Performance of a 500 kW_P grid connected photovoltaic system at Mae Hong Son Province, Thailand

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Abstract

This paper summarises the first eight months of monitoring of the PHA BONG photovoltaic generation project, a 500 kW_p photovoltaic pilot plant, in Mae Hong Son province, Thailand. The local grid in this remote area in the North West of Thailand is very limited in its capacity and cannot be enlarged. It has been in operation since 20 March 2004 by feeding into 400 V_{AC}, 22 kV medium voltage grid. The system consist of a photovoltaic array 1680 modules (140 strings, 12 modules/string; 300 W/module), power conditioning units and battery converter system. During the first eight months of this system's operation, the PV system generated about 383,274 kWh. The average of generating electricity production per day was 1695.9 kWh. It ranged from 1452.3 to 2042.3 kWh. The efficiency of the PV array system ranged from 9 to 12%. The efficiency of the power conditioning units (PCU) is in the range from 92 to 98%. The final yield (Y_F) ranged from 2.91 to 3.98 h/d and the performance ratio (PR) range from 0.7 to 0.9.

Keywords: Solar power system; Performance; Grid connected system

1. Introduction

Mae Hong Son province is situated in North Western of Thailand on the bounder with Myanmar. The Province has only 22 kV distribution lines which take power from Chiang Mai substation and passes through trees and hills for 250 km. The supply often fails, as trees touch the conductors. The main electricity supply of Mae Hong Son, in the province's amphur muang zone, has three sources, The Pha Bong dam (PB-Dam;1× 850 kW), The Mae Sa Yha Dam (MSY-Dam; 2×3375 kW), and Mae Hong Son Diesel generator (MHS-Diesel; 3×1000 kW, 3×1250 kW). The total generation capacity of this installation is about 14,350 kW. Normally power generation from dams is able to supply electricity about eight months per year, and is shut down in summer and winter seasons. The PB-Dam can supply about 460 kW and the MSY-Dam can supply about 2000–4000 kW. Generation capacity depends on the season as the dams were not built for storage. The MHS-Diesel generator can only supply about 6000 kW. The policy of the Electricity Generating Authority of Thailand (EGAT) gives first priority to generation from the dams, a renewable energy resource. If the supply from dams is insufficient, diesel generation used to supplement the supply. In this way the use of costly diesel oil is minimized. The peak demand on 10 October 2004 at 19.30 p.m. was about 4660 kW and the maximum day-load at 15.00 p.m. was about 3030 kW. The supply constrains require careful planning of the electricity supply in Mae Hong Son.

EGAT, the organization responsible for supply and generation of electricity in Thailand, encourages the study, exploration and planning for use of renewable energy in this province. It has initiated a pilot PV project in Mae Hong Son, the 500 kW Pha Bong photovoltaic generation. The project has three objectives; to increase power supply, to decrease consumption of diesel fuel during daylight hours and finally to encourage a national strategy in the production photovoltaic cell and accessories. Work on the Pha Bong photovoltaic generation was commenced on 11 February 2003. The system first began to supply the first electricity to 22 kV grid system of Provincial Electricity authority (PEA) on 20 March 2004 and has been completely operational since 24 March 2004. The project was handed over to EGAT on the 9 April 2004. However, far the performance of their paper data was collected from 24 March 2004 when the project was completely operational and being fully monitored until 31 October 2004 [1–3].

This paper presents an evaluation of the performance of system during the first eight months of operation. The performance of the components of the system (PV arrays, power condition unit) are analyzed, and finally the performance of the whole system is investigated. A later paper will review information about the performance of the battery and converter system used to improve the reliable of the system and its connection to the grid.

2. System component, design and feature

The PHA BONG photovoltaic generator has a total power capacity of 500 kW_p. It consists of a 1680 PV modules (140 strings, 12 modules/string, 300 W/module). The generator is divided into two, 250 kW_p, sub-arrays of double glazed ASE-300-DG-FT

