A Demand-Side Response Smart Grid Scheme to Mitigate Electrical Peak Demands and Access Renewable Energy Sources

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ABSTRACT

Growing demands are causing increased pressure on the electricity infrastructure and perpetually escalated energy prices. Typically, there are daily and seasonal demand fluctuations oscillating between excessive- peak and equally excessive-low demands. Peak demands, at times, are causing congestions on the transmission and distribution network associated with compromised quality, risk of outages and high-priced energy supply. Expensive-to-run power plants are usually operated for short periods of time to meet peak demands what makes their operation even more expensive. Low-demands, usually supplied by base-load power stations, could be driving the electrical capacity and network to be operated well below a sustainable economic feasibility. Spreading out the demand profile on a moderated level would achieve an improved utilization of the electrical infrastructure. This research presents a demand-side response scheme to be implemented at end-user's premises contributing shifting loads to the right time of the day targeting spreading out the demand profile and allowing utilization of renewable energy sources. The technology uses programmable internet relays controlling appliance switches to operate loads automatically. The paper presents simulations of the economic model corresponding to the above described scheme representing an incentive-based demand response. In the simulation the impact of these programs on load shape and peak load magnitudes, financial benefit to users as well as reduction of energy consumption are shown. The results demonstrated more moderated load profile at lesser peak load magnitude and reduced energy cost.

Keywords – demand-side, smart grid, relay, curtailing, switches.

INTRODUCTION

Based on data of 31 December 2008, Queensland total electricity generating capacity was 12487 MW; coal-fired power stations provided 70 % of this total capacity, while gas-fired electricity accounted for 17 % and renewable energy accounted for around 5 % as stated by the Department of Employment Economic Development and Innovation (2010). These power generations are used to provide electrical energy for all consumers in the Queensland area: residential, commercial and industrial consumers. However, the amounts of energy produced from various generators depend on market demand, price and availability of sources. **Figure 1** illustrates electricity generation in Queensland according to the Department of Employment Economic Development and Innovation (2010).

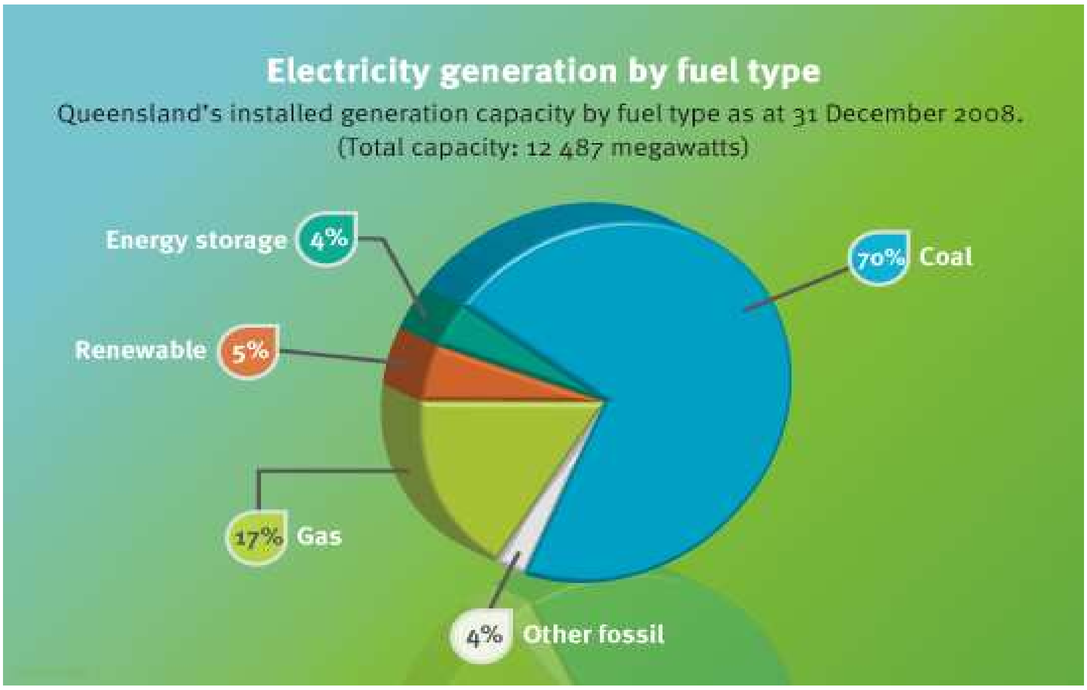

Fig. 1: Electricity generation in Queensland as described by Department of Employment Economic Development and Innovation (2010)

The Department of Employment Economic Development and Innovation (2009) summarized in **Figure 2** fluctuation of electricity price in Queensland, from 1998 to 2008. This chart illustrates that the electricity price during that time was \$20-\$50/MWh, however, extreme prices occurred exceeding \$60/MWh in 2007.

