International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

Techno-Economic Feasibility of Applying Sugarcane Waxbased Phase Change Material to Lower Photovoltaic Panel Temperature

Apinya Puengpan[1], Wanwisa Skolpap[2]
[1,2] Department of Chemical Engineering, Center of Clinical Engineering, School of Engineering, Thammasat University
Pathum Thani, Thailand 12120

ABSTRACT: A reduction in power output from a solar photovoltaic (PV) panel is caused by a high operating temperature resulting mitigating economic benefits. Therefore, phase change material (PCM) situated in the back of a solar panel is used to maintain the surface temperature of the panel close to ambient. This research aimed to improve solar power generation efficiency by selecting a suitable thickness of encapsulated phase change material (EPCM) based on energy efficiency and economic analysis. At the increase of the EPCM layer thickness from 4 mm to 7 mm, the maximum power generation efficiency was improved by 15.86% owing to the EPCM heat storage capacity. The efficiency of solar panels-7 mm layer EPCM module was 6% higher than the PVs without EPCM. Adding an EPCM on the back of a solar panel lasted 16 days under natural conditions. However, a net present value (NPV) over a 25-year project of solar systems with a 7 mm thick EPCM layer is negative while that of solar systems without EPCM is more profitable than that of solar systems with a 4 mm thick EPCM layer. Applying sensitivity analysis to NPV of PV-EPCM modules was studied under changes in material cost of EPCM and power feed-in tariff. The result of sensitivity analysis of PV-7 mm thick EPCM layer shows 40% reduction in material cost of EPCM or 50% increase of energy price contributes to positive profitability.

KEYWORDS: EPCM, Net Present Value, Phase change material, Power generation efficiency, Solar Panel

INTRODUCTION

After the global economic fallout caused by the coronavirus (COVID-19) pandemic, sanctions against the Russia-Ukraine war have contributed to escalating food and energy crisis. Higher and more unpredictable energy prices make renewable energy investment attractive for customers and investors, particularly solar energy for tropical regions. Higher and more unpredictable price makes renewable energy investment attractive for customers and investors. As the surface temperature of a PV cell increases, its efficiency and power output decrease due to overheating [1]. Attaching a phase change material (PCM) to the back of a PV module for heat absorption has the potential of providing an efficient method of heat storage via latent heat of solid-liquid phase transition. The commonly used PCMs are organic and inorganic materials. Advantages of organic PCMs such as paraffin and sugarcane wax are non-corrosive and chemical and thermal stability while their disadvantages are low thermal conductivity, flammable and relatively low phase-change enthalpy [2]. The advantages of inorganic PCMs such as metals and salt hydrates are larger phase-change enthalpy, but their disadvantages are corrosive, phase separation and overcooling. The overcooling problem meaning PCMs are hardly crystalline when reaching the freezing point [3]. The chargedischarge cycle of microencapsulated PCM (EPCM) prepared from sugarcane wax on the back of PV panel improve the power generation and temperature reduction of front-facing glass solar panel [4]. In this study, sugarcane wax-based EPCM prepared by the group of Tangsiriratana (2019) was situated in the back of a solar panel to hypothetically maintain the performance of the solar panel by reducing excess heat produced during the operation time. Hence, this study aimed at investigating the effect of back surface temperature of solar panel on power generation efficiency and evaluating economic feasibility of utilization of the EPCM for a 1 megawatt (MW) solar Power plant.

THEORETICAL FRAMEWORK

An EPCM consisting of sugarcane wax-Al2O3 composite as the core material and gelatin-gum Arabic as the shell material, an organic PCM, has the heat capacity of 2.86 J/g·°C [4]. At the increase of the EPCM layer thickness from 4 mm to 7 mm, the solar panel's front-facing glass temperature was lower by 4% and the photovoltaic power generation was by 12% at the peak during 28 h observation. The EPCM layer absorbs solar radiation which is converted to thermal energy in a form of the latent heat, with the

ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

increase of temperatures of EPCM layer. When there is no solar radiation, the stored latent heat energy is released causing the decrease of an outer surface temperature of EPCM layer followed by solidification of the EPCM layer as Figure 1.

