International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 11, No. 1, March 2020, pp. 442~450
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v11.i1.pp442-450

Applied measurement of the motor speed controller for washing machine with random loads, part II

Khalid G. Mhammed[1], Jabbar A.F. Yahaya[2], Reyasudin Basir Khan[3]
[1] Department of Scientific Affairs, University of Diyala, Iraq.
[2] Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn, Malaysia.
[3] Universiti Kuala Lumpur, British Malaysian Institute, Malaysia.

Article Info

Article history:

Received Sep 7, 2019
Revised Nov 2, 2019
Accepted Nov 28, 2019

Keywords:

DC motor
Motor Controller
Speed Control
Three phase
Washing Machine

ABSTRACT

This research presents a very important industrial issue of controlling the production target, despite changing loads. Engines of various types, whether synchronous or synchronous, operate on single and three phase AC, DC motors or special motors such as stepper and servo. In all these motors, the speed control of the torque and speed of the above motors has gained considerable importance. There are three main ways reviewed in the current search, the second that completes the previous research referred to in the references. The three methods are PID method, LQR method and feeding – forward control methods. A real DC motor was used in electrical engineering machine laboratory at University of Diyala, Iraq. Where the actual parameters of the DC motor were actually calculated. The practical parameters were then integrated into the three control method Matlab codes for the purpose of comparing the results and representing the motor performance in the indicated control methods.

Corresponding Author:

Khalid G. Mhammed,
Department Scientific Affairs,
University of Diyala, Baqubah, Iraq
Email: khalid_alkaisee@engineering.uodiyala.edu.iq

1. INTRODUCTION

The There are many types of control units which are used in the control field of electrical and mechanical equipment's. Most of electrical machines such as single or three-phase AC induction motors, AC Synchronous motors and DC motors depend mainly on the control feedback units to achieve optimum performances [1]. The feedback control units which are used with the motors are composed of different types of sensitive electronic devices: sensors, transmitters, comparator, and servo-controller [2]. A controller unit is very significant to get the steady state in shorter time and to reduce the rise time, overshooting and settling time [3]. This paper presents two main developments concern the mechanism of the washing machine: applying armature control which allows to control the speed of separately excited dc motor using PID controller, modelling the system of the DC motor and using MATLAB for representing the performance and analyzing the whole control system.

2. GENERAL SETUP OF WASHING MACHINE

The washing machine is an apparatus which is capable of operating in constant changing load and can be found using either AC or DC motor. The motor speed increases or decreases depending on the load. Varying of motor speed with varying the load causes decrease the efficiency of the motor and then decrease the speed the machine agitator [4]. So, it is very necessary to get a good performance of the machine we have to get the speed and torque constants whenever the load is changed. When the power that is supplied to the four-pole motor, the rated speed reaches slightly around 1500 rpm at no-load condition. This rated speed is high and is very difficult to run with a loaded agitator in the washing machine. Therefore, the speed of the agitator should be reduced to suitable and safe load speed. The safe load speed can be achieved using two different diameters of the motor and agitator pulleys. The choice of the diameters is based on the speed ratio between the motor and safe speed of the agitator. The second important matter is how to keep the speed of the agitator is invariant with the variable load. To get a constant speed of the agitator and its motor whatever the load is changed represents the main work of this project. Figure 1 depicts a washing machine which contains the electrical motor, pulleys and agitator.

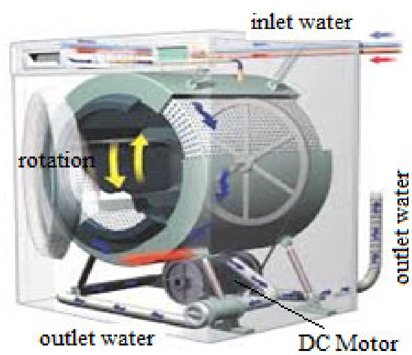

Figure 1. Real and internal sector diagram of the washing machine [4].

2.1. Separely excited DC motor

As per Figure. 2, the equivalent circuit of the DC motor is attached with the external variable load on the armature shaft of the DC motor. The equivalent circuit is composed of two parts: the first is the stator field windings or may be permanent magnets and the second pat is the rotary armature circuit [5-8]. The DC motor used in this paper is manufactured by KI Company (Taiwan) with its ratings shown in Figure 2.