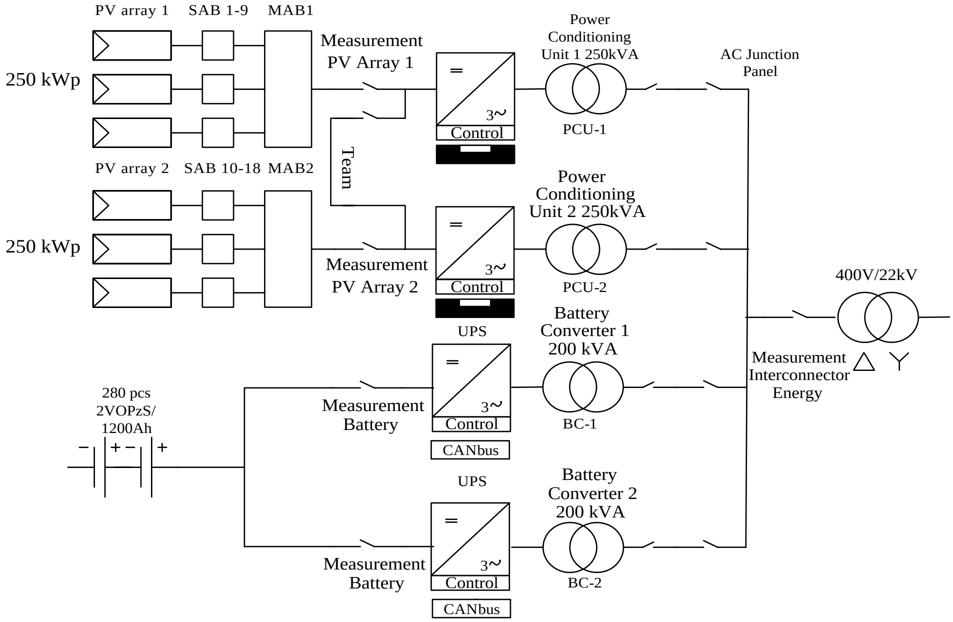

Fig. 1. Schematic block circuit diagram of the PV system.

modules from RWE SCHOTT Solar. There are 1.28 m wide, 1.90 m long and a face south and are tilted at 15°. For grid coupling two power conditioning unit (PCU1, PCU2) each with a nominal power of 250 kVA are used. The Inverters function according to the new sunny team principle ensuring a high reliability due to the optimized efficiency in the lower part-load range. Two bi-directional battery inverters (BC1 and BC2), each with a power output of 200 kVA, are operated in parallel. The battery inverters are connected to a battery bank (280 pcs 2 V/pcs; 560 V, total 1200Ah) and can feed into the grid in addition to the PV power. A drastic and rapid change of the grid feeding power, for example if the PV array is shaded by cloud, is avoided by using fast microprocessor—based compensation of the battery inverter. Batteries are charged between 22.00 p.m. and 06.00 a.m. If the PV array cannot produce, the batteries will discharge continuously to system in a short time less than 5 min. The PCUs and battery converters have their own operational control and can be operated independently of the system controller's status. To realized the grid connection an AC junction box (AJP) is used. For visualization, data logging and some operations a system controller and two operating personal computers are used, see Fig. 1 [4].

3. Monitoring system

The PV system is fully monitored to assess the potential of PV technology and performance of the system with the local power grid. The monitoring system was designed

Table 1
Parameter of the system

Electrical parameter:	Meteorological parameters:
DC voltage PV array1 and 2	Global irradiance (Pyranometer class 3 M)
DC current PV array1 and 2	Total irradiance (reference cell)
DC power PV array1 and 2	Cell temperature PV array 1
Grid voltage PCU1 and 2	Ambient temperature
Grid current PCU1 and 2	Wind speed
Status of PCU1 and 2	
Fault of PCU1 and 2	
DC voltage battery (BC1 and 2)	
DC current battery (BC1 and 2)	
Status of BC1 and 2	
Fault of BC1 and 2	
Frequency	
Grid voltage	
Grid current	
Active grid power	
reactive grid power	
Energy value form and into the grid	
Measuring of total harmonic distortion (THD)	
'current' and 'voltage'	
Daily energy	
Monthly energy	
Annual energy	

to meet guideline of standard IEC 61724 [5,6] and within the framework of the International Energy Agency Photovoltaic Power System (IEA PVPS) Program TASK 2 [7,8]. For the general data acquisition, a multi-function measuring device measures the parameters show in Table 1:

The quantities used to assess the performance of the grid connection was be given as:

$$Y_A = E_A/P_O \text{ (kWh/kW}_p\text{ d)} \quad \text{: array yield} \tag{1}$$

$$Y_R = H_T/G_{STC} \text{ (kWh/kW}_p\text{ d)} \quad \text{: reference yield} \tag{2}$$

$$Y_F = E_{PV}/P_O \text{ (kWh/kW}_p\text{ d)} \quad \text{: final yield} \tag{3}$$

$$L_C = Y_R - Y_A \text{ (kWh/kW}_p\text{ d)} \quad \text{: capture losses} \tag{4}$$

$$L_S = Y_A - Y_F \text{ (kWh/kW}_p\text{ d)} \quad \text{: system losses} \tag{5}$$

where

P_O peak power (WP)
H_T mean daily irradiance in array plane (kWh/m^2 d)
G_{STC} reference irradiance at STC (1 kW/m^2)

E_A array output energy (kWh)
E_{PV} energy to grid (kWh)

4. Analysis system operation

4.1. Analysis of the performance of PV array

The efficiency of the PV modules used, measured under standard testing conditions (STC), is 13% (JIS C8918, IEC1215) [9]. At the project site, measured on 19th September 2004, Fig. 2 shows the efficiency range of PV array system was from 9 to 12%. The maximum value of DC Power generated was equal to 436.1 kW at 12.10 a.m. The module temperature was 59.0 °C with an ambient temperature of 32.4 °C. A decrease in efficiency can be caused by the difference between working temperature at the site and the condition at STC. Total spectrum of solar irradiance at the project location was between 0 and 1080 W/square meter depend on time of day. This resulted was caused output power being lower than at STC. Dirt accumulation on the front surface of PV modules also influences the output power.

The DC power generated by the PV modules is linearly dependent on the irradiance, except for small values of irradiance, lower than 20.95 W/square meter, when the output power is zero, see Fig. 3. System performance analysis shows that the efficiency of the PV array is not only strongly depends on irradiance but also depend on the module temperature. This dependence can be seen in Fig. 2. In comparison, at the beginning of

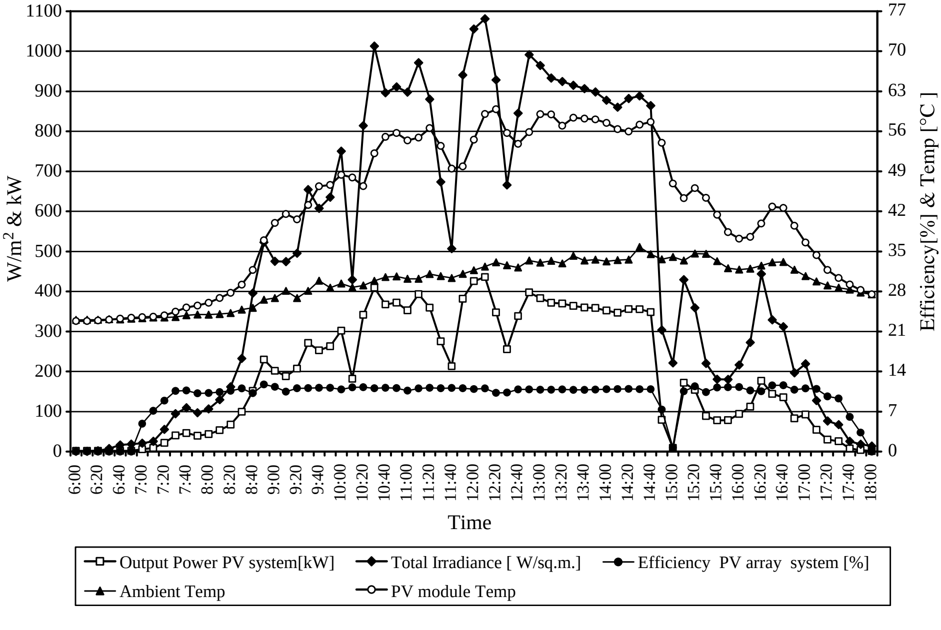

Fig. 2. The efficiency PV modules versus irradiance in 19 September 2004.