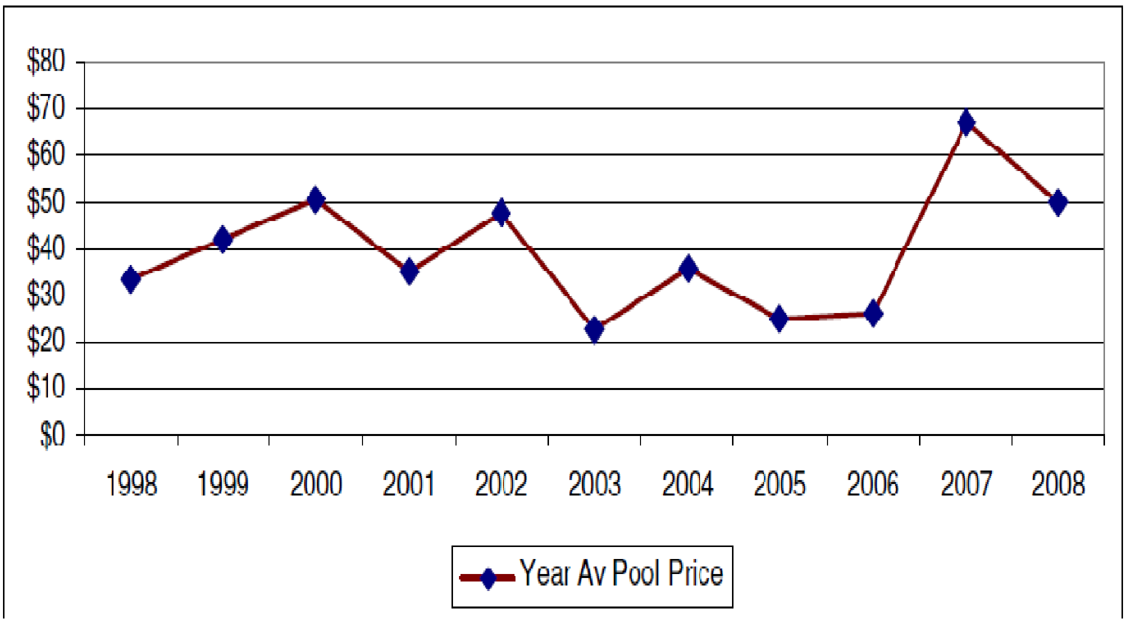

Fig. 2: Queensland yearly average pool price as stated by Department of Employment Economic Development and Innovation (2009)

Demand-Side Response and Smart Grid to Mitigate Peak Demands and Renewable Energy Sources

According to Forte, V. J (2010), smart grid refers to a system that comprises intelligent electricity distribution devices and a specialized computer system to enhance reliability performance, enhance customer awareness and choice, and encourage greater efficiency. Further on, Potter, C. W. et al (2009) suggest modern communication are allowing the consumer to better control their energy usage and provide more choices to the costumer, enabling more agile responses to system behaviour. Therefore, using this technology will improve reliability, efficiency and responsiveness of the electrical power system.

The concept of the smart grid according to Li, Zhongcheng & Tong Yao (2010) is the electric grid delivers electricity in a controlled smart way from points of generation to consumers.

Vos (2009) suggests demand response (DR), an integral part of the smart grid, is a cost effective, rapidly deployed resource that provides benefits to utilities and customers. Further on, demand response is a tariff or program established to motivate change in electricity consumption by end-user customers in response to change in the price of electricity over time as stated by Parvania, M. & M. Fotuhi-Firuzabad (2010).

The benefits of DR according to Greening (2010) are: increased economic efficiency of the electricity infrastructure, enhanced reliability of the system, relief of power congestions and transmission constraints, reduced energy price and mitigated potential market power. Renewable energy combined to the grid can have a significant impact on removing peaks on the electricity network.

