UNIVERSITI TEKNOLOGI MARA

# MODULE TEMPERATURE MODELLING FOR FREE-STANDING PHOTOVOLTAIC SYSTEM IN EQUATORIAL CLIMATE

HEDZLIN BINTI ZAINUDDIN

PhD

January 2014

# AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Teknologi MARA. It is original and is the result of my own work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been submitted to any other academic institution or non-academic institution for any other degree or qualification.

I hereby, acknowledge that I have been supplied with the Academic Rules and Regulations for Post Graduate, Universiti Teknologi MARA, regulating the conduct of my study and research.

| | |
|---|---|
| Name of Student | : Hedzlin binti Zainuddin |
| Student's ID No. | : 2008525785 |
| Programme | : Doctor of Philosophy in Applied Sciences (AS990) |
| Faculty | : Faculty of Applied Sciences |
| Thesis Title | : Module Temperature Modelling for Free-Standing Photovoltaic System in Equatorial Climate |
| Signature of Student | : ....................................... |
| Date | : January 2014 |

## ABSTRACT


The final generation of energy is always one of the important issues in any assessment protocol in determining the performance of a photovoltaic (PV) system. This energy generation depends on several key factors, which may be linked and formulated in a mathematical model that addresses the operating PV module temperature (MT). Whilst much effort have been put into modelling these relationships, very few studies have been conducted in this aspect under equatorial rainforest and fully humid climate region, vis-a-vis Malaysia. Moreover, none of these models developed in Malaysia are for free-standing (FS) systems. This has large impact on solar farms, as an accurate model is critical, in view of the proliferation of such farms in Malaysia. This study presents the development of MT models for FS PV system in Malaysia via simple linear regression (SLR), multiple linear regression (MLR) and multi layer feed-forward neural network (MLFFNN) techniques. These techniques address two specific issues; quantification of relative contribution of predictors to MT model such as: solar irradiance (SI), ambient temperature (AT), relative humidity (RH) and wind speed (WS); and the modelling performance of the simple linear, multiple linear and MLFFNN models. The modelling performance was analysed using root mean square error (RMSE), coefficient of determination ($R^2$) and mean absolute percentage error (MAPE). This study was done in four segments which are: field testing; mathematical modelling; statistical analysis; and artificial neural network (ANN). The field testing was conducted at a grid-connected PV system in Shah Alam, Malaysia. The mathematical and statistical segments are done to establish simple linear and multiple linear models. These models are developed using SLR and MLR techniques. Finally, the ANN segment is done to establish a nonlinear model via MLFFNN technique. The modelling performance of the models developed is then compared with other published models. In this work, a new and novel data filtration technique was developed and a new threshold value of SI was established. The technique is called thermal equilibrium point (TEP) and the threshold value is 40 $Wm^{-2}$. With respect to the quantification of the relative contribution of the predictors towards MT, it was found that SI = 53.8 %, AT = 37.2 %, RH = 4.9 % and WS = 4.1 % respectively. In addition, the MLFFNN model perform better than the multiple linear model by 12.0 % and 5.3 % in terms of RMSE and $R^2$ respectively; but the multiple linear model perform better than MLFFNN model by 1.0 % in terms of MAPE. This shows that MLFFNN MT model is the best model in terms of modelling performance. In conclusion, this study has succeeded in quantifying the relative contribution of solar irradiance (SI), ambient temperature (AT), relative humidity (RH) and wind speed (WS) towards MT; establishing a new data filtration technique; identifying a new threshold value; and developing an accurate MT model for FS PV system in Malaysia.

## ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful.

Alhamdulillah, with His graciousness and blesses, this thesis is completed. Throughout the journey of completing the thesis, make me realise that my knowledge is less than a drop of water from Almighty Allah's bountiful ocean of knowledge. I humbly admit that He is the Most Wisdom who created this small earth within the infinite galaxy in a complex, balance and not comparable way. All the obstacles I've went through have been guided by Him with two most undeniable references, namely Al-Quran and As-Sunni.

I wish to extend my deepest gratitude to my main supervisor, Associate Professor Dr. Sulaiman Shaari for guiding me through this work from the beginning until the end. The journey he had planned for me has really enriched my life experience. I also wish to extend my appreciation to my first co-supervisor Associate Professor Dr. Ahmad Maliki Omar for his significant inputs especially in terms of technical aspect. My inmost gratitude is also directed to my second co-supervisor Dr. Shahril Irwan Sulaiman for his valuable inputs throughout this work especially in guiding me through the ANN task. To all my supervisors, thank you for the countless moments of attention, dedication and stimulating comments.

I am greatly indebted and pleased to my husband who has assisted me in all possible means from emotional support, technical support, understanding and inspiration. I am also indebted to my beloved children for sacrificing their prime development time in order for me to pursue my P.hD. I thank my family, to whom this work is dedicated – my husband, Mohamad Fahim Mohamed Jamli, and our lovely kids Arif, Ameer and Umar. Finally my appreciation goes to my beloved understanding and compassionate mother, Norhabibah Joned, my caring father, Zainuddin Abdul Malek, my thoughtful mother in law, Maimunah Ibrahim and my wise late-father in law, Mohamed Jamli Awang Lirai. My sincere appreciation goes to my brothers and sisters for your supports.

My appreciation also goes to Dr. Zamalia Mahmud (FSKM, University Technology of MARA), Dr. Marcus Rennhofer (Austrian Institute of Technology, Vienna) and Malaysia Green Technology Corporation (MGTC) for providing me with technical supports and valuable insights.

My heartfelt gratitude also goes to my colleagues: Asiah, Nazli, Dr. Zain, Dr.Ismail, Khairul Safuan, Fairus, Atiqah, Zhafran, Jia, Ija, Najwa, Izzati, Ida, Ika, Fatin, Norzita, Pija, Wan Razarinah, Noraini, Langga, all FSG Physics members, all ex-PVMC staffs and GERC staffs.

I also wish to thank University Technology MARA (UiTM) and Ministry of Higher Education Malaysia (MOHE) for providing me the opportunity and scholarship to pursue my P.hD.

May this humble work be a contribution to future studies and research.

# TABLE OF CONTENTS