

Personal air-conditioning system using evapolar as heat waste management

Nor Azazi Ngatiman¹, Abdul Qaiyum Mohd Shariff², Tole Sutikno³, Suparje Wardiyono⁴,
Mustafa Manap⁵, Mohd Hatta Jopri⁶

^{1,2}Department of Mechanical Engineering Technology, Faculty of Mechanical & Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia

³Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia

⁴State-Owned Enterprise Power Company (PLN), North Kalimantan Province, Indonesia

^{5,6}Faculty of Electrical and Electronic Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia

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ABSTRACT

Air-conditioning system that uses compressor-based initiate more energy and affects bill rate. As a result, an application of the Peltier impact module, a portable air-conditioning system is introduced to compensate user convenience by lowering sensible and latent heat inside the office area. Thermoelectric Peltier module is a thermoelectric semiconductor that offers cooling and hot plate once the plate is supplied by electric. The result reduces the cost, power consumption, and give thermal comfort in a dedicated space. The advantage of the study is the ability to cost deduction due to low power consumption and green technology devices factor because without refrigerant that harms the environment. Redesign the product with evapolar as heat waste management affect the performance and need to be validated. The development stage of this product is better compared to a previous product which offers small scale, light, and portable. This product focuses on the office room, which gives a good feeling to users. This product uses air to remove the heat waste and the result indicates evapolar is fit enough in dissipating heat. Finally, the performance of this system developed demonstrated that it can attain thermal comfort level.

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Corresponding Author:

Nor Azazi Ngatiman

Department of Mechanical Engineering Technology

Faculty of Mechanical & Manufacturing Engineering Technology

Universiti Teknikal Malaysia Melaka, Malaysia

Email: azazi@utem.edu.my

1. INTRODUCTION

The cooling unit to cool a room usually uses a split unit which has a larger amount of cool air to distribute. For example, a standard office with an area 12'x12' will be a waste to cool the whole room since the space needed is a small area. In-office buildings, occupants will have a restricted space to move and have to control their movements. It will give an uncomfortable zone due to unbalanced comfort ventilation [1]-[5]. This proves that a portable air conditioner can cool with a range of 1 meter around a person will be more suitable than split units since it conserves less energy. Hot temperatures in a space must be removed to achieve a thermal comfort zone [6]-[9]. The previous researcher found that the Peltier module can cool down temperature and develop it as a portable air conditioner [10]-[13]. It is proven to overcome waste energy consumption in portable air conditioning, Peltier module was used. Hot effects on the hot side of the Peltier module cannot fully be utilized while vice versa on the cold sides [14], [15]. The problem with the hot sides

that not be used in Peltier module must be utilized because portable air conditioning using Peltier module have a great achievement in transferring cool air to surroundings [16], [17]. Peltier module will be affected due to a lot of heat waste in the surroundings. The latest researchers [18]-[20] found that heat waste from portable air conditioning using a Peltier module can be used as heat energy. This study also showed that thermal efficiency in the heat recovery process proves that higher thermal conductivity produces higher heat transfer to the surface. Less amount of heat loss occurred during the study [11], [21]-[23].

From the latest product of portable air conditioning system design [16], [24]-[26], the heat waste is released to the surrounding in large amounts due to unorganized energy [27]-[32]. The thermal comfort zone standardized by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is around 22 to 24°C for most buildings in Malaysia [33]-[35]. Heat waste from the Peltier module spread to the air and cause uncomfortable to users. Due to limited space in a room, users feel hotter because of Peltier module generates the same capacity of hot and cold energy. Adding external energy such as electrical equipment and body, the temperature increase and hot temperature will overwhelm cold temperature [36]-[40] So in favour of producing thermal comfort zones, this research will design new ways on how to recover the heat waste from release to surroundings [41]-[43]. In terms of ergonomics to users, this product needs to be upgraded for a better purpose. The heat waste from the product needs to be recovered to ensure the product will be convenient and increase efficiency [44]-[46]. This method also is a new idea in managing heat waste using evaporator and finding ways to increase the effectiveness of the system.

