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Efficiency Improvement Based on Cooling Effect via Immersion Technique in a PV Solar Panel: Tropical and Cloudy Weather Setting

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Abstract: For decades, world's energy crisis was a major concern to the world and lots of study have been carried out in renewable energy sources field particularly on solar energy. However, the solar panel only receives around 20% from the energy of sunlight. Research shows that the efficiency of Photovoltaic (PV) solar panel is actually inversely proportional to temperature and resulted in low efficiency in the energy conversion. This is further negatively compounded by the presence of widely scattered clouds and the location of the sun which is directly overhead at noon times in the regions marked along the earth geographical's Equator line for example Malaysia and others. In this project, panel efficiency improvement caused by cooling via immersion technique was studied and the experimental setup system was installed on the rooftop of one the building at University College of Technology Sarawak, Sibu. Different cooling media were used in order to gauge the performance of different cooling effect caused by different cooling media to the efficiency of solar panel. Up-to-now, there is no technical data reported so far in the tropical weather particularly in Malaysia on this subject considering different weather, humidity and geographic location.

Keywords: Renewable Energy; Immersion Cooling Technique; Efficiency Improvement; Tropical Weather Setting.

I. INTRODUCTION

Solar power is one of the most widely used alternative pathway in the renewable energy domains or sources. The global demand/installation and production of PV modules are parallely increasing exponentially for the past 10 years with the largest share/development located in Europe followed by Asia Pacific region [1]. The beauty of solar energy lies on the the capability of the solar cells or panels to generate potential differences at the junction of two different materials resultant from sunlight radiation or in a technical term, photovaltaic effect [2-4]. This means that electrons are emitted from the material upon absorbant of light with specific frequency which is above a material-dependent threshold frequency or called photons.

This characteristic serves as the foundation or the "holy grail" of working operation of a solar cell. Upon absorption of radiation from the sun or photons by the materials, its energy is subsequently used to excite an electron from valence band to conduction band (higher energy level from initials) if the different of energy is higher than the bandgap energy. This will create a hole in the valence band and electron in the conduction band. In order for the solar cell to work, semi-permeable membranes must be presence at both sides of the absorpant materials, each for holes and electrons. Usually the electroncs and holes will gradually recombine with each other. However, with semi-permeable membranes on both sides, both holes and electrons can be separated for use. With the external connection and in a closed circuit, electrons flow and the solar energy is finally converted to electricity. Cascading more panels or cells will subsequently yield higher power and current. The working principles are summarized in Figure 1 below.

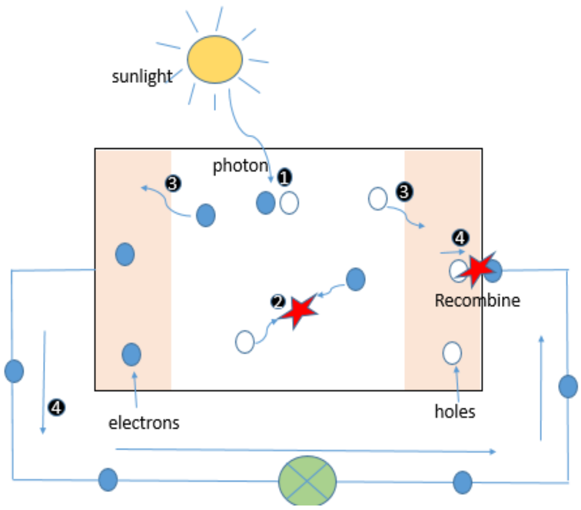

Fig. 1: Illustration of a simple solar cell operation modus. (1) Absorption of a photon that leads to generation of an electron-hole pair. (2) Normally, generated electrons and holes will subsequently combined. With the existence of semi-permeable membranes, both electrons and holes can be separated. (3) Both electrons and holes are drived to different membranes. (4) In a closed circuit, both electrons

and holes are flowing in opposite directions. Current flows. Sunlight radiation is finally converted into electricity [4].

