Power Supply Quality Improvement: Harmonic Measurement and Simulation

Dalila Mat Said, Nasarudin Ahmad, and Abdullah Asuhaimi Mohd Zin

Abstract--**This paper presents the harmonic measurement and simulation in a power distribution network and then gives suggestion of filter installation to improve harmonic distortion. The specific case study has been conducted at Faculty of Electrical Engineering, UTM building where non-linear loads such as computers and fluorescent lamps which produce the harmonics are connected. Measurements are conducted at each sub-switch board (SSB), main-switch board (MSB) and sub-station of the faculty. The selected networks are modelled and simulated using SKM-Power Tools for Windows software. The results from the measurement are compared with the simulation result, and it is found that there are quite close to each other. Based on the simulation, harmonic distortion improved after filter installation.**

Keywords--**Power Supply Quality, Non-linear Load, Total Harmonic Distortion, Distortion Spectrum, Single Tuned Filter, Power Distribution System, Fluorescent Lamp, Sub Switch Board, Main Switch Board, Substation, Resistive load.**

I. INTRODUCTION

Nowadays power quality has become a great concern for both utilities and customers. With the increasing use of non-linear load being connected to the power system, more studies on the effects of harmonic penetration in power distribution system are needed. The problems associated with high harmonic content in the power system do not only result in the poor quality of supply but also the operation of the system will get affected [1]. The major sources of harmonics are from the three categories of equipment, which are power system equipment, industrial loads and residential loads [2]. Harmonic currents are generated to a small extent and low distortion level by generation, transmission and distribution equipments, and to a larger extent by the industrial and domestic loads.

II. HARMONIC FIELD MEASUREMENT

In carrying out harmonic measurement at Faculty of Electrical Engineering distribution network, six blocks were selected. Some of the block represents the types of load that are largest contributor of harmonic current, which are the computer and fluorescent lighting. The measurement are conducted at:

- Main Switch Board (MSB) blocks P02, P06, P07, P08, P15 and DK.
- Sub-Switch Board (SSB), Side A (right) and B (left), Level 1, 2, 3 and 4 Blocks P02, P06, P07, P08, P15 and DK.
- Substations PE-19 & PE-20

During the selection of study sites, considerations are made on the types of loads connected to the system. The voltage level, accessibility to site and also the type of equipment available at the site to facilitate the connection of measuring equipment are the main priority in selecting the study site. All the measurement was made at 415V bus.

Total Harmonic Distortion (THD) can be calculated by using the following equation [3]:

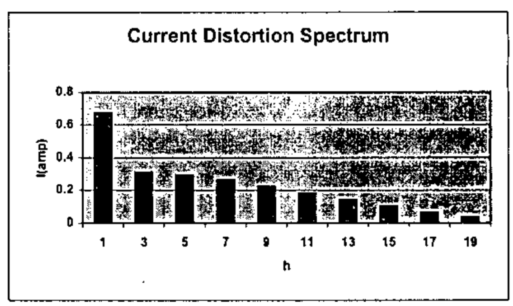
$$THD = \frac{\sqrt{\left(\sum_{n=2}^{50} U_n^2\right)}}{U_1} \times 100\% \qquad (1)$$

Where U_1 and U_n are the fundamental and harmonic component of either current or voltage respectively and 'n' denotes harmonic number.

A. Harmonic Distortion for Personal Computer

The result from measurement of current distortion spectrum and voltage distortion spectrum of personal computer are shown in Fig. 1 and Fig. 2. From the graph the total harmonic distortion for computer can be calculated by using (1) and the value as stated below:

Current Total Harmonic Distortion (ITHD%) = 89.7%



Voltage Total Harmonic Distortion (VTHD%) = 1.5%

Fig. 1. Current distortion spectrum for computer

Dalila Mat Said, Nasarudin Ahmad, and Abdullah Asuhaimi Mohd Zin are with Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Tel: +60-075535930, Fax: +60-07-5566272 (e-mail: dalila@fke.utm.my).