2. METHOD

A strategy to develop a portable air conditioning system using evaporator from several previous research is discussed. Different criteria and mechanical engineering concepts are used as a significant strategy [47]-[50]. This section includes the examination, evaluation, preparation, production, improvement, and testing [51], [52]. Figure 1 depicts the process of developing portable air conditioning and also identifies the performance of the product. It starts from defining the standard condition until analysis of the developed product. Design is a process of designing a system to fulfil the outcome for this study, which provides a thermal comfort zone with the help of an evaporator. A good design is defined to achieve the objective by the product's engineering characteristics. The great design of this device can be created by following a standard conventional method which is the Morphological method and Pugh method.

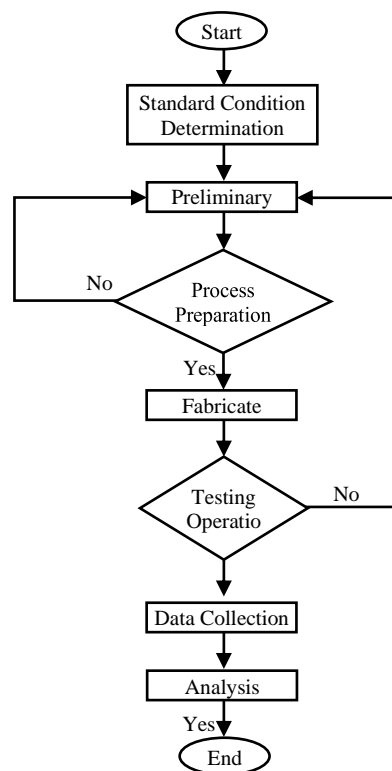


Figure 1. Process phase of energy saving personal air-conditioning development

2.2. Morphological chart

The morphological technique is the study of shape as well as forms before the product is being developed [53]-[56]. The basic idea of the morphological technique is to elaborate the overall design issue into few variables to generate a solution for each criterion. It also systematically mixes up criteria solutions into multiple effective solutions and evaluate all combinations. It is a visual aid that comes with several ideas for selecting the suitable element throughout the design technique. Table 1 shows the morphological chart attributes for portable air conditioning system.

Table 1. Morphological chart of portable air conditioner

Characteristics	Option 1	Option 2	Option 3
Heat Sink	Fin	Flare	Flare
Size	Medium	Small	Big
Blower	Draw Through Fan	Centrifugal	Axial
Sensing Element	Thermocouple	RTD	Bimetallic Strip
Power Source	Electrical	Solar	Mechanical
Casing Material	Metal Sheet	Plastic	Aluminum Sheet
Supply Connection	Direct	Wireless	USB

2.2. Pugh method

The Pugh method was introduced by Stuart Pugh, a plan division head at the University of Strathclyde in Glasgow [57]. Pugh is used to assess different alternatives by calculating the overall score between the choices [58]-[60]. The selections derive from the morphological method in which three concepts have produced the character of the product. Pugh method evaluates three concepts in terms of choosing a good concept based on the total raw score. The weightage describes the crucial feature, which should be carefully measured before selecting the best idea as shown in Table 2.

Table 2 shows option 1 is the best concept among other concepts due to the highest total raw score. Option 1 from the morphological method applies an electrical power supply, medium device, draw through fan, Arduino controller, thermocouple sensing element, metal sheet casing, finned heat sink, and connect directly. By using these methods, the design of the product is made and the results are shown as in Figure 2.

