Optimum Demand Side Response of Smart Grid with Renewable Energy Source and Electrical Vehicles

M. Marwan and F. Kamel

Abstract--**The paper presents a demand side response scheme, which assists electricity consumers to proactively control own demands in such a way to deliberately avert congestion periods on the electrical network. The scheme allows shifting loads from peak to low demand periods in an attempt to flattening the national electricity requirement. The scheme can be concurrently used to accommodate the utilization of renewable energy sources, that might be available at user's premises. In addition the scheme allows a full-capacity utilization of the available electrical infrastructure by organizing a wide-use of electric vehicles. The scheme is applicable in the Eastern and Southern States of Australia managed by the Australian Energy Market Operator. The results indicate the potential of the scheme to achieve energy savings and release capacity to accommodate renewable energy and electrical vehicle technologies.**

Index Terms-- **consumer, control, demand, electrical, energy, network, potential, response, shifting, vehicles.**

I. Nomenclature

AEMO : Australian Energy Market Operator
DSR : Demand Side Response
PCF : Plant Capacity Factor
RRP : Regional Reference Price
EUAA : Energy Users Association of Australia
CSIRO : The Commonwealth Scientific and Industrial Research Organization
V2G : Vehicles to Grid
EV : Electrical Vehicles

II. Introduction

CONTEMPORARY competitive electricity markets are mainly targeting improved utilization of the electricity infrastructure and reduced energy cost. This should lead, on long term, to environmental and economic advantages and ultimately to reduced energy prices. However, current electricity markets have, in most cases, evolved to a state where entities of generation, transmission, distribution and retail are undertaking market design and operating decisions in isolation of consumers. Most electricity markets do not treat consumers as a partner capable of making rational decisions but simply as a load that needs to be served under all conditions[1].

It is generally agreed that consumers, at the tail-end of this market, inherently possess the ability to moderate the market and avoid most of the currently experienced problems occurring mainly due to demand congestions, lack of coordination between consumers and deficient use of generating capacities. With adequate information about basic economic and technical market operating conditions, consumers could be able to contribute alleviating demand congestions and achieve improved economic performance. This can be achieved by engaging consumers in incentive based programs with evidenced monetary return in case the consumer is observing market conditions and appreciating the value of energy related to the appropriate time of use.

Under the smart grid, consumers will be an integral part of the power system, where they are encouraged to participate in system operation and management. From the perspectives of market operators controllable demand is another resource; it will help balance supply and demand to ensure system reliability. From the perspectives of consumers the mechanisms offered by the smart grid are transforming the energy consumption into an economic choice decided by the returning value on social welfare [2].

In the current market, a limited number of consumers have the ability to reduce or reschedule their demand in response to the electricity prices. For example, if prices are high, some industrial consumers may forego production if it is not profitable at that price level. Consumers who have the ability to store energy or some intermediate product may reorganize their production [3]. Most of the current demand-side management programs exhibit common problems of low level of consumer's participation, poor managerial flexibility and poor real-time demand-side data [2].

This paper presents a demand side response (DSR) scheme that enables electricity consumers to achieve improved economic conditions for their consumption by maximizing

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financial benefits. The paper is describing a low-cost DSR scheme which if implemented at the user's premises; it allows shifting loads from peak to off-peak demand periods to match network conditions. The scheme is aiming at reducing the electricity price volatility by avoiding high-priced peak demands and utilizing on-site renewable energy sources. This helps to enhance grid reliability, reduce energy cost and optimize energy consumption. It allows electricity consumers to "spread-out" significant peaks, which represents essential improvement to the demand profile.

The scheme is acting upon publicly available 30 minutes periodical information on demand and price conditions updated by the Australian Energy Market Operator (AMEO) on the internet. The information include a day-ahead market condition as well, which gives consumers even more opportunities to plan for a next-day operation. Shifting loads from peak to off-peak periods is considered equivalent to providing additional generating capacity yet 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 consumers to observe electricity prices and load strains on the electrical network consumers are entitled to be sharing responsibility on the operation of the electricity market. Finally, with the consumers equipped with the tools to manage their own power consumption they will be provided also the ability to concurrently interconnect to other on-site renewable energy sources and to carryout proper charging/discharging of electrical vehicles.