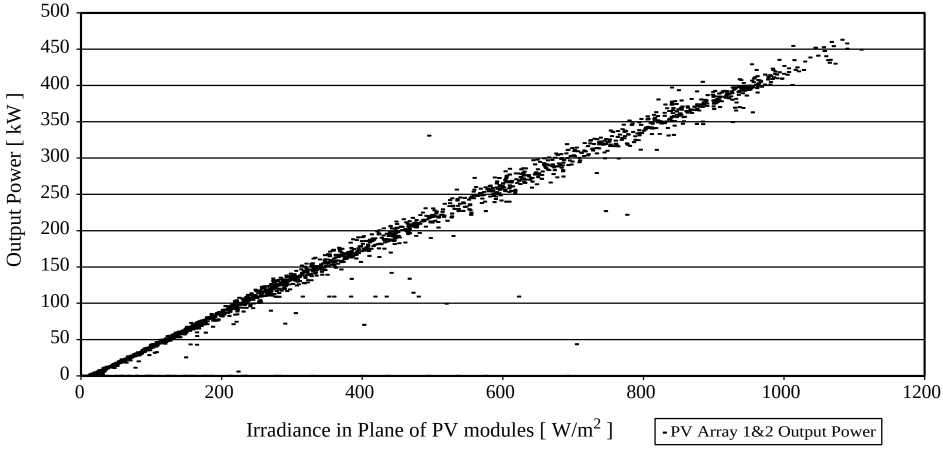

Fig. 3. The output power versus irradiance in September 2004.

the day the output power of PV array increased gradually from 5.8 to 230 kW within 1 h 50 min by the temperature of PV module changed from 23.6 to 36.9 °C. Thus The PV array power changed at rated (230–5.8 kW)/(110 min) equal 2 kW/min and the PV array power changed to depend on temperature at rated (230–5.8 kW)/(36.9–23.6 °C) equal 16.85 kW/°C. When the PV output power became the highest power so the temperature of PV module was high. It changed power at rated (436.1–381.8 kW)/(20 min) equal 2.7 kW/min but the PV array power changed to depend on temperature at rated (436.1–381.8 kW)/(59.8–49.9 °C) equal 5.46 kW/°C. This means that the higher temperature PV module was the lower PV array power output was. However, the DC output power still depended on the irradiance. The PV module temperature became hot, but the efficient of the PV array system did not change. When the irradiance decreased at the end of the day, a lower DC power was generated with the same irradiance trend.

4.2. Analysis of the performance of power conditioning units (PCU)

The inverters (PCUs) function according to the new sunny team principle, with maximum power point tracking (MPPT), ensuring a high reliability due to the optimized efficiency in the lower part—load range. The PCU1 and PCU2 are operated according to the team concept. This means, that in case of low generating capacities PV array1 and PV array 2 are connected in parallel via two DC contactors in order to increase the efficiency. Under these conditions only the PCU2 operates and the PCU1 is switched off. In case of higher generating capacities the parallel connection disconnected. The PCU1 is started and two PCU operate independently of each other.

The efficiency of PCU1 and PCU2 for irradiance values higher than about 20.9 W/square meter was approximately constant and in the range from 92 to 98%. The lower irradiance, when only PCU2 was operating, optimized efficiency was about 98%. The efficiency curve of PCU is shown in Fig. 4.

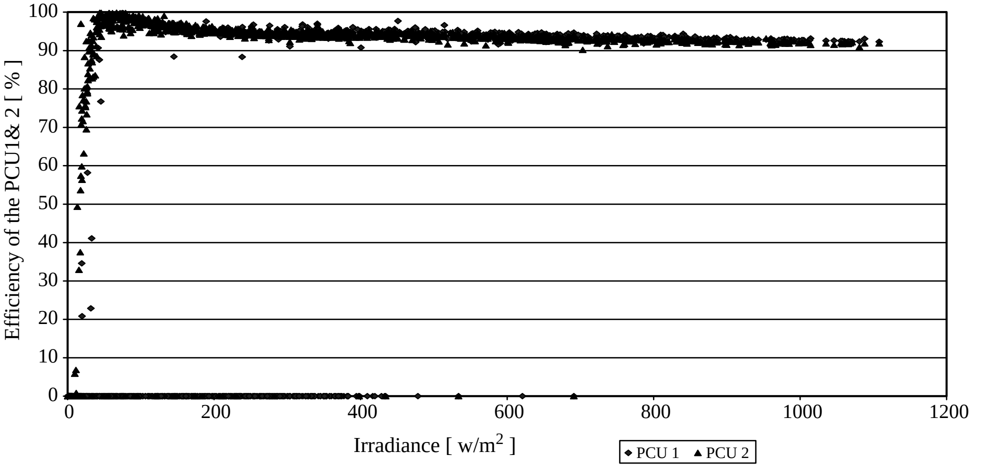

Fig. 4. Efficiency of the PCU 1 and 2 versus irradiance in September 2004.