In gauging the performance of a solar PV system, not only electrical parameters such as maximum power, maximum power current, maximum power voltage, fill factor (FF), open-circuit voltage (Voc), tolerance rated value %, short-circuit current (Isc) are the key indicators but also, one has to take into consideration of surrounding factors and negative impact of nature such as ambient temperature, humidity, rains, spectrum and angle of radiation, global solar radiation intensity and etc [5-7]. PV panel temperature plays a crucial role in the energy conversion process. Operating panel temperature influences the speed of the induced electrons and holes (by photons) flow through a circuit. This is due to the fact that the material resistance increases linearly with the increase in temperature. Likewise, resistance is dropping when the temperature decreases. This simply pointed to a point that the efficiency of the panel increases when the temperature decreases or maintains below around 45 ◦C. All previous works seconded this point and agreed that the panel efficiency increases when the panel temperature or operating temperature decreased [8-10].

II. LITERATURE REVIEW

As the temperature of solar panel is inversely proportion to efficiency of solar panel, various investigation have been carried out to decrease the working or operating panel temperature implementing different strategies towards achieving the higher energy conversion efficiency [11]. Many works have been performed and demonstrated cooling parts of the panel with water did succeed in bringing down the operating panel temperature and subsequently increase the panel (energy conversion) efficiency [2, 5, 11-16]. Backside cooling of the panels were widely reported and studied so far via immersion technique [12, 14, 15]. Mehrotra et al. demonstrated optimally the use water immersion cooling technique (backside of panel) in decreasing the panel operating temperature [15]. The group used 2 Watts of polycrystalline solar panel and partially-submerged in a plastic container filled with water. The key parameters such as output voltage, solar irradiance, surface temperature of solar panel, average water temperature, and average current were carefully recorded under different water depth ranging from 0 cm to 6 cm. This experiment was carried out in India for seven hours each day continuously for the period of 6 days. The group reported the maximum solar panel efficiency indeed increased to 17.8% when solar panel was immersed in water depth of 1 cm.

On the other hand, Abdulgafar et al. studied the efficiency of immersed solar panel in a different cooling media, in this case, distilled water [14]. In this experiment, a piece of polycrystalline solar cell was tested in Dohuk, Iraq for the period of two months. Polycrystalline solar cell was tested in distilled water under different water depths from 0 cm to 7 cm. This method is similar to the immersion method reported previously but with distilled water as the cooling media. The group found that the efficiency of solar panel had increased about 22% at water depth about 6 cm for which is in contrast than previously reported efficiency and water depth [14, 15]. This could be different because of the size of panel use and rating of the panels used in the studies. Other distinct works on using different cooling media in deionized water and dielectric liquid have been both reported respectively by Han et. al. [17, 18].

Air cooling was also reported to be an alternative way of cooling parts of the panels via backside of the panel. Mazón-Hernández et al. reported backside cooling the solar panel by air method [19]. Air cooling can be split into two methods which are natural convection or air forced method. For the air convection, the different sizes of underneath space of solar panel were tested. The team discovered that the solar panel efficiency with larger underneath space increased by 0.9% than smaller underneath space solar panel [19]. For the air-forced method, one of the solar panel was installed with fan. Mazón and his group found that the electrical power of solar panel cooled by fan is 3-5% higher than by natural convection.

Salih et al. studied the enhancement of PV array based on water spraying technique [20]. This experiment was carried out in Ramadi, Iraq in daytime for a day. The method was done by a thin continues film water flowing on the front of the panels for the cooling purpose and also reducing reflection loss. The team used five solar panels and connected in parallel. Each unit of solar panel is 216 W. They found that the average efficiency for spraying system along one day was 17.8%. The output efficiency was exactly same with the water immersion method [15, 20]. However, the spraying method uses more equipment than immersion method and the installation of the operating system is more complicated than immersion method.

Rasham et al. compared the method that cooling solar panel by intermittent cooling technique (ICT) and continuous cooling technique (CCT) [21]. The team used two mono-crystalline solar panel and placed them orientation. One of the solar panel was sprayed by thin water layers for 35 minutes continuously (CCT). For ICT, the solar panel was sprayed by thin film waters layers for 30 seconds and then stopped spraying for three minutes and repeated the work. The time used for both is 35 minutes. The result showed the output power, fill factor are improved to for ICT 7.349% and 5.587% and CCT 6.313% and 2.630% respectively. The enhancement of electrical efficiency of ICT and CCT are reported to be 8.389% and 6.826% [21].

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Musthafa et al. studied the water cooling of solar panel by water absorption sponge method [13]. Droplets of water circulation through sponge was used to maintain the temperature of the solar panel. An area of 36 x 27 cm2 and 12 Watts polycrystalline solar panel was tested. Five litres of water cane, hose with flowing knob, water absorbing sponge and drain pipe for collecting the water form a cooling system of solar panel. The efficiency of solar cells increased by 12% when temperature dropped maximally by 4°C [13].