Some countries have applied smart grid technology for renewable energy. In the United States, the research of smart grids is focused in intelligent metering and advanced communication system to master the fluctuation and fault in the grids, and united solar, wind and geothermal powers system as said by Li, Zhongcheng & Tong Yao (2010). China's power grid, based on objectives as to prove level of safe operation of power system, to implement energy-saving generation scheduling, to promote large scale scientific use of wind, energy and other renewable energy, analyze technical issues may appear after joined in renewable energy as mention in Ochoa, L. F. & G. P. Harrison (2010).

The following **Figure 3** indicates an example of the dynamic energy management infrastructure applied to a generic building.

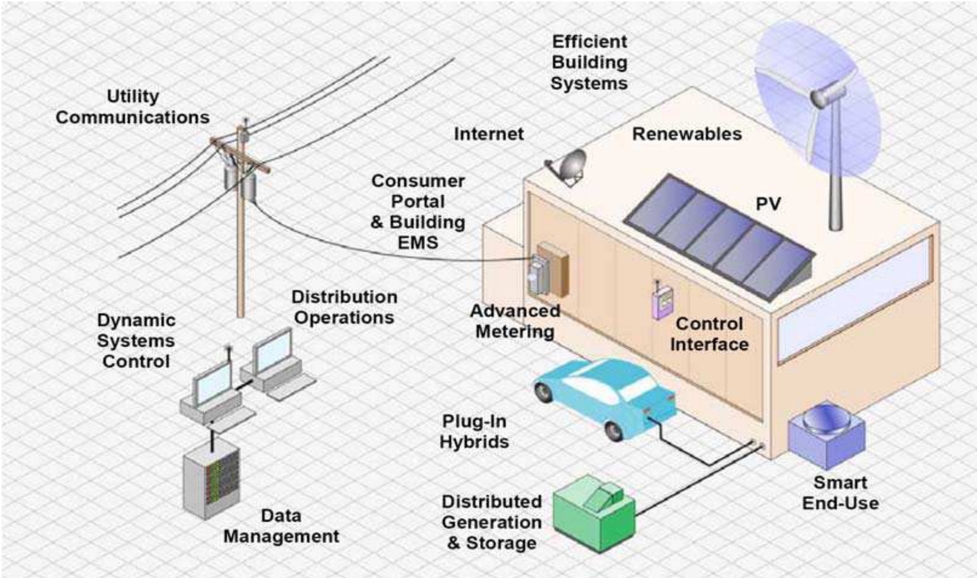

Fig. 3: Smart grid network diagram as said by Gellings, Clark W (2008)

Different models are used in Demand Side Response program planning as described by the Federal Energy Regulatory Commission (2006) . In the report of the strategic plan of the International Energy Agency (2010), DSR is divided into two basic categories, namely, the time based program and the incentives based program.

METHODOLOGY

This work is presenting a low-cost Demand-Side-Response (DSR) scheme at user's premises, which assists electricity end-users to be shifting loads averting peak-demand periods and making use of on-site renewable energy sources. This shall help users to be engaged in mitigating peak demands on the electricity network. The proposed scheme will comprise a technical set-up of a programmable internet relay, a router, solid state switches in addition to the suitable software to control electricity demand at user's premises. The softwares on appropriate multimedia tool (CD Rom) developed in framework of this research shall help users curtailing/shifting electric loads to the most appropriate time of the day or connect to on-site renewable energy sources as appropriate. The scheme involves an economic model based on the maximization of financial benefits to electricity users. Additionally the scheme is designed to be targeting the national electrical load to be spread-out evenly throughout the year in order to satisfy best economic performance for electricity generation, transmission and distribution. The scheme is applicable in region managed by the Australian Energy Management Operator (AEMO) covering states of Eastern-, Southern-Australia and Tasmania.

The proposed scheme will be enabling customers to achieve savings by curtailing electrical consumption or shifting loads from high- to low-priced times averting periods of peak demand congestion, e.g. making use of on-site renewable energy sources and/or night tariffs instead of day tariffs. Usually the electricity price will be high during peak demands and low at off-peak periods. Customers are controlling consumption on self controlled load preferences. In case the user is on another DSR program agreement with the supplier, the scheme is still allowing additional savings besides the benefits and saving already achieved through the DSR agreement. The proposed scheme is securing financial and energy savings to user's besides benefits from any additional DSR program.

Figure 4 illustrates the proposed demand side response scheme at user's premises, where user's are enabled to control own loads and make use of on-site renewable energy sources.