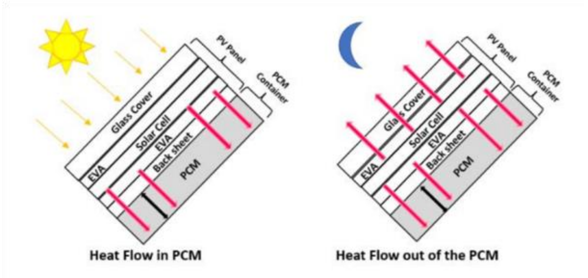

Fig 1. Thermal and electrical management of photovoltaic panels using phase change materials

The power generated was determined from the measurement of voltage across the resistor using Eq. (1).

$$P = \frac{V^2}{R} (1)$$

where P is a power output of the PV module
(W, Watt), V is the voltage output (V, Volt) and R is the electrical resistance (Ω, Ohm).

The conversion efficiency of a PV cell is calculated as the yield of electrical energy using Eq. (2).

$$\eta = \frac{P_m}{E \times A_c} (2)$$

where η is the efficiency of a PV panel (%), Pm is the maximum output power of PV panel (W), E is solar radiation (W/m2) and AC is the area of the PV panel (m2).

EXPERIMENT SETUP

Three NUNSolar 5 W polycrystalline silicon solar panels with the specifications is shown in Table 1. An EPCM consisting of sugarcane wax-Al2O3 composite as the core material and gelatin-gum Arabic as the shell material, an organic PCM that was prepared by the group of Tangsiriratana et al. (2019), has the heat capacity of 2.86 J/g·°C. The prepared EPCM was coated on the back side of each PV panel with different thicknesses (0, 4, and 7 mm) as shown in Figure 2. The solar irradiation, temperature and wind speed were measured from a height of 1.2 m above the ground and recorded every 10 min throughout 16 days between 9:00 and 17:00. All modules were tilted at an angle of 15° facing due south which was an optimum tilt angle for Thailand [5] and without wind across the panel. K type thermocouples that were used to measure temperature, mounted along the depth of the EPCM layer.

Table 1. NUNSolar 5 Watts PV module

Watts NUNSolar PV module	
laximum power	W
ptimum power voltage	8.29 V
ptimum power current	.28 A
hort-circuit current (Isc)	.30 A
esistance	5 Ω
perating circuit voltage	2.14 V
imension	70×200×17 mm

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

Fig 2. Solar panel after EPCM coating on the back panel at 4 and 7 mm thickness

The load resistor of 50 Ω was connected to each of the PV modules. The temperature readings from the thermocouples, the voltage and current of each of the modules were recorded by Agilent 34972A LXI Data Acquisition / Data Logger Switch Unit, USA.

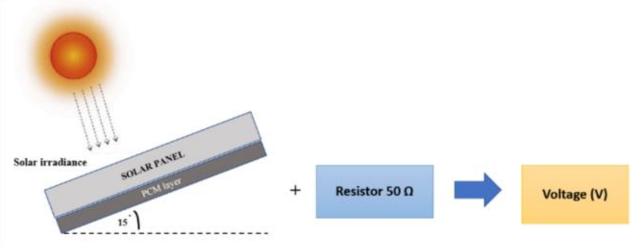

Fig 3. Method of connecting a device to measure voltage from a solar panel.