III. BACKGROUND

The Australian Energy Market Operator (AEMO) is responsible for the management of power flows across the national electricity market in the states of Australian Capital Territory, New South Wales, Queensland, South Australia, Victoria and Tasmania. In order to achieve a high quality service to all consumers, the AEMO updates price/demand information to the public every 30 minutes.

Fig. 1 depicts an example of actual energy demand and price conditions regularly released on the internet by the AEMO. The price pattern is closely following that of the demand. Electricity price is typically at its lowest level during times of low demand (off-peak) e.g. at night. Traditionally, prices soar twice daily following morning and evening peak demands.

Fig. 2 summarizes an example of classic fluctuations in electricity prices in Queensland (QLD), New South Wales (NSW), South Australia (SA), Tasmania (TAS) and Victoria (VIC) from 1st January 2010 to 30th December 2010. Figure 2 illustrates that the average price during that time was in the range of \$20/MWh (¢2/kWh) regional reference wholesale price (RRP), however, extreme prices occurred exceeding \$1800/MWh (180¢/kWh). The graph indicates also that excessive prices are occurring regularly in all states on the interconnected power network. Additionally, consumers bound.

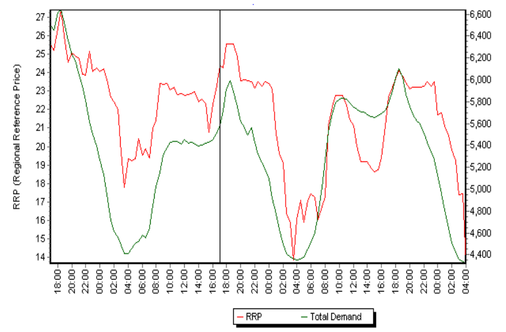

Fig. 1. Wholesale electricity price in Queensland on 21th - 24th April 2011 [4].

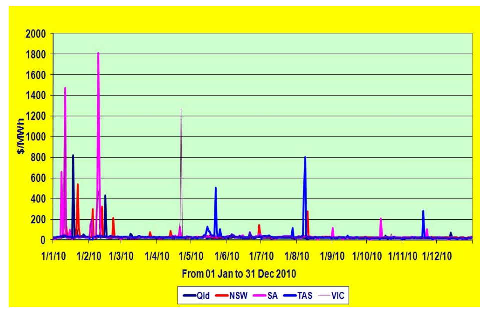

Fig. 2. Fluctuation of Electricity Prices in Queensland, New South Wales, South Australia, Tasmania and Victoria.

Fig. 3 illustrates the occurrence of electrical demand in Queensland during the year 2010. The figure indicates mainly the fact that the higher the load above the base load, the lesser likely the extent of its duration. Base load power stations are those operated at full rated capacity twenty four hours a day throughout the year corresponding to a plant capacity factor (PCF) of unity providing thus the most economic operation and the least possible energy cost [5]. Any loads exceeding the base load are usually covered by other power plants operated for shorter periods at plant capacity factor lesser than unity providing thus higher energy prices. This implies that the higher the peak demand is, the higher the energy price will be. Accordingly, the limited operation of the more expensive power plants makes their operation even more expensive.

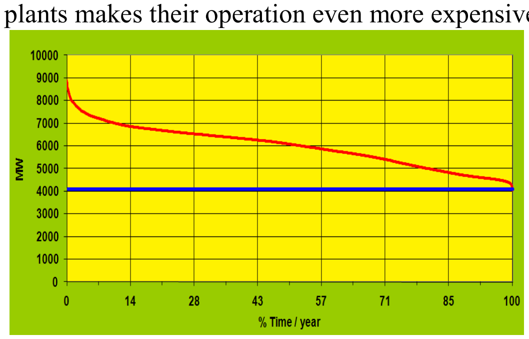

Fig.3. Occurrence of electrical energy demand in Queensland during 2010. peak demand 8890.66 MW, base-load 4055 MW and total supplied electrical energy 52.324 TWh. Data extracted from the Australian Energy Market Operator.