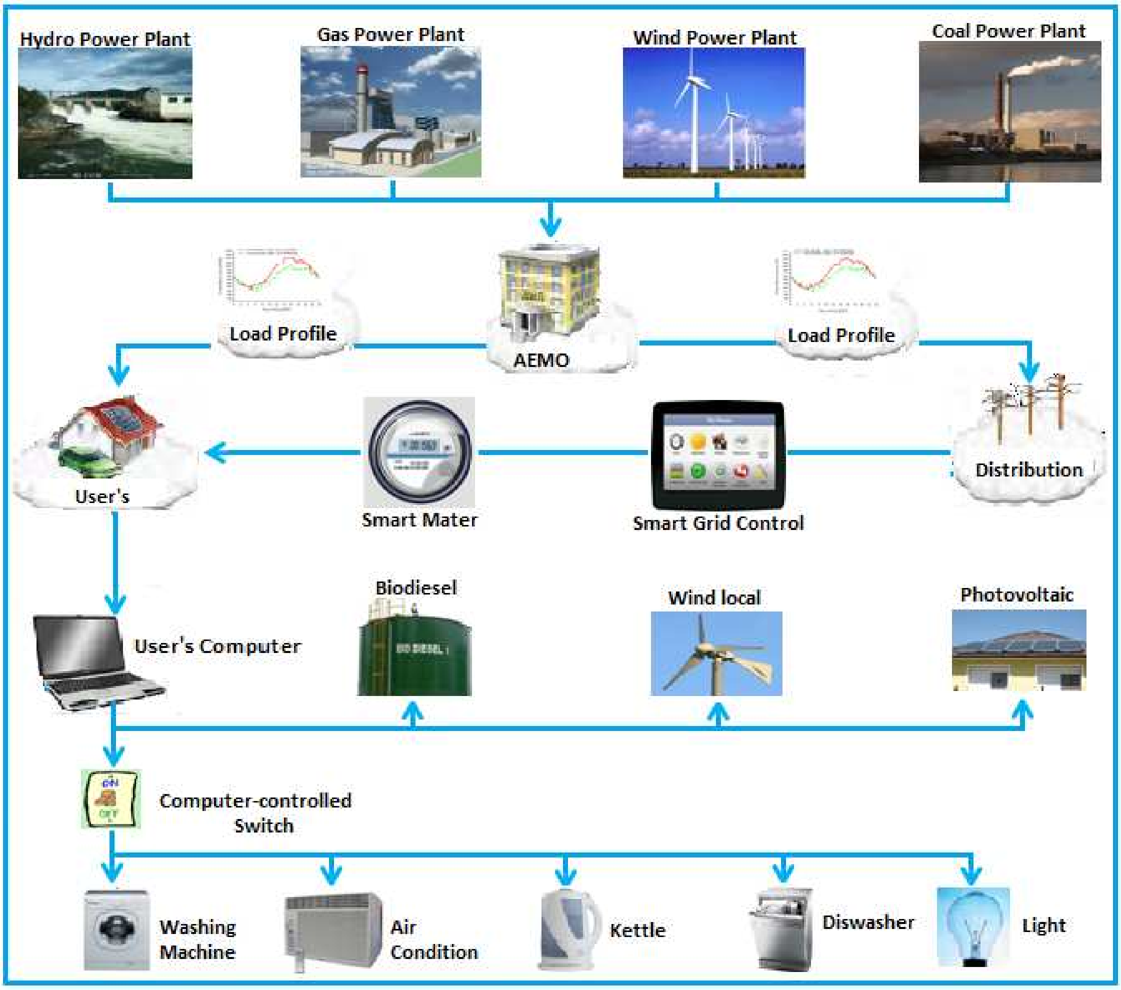

Fig. 4: The proposed demand side response scheme

The scheme enables commercial and industrial customers on fluctuating energy prices to be achieving immediate financial savings. For domestic customers on flat-rate tariffs, in contrast, users are gaining financial benefits from reducing energy consumptions at certain times a day; mainly averting peak-load periods. Domestic customers on different tariffs, where energy price differs with day time and network conditions (e.g. night tariffs), they will be gaining financial benefits also from shifting loads from day- to night-times, where electricity is cheaper. The following **Figure 6** describe for the proposed schema scenario.