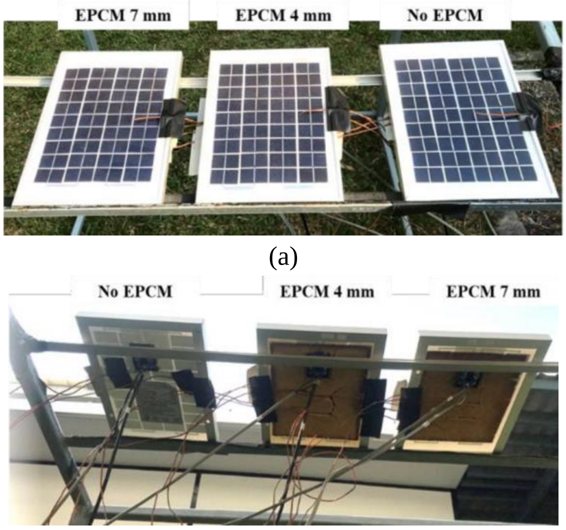

Fig 4. PV modules coated with EPCM at a thickness of 4 mm and 7 mm and PV module without EPCM (reference) (a) front and (b) rear of the panels

Economic analysis of PV-EPCM systems

The economic feasibility of PV-EPCM system was evaluated using net present value (NPV) based on the difference between the present value (PV) of cash inflows and that of cash outflows over a period of time at a given interest rate by using Eq. (3). A positive NPV indicates the project is profitable while a negative NPV indicates the project is undesirable.

$$NPV = \sum_{n=1}^{T} \frac{CF_t}{(1+\delta)^n} - I \quad (3)$$

where CFt is cash flow at t is number of periods, I is the initial investment, δ is an annual interest rate of 13% and n is the project lifetime of 25 years.

Cost evaluation of each of PV modules for 1 MW solar power plant are summarized in Table 2.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

Table 2. Economic parameters of 1 MW solar farm in Thailand

ıolar power plant information			
ınstalled capacity (MW)			.
'roject periods (year) [6]			5
ınnual discount rate (%) [7]			3
:ost information of solar power lant	**'V module without :PCM**	**'V module with 4-mm thick :PCM layer**	**'V module with 7-mm thick :PCM layer**
ıolar panels (installation, ontracting, inverter and quipment) [8]	0,197	0,197	0,197
⁄aterial cost of EPCM (USD per ear)		61,986	69,976
'urchased equipment cost for :PCM preparation		,045	,045
:ost of renting equipment for :PCM preparation (USD per year)		5	5
⁄aintenance cost (USD per year)	,708	,708	,708
ıalaries	,414	,414	,414
ıolar farm income			
'eed-in tariff rate (USD per kWh) 9]	.063	.063	.063
ıverage solar panel efficiency (%)	.02	.06	.48

EPCM replacement is performed every 15 days due to the 16-day product lifetime. A straight-line depreciation was calculated using the total purchase cost of equipment related to EPCM preparation over 10-year useful life of the equipment.

DISCUSSION

Most of solar radiation is absorbed and converted to heat which causes the increase of ambient temperature resulting in an increase of the surface and backside temperature of the PV and that of the PV energy output. Heat flows from higher temperature of the module surface to lower temperature of the backside of the module coated with EPCM, which in turn causes the temperature of the backside of the PV module higher than the ambient temperature. At the beginning of the experiment. The effects of backside temperature of the modules at different EPCM thicknesses on the PV panel efficiency over 16 days of experiment between from 10:20 to 13:20 and from 14:20 to 16:40 are illustrated in Figures 4-6. PV system exhibits solar irradiance-dependent electricity generation, because the efficiency of the module with 7 mm thick EPCM layer reached 9.96% between 10:00 am and 13:20 pm as shown in Figure 4. The temperature of backside of the module was 36.2 C that was higher than that of the module surface of 45.2 C during this period since the heat was transferred from the module surface to the back [10]. The light intensity decreased from 290.5 W/m2 to 40.8 W/m2 between 14:20 pm and 16:40 pm, meanwhile, the amount of heat stored in the EPCM caused rising in the backside temperature. The efficiency of the PV module was lower reaching to zero, as a result of the decrease of the solar intensity during this period. The coefficient of multiple determination (R2) of 0.709 indicates moderate linear relationship [11] between efficiency of PV-7 mm-thick EPCM layer and the backside temperature of the module as shown in Figure 4.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