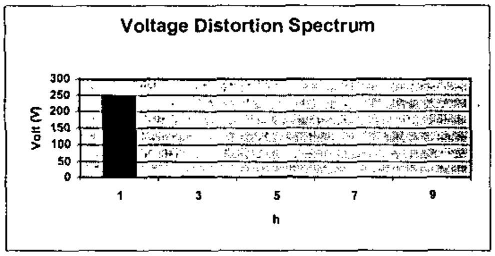


Fig. 2. Voltage distortion spectrum for computer

B. Harmonic Distortion for Printer

The current distortion spectrum and voltage distortion spectrum for printer are shown in Fig. 3 and Fig. 4. The Total Harmonic Distortion can be calculated, and the value is given below,

Current Total Harmonic Distortion
(ITHD%) = 88.5%
Voltage Total Harmonic Distortion
(VTHD%) = 1.4%

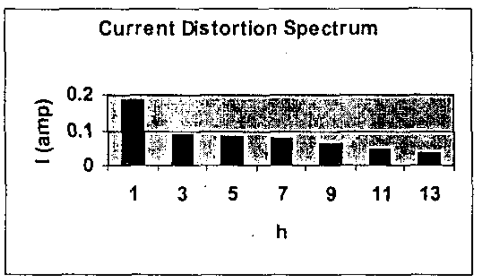


Fig. 3. Current distortion spectrum for printer

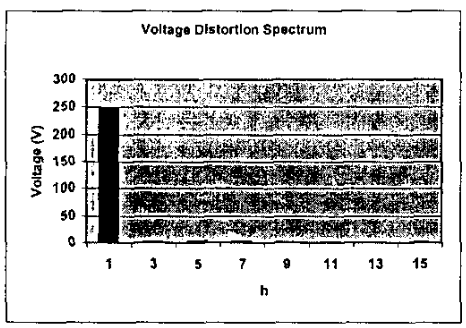


Fig. 4. Voltage distortion spectrum for printer

The data of harmonic measurement from the computer and printer show that current harmonic sources are the largest contributor compared to the voltage harmonic sources. It is because of the nonlinear load (kW) is highest than resistive load (kW) for both equipment.

III. HARMONIC SIMULATION

The sources of harmonic are simulated as coming from lighting fluorescent and typical silicon control rectifier. The method, which is used to reduce or eliminate the harmonic distortion such as harmonic filter, is presented in this work.

Three scenarios are assumed in carrying out simulation on the selected network based on the possible loading condition of the circuit. The scenarios are:

- The harmonic generating loads are coming from fluorescent lighting and computer at the location where measurement were taken
- The harmonic generating loads are distributed and connected to all the bus bars in the circuit.
- Typical Silicon Control Rectifier represented the source of harmonic from computer loads.

Harmonic simulation is carried out based on the above scenarios on the selected circuit and comparison was made between simulation result and measurement data.

A. Harmonic Simulation for Block P02

The harmonic simulation has been carried out for block P02. The current THD% from the simulation is shown in Fig. 5. This result is compared to the measurement result as shown in Table 1.

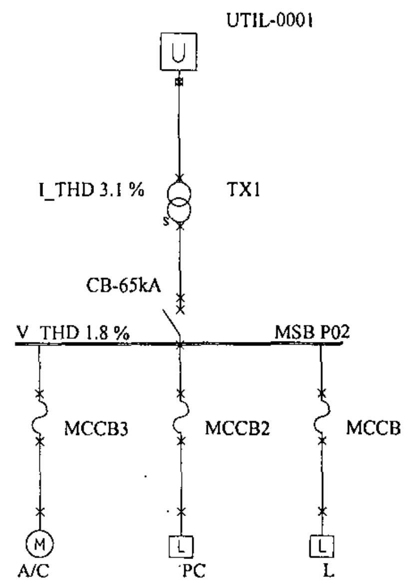


Fig. 5. Schematic diagram for block P02 (Daytime)

TABLE 1
COMPARISON DATA OF (a) VOLATGE AND (b) CURRENT THD% P02 (DAYTIME)

THDv% (MEASUREMENT)	THDv%(SIMULATION)
R = 2	
Y = 2	1.8
B = 2	

(a)

THDc% (MEASUREMENT)	THDc% (SIMULATION)
R = 3	
Y = 2	3.1
B = 4	

(b)

Table 1(a) shows the voltage THD% from the measurement and simulation. The voltage THD% from measurement is 2% and 1.8% from simulation. The current

THD% as shown in Table 1(b) is 3.1% from simulation; this value is very close to the measurement result.