With the emerging of the micro-nano-systems, one research team tapped and integrated this technology into cooling of the panels as reported by Micheli [22]. Kermani et al. proposed the use of miniaturized manifold micro-channels to cool in achieving higher panel efficiency [23]. On the similar direction, Tang et. al. demonstrated proof-of-principle using novel micro heat pipe array to cool the solar panel [24]. The heat pipe was divided into two section which are evaporator section and condenser section. The heat from solar panel vaporizes the liquid in the evaporator section and transfer to the condenser section. The theory that the team used was heat conversion method. The efficiency by using air- cooling increases by 2.6% when compared to ordinary solar panel, while the efficiency by using water cooling increases by 3% when compared to air-cooling method. Hence, the author suggested that water cooling could get the better performance of solar panel than air-cooling method.

III. EXPERIMENTAL SETUP

The experiment of immersion solar panel cooling technique was carried out under the meteorological condition of Sibu, in the state of Sarawak, Malaysia shown in figure 2. The latitude and longitude in Sibu is 2.2873° N, 111.8305° E. The data was collected or the duration of 7 days from 6 April 2016 to 13 April 2016. The experiment was conducted from 8.00 a.m. in the morning to 5.00 p.m. in the evening with the total of 10 hours per day.

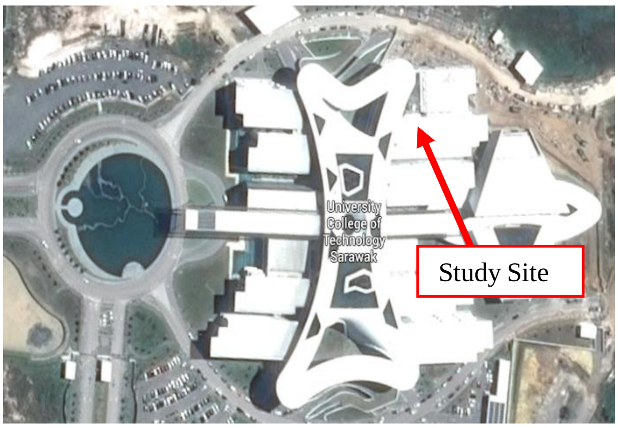


Fig. 2: Location of the study site at 2.2873° N, 111.8305° E.

Figure 3 and 4 illustrates the setup showing three solar panels being immersed in different cooling media (water, distilled water, rainwater) and a solar panel without cooling media were placed on the rooftop of one of the building at UCTS where sufficient sunlight could be captured. In order to investigate the optimum level of cooling solar panel, the electrical parameters (Voc, Isc, Vmax, Imax, Pmax, Fill Factor, Electrical Efficiency) at a particular depth of immersion is read and recorded by using Solar Module Analyzer. Next, the PV solar panel is readjusted to a new depth, submerging PV solar panel in the cooling media. This is why this technique is called immersion method. Initial water surface is labelled as 0 cm depth. Subsequently, the panel was immersed with depth increment of 1 cm each time until maximum depth of 5 cm is reached for all water pools. Electrical parameters are recorded at every depth of immersion. At 5 cm, the PV solar panel is completely immersed in the water.

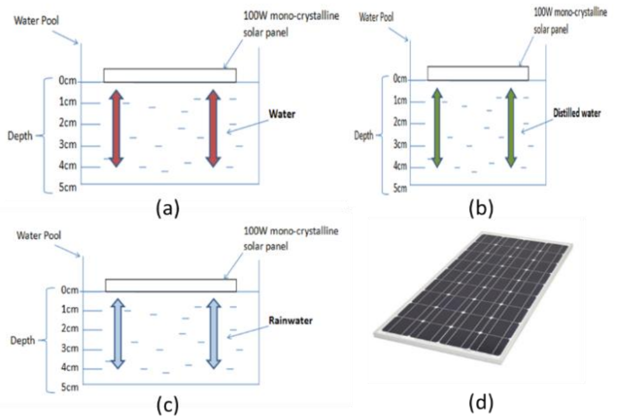


Fig. 3: Illustration on the experimental setup. Three mono-crystalline solar panels (100 W, area size of 0.625 m^2 each) as shown in (d) were immersed in three different type cooling media. All panels were placed at the segmented water pool in the z-axis (depth). Readings were recorded according to the time interval of an hour and in the direction of increasing immersion depth until 5 cm. An additional similar capacity solar panel is placed on the ground as a reference point in (d).