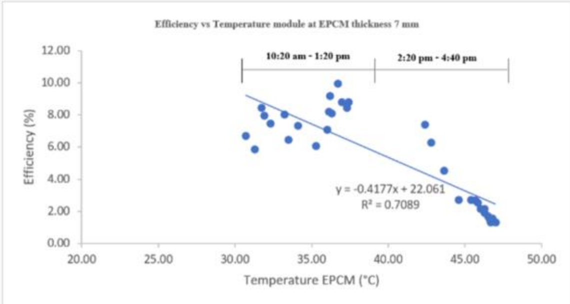

Fig 4. The effect of back side temperature of 7 mm- thick EPCM layer on PV panel efficiency

At the start of the experiment, the temperatures of all modules were the same at 9:00 am; however, as time progressed, the difference in temperature among three modules were observed. The efficiency of the module with 4 mm thick EPCM layer reached 8.38% between 10:00 am and 13:20 pm as shown in Figure 5. The temperature of backside of the module coated with 4 mm-thick EPCM layer was 35.0 C that was higher than that of the module surface of 46.0 C during this period due to the heat transfer from the module surface to the back. The coefficient of multiple determination (R2) of 0.674 indicates moderate linear relationship [11] between efficiency of PV-4 mm-thick EPCM layer and the backside temperature of the module as shown in Figure 5.

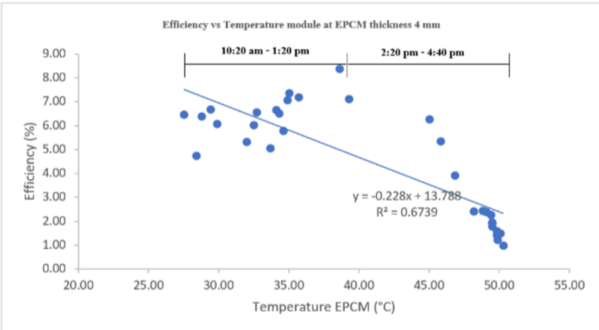

Fig 5. The effect of back side temperature of 4 mm- thick EPCM layer on PV panel efficiency

Temperature of the backside of the module without coating with EPCM between 10:00 am and 13:20 pm was 54.1 C that was higher than that of the module surface of 48.6 C. As a result, PV generated more electricity during this period compared to period between 14:20 and 16:40 since PV power output depends on the solar radiation intensity. The coefficient of multiple determination (R2) of 0.655 indicates moderate linear relationship [11] between efficiency of PV without EPCM and the backside temperature of the module as shown in Figure 6. Temperatures in both surface and backside of the module without EPCM were higher than those of modules with coated EPCM since thermal energy is extracted from the back of the module with the aid of the coated EPCM [10].

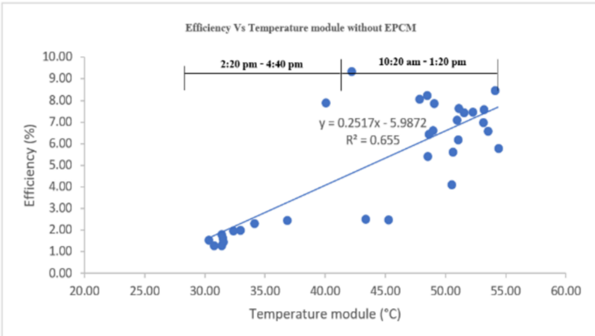

Fig 6. The effect of back side temperature of PV module without EPCM on PV panel efficiency

 *Corresponding Author: Wanwisa Skolpap

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

The service lives of EPCM at two different thicknesses were investigated by extending the length of observations. After 16 dayexperiment under natural conditions, EPCM was losing its ability to absorb, store and release thermal energy from solar due to surface cracks as shown in Figure 7.