Table 2. Pugh method of portable air conditioner

Characteristics	Weightage	Option 1	Option 2	Option 3
Heat Sink	0.2	1	-1	-1
Size	0.2	1	-1	0
Blower	0.2	1	-1	0
Sensing Element	0.2	1	0	-1
Power Source	0.1	0	-1	1
Casing Material	0.1	1	-1	0
Supply Connection	0.1	1	0	1
	Total	1.3	-0.6	0

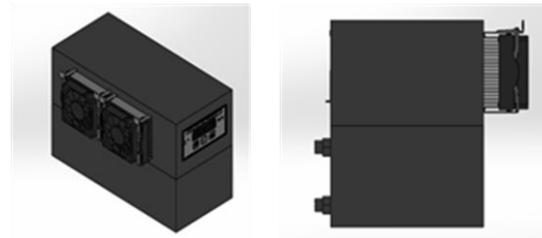


Figure 2. Conceptual of personal air-conditioning development

2.3. Testing condition

A field measurement is carried out in this research to investigate the performance of a product in an office room [61]-[63]. This room size is measured and it is situated in Ayer Keroh, Melaka. It used a VRF (variable refrigerant flow) fan system where it is efficient and reliable. The ceiling measurement height from floor to ceiling is 2.5 meters. The collected data will be summarized. This equipment will be placed on the table at 1-meter height from the ground.

2.4. Peltier performance

The efficiency of both generators and coolers conclude the greater the value of this term, the greater the efficiency [64]-[66]. The heat flux gives the value of the thermoelectric of merit between hot and cold sides due to conduction is:

$$Q_m = SIT_c - 0.5I^2R - k(T_H - T_C) \text{ KJ} \tag{1}$$

Where S is Seebeck coefficient=0.053 V/K, K is Lattice thermal conductivity=0.3 w/m.K, R is electrical resistance=0.45 Ω , and I is current. Electrical power consumed by the module is calculated based on the heat flux difference of the two sides of the module as, where I is current, V is voltage, and t is time.

$$E_m = IVt \text{ (KJ)}$$

$$\text{COP} = Q_m / E_m \quad (2)$$

2.5. Performance coefficient of device

A previous thermoelectric air-conditioner (heat pump) typically contains a large number of n-type and p-type bulk semiconductor thermoelements linked electrically in series by copper strips and sandwiched between two electrically insulating, but thermally conducting ceramic plates. In the cooling mode, the cooling capacity performance of the cooling effect is expressed as (3).

$$\text{COP}_c = \frac{1}{\frac{T_{\text{hot}} - T_{\text{thin}}}{T_{\text{cin}} - T_{\text{cout}}} C_r - 1} \quad (3)$$

Where C_r is heat capacity ratio as (4)

$$C_r = \frac{mcp_c}{mcp_h} \quad (4)$$

The arithmetical average temperature of the thermocouple is as (4).

$$T_m = \frac{1}{2} (T_H + T_c) \quad (5)$$

V is an electrical voltage as (6).

$$V = \frac{\alpha \Delta T}{\sqrt{1 + ZTm} - 1} \quad (6)$$

Hence, the power can be obtained by using the volt calculated, as shown in (6).

$$P = v \times I \quad (7)$$

3. RESULTS AND DISCUSSION

The newly developed product is considering design parameters defined from the morphological chart where the combination of specific conditions for the creation of a product is shown in Figure 3. The system features use Peltier as a cooling source, a heat sink with aluminium finned to increase the heat transfer rate of a wood case to guard the internal component, evaporator as a medium to cool down condenser and the fan to blow the cool air.