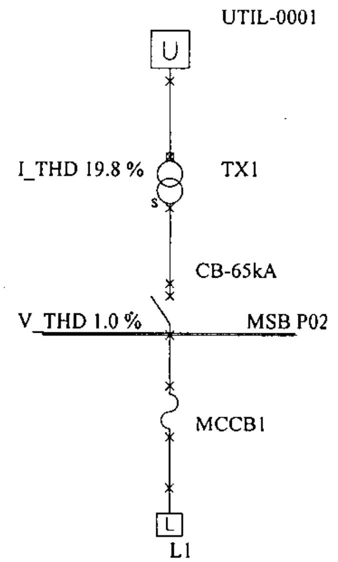


Fig. 6. Schematic diagram for block P02 (Night)

Fig. 6 shows the harmonic simulation during nighttime. For this case the load considered is fluorescent lighting. The comparison data of simulation and measurement are shown in Table 2.

TABLE 2
COMPARISON DATA OF (a) VOLTAGE AND (b) CURRENT THD% P02 (NIGHT)

(a)

THDv% (MEASUREMENT)	THDv%(SIMULATION)
R = 2	
Y = 2	1
B = 2	

(b)

THDc% (MEASUREMENT)	THDc% (SIMULATION)
R = 12	
Y = 17	19.8
B = 20	

The result from simulation and measurement as shown in Table 2 are approximately similar.

B. Harmonic Simulation for FKE-Complex

Fig. 7 is the schematic diagram of FKE based on the condition of daytime load. PE-19 are connected to block P07, HLV1 and HLV2, where PE-20 are connected to block P02, P15, P08 and DK. From simulation result, the current THD% of TX-1 is 4.5% and 2.6% for TX-2, and the voltage THD% for PE-19 is 1.9% and 1.7% for PE-20.

TABLE 3(a)
COMPARISON CURRENT THD% FOR THE BRANCH (DAYTIME)

BRANCH	MEASUREMENT(I_THD%)	SIMULATION (I_THD%)
TX1	R = 5 Y = 4 B = 3	4.5
TX2	R = 3 Y = 2 B = 3	2.6

TABLE 3(b)
COMPARISON CURRENT THD% FOR THE BUS (DAYTIME)

BUS	MEASUREMENT(V_THD%)	SIMULATION (V_THD%)
PE-19	R = 2 Y = 1 B = 1	1.9
PE-20	R = 2 Y = 1 B = 2	1.7

Table 3(a) and Table 3(b) are the comparison data from measurement and simulation result of this circuit. The data show that the result from the simulation and measurement are approximately in agreement.

TABLE 4(a)
COMPARISON CURRENT THD% AT THE BRANCH (NIGHT)

BRANCH	MEASUREMENT(I_THD%)	SIMULATION (I_THD%)
TX1	R = 14 Y = 16 B = 19	18.7
TX2	R = 16 Y = 14 B = 20	20.4

TABLE 4(b)
COMPARISON VOLTAGE THD% FOR THE BUS (NIGHT)

BUS	MEASUREMENT(V_THD%)	SIMULATION (V_THD%)
PE-19	R = 2 Y = 2 B = 2	0.8
PE-20	R = 1 Y = 2 B = 2	0.6

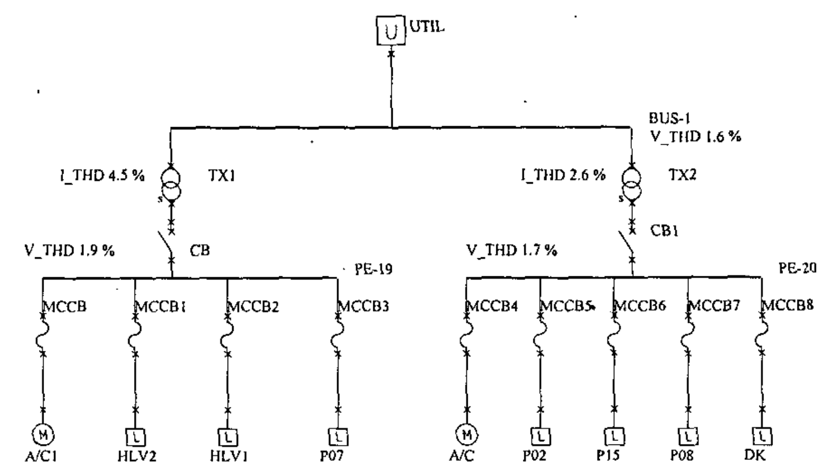


Fig. 7. Schematic diagram of FKE (Daytime)