IV. RESULT AND DISCUSSION

MATLAB simulation was carried out to relate and narrate the changing effect of solar irradiation and the temperature of solar cell to the electrical parameters of a solar cell, mimicking on-ground situation of ever-changing whether at the study site. Results are shown in figure 5 below. Simulated electrical characteristics behaves as per predicted whereby voltage decreases as the surface temperature increases and for a fixed temperature value, increasing solar irradiance value will linearly increases the corresponding current value. Site's metrology condition during this study such as average solar irradiation, relative humidity and ambient temperature was recorded and shown in figure 6 respectively.

Average surface temperature of PV solar panel placed on the ground/rooftop for seven days was shown in figure 6 together with the voltage and current readings respectively. Panel on the ground which acts as a reference point to investigate the efficiency caused by the cooling effect. The results shows that the range of surface temperature of solar panel from 10 a.m. (1000 hours) in the morning to 5 p.m. in the evening was greater than 45 °C at all times. Once the temperature increases above 45 °C, it was reported that the efficiency of the panel will drop drastically. This can be seen from the Figure 6 where the voltage drops within that period of time as compared to 8 a.m. (0800 hours) in the morning and 9 a.m. (0900) in the morning. Meanwhile, the current does not change too much and only slightly increase within that time range.

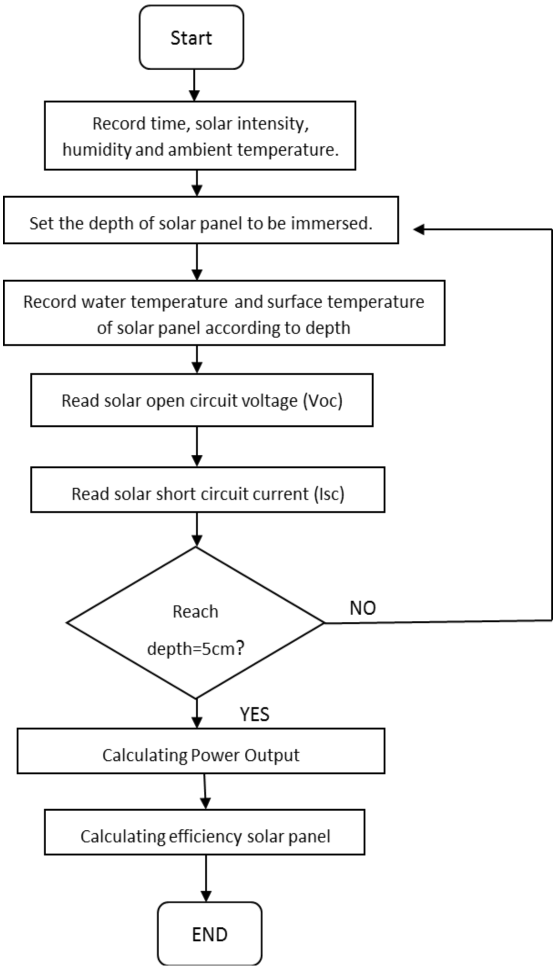
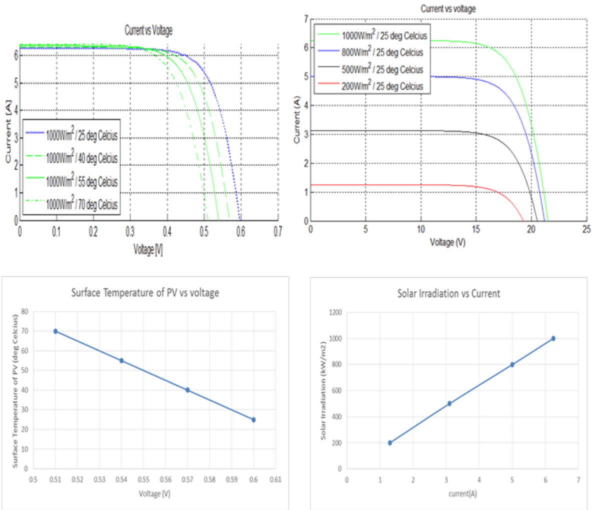


Fig. 4: Work flow on recording of the experimental data in this study.