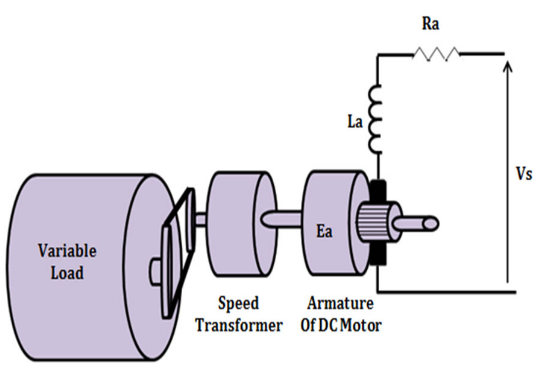

Figure 2. Schematic diagram of the DC motor, pulleys, and the load inside the washing machine.

The main relation between the speed *N* of the DC motor and applied voltage source V_{dc} on the armature and its stator flux φ can be identified by (1).

$$N = \frac{(V_{dc} - I_a R_a)}{\varphi} \quad (1)$$

Where $I_{a,}$ is the armature current, R_a represents the armature resistance, the armature inductance represents by L_a. T_m represents the motor torque in newton-meter (N.m). The measurement for rotating inertia of motor bearing is represented by J and damping coefficient is expressed by B [9-13].

2.2. PID controller

Generally, the schematic diagram of the PID controller is consisted of three main parts as shown in Figure 3. The real PID used is manufactured by Telefunken Company (Germany) which is available in the electric machine laboratory, COE, Diyala University as sown in Figure 4. The transfer function (T_F) of the PID controller can be represented by (2). Where the PID parameters are Proportional gain (K_p), Integral gain (K_I) and the derivative gain (K_d) [14-18].

$$T_F = K_P + \frac{K_I}{S} + K_D S \quad (2)$$

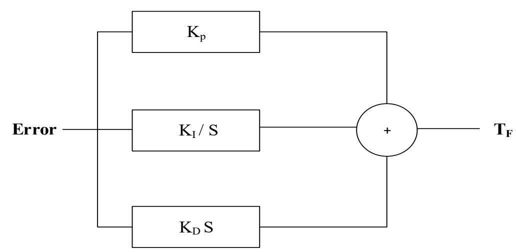

Figure 3. Schematic Diagram of the PID controller which is used to correct and reduce the error.

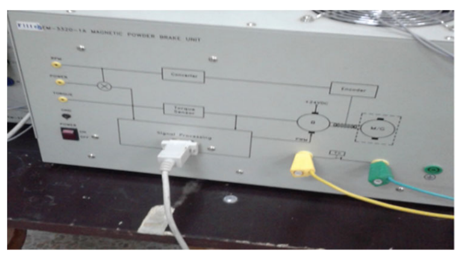

Figure 4. The real torque/speed controller used in the test is modelled as EM-3320-1A by which is available in the electric machine laboratory, COE, University of Diyala.

The mathematical relations among the three parameters K_p, K_I and K_d of the PID controller and their effects on the response parameters: rise time, overshoot, settling time and steady state error [19-22] are shown in Table 1.

Table 1. Expected tunning behaviour of the response parameters of the PID controller.

Parameter	Rise Time	Overshoot	Settling Time	Steady state error
Kp	Decline	Rise	Light Change	Decline
Ki	Decline	Rise	Rise	Remove
Kd	Light Change	Decline	Decline	Light Change

The tachometer used in this experiment is manufactured by Telefunken, Germany. It will be used as an instrument to measure the rotating speed of the used electrical machine. The voltage generated by the tachometer E_{tac} is given by:

$$E_{tac} = K_{tac}.N_{tac} \quad (3)$$

Where the symbols K_{tac} is a proportional constant and N_{tac} is the angular velocity of the tachometer. The transfer function of the DC motor is clarified in Figure 5.