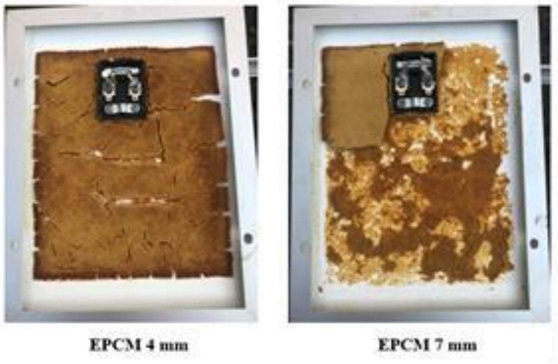

Fig 7. Surface of EPCM after 16 days under natural conditions

Annual energy production is the electrical energy produced from 1 MW solar farm in the period of 365 days based on average PV efficiency of each PV module for approximately 6 hours per day. A solar power plant project depreciated 100% over 25 years [6]. The NPV method was used to evaluate the economic feasibility of applying prepared EPCM at different thicknesses (0, 4, and 7 mm). For 1 MW solar power plant with lifetime of 25 years and the annual discount rate of 13%, NPV values of PV module without EPCM, PV module with 4-mm thick EPCM layer, and PV module with 7-mm thick EPCM layer were 818,184,236, 51,732,487 and -484,246,084 USD, respectively. Results show that the conventional solar power plant is more economically feasible than PV module with 4-mm thick EPCM layer, while PV module with 7-mm thick EPCM layer is not economically feasible. The PV-EPCM configurations were further analyzed from sensitivity perspective in terms of EPCM material cost and power feed-in tariff variation from -90% to +90%. Changes of +10% and -40% of material cost of EPCM as compared to the base line cost shown in Table 2 lead to negative and positive NPV values of PV modules with 4-mm and 7-mm thick EPCM layers resulting in a negative -2,181,363 USD and 91,643,332 USD, respectively. A change of -10% on solar electricity tariff as compared to the base line cost shown in Table 2 causes economically infeasible for PV modules with 4-mm thick EPCM layer resulting in a negative -34,391,348 USD (Figure 8). A change of +50% on solar electricity tariff as compared to the base line cost shown in Table 2 leads to profitable for PV modules with 7-mm thick EPCM layer resulting in 3,043,211 USD (Figure 9).

This sensitivity analysis result suggests that a reduction in material cost of EPCM and an increase of electricity tariff leads to better economic satisfactory of applying EPCM with the conventional PV module.

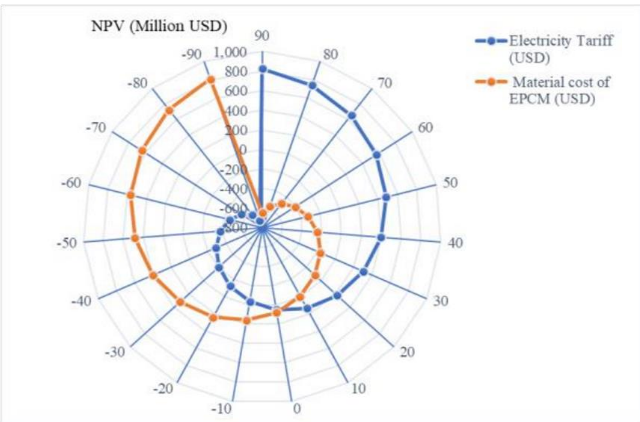

Fig 8. Sensitivity analysis on EPCM cost and electricity tariff for PV module with 7-mm EPCM thick layer

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 05 Issue 07 July 2022
DOI: 10.47191/ijcsrr/V5-i7-49, Impact Factor: 5.995
IJCSRR @ 2022
www.ijcsrr.org

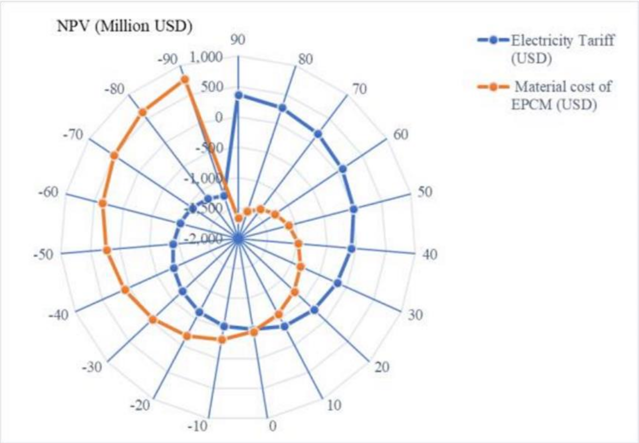

Fig 9. Sensitivity analysis on EPCM cost and electricity tariff for PV module with 4-mm EPCM thick layer