DEPLOYMENT OF THE PROPOSED DSR SCHEME

Multi-tiers smart grid network architecture is presented in **Figure 5**, where the smart grid under consideration is divided into multiple tiers in contrast to conventional smart grid networks, where a central control station is responsible for overall network management. In the proposal multi-tier smart grid network, smart devices within a certain geographical area (e.g., houses in the same street or suburb) constitute an Ad-Hoc network which can be considered as the second tier of the overall smart grid network. Multiple such second tier Ad-Hoc networks will constitute the top tier of the smart grid network. This two-tier network will introduce great flexibility to network management. Users within the same geographical area will be able to share their network usage information and coordinate their electricity consumption through peer-to-peer communications. The central users representative control station is thus free of managing the smart devices in each individual household but concentrates on the management of the local nodes of the second-tier ad hoc networks.

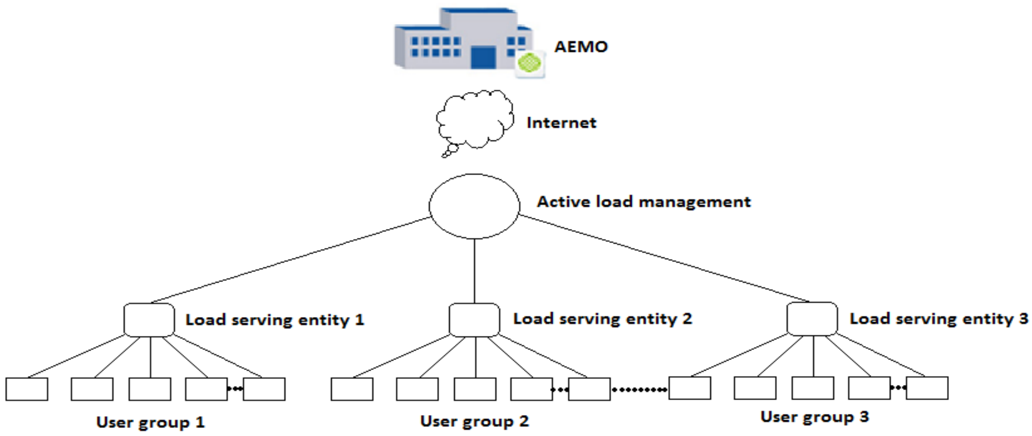

Fig. 5: Two-tier smart grid network architecture

Appliance	Start After	Finish Before	Session Time
Air Condition	20:00:00 PM	12:00:00 AM	Off-Peak Session
Dishwasher	20:00:00 PM	12:00:00 AM	Off-Peak Session
Washing Machine	20:00:00 PM	12:00:00 AM	Off-Peak Session
Kettle	20:00:00 PM	12:00:00 AM	Off-Peak Session

Tab.1: An example of an appliance profile

ANALYSIS AND RESULTS

In order to simulate the effect of the proposed scheme on electricity energy saving the electricity price/demand in Queensland for period 26th – 27th October 2010 has been used taking into account a time-of-use (TOU) program with day/night different tariffs. In the following, five scenarios have been formulated to demonstrate the results as presented in **Figure 6** and summarized in **Table 2.**

Scenario 1: users are shifting 1500 MWh peak electricity usage in Queensland occurring between 10:00 am-20:00 pm towards the time period 20:00 pm-23:00 pm when energy demand and prices are low. For example, air conditioning, washing machines and dishwashers as described in **Table 1**. Achievable savings $37600 per day

Scenario 2: users are shifting peak demand of 1500 MWh occurring between 10:00 am-20:00 pm to the period between 23:00 am to 02:00 am. Achievable savings $112800 per day

Scenario 3: users are shifting peak demand of 1500 MWh occurring between 10:00 am-20:00 pm to the period between 02:00 am to 04:00 am. Achievable savings $112800 per day

Scenario 4: users are shifting peak demand of 1500 MWh occurring between 10:00 am-20:00 pm to the period between 04:00 am to 06:30 am. Achievable savings $112800 per day

Scenario 5: users are shifting peak demand of 100 MWh occurring between 08:30 am-09.30 am to the period between 06:30 am to 08:00 am. Achievable savings $2507 per day