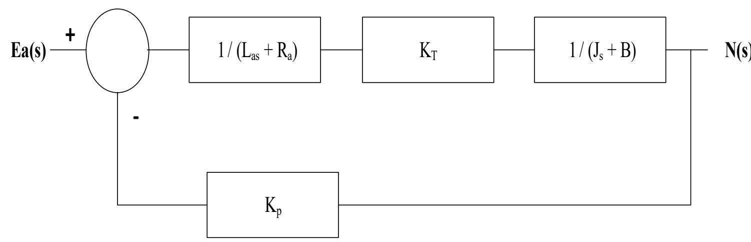

Figure 5. Block diagram of close-loop controlled system of the separately excited DC motor in the washing machine without PID controller.

$$T_F(s) = \frac{N(s)}{E_a(s)} = \frac{K_T}{[(R_a+L_a).(B+J_r)]+K_b.K_T} \quad (4)$$

In the DC motor, armature inductor L_a can be neglected due to its small value in practice, so, the T_F *(s)* can be simplified through (5) and (6).

$$T_F(s) = \frac{K_T}{R_a(B+J_r)+K_b.K_T} \quad (5)$$

let. (5) = $D_{c(s)}$

$$T_F(s) = \frac{D_{c(s)}}{1+\frac{R_a.J_s}{R_a.B}+K_bK_T} \quad (6)$$

denominator of the (6) can be expressed into

$$T_F(s) = \frac{K_m}{1+T_s} \quad (7)$$

the motor gain K_m involves four parameters: R_a, B, K_b and K_T as shown in (8).

$$K_m = \frac{K_T}{R_a.B+K_bK_T} \quad (8)$$

the time constant of the DC motor τ is given as:

$$\tau = \frac{J}{B} + K_bK_T \quad (9)$$

The transfer function of the completed DC motor electric control circuit applied in the proposed electric washing machine is clarified in Figure 6.

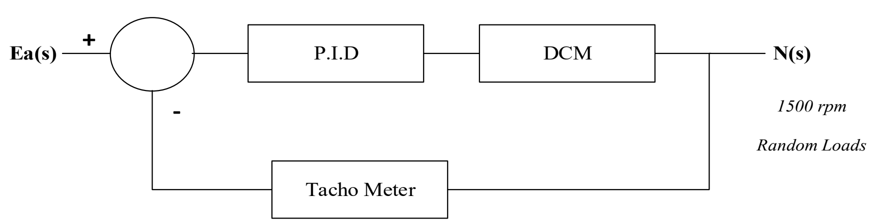

Figure 6. Block Diagram of closed loop-controlled system of the separately excited DC motor in the washing machine with PID controller.

2.3. Feed forward controller

It is a set of methods and procedures used by the designer to identify and discover any factors that may limit the success of the process in determining the target early so it is called Pre-censorship, thus for avoiding any problems and monitoring any changes. At the operational level, prior control requires the designer to focus his efforts towards selecting inputs, outputs and procedures with complete care to minimize potential problems. In the strategic level, pre-censorship is designed to alert and warn the designer of any practical changes that will affect long-term objectives [23, 24].

2.4. Linear quadratic controller

The goal of this theory is to control the ideal performance of the system at the lowest economic cost. The system is described by a set of differential linear equations. The cost is described by a quadratic function called LQ. One of the most important results of the theory is to obtain a feedback system with the LQR system, which is part of the LQG solution.

The mathematical algorithm that controls the cost reduction process at the same time controls the reduction of deviations from the main goal, such as voltages or speed. The results will be compared with the reference objectives of the required design, which are considered as standard objectives. The process of control is an iterative process, and in the end the parameters are adjusted to produce the best values for the system goal.

The frontal feed system in this method is to adjust the control of the target variable not based on error as in the PID method. It is based on practical knowledge of the measure of disturbance in the signal based on a mathematical model [25-28]. Figure 7 shows the name plate of the DC motor used in the test which is available in Electric Machine Laboratory, COE, University of Diyala.

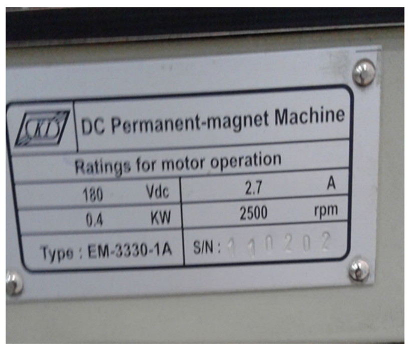

Figure 7. Photo of the DC motor which is used in the test. Electric Machine Laboratory, COE, University of Diyala.