Fig. 4 illustrates the occurrence of the regional reference price (RRP) in Queensland during the year 2010. The figure indicates mainly that low-priced supplies are taking place at very high occurrences of more than 60% a year, while high prices occur at lower frequencies. For instance, prices around AUD $20/MWh are occurring at frequencies of about 60 %, while prices of over $30/MWh have occurrences of less than 10 %.

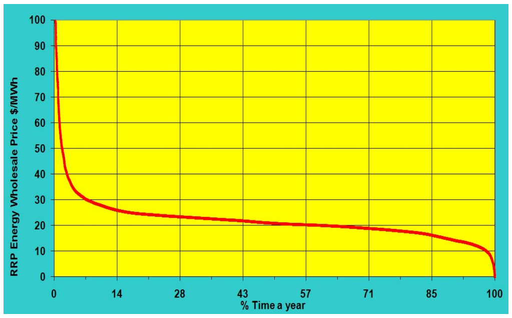

Fig. 4. Occurrence of electricity prices in Queensland 2010

IV. Demand Side Response Program (DSR) in Australia

In Australia, implementations of the DSR programs have been conducted several years ago. In late 2002, the Energy Users Association of Australia (EUAA) conducted a trial to demonstrate the benefits of a DSR aggregation process which would enable electricity consumers to respond to both the extreme prices and extreme peak demands [6]. This experiment was conducted by end-users to determine the value of an effective DSR for electricity consumers and its impact in terms of supporting an energy saving program. This trial was supported by the Victorian, New South Wales and Commonwealth Government, as well as the CSIRO, to implement a Demand Side Response Facility Trial [6].

In the experiment described above, the Australian Government through the EUAA involved consumers to participate in the DSR trial. This experiment was conducted in three regions that fall under the National Electricity Market operation, New South Wales, South Australia and Victoria [7]. These areas are regarded to represent the electricity load in Australia, and the results obtained show some significant benefits of using DSR for consumers and electricity providers. Hence, in December 2003 the Ministerial Council for Energy advised the Council of Australian Governments (COAG) on the need for further reform of the energy market to enhance active energy user participation [7].

The energy users association of Australia targeting a DSR action summarizes that, for example, South Australian electricity consumers only use the highest 10% of their maximum electrical demand on the network less than 0.5% of the time per year, i.e., for about 40 hours per year [6]. The report is stating further: while the electricity consumers are insulated from price volatility by ‘flat’ electricity prices, they are also paying a significant and undisclosed (hard to evaluate) premium in their retail electricity prices to cover the retail supplier’s costs of managing the risks of the extreme price volatility.

It is very important to electricity consumers and the Australian economy that electricity costs are minimized. DSR is an effective way to address cost effectiveness and peak demand. It is important that electricity consumers become better informed about the opportunities from DSR. As said previously, these case studies are seen as an initial project in a broader EUAA Customer Awareness Program designed to help facilitate DSR. The need for additional Customer Awareness is critical and how this can be achieved will be reviewed when this project is complete [6].

The following set of objectives was established for this project [6]:

1. To make electricity consumers more aware that there are commercial and broader economic benefits from effective DSR; and

2. To demonstrate through practical Case Studies those electricity consumers can gain significant benefits from relatively small and occasional responses to extreme National Electricity Market prices and demands, or peaks in network demand, and the extent of those benefits.

V. Integrating On-Site Renewable Energy Source and Electrical Vehicles To DSR Program

On-site renewable energy with DSR smart grid tools is a new way to improve reliability, sustainability and cost effectiveness. Renewable energy combined to the grid can have a significant impact on removing peaks on the electrical network [8]. The key challenges that need to be considered in the composition of future network include distributed generation and the integration of renewable energy sources, such as biomass, wind and solar [9]. The utilization of renewable energy is expected to be leading to the harmony between humans and nature with low pollution and sustainable accessibility to resources.