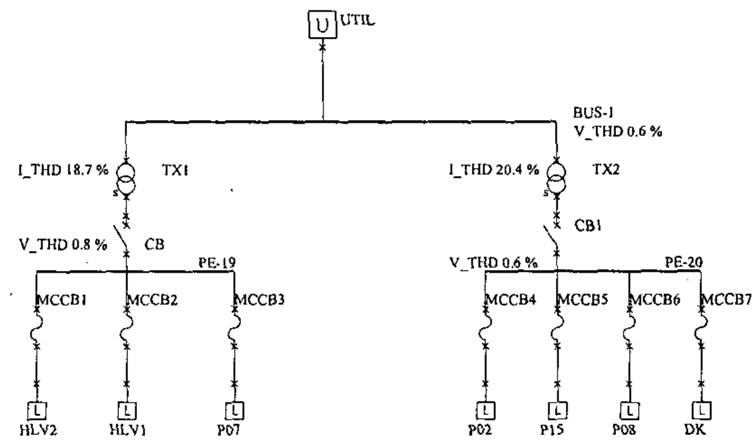


Fig. 8. Schematic diagram of FKE (Night)

Table 4 (a) and Table 4(b) are the comparison data from measurement and simulation result of this circuit. The data show that the result from the simulation and measurement for current THD% are approximately equal.

The circuits are modeled in two condition of load. The first circuit in Fig.7 is modeled based on the measurement data during daytime and the second circuit in Fig.8 is based on measurement data at night. The simulation is carried out based on the data collected and suitable harmonic sources. Blocks P02 and P08 have the largest number of computer connected to the block compared with P15, P07, P06 and DK. The Total Harmonic Current Distortion (THDc%) from simulation result bears very close relation with the measured data. From the simulation result obtained, the Total Harmonic Voltage Distortion shows great different between simulation and measured data, because of the difficulty in determining each load connected to the distribution network when the measurement were made.

IV. HARMONIC FILTER DESIGN

The single tuned filters and the second order-damped filters are the widely used filters. The second order-damped filters are normally used, as high pass filter .The single tuned filter is designed to cut the 5th harmonic component of the system, which has been studied, but if the voltage or current distortions exceed the limit given by IEEE519-1992 another harmonic components must be reduced.

The single tuned filter is designed to trap a certain harmonic by adding reactor with $X_L = X_C$ at the tuned frequency (nf).The steps in designing single tuned filter to n h harmonic as follow [4]

1) Determine the capacitor size Q_C

$$Q_C = P[\tan(\cos^{-1} PF0) - \tan(\cos^{-1} PF1)] \tag{2}$$

Where
PF0 = power factor of the system
PF1 = desired power factor
P = real power, kilowatt

2) Then capacitance reactance

$$X_C = \frac{V^2}{Q_C} \quad (3)$$

Where:
V = voltage at the PCC
Qc = capacitor size, kVAR

3) To trap the h_n harmonic, then the reactor size calculated as.

$$X_L = \frac{X_C}{h_n^2} \quad (4)$$

Where:
Xc = capacitive reactance, ohm
X_L = inductive reactance, ohm

4) The reactor resistance is found as

$$R = \frac{Xn}{Q} \quad (5)$$

and

$$Xn = \sqrt{X_L X_C} = \sqrt{\frac{L}{C}} \quad (6)$$

Where:
Q = filter's quality
Xn = reactance characteristic, ohm
L = inductance, Henry
C = capacitance, Farad