3. EXPEREMENTAL RESULTS AND DISCUSSION

In Based on Table 2, the motor will be tested under 1500 rpm with random loads. *K* parameter or called torque/ampere is the relation between the torque of the DC motor shaft and the input armature current. Practically, the ratio can be determined by applying a variable torque to the shaft and measuring the drawn armature current of motor. The *b* parameter or called volt/speed parameter is the relation between the input voltage of the DC motor and the shaft speed. Moment of inertia is determined mathematically depending on the summation of inertias rotor and load masses and its diameter. Armature resistance *R*, is measured using an Ohmmeter directly. Inductance of the armature, is determined practically by applying a low AC voltage on the two terminals of the armature and measuring the passing current. Calculating the impedance of the armature requires information of *R* which is found to be L = 2.75µH. The experimental values of *K, b*, *J* and *R* are mentioned in Table 2.

Table 2. Parameters setup.

K (Nm/A)	*b* (Vs/rad	*J* (Nms^2/rad)	*R* (Ω)
0.5217	0.625	0.0018	5.8

There are three case studies which are implemented using MATLAB coding. Each study explains the differences between two output responses due to two inputs: ideal step and disturbance step. The output response are steady state error, overshoot, settling time and rise time. Figure 8 explains the angular velocity response to due to a step change in voltage.

Table 3. Continuous-time state-space model parameters.

	a		b		c	d	
	X1	X2	U1	U2	Y1	U1	U2
X1	-347.2	1.18×10^4	0	32	17.36	0	0
X2	0	-2.1×10^6	512	0	0		

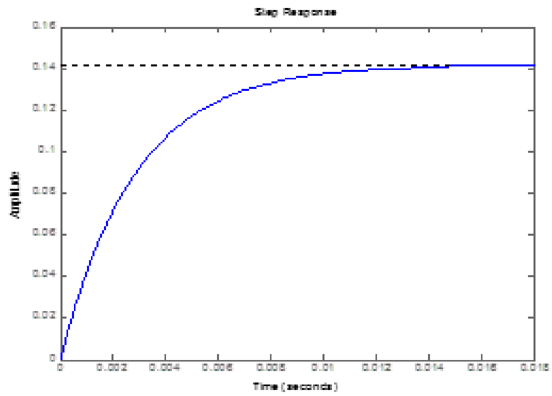

Figure 8. The angular velocity response to a step change in voltage.

3.1. Feedforward control design

The Root locus of the system with using integrator K/s is shown in Figure 9. The roots of the DC motor system used explains that the system is stable. These roots depends on the entire system specifications.

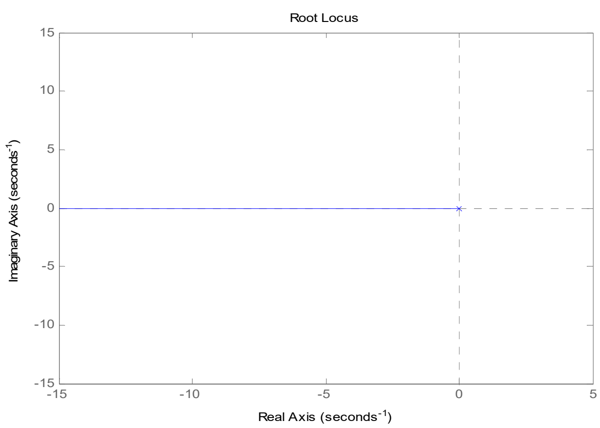

Figure 9. Root locus of the system with using integrator K/s.

3.2. LQR control design

To further improve performance, try designing a linear quadratic regulator (LQR) for the feedback structure shown below in Figure 10.

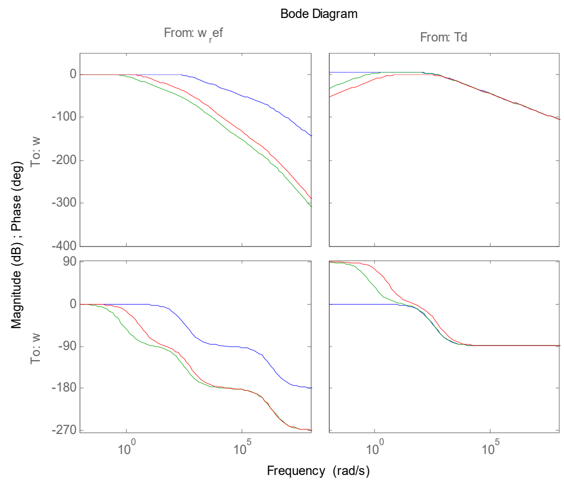

Figure 10. This plot compares the closed-loop Bode diagrams for the three designs.