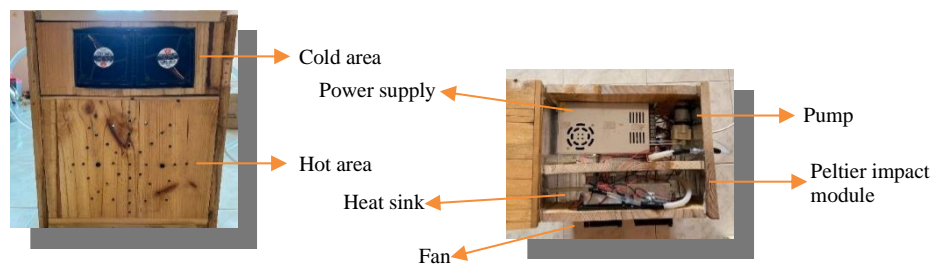


Figure 3. Final product assembled

3.1. Thermoelectric performance

This measurement repeated three times to prove whether the product achieve efficiency at different times. Table 3 shows the time taken to the temperature of Peltier becomes hot and cold. The temperature is measured every 5 minutes and COP for Peltier performance is calculated. Figure 4 shows the relationship between the Cop of Peltier performance after several tests. The trend of the chart is almost similar. Based on the previous research, the highest COP for Peltier reach 0.3205, which had different conditions that need to be counted. For this experiment, it shows COP for Peltier can reach 0.58 with proper conditions which show

that for series connection and condition inside a room can affect the performance of Peltier. Thermal paste was used in this Peltier to lessen heat transfer losses that occur and increase the efficiency of Peltier.

Table 3. Summary of data for all test

No	Time (sec)	Tc (K)	Th (K)	ΔT (°C)	Current (A)	Volt (V)	Q_m	E_m	COP_m
Test 1	1800	296.90	324.70	27.8	3.50	12	43.978	75.600	0.581
Test 2	1800	296.10	324.40	28.3	3.50	12	43.680	75.600	0.577
Test 3	1800	296.90	324.90	28.0	3.50	12	43.918	75.600	0.580
Average	1800	296.63	324.66	28.0	3.50	12	43.858	75.600	0.579

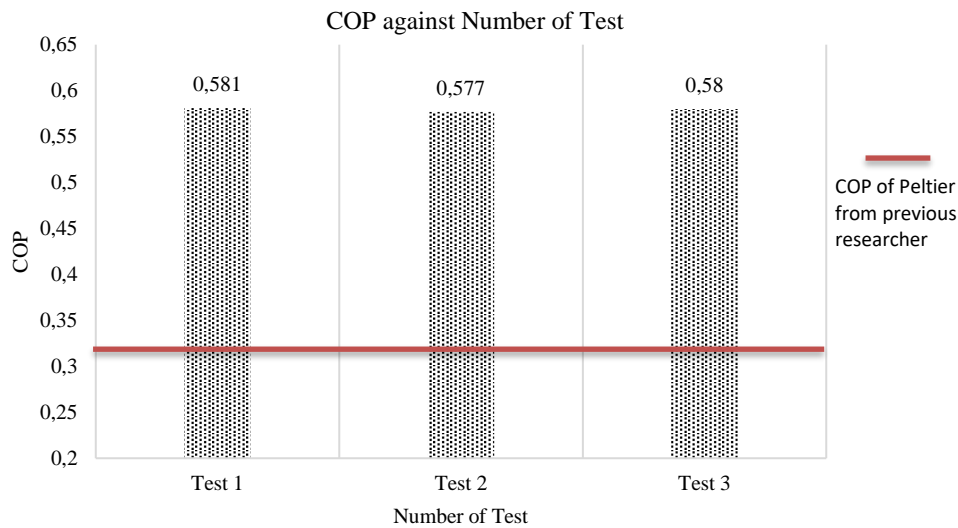


Figure 4. COP against the number of tests compared to the previous researcher [68]

From Figure 5, the temperature difference is increasing and the longer time is taken, the higher the temperature difference will occur. The efficiency of the Peltier can be seen due to the series connection to the wiring for all Peltier. When the current is in series connection it increases the voltage to the maximum while parallel connection increases the current to maximum [67]. For this experiment, R^2 values that are near to 1 are shown and R^2 data for each analysis reaches a suitable determinant coefficient. The data obtained is acceptable for the overall result of testing because it is higher than the set value where $y=1.4771x + 23.18$ can be used to calculate the difference in temperature at any point for this product.