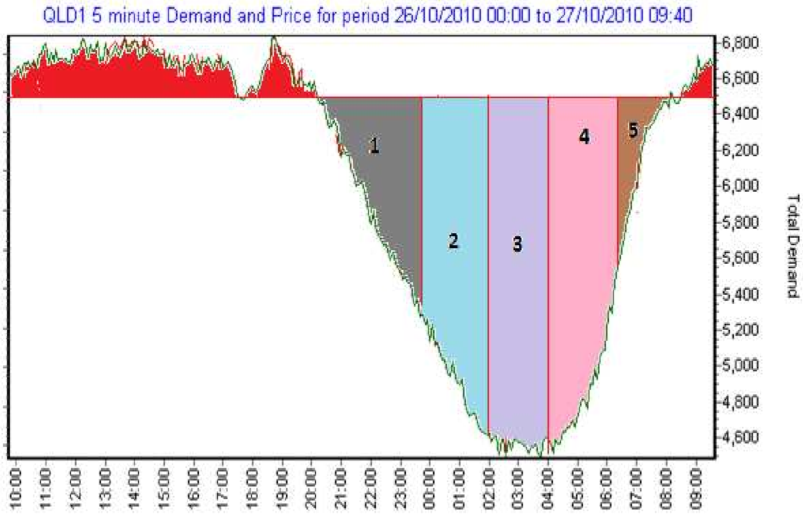

Fig. 6: Scenarios 1, 2, 3, 4 and 5

Table 2 summarizes the results of the described scenarios with load reduction, energy consumption, cost of electricity and customer benefit.

Scenario Nr	Time to Curtail load	Time to reconnect load	Load to Curtail (MWh)	Day tariff 18.84 c/kWh Energy cost ($)	Night tariff 11.32 c/kWh Energy cost ($)	Saving ($)
1	10.00 am	20:00 pm to 23:00 am	1500	282600	245000	37600
2	to	23:00 pm to 02:00 am	1500	282600	169800	112800
3	20.00 pm	02:00 am to 04:00 am	1500	282600	169800	112800
4		04:00 am to 06:00 am	1500	282600	169800	112800
5	08:30 am to 09.30 am	06:30 am to 08:00 am	100	18840	16333	2507

Tab.2: Result of operating scenarios

CONCLUSIONS

The paper is describing a low-cost DSR scheme implemented on user's premises which allows shifting loads to match network condition. The scheme also allows an automatic injection of on-site renewable energy sources as appropriate. The scheme is aiming to reduce the energy price volatility by avoiding peak demands and the utilization of on-site renewable energy sources. This helps increasing grid reliability, reducing energy cost, and optimizing energy consumption. The scheme allows electricity end-users to “spread-out” significant peaks. Information provided on the internet about electricity market conditions will be used to operate loads accordingly to maximize benefit for user and supplier. The scheme is providing additional capacity more quickly and more efficiently than building new supplies. The flexibility provided lowers the likelihood and consequences of forced outages as well. Most importantly, by enabling end-users to observe electricity prices and congestions on the electrical network it allows them to be positively sharing responsibility by reducing and optimizing energy consumption and using renewable energy sources realizing electricity savings and sustainable energy supply.

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BRIEF BIOGRAPHY AND CONTRIBUTION OF PRESENTERS

Marwan Marwan, born January 1st 1975. He is working at The State Polytechnic of Ujung Pandang Makassar Indonesia as a lecture in energy conversion department from 2001 to the present. He prepared a master degree at the Queensland University of Technology QUT Australia in 2006. Presently, He is preparing Ph.D at the University of Southern Queensland (USQ) in Toowoomba, Australia. Marwan carried out information collection, literature review, and preparation of graphs, testing and operation of data-controlled switching.

Dr. Fouad Kamel is a senior lecturer at the University of Southern Queensland in Toowoomba, Faculty of Engineering and Surveying, Department of Electrical and Computer Engineering since February 2008. Graduated Diploma Engineer and PhD in photovoltaic systems from Hanover University in Germany 1984, Dr. Fouad worked as a lecturer and associate professor at the Suez Canal University in Egypt during 1985-1999. In 1999 he moved to New Zealand and worked there between 2000 and 2007 for tertiary education and research at Christchurch Polytechnic Institute of Technology and the Southern Institute of Technology. Fouad set general concept of the undertaking, carried out structure of the paper, sourcing out and presenting data of electrical consumption from the AEMO and is covering electrical power engineering elements of the subject.

Dr. Wei Xiang is a senior lecturer at the University of Southern Queensland in Toowoomba, Faculty of Engineering and Surveying, Department of Electrical and Computer Engineering.