A. Filter at PE-19 (Daytime Circuit)

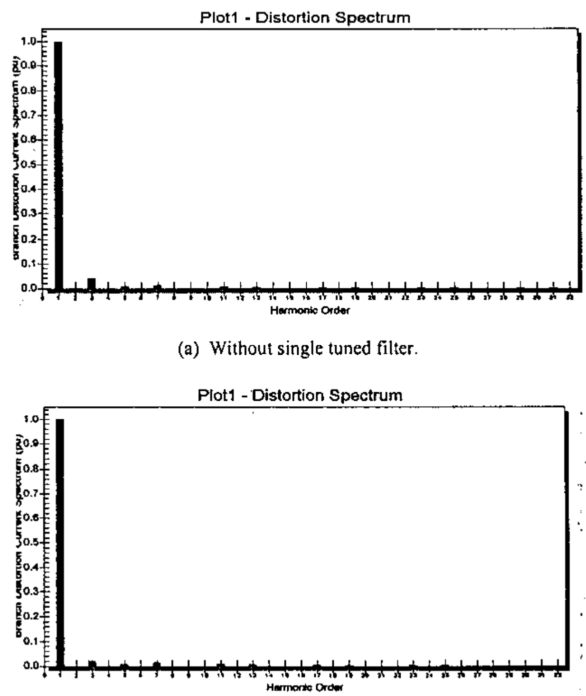
Fig. 9(a) shows the current distortion spectrum from harmonic simulation for daytime circuit before filter installation. When the 3rd single-tuned filter is installed at PE-19, the 3rd current harmonic distortion at branch TX-1 is suppressed as show in Fig. 9(b). The value of THD before and after filter installation is shown in Table 5(a).

B. Filter at PE-19 (Night Circuit)

Based on the simulation result for night circuit, the THD before filter installation is 18.7%, this value can be obtained directly from harmonic analysis in SKM-PTW. The harmonic distortion spectrum at branch TX-1 is shown in Fig.10 (a). When the 5-th single-tuned filter is installed, the THD is decreased to 2.8% as shown in Fig. 10(b).

C. Filter at PE-20 (Night Circuit)

Fig. 11(a) shows the current distortion spectrum at PE-20 without filter installation. It can be seen that the 5-th harmonic is the highest harmonic distortion. So to improve this harmonic problem, the 5-th single tuned filter is installed at PE-20. After filter installation the 5-th harmonic is suppressed as show in Fig.11 (b)



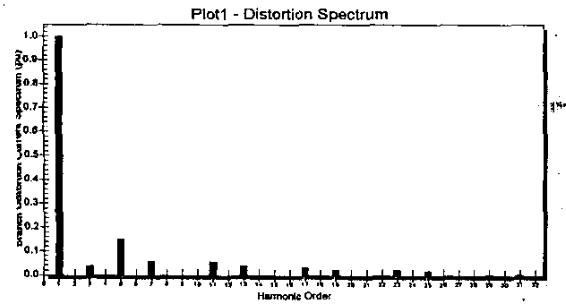
(a) Without single tuned filter.

(b) With single tuned filter.

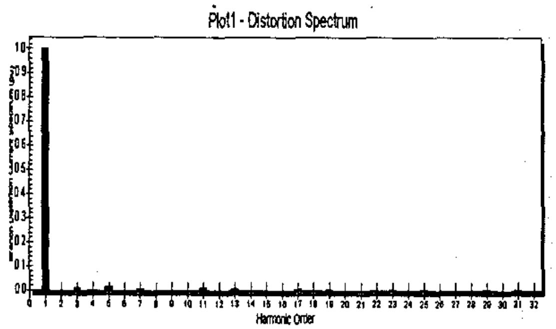
Fig. 9. The current distortion spectrum from harmonic simulation for daytime circuit before filter installation.

D. Filter at PE-19 and PE-20 (Night Circuit)

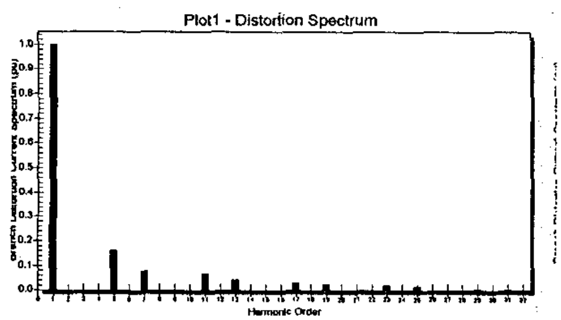
Fig.10 (a) is the current distortion spectrum for PE-19 and Fig.11 (a) is the current distortion spectrum for PE-20. These spectrums are from the simulation of night circuit. Both PE-19 and PE-20 have the high value of current THD%. When the filter is installed at PE-19, only the distortion spectrum at TX-1 is suppressed as shown in Fig 10(b) and when the filter is installed at PE-20 the current distortion spectrum is reduced at branch TX-2 as shown in Fig 11(b). Due to this problem, filters need to be installed at the both substations. This result is stated clearly in Table 5(b)



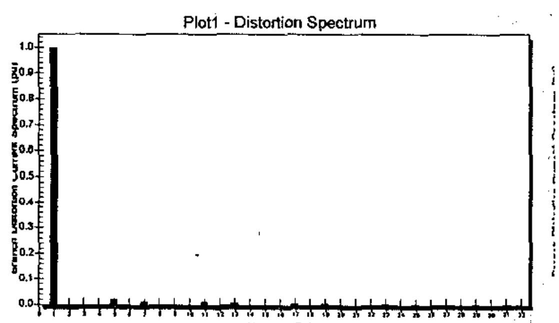
(a) Without single tuned filter.