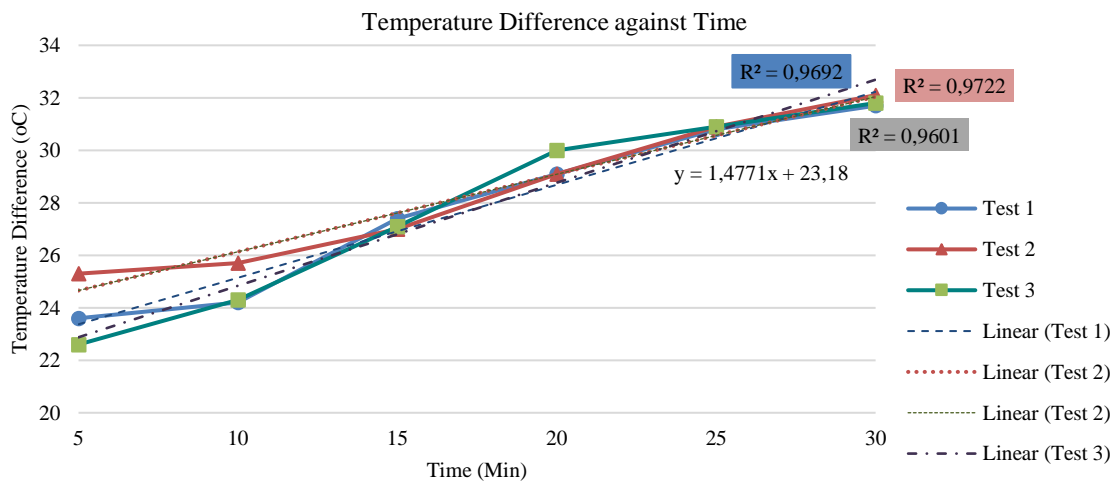


Figure 5. Temperature difference against time

Figure 6 shows the different numbers of tests in the same conditions of the product. All of the temperatures have a minimal difference, which shows that the limit of the product that can be reached. Test 1 shows that for TCout, the temperature that blows to occupants can reach 26.9°C when ambient temperature which TCin, at 31.8°C. Next, THin which temperature of the air outside shows 35.7°C while the temperature inside can reach 48.5°C. This data showed that with the evaporator mechanism, the amount of heat waste that could be removed is high and more productive.

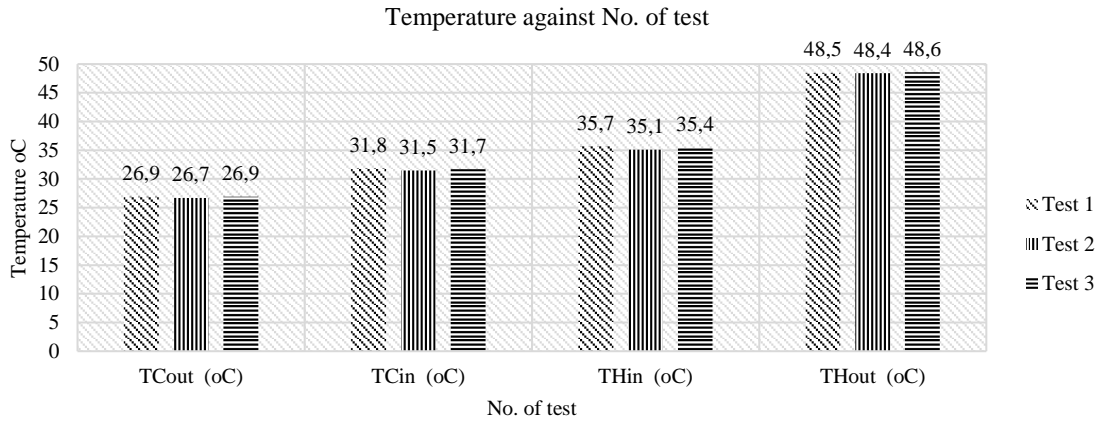


Figure 6. Different in temperature hot and cold with the number of tests

3.2. Coefficient of performance on product

Table 4 shows the summarize of data for all three tests. It demonstrates that there are no significant changes for each test since an average of temperature shows a consistency of data.