4.3. Analysis of the performance of entire PV system

During the first eight months of operation, the PV system generated about 383,274 kWh. The average of electricity production per day was 1695.9 kWh. It ranged from 1452.8 kWh (March 2004) to 2042.3 kWh (April 2004). Normalized parameter Y_F, L_S and L_C, as defined in IEC 61724, are shown in Fig. 5 for each month between March

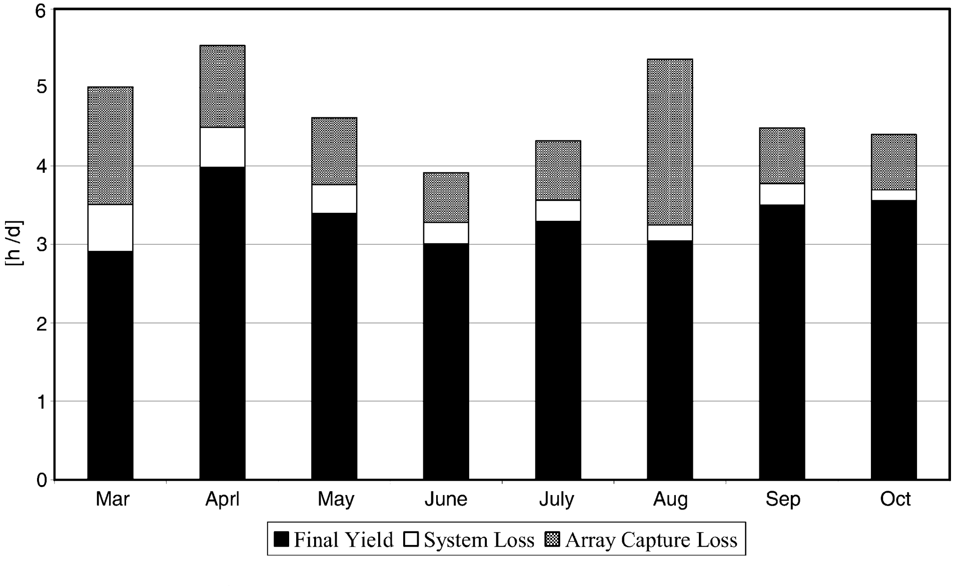

Fig. 5. Normalized parameters Y_F, L_S and L_C in Mar 2004–Oct 2004.

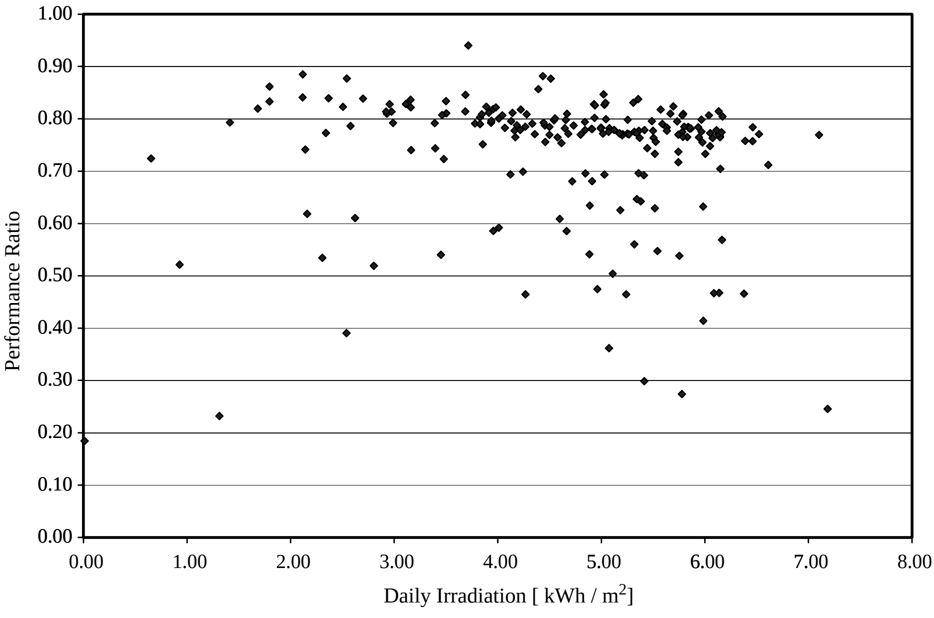

Fig. 6. Normalized performance ratio versus daily irradiation Mar 2004–Oct 2004.