(b) With single tuned filter.
Fig. 10. Distortion spectrum at branch TX-1.



(a) Without single tuned filter.



(b) With single tuned filter.

Fig. 11. Distortion spectrum at branch TX-2.

Table 5 summarized the data of before and after filter installation. Table 5(a) is the result of current THD before and after filter installation for daytime circuit. When the filter is located at PE-19 for daytime circuit, the 3 rd harmonic current is suppressed from 4.5% to 3.2%. The harmonic filter needs to be installed near the load-producing harmonic. With reference to Table 5(b), if the filter is only installed at PE-19, the harmonic contents at TX-2 is not reduced, however if the filter is located at both PE-19 and PE-20, both the harmonic contents at TX-1 and TX2 reduced to the standard limit, maximum 4%.

V. CONCLUSIONS

From measurement data at SSB for each level of every block, the THD% current is highest at level that accommodates many computers. The result from simulation and measurement at the substation are approximately similar but there are still differences due to difficulties of determining accurately the main harmonic source at the block. Pattern of THD current at night is higher than daytime because of the presence of unbalanced load at night, means the nonlinear load (kW) is highest than resistive load (kW). Filtering is one of the solutions to prevent the harmonic from entering the rest of the system. With the installation of single tuned filter, it is observed that the harmonic content is suppressed within the limit as specified by IEEE standards (519-1992). Passive filter can be employed successfully, providing power factor correction and harmonic suppression. Passive filters also represent very interesting approach, cost effective, high efficiency, robust and applicable to plant with non-linear load. Using power supply with internal harmonic control and power factor correction is one of the solutions of harmonic problem. Based on this study, single tuned filters need to be installed at PE-19 and PE-20 for harmonic and power supply quality improvement. The best location of the filter is closer to the harmonic source.

VI. REFERENCES

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TABLE 5(A)
FILTER INSTALLATION (DAYTIME)

	Total Current Harmonic Distortion (%)	
Branch	Before filter installation	Filter at PE-19
TX1	4.5	3.2
TX2	2.6	2.7

TABLE 5(B)
FILTER INSTALLATION (NIGHT)

	Total Current Harmonic Distortion (%)			
Branch	Before adding filter	Filter at PE-19	Filter at PE-20	Filter at PE-19 and PE-20
TX1	18.7	2.8	18.7	2.9
TX2	20.4	20.4	2.6	2.9

VII. BIOGRAPHIES

Dalila Bt Mat Said was born in Pulau Pinang, Malaysia on September 11,1978. She received the B.Sc. and M.Sc. degrees from Universiti Teknologi Malaysia in 2000 and 2003, respectively, all in electrical engineering. Her research interests are power factor and harmonic for power supply quality improvement.

Nasarudin b. Ahmad received the B.Sc. and M.Sc. degrees in electrical engineering from Universiti Teknologi Malaysia, in 1998 and 2000 respectively. Since 2000 he has been a lecturer in the Control and Instrumentation Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia. His interest for research activities are application of control technique in power system.

Abdullah Asuhaimi bin Mohd.Zin is currently a Professor, and Head of Electrical Power Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia. He received his B.Sc. degree (1976) from Gadjah Mada University, Indonesia, M.Sc. degree (1981) from University of Strathclyde, United Kingdom and Ph.D degree (1988) from UMIST, United Kingdom. He authored/co-authored over 80 technical papers. His research interests include power system protection, application of neural network in power system, arcing fault in underground cables, power quality and dynamic equivalent of power system. Dr. Abdullah is also a Corporate Member of Institution of Engineers, Malaysia (IEM), a Member of IEE (UK) and a Senior Member of IEEE (USA). He is a registered Professional Engineer (P.Eng.) in Malaysia and Chartered Engineer (C.Eng.) in United Kingdom.