Comparison of the three designs in Figure 11, the input signal takes the zero value for five seconds and then subtracts the torque value to -0.1 for 5 seconds. This disturbance in the output signal on the lip will be examined and tested in three cases: the output response in the case of using feed forward system is as shown in blue color line behaves as a pulse according to the torque input signal Td.

If the same input signal Td is used to change the input torque with the feed back root locus, the output response in the green color will need more time to reach the stability state, ie, the transient period is greater than the first.

In the case of feeding LQR, the change in output response (red line) with change in input torque Td is better between the two previous cases feedforward and feeback. In spite of the disturbance in the input signal Td, the external response is good and stable. The transint period does not exceed one and a half seconds, and the change in the amount of external signal does not exceed 0.2.

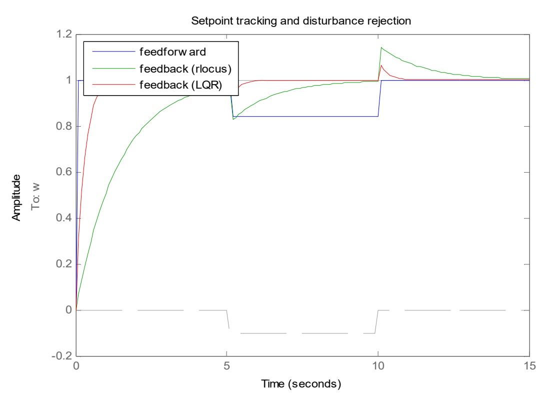

Figure 11. Setpoint tracking and disturbance rejection

4. CONCLUSION

This paper presents study of three methods of control to modify and correct the dropping in the speed of the electrical motor of a washing machine due to sudden or pre-starting loads. The feedback controller consists of comparators such as PID, LQR and feed forward to make improvement and minimizing to the difference between the actual and setting speed of the motor under variable loads. The actual/real motor is measured and the parameters are implemented into MATLAB coding to emulate in reality the optimized performance of the motor in required case study. It is observed from the experiment that in the case of a step responses change in the DC motor, it is preferable to use a LOR control rather than PID, and PID is better than feedforward while the cost of feedforward is the best of all control methods PHD and LQR.