2004 to October 2004. The Y_F of this 500 kW_P PV system ranged from 2.91 h/d (March 2004) to 3.98 h/d (April 2004).

L_S were due to losses in DC to AC energy conversion. L_C was due to PV array losses. In April 2004, a month when the monthly's energy production was largest (61,269 kWh), the Y_F was 3.98 h/d, L_C were 1.04 h/d, L_S were 0.51 h/d, the PR was 0.72.In August 2004, when the monthly's energy production was the least (43,914 kWh), the Y_F was 3.04 h/d, L_C were 2.11 h/d, L_S were 0.19 h/d, the PR was 0.62.

Fig. 6 shows the PR of the PV system, as defined in IEC 61724, ranged from 0.70 to 0.90 for daily irradiation higher than 2.0 kWh/square meter. The maximum PR in October 2004 was 0.81. Some data had high daily irradiance between 4.12 and 6.38 kWh/square meter, but the PR was lower than 0.70. These low values were the result of the PV system being shut down when the grid system faulted due to contacted between trees and the conductors.

5. Summary

EGAT commenced work on the PHA BONG photovoltaic generation project in Mae Hong Son province, in early 2004 and the project was full operation by 24 March 2004. The local grid in this remote area in the North West of Thailand is very limited in its capacity and cannot be enlarged. Local generation capacity are also limited. The PV generation was initiated to increase the power supply, decrease the use of diesel consumption and encourage a national strategy in the production photovoltaic cell and accessories.

In this paper climatic and solar radiation condition at the site are reviewed and the performance of the system is assessed from a component perspective (PV array, power conditioning unit) and from a global perspective, AC power delivered to the grid, system efficiency and system reliability.

During the first eight months of the Pha Bong Projects' operation, the system generated about 383,274 kWh. The average of electricity production per day was 1695.9 kWh. It ranged from 1452.8 kWh (March 2004) to 2042.3 kWh (April 2004). The efficiency of the PV array system ranged from 9 to 12%. The efficiency of the Power Conditioning Units (PCU) was in the range from 92 to 98%. The final yield (Y_F) ranged from 2.91 h/d (March 2004) to 3.98 h/d (April 2004) and the performance ratio ranged from 0.70 to 0.90.

Acknowledgements

The authors wish to thank Mr. Apichart Dilogsopon, Assistant Governor Demand Side Management, Electricity Generating Authority of Thailand for Participating in the project by giving authorization to collected and used data for this research. We also thank Mr. Jerasak Thongsuk of the Mae Hong Son Diesel Power Plant, Electricity Generating Authority of Thailand for supporting and providing data in Mae Hong Son Province, The Energy Policy and Planning Office (EPPO) for scholarship support in this research. We also thank Mr. Nipon Ketjoy for his valuable and useful suggestion.

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Yammen Suchart was born in Thailand. He received the Bachelor of Electrical Engineering (Hons, First Class Rank in Electrical Engineering) from Chiang Mai University, Thailand in March 1988, and graduated both the M.S. degree with a very excellent 4.0 GPA and the Ph.D. degree with a very excellent 4.0 GPA from Vanderbilt University, USA in August 1998 and May 2001, respectively. In 1988, he was appointed a supervisor of the Colgate-Palmolive (Thailand) Co., Limited and served in the powder plant. From 1989 to 1993, he worked with the Siam Cement (Public) Co., Limited, Thailand, as a production engineer, a maintenance engineer and a project engineer. In the late 1993, he jointed with the Auto-system Co., Limited, Thailand as an engineering manager. Since 1994, he has served Naresuan University as a lecturer of Department of Electrical and Computer Engineering, and Dr. SUCHART has been promoted as an assistant professor of Electrical Engineering since May 2004. In addition, he was the associate dean of Faculty of Engineering, Naresuan University from 2001 to 2003. His research interests currently include the various fields of electric distribution systems and renewable energy sources, signal processing, communication and control theory, system identification and modeling, and numerical algorithms. He is currently a registered professional engineer associated with the council of engineers in Thailand as a fellow member in electrical engineering (power) and an associate member in electrical engineering (telecommunications/electronics) as well as with the Engineering Institute of Thailand under H. M. the King's Patronage as a fellow member. Dr. SUCHART also is a member of the IEEE.