In this study, four different experiment design were carried out simultaneously which different cooling media were used to cool the back side of mono-crystalline PV solar panel via immersion technique in water, distilled water and rainwater. All results are shown in Figure 8 below.



(a) (b)

Fig. 5: MATLAB Simulation results. (a) I-V Characteristics of solar cell with constant solar irradiation and corresponding extrapolation at I = 0 A, 1000 W/m2 showing when temperature of solar cell increases, open-voltage drops, (b) I-V Characteristics of solar cell with constant temperature and corresponding extrapolation at V = 0 V, 25 °C showing that solar irradiation increases, short-circuit current increases.

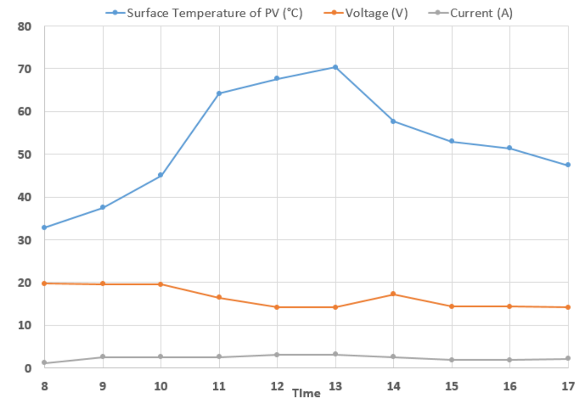
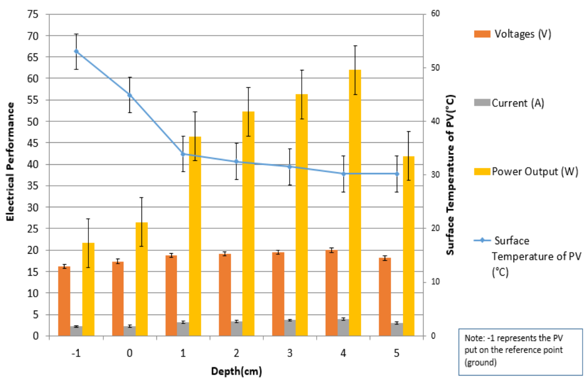


Fig. 6: Recorded surface temperature and corresponding voltage and current value of a PV solar panel on the ground.



(a)

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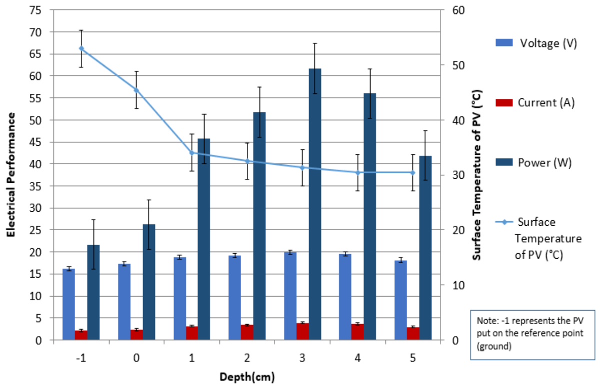
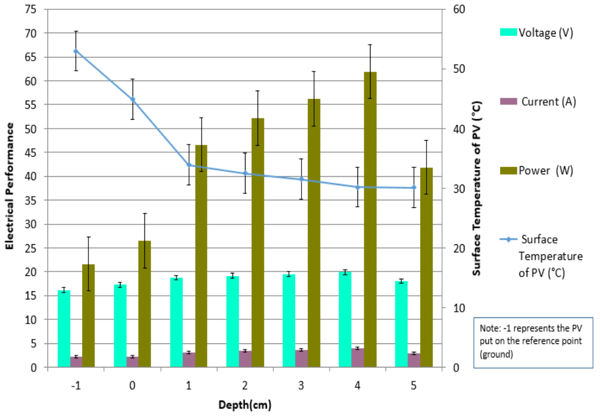
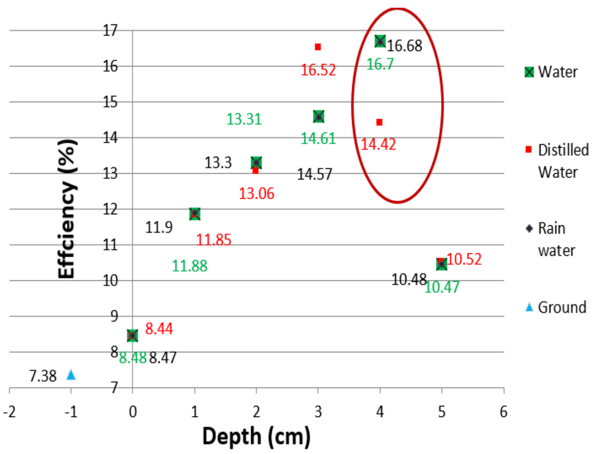