Table 4. Summary of all type of temperatures collected

No	TC _{out} (°C)	TC _{in} (°C)	TH _{in} (°C)	TH _{out} (°C)
Test 1	26.9	31.8	35.7	48.5
Test 2	26.7	31.5	35.1	48.4
Test 3	26.9	31.7	35.4	48.6
Average	26.8	31.6	35.4	48.5

3.3. Tariff of the device

A number of tests with the temperature of Peltier recorded is shown in Table 5. From the table shown, the data for current and voltage are stable and good result is determined with the greater temperature different, ΔT [46], [69]. All three set of collected data shows a stability of the system developed.

Table 5. Number of tests with the temperature of Peltier

No	T _c (K)	T _h (K)	ΔT	Current (A)	Volt (V)
Test 1	296.90	324.70	27.8	3.50	12
Test 2	296.10	324.40	28.3	3.50	12
Test 3	296.90	324.90	28.0	3.50	12
Average	296.63	324.66	28.0	3.50	12

Referring to Table 6, the estimation of the bill depends on the Malaysian tariff [70]. Compared to the previous researcher [68], 2.88 kWh power per day was used instead of 6.894 kWh. The monthly energy consumed is 137.88 kWh, while this product consumes only 57.74 kWh, which can save almost 58% of its electricity.

Table 6. Tariff of the device for product

Period	Time operates	Electricity consumption (kWh)	Price (RM)
Day	8 am to 5 am=9 hours	9 x 320.83=2.88	1.12
Week	Monday to Friday=5days 5days x 9hours=45hours	45 x 320.83=14.43	5.62
Month	One month=4weeks 4 weeks x 45hours=180hours	180 x 320.83=57.74	22.51
Year	January to December=12month 52 weeks x 45hours=2340hours	2340 x 320.83=750.74	292.78

Figure 7 shows the amount of the bill per day to be paid for this product is RM1.12, which the previous shown RM1.50, which can save 25% of the bills per day. Besides, the margins are increasing as compared in the month that this new product can save 26%. Based on the above information, this product provides consumers with fewer electricity bills while providing an individual with comfort.

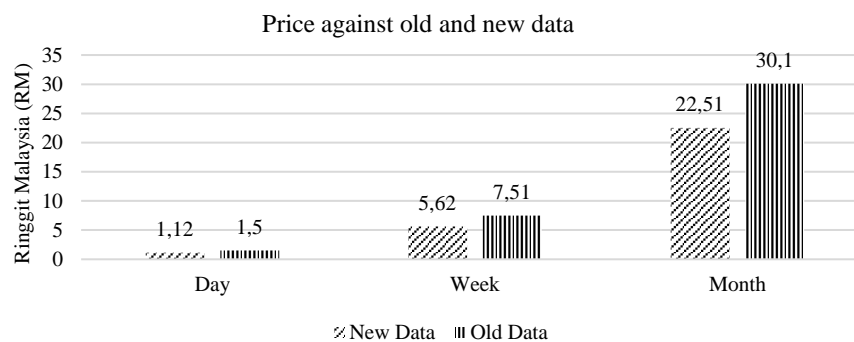


Figure 7. Price comparison with the previous researcher [68]

4. CONCLUSION

The performance study of an office scale portable Peltier air conditioner is demonstrated. The product can reduce the temperature inside the room. The objective of the study has achieved which design is made based on the Pugh method and Morphological chart. The design process has also been done using Solid Work Software. The performance of the product using evaporator as heat waste management has been discussed. It reaches the purpose to remove heat from the inside of the product to the outside using evaporator as heat removal. The coefficient of performance is similar to the level of the previous product, which means it can provide higher efficiency despite no controller temperature. Tariff for electricity shows this product can save energy approximately by 25% compared to previous one.

