oleh kos yang tinggi, kebolehpercayaan yang lemah, penyelesaian CSP berskala kecil sedia ada (Dish-Stirling) belum lagi berada di pasaran. Kajian ini bertujuan untuk menangani kelemahan CSP berskala kecil dengan menggabungkan solar piring dengan teknologi mikro gas turbin (MGT) yang padat dan agak murah. Objektif kajian adalah untuk menyiasat prestasi dan daya maju 30kW dish-MGT di Malaysia. Di dalam kajian ini, sistem hibrid turbin gas mikro solar dengan ruang pembakaran diselidik. Sistem MGT dengan tiga komponen utama: penumpu, penerima dan turbin gas mikro merupakan subjek kajian ini. Matlab Simulink digunakan untuk mensimulasikan setiap komponen utama di dalam model sistem piring MGT. Selain dari itu, prestasi tiga komponen utama diuji dalam tiga kadar pancaran solar yang berbeza: rendah, sederhana dan tinggi. Oleh yang demikian, lima lokasi telah dipilih untuk kajian ini dengan mempertimbangkan nilai Direct Solar Irradiance (DNI) yang tertinggi berdasarkan wilayah masing-masing. Di bahagian utara Semenanjung Malaysia, George Town mempunyai nilai DNI yang tertinggi. Selain itu, wilayah Subang di bahagian tengah Semenanjung Malaysia, Kuantan di pantai timur Semenanjung Malaysia, Senai di bahagian selatan Semenanjung Malaysia dan Kuching di Malaysia Timur. Model termodinamik telah dibina di dalam kajian ini bagi menyiasat kesan keadaan iklim terhadap prestasi sistem dan penjanaan tenaga elektrik. Kuasa keluaran kitaran sinaran matahari tertinggi untuk kawasan bukaan pengumpul seluas 81 m^2 adalah 30kW, dengan kecekapan solar ke elektrik sebanyak 36%. Piring-MGT mempunyai jumlah tenaga tahunan yang lebih tinggi iaitu 87kWj, Levelized Cost of Energy (LCOE) dan faktor kapasiti masing-masing sebanyak MYR 1.01/kWj, dan 33%, berbanding sistem piring tradisional iaitu piring – Stirling. Model piring MGT yang dibangunkan ini menunjukkan bahawa sistem ini boleh dilaksanakan secara teknikal, namun ia tidak ekonomikal dan tidak mampan. Kesimpulannya, hasil kajian menunjukkan sistem piring-MGT Malaysia mampu memenuhi permintaan tempatan dengan berkesan. Walau bagaimanapun, untuk memperbaiki LCOE dan mengurangkan pelepasan CO2, pengubahsuaian yang lebih baik diperlukan. Oleh itu, penemuan kajian ini dapat membantu memberikan maklumat yang berguna kepada penggubal dasar dan pihak yang mengawal selia dalam memahami potensi pembangunan CSP di negara ini dan juga negara-negara khatulistiwa yang lain.

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LIST OF SYMBOLS

A_a	-	Aperture area of the parabolic dish
A_r	-	Area of the solar receiver window
η	-	efficiency
η_{conc}	-	Concentrator's optical efficiency
CR_g	-	Geometrical concentration ratio
CR_{opt}	-	Optical concentration ratio
r_p	-	Pressure ratio
ρ_h	-	Heat input
ρ_l	-	Heat release
$\boldsymbol{q_{in}}$	-	Heat input to the system
$\boldsymbol{I_{DNI}}$	-	Solar irradiance
$\boldsymbol{A_{dish}}$	-	Concentrator's aperture area.
$\boldsymbol{q_H}$	-	Solar power intercepted by the receiver
ρ	-	Reflectivity of the concentrator
ϕ	-	Intercept factor
$\boldsymbol{P_{ele}}$	-	Power output
$\boldsymbol{\eta_{ele}}$	-	Electrical efficiency
$\boldsymbol{P_t}$	-	Turbine power

$\boldsymbol{P_{cm}}$	-	Compressor power
$\boldsymbol{P_{net}}$	-	Net power
$\boldsymbol{P_{parasitics}}$	-	Parasitic power
$\eta_{\boldsymbol{opt}}$	-	Optical efficiency
$\eta_{\boldsymbol{overall}}$	-	Overall efficiency
C_{fuel}	-	Annual fuel cost
E_{net}	-	Net annual electricity
α	-	Annuity factor
i	-	Interest rate
$\eta_{\boldsymbol{op}}$	-	Power plant operating lifetime
$\boldsymbol{C_f}$	-	Capacity factor
P_{nom}	-	Rated output
f_{co_2}	-	Specific carbon dioxide emissions
$m_{\boldsymbol{f}}$	-	Fuel mass flow
$\mu_{\boldsymbol{f}}$	-	Carbon content
ε_{HS}	-	Solar heat exchange efficiency
ε_t	-	Turbine isentropic efficiency
ε_c	-	Compressor isentropic efficiency

LIST OF ABBREVIATIONS

BESS	-	Battery Energy Storage Systems
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CPV	-	Concentrated Photovoltaic
CSP	-	Concentrated Solar Power
DNI	-	Direct Normal Irradiance
HC	-	Hydrocarbons
HRSG	-	Heat recovery Steam Generator
HSRC	-	Hybrid Solar Receiver Combustors
HTF	-	Heat Transfer Fluid
ISOC	-	Integrated Solar Combined Cycle
LCOE	-	Levelized Costs of Electricity
LVG	-	Negligible Value Gate
MGT	-	Micro Gas Turbine
NO_x	-	Nitrogen Oxides
O&M	-	Operation And Maintenance
OMSoP	-	Optimized Microturbine Solar Power
PD	-	Parabolic Dish

PV	-	Photovoltaics
RE	-	Renewable Energy
RSiC	-	Recrystallized Silicon Carbide
SAM	-	Solar Advisor Model
SiC	-	Silicon Carbide
STIG	-	Steam Injection Gas Turbines
TCES	-	Thermochemical Energy Storage
TES	-	Thermal Energy Storage
TIT	-	Turbine Inlet Temperature
TRANSYS	-	Transient Systems Simulation Program With A Modular Structure
UAV	-	Unmanned Air Vehicles

LIST OF APPENDICES