REFERENCES

[1] B. J. Chalmeres., "Electric motor handbook," *London: Butterworths*, 1988.
[2] B. K. Bose., "Modern power electronics and AC drives," *Tennessee, USA*: *Prentice Hill PTR*, 2000.
[3] N. Mohan, T. Undeland, W. Robbins, "Power electronics: converters, applications, and design," *New York: Wiley*, 1994.
[4] Ali M Humada, Mushtaq Najeeb, Ramdan, bin Razali, KG Mohammed, Hamdan bin Daniyal., "PID Parameters Improvement for AGC in Three Parallel-Connected Power Systems," *The National Conference for Postgraduate Research 2016, Universiti Malaysia Pahang*, pp. 544-551, 2016.
[5] Thiraja, "*Electrical technology*," Book, Edition, New Edition, Chand and company limited, pp.1267-1294, 2010.
[6] E. S. Hamdi., "Design small electrical machines," *John Wiley & Sons, Inc., 605 Third Avenue, New York, NY* 10158-0012, USA, 1996.
[7] A. K. Sawhne., "A course in electrical machine design," Dhanpat raians' sons 1682, *Nai Sarak, Delhi*, 1984.
[8] Jimmie J., "Electric machines, analysis and design applying matlab," *Cathey*, pp: 492-510.
[9] Khalid G. Mohammad., "New design correlations for single phase induction motor squirrel cage," *Diyala Journal of Engineering Sciences*, vol. 03, no. 2, pp. 134-144, December 2010.
[10] Dr. Settar S. Keream, Khalid G. Mohammed, Mayyada Sahib Ibrahim., "Analysis study In Principles Of Operation Of DC machine," *Jour of Adv Research in Dynamical & Control Systems*, vol.10, no. 2, pp. 2323-2329, 2018.
[11] Khalid G. Mohammed, AQ Ramli, UAA Amirulddin., "A new approach in designing a small three-phase synchronous machine," *International Review on Modelling and Simulations*, vol. 6, pp .1103-1111, 2013.
[12] Stephen J. Chapman., "Electric Machinery Fundamentals," *McGraw-Hill*, 1991.
[13] Settar S. Kercam, Khalid G. Mohammed, Mayyadah Sahib Ibrahim., "Analysis study in Principles of Operation of DC Machine," *Jour of Adv Research in Dynamical & Control Systems*, vol.10, pp. 2323-2329, 2018.
[14] George McPherson., "An introduction to electrical machines and transformers," *John Wiley & Sons*, 1981.
[15] Khalid G. Mohammed, A. Q. Ramli, U. A. Ungku Amirulddin., "design of outer rotor single phase squirrel cage induction motor," *International Review on Modelling & Simulations*, vol. 5, pp. 245-255, 2012.
[16] B. L. Theraja & A. K. Theraja., "Electrical technology," *Nirja Construction & Development*, 1989.
[17] Khalid G. Mohammed, AQ Ramli, UAU Amirulddin., " A novel design of DC-AC electrical machine rotary converter for hybrid solar and wind energy applications," *IOP Conference Series: Earth and Environmental Science*, vol. 16, pp. 012-052, 2013.
[18] M. S. Sarma., "Electric machines," *West Publishing Company*, 1994.
[19] Settar S. Keream, Ruzlaini Ghoni, Ahmed N Abdalla, Mohd Razali Daud, Youssif Al Mashhadany., "Robust dynamic inverse controller for spacecraft model," *International journal of scientific research (IJSR)*, vol. 3, pp. 113-117, 2014.
[20] Settar S. Keream, Ahmed N Abdalla, Mohd Razali Bin Daud., "nonlinear dynamic inverse controller based in field oriented with SVPWM current control," *Science & Technology*, vol. 25, pp. 37-44, 2017.
[21] R. B. Ashok & B. M. Kumar, "Performance analysis of high-power brushless DC motor drive," in *Advances in Power Systems and Energy Management*, ed: Springer, pp. 719-728, 2018.
[22] N. Chuang, T. J. Gale, R. A. Langman., "Developing measuring inductance strategies on a direct current machine using a DC source with magnetic saturation," *International Journal of Circuit Theory and Applications*, vol. 44, pp. 1094-1111, 2016.
[23] Z. Hui, T. Shucheng, X. Xi, Z. Na, "Control strategy of energy storage converter with DC machine characteristics," *High Voltage Engineering*, vol. 44, pp. 119-125, 2018.
[24] S. R. Hunt., "Calibrated slip direct current (DC) machine," ed: *Google Patents*, 2017.
[25] J. A. Melkebeek., "Modelling and dynamic behaviour of DC machines", in *Electrical Machines and Drives*, ed: Springer, pp. 577-589, 2018.
[26] J. A. Melkebeek., "DC commutator motor drives", in *Electrical Machines and Drives, ed: Springer*, pp. 345-354, 2018.
[27] J. A. Melkebeek., "Basics of controlled electrical drives," in *Electrical Machines and Drives, ed: Springer*, pp. 443-458, 2018.
[28] J. A. Melkebeek., "Small electric machines and their power electronic control", in *Electrical Machines and Drives, ed: Springer*, pp. 459-471, 2018.

BIOGRAPHIES OF AUTHORS

Khalid G. Mohammed Assist Prof. Dr. Engineer researcher in electrical power engineering, machine design and power electronic drives. He has completed his PhD in University Tenaga National, Kuala-Lumpur, Malaysia 2015. His practical experience since 1993 was focused on repairing and maintenance different electrical machines in industrial factories. After that he completed M.Sc. in Baghdad University, Iraq 2005. He has been working in managing and teaching since 2006 in the college of engineering, Diyala, Iraq.

Jabbar Al-Fattah graduated from University of Leeds and received his B.Sc. Eng. (Hons) in 2005, M.Sc. Eng. from Universiti Malaya (2010) and his Ph.D. in electrical engineering (2017) from Universiti Tenaga Nasional. During the years 2006 – 2010, he worked as an engineer involves site installation, maintenance, and converter systems. His main interests included power electronics and renewable energy systems.

Mohammed Reyasudin Basir Khan is a researcher, senior lecturer and postgraduate coordinator at University of Kuala Lumpur, Malaysia. Currently, he is working on micro-grid controls and energy management systems. His research interest includes Hybrid Renewable Energy System, Micro-grid System, Building Automation System, Autonomous Technologies and Energy Monitoring and Harvesting Devices. He graduated with a B.Sc. Eng. and PhD in Electrical Engineering from Universiti Tenaga Nasional (UNITEN) in 2011 and 2016 respectively. He has seven years of research, teaching and administration experiences