CONCLUSION

Although increasing EPCM thickness improves the electrical conversion efficiency, it becomes less attractive investment of applying EPCM to conventional PV system for investors. The NPV of PV module with 4-mm EPCM thick layer become negative leading to rejection of the project when increasing the material cost of EPCM by +10% or decreasing electricity tariff by -10%. The NPV of PV module with 7-mm EPCM thick layer become positive leading to acceptance of the project when decreasing the material cost of EPCM by-40% or increasing electricity tariff by +50%. Therefore, PV-EPCM module is not economic benefit that suggests to overcome research challenges in achieving lower material cost of EPCM and more durable EPCM.

ACKNOWLEDGMENTS

This work was financially supported by the School of Engineering, Thammasat University. The authors are grateful to Dr. Kobsak Sriprapha' research group of solar energy technology, Nation electronics and computer technology center (NECTEC), National Science and Technology Development Agency (NSTDA), Thailand, with support from lab assistant Mr. Vichit Saengsuwan for their contribution in the field of thermal and electrical measurement and instrumentation. The authors also thank Dr. Kittiwut Kasemwong, NANOTEC Research Unit, NSTDA, Thailand, for providing sugarcane wax.

REFERENCES

1. B. B., C. B., M. R., & Hongxing, Y. (1997). Thermal regulation of photovoltaic cladding. Solar Energy, 169-178.
2. Giro-Paloma, J., Martínez, M., Cabeza, L. F., & Inés, F. A. (2016). Types, methods, techniques, and applications for microencapsulated phase change materials (MPCM): A review. Renewable and Sustainable Energy Reviews, 1059-1075.
3. Kandelousi, M. S. (2018). Introductory chapter: Nano-enhanced phase-change material. In Thermal energy battery with nanoenhanced PCM (pp. 1-9). London: IntechOpen.
4. Tangsiriratana, E., Skolpap, W., Patterson, R. J., & Sriprapha, K. (2019). Thermal properties and behavior of microencapsulated sugarcane wax phase change material. HeliyonJacobson, M. Z., & Vijaysinh, J. (2018). World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels. Solar Energy, 55-66.
5. greenmatch. (2022, June 25). Retrieved from lifespan-of-solar-panels: https://www.greenmatch.co.uk/blog/2015/01/thelifespan-of-solar-panels
6. Krungsri Bank. (8 April 2022). Retrieved from https://www.krungsri.com/th/personal/loans/personal-loans/revolvingloan/contact?utm_source=sem&utm_medium=sem_gn&utm_term=l&utm_co
7. ecoenergythailand. (2022, June 27). Retrieved from https://www.ecoenergythailand.com/
8. Energy Policy and Planning Office. (2022, June 28). Retrieved from MINISTRY OF ENERGY: http://www.eppo.go.th/index.php/th/graph-analysis/item/16515-nepc-prayut25-12-63

9. Idoko, L., Anaya-Lara, O., & McDonald, A. (2018). Enhancing PV modules efficiency and power output using multi-concept cooling technique. Energy Reports, 4, 357-369.
10. Ratner, B. (2009). The correlation coefficient: Its values range between +1/-1, or do they? J. target. meas. anal. mark., 139-142.
11. Sait, H. H. (2021). Solidification and melting of phase change material in cold thermal storage systems. In Paraffin-Thermal energy storage applications (pp. 1-23). London: IntechOpen.

Cite this Article: Apinya Puengpan, Wanwisa Skolpap (2022). Techno-Economic Feasibility of Applying Sugarcane Waxbased Phase Change Material to Lower Photovoltaic Panel Temperature. International Journal of Current Science Research and Review, 5(7), 2644-2651