(b)



(c)



(d)

Fig. 8: Results showing important electrical parameters (average value) upon cooling by immersion technique in (a) water, (b) distilled water and (c) Rainwater accordingly to increasing of depth, (d) overall PV panel efficiency derived from the data measurements from (a) to (c).

Based on the results in Figure 8, it was observed that the grounded/rooftop PV solar panel has the lowest electrical efficiency of 7.38%. This is because the temperature of PV solar panel is the highest (> 65°C) when compared to others. Temperature of the immersed panel dropped quite drastically to around 45 °C in all cases when the panel is partially-submerged at the depth of 2 cm and beyond. It was also observed that through immersion from back side, PV solar panel has the highest electrical efficiency when immersed in pipe-water and rainwater in depth 4 cm which are 16.7% and 16.68% respectively while the efficiency of immersed PV solar panel in distilled water at depth 4 cm is estimated to be 14.42%. However, the PV solar panel immersed in distilled water at the depth 3 cm is the highest, 16.52% when compared to other depth. Therefore, the result could be concluded that the optimum depth to immerse the PV solar panel in pipe- water and rainwater are 4 cm depth, while the optimum to immerse the PV solar panel in distilled water is at 3 cm depth.

This could be due to the low heat transfer coefficient (5 to 100 W/m2K) of cooling media itself, in this case is the distilled water. Low heat transfer coefficient simply means that the heat from the direct incoming sunlight is transferred at the lower rate compared to others. In this case, at the depth of 3 cm immersion in distilled water, the temperature is much lower and the efficiency is the best optimum.

Where-else, for the water and rainwater cooling media, both media has higher heat transfer coefficient value which are typically ranging from 100 to 1200 W/m2K and 700 to 850 W/m2K respectively. Therefore, the heat transportation between the direct incoming sun light and cooling media is faster and this often required deeper aspect of cooling which in return was observed to be at 4 cm depth. However, further study needs to be done to verify these points.

V. CONCLUSION

This paper presented on efficiency improvement based on different cooling media via immersion technique in a PV solar panel focusing on tropical weather setting. From this study, the efficiency of PV solar panel without cooling (grounded PV solar panel) is the lowest, 7.38%. The optimum depth to immerse the solar panel into water (pipe-water) and rainwater is 4 cm. The efficiency of water (pipe-water) and rainwater are 16.7% and 16.68 % respectively which corresponds to 38.7% and 38.62% efficiency improvement with reference the panel without cooling. However, the optimum depth of solar panel immersed in distilled water was found to be 3 cm and the efficiency is 16.52% and has overall efficiency improvement of 37.96% compared to reference point/ground.

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BIOGRAPHIES

T. S. Y. Moh received his engineering degree (with Honours) from University Technology of Malaysia in Electrical Engineering in 2005. A year later, he received his Master of Engineering from the same university. Later, he obtained his Master of Science degree in bio-photonics from École Normale Supérieure de Cachan, Paris, France in 2008. Subsequently, he joined Microsystems Lab at Royal Institute of Technology Stockholm, KTH, Sweden to work on fabrication and packaging of microfluidics for European FP6 project. In 2013, he received his PhD from Delft University of Technology, The Netherlands in the fabrication of Silicon Nanowires Transistor for biosensing application. Now he is an Associate Professor in University College of Technology Sarawak, Sibu, Malaysia.

E.M.S. Ting received his technical education (Diploma) from Kolej Laila Taib in Electrical & Electronics Engineering back in 2013. Then, he continued his tertiary education in University College of Technology Sarawak, Sibu pursuing Bachelor degree of Engineering Technology in Electronics and Electrical. He graduated in 2016 and now he is a trained engineer in the field of electronics, electrical power particularly in solar energy and renewable energy. Elvin participated in the national innovation competition organized by Ministry of Higher Education (MOHE), Malaysia in 2014 and worked as an intern in Pansar Berhad prior to his graduation. Now he is working as an operation engineer/executive at Tenn Pacific Sdn Bhd.