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BIOGRAPHIES OF AUTHORS



Nor Azazi Ngatiman received the B.Sc. degrees in Mechanical Engineering from Universiti Kebangsaan Malaysia, in 2005 and M.Sc. degrees in Manufacturing Systems Engineering from Universiti Putra Malaysia in 2010. He experienced with engineering research and development field industry for over 5 years from 2005. In 2021, he got a PhD degree in Mechanical & Material Engineering from Universiti Kebangsaan Malaysia. His current research interests include condition-based monitoring, mechanical signal analysis, vibration analysis and machine learning. He can be contacted at email: azazi@utem.edu.my



Abdul Qaiyum Mohd Shariff worked as a Technical Support for Carrier (M) Sdn Bhd, designing fan coil units (FCUs), air handling units (AHUs), and calculating heating and cooling loads. Now employed as a Service Engineer at Panasonic Air Conditioning System, where he is responsible for servicing variable refrigerant flow (VRF) systems. He can be contacted at qaiyumshariff@gmail.com



Tole Sutikno is a Lecturer in Electrical Engineering Department at the Universitas Ahmad Dahlan (UAD), Yogyakarta, Indonesia. He received his B.Eng., M.Eng. and Ph.D. degrees in Electrical Engineering from Universitas Diponegoro, Universitas Gadjah Mada and Universiti Teknologi Malaysia, in 1999, 2004 and 2016, respectively. He has been an Associate Professor in UAD, Yogyakarta, Indonesia since 2008. He is currently an Editor-in-Chief of the TELKOMNIKA since 2005, and the Head of the Embedded Systems and Power Electronics Research Group since 2016. His research interests include the field of industrial applications, industrial electronics, industrial informatics, power electronics, motor drives, renewable energy, FPGA applications, embedded system, image processing, artificial intelligence, intelligent control, digital design and digital library.



Suparje Wardiyono was born in Sleman, Indonesia on 1978. He received his B.Eng in Electrical Engineering from Faculty of Engineering, Gadjah Mada University, Indonesia in 2001, M.Sc. in Electrical Power Engineering from Rheinisch-Westfälische Technische Hochschule Aachen (RWTH), Germany in 2011. He is an experienced electrical engineer and since 2002, he has been serving well-known State-Owned Enterprise Power Company in Indonesia, PLN and held various engineering, procurement, asset management, retail and customer service in various units PLN in Indonesia. His focus areas are Engineering, Management and Customer Service. Currently he is serving PLN as Customer Service Manager for North Kalimantan Province, Indonesia.



Mustafa Manap was born in Kuala Lumpur, Malaysia on 1978. He received his B.Sc from Universiti Teknologi Malaysia in 2000 and Msc. in Electrical Engineering from Universiti Teknikal Malaysia Melaka (UTeM) 2016. Since 2006, he has been an academia staff at Universiti Teknikal Malaysia Melaka (UTeM). He registered with Malaysia Board of Technologist (MBOT), and a member of International Association of Engineers (IAENG). His research interests are power electronics and drive, instrumentation, and DSP application.



Mohd Hatta Jopri was born in Johor, Malaysia on 1978. He received his B.Eng from Universiti Teknologi Malaysia (UTM), Msc. in Electrical Power Engineering from Rheinisch-Westfälische Technische Hochschule Aachen (RWTH), Germany, and PhD from Universiti Teknikal Malaysia Melaka (UTeM), respectively. Since 2005, he is an academia and research staff at UTeM. He registered with Malaysia Board of Technologist (MBOT), and a member of International Association of Engineers (IAENG). His research interests include power electronics and drive, power quality analysis, signal processing, machine learning and data science.