Some countries have applied smart grid technology for renewable energy utilization. In Japan, using solar power generation systems in every ordinary house is the most active project in smart grid researches [10]. The significant amount of installed wind power in the German power system in 2008 was more than 22 GW producing between 1500 - 7700 GWh/month [9].

On the other hand, electricity vehicles (EV) technology brings impacts to the electrical distribution grid. The vehicle can not only charge, but also discharge and thus inject energy to the grid [11]. In addition, there are social, environmental and economic advantages in switching to electricity vehicles [12]. The following figure 5 indicates schematic of the proposed scheme with vehicle to grid (V2G) and renewable energy systems [13].

Fig. 5 shows the basic idea of the vehicle to grid technology. Electric vehicles can be connected either to the house or to the facility and perform the V2G. Charging or discharging of the vehicles battery can be performed according to the remote commands from the grid operator or demand side response scheme [14].

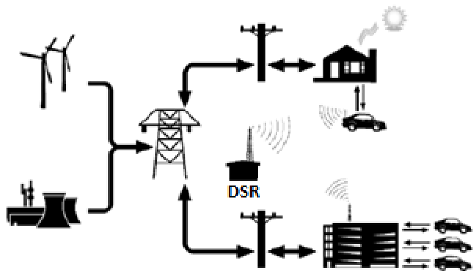

Fig.5. Schematic of proposed scheme with renewable energy and electrical vehicle implementation [13]

VI. METHODOLOGY

This work aims at developing an integrated energy scheme that enables electricity consumers an automated control of energy consumption and optimized use of renewable energy sources and electrical vehicles. The main purposes of this control is for users to be averting peak-demand periods on the electrical network helping thus to mitigate detrimental impacts and risks of heavy congestions.

The scheme uses programmable internet relay, a router and solid-state switches to control electricity demand at user's premises. The relay is programmed to receive and act upon information received about electricity demand/price conditions from the Australian Energy Market Operator (AEMO) over the internet. In order to achieve the aims and objectives of this research, a multi media tool to be developed in frame of this research for use on user's premises, in order to enable users to effectively and continuously apply the model.

The scheme is structured to maximize benefits for end-users of the electricity supply chain. Consumers are gaining an automated control on consumption according to own preferences. In case the user is already in a DSR program agreement with the supplier, the model is allowing additional savings besides the benefits and saving already achieved through other DSR agreements. The proposed model is securing financial and energy savings to consumers.

The scheme is applicable for commercial and industrial consumers on fluctuating energy prices as well. For domestic consumers on flat-rate tariffs, users are gaining financial benefits from reducing energy consumptions at certain times a day; mainly averting peak-load periods. Domestic consumers 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 scheme involves an economic model based on the maximization of financial benefits to electricity users. Implicitly, the scheme targets 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 helping engaging end-users to be participating in solving the peak demand crisis on the electrical network in Australian States covered by the Australian Energy Market Operator (AEMO) covering states of Eastern-Australia, Southern-Australia, and Tasmania and other electricity markets under similar operation condition.

The following fig. 6 describes the proposed model, are connected to renewable energy source and electrical vehicles.

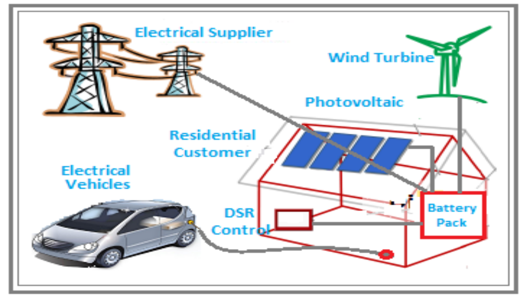

Fig. 6. Power flow of demand side response smart grid system integrating on-site renewable energy sources and electrical vehicles

VII. ANALYSIS AND RESULTS

Fig. 7 shows the impact of implementing the scheme on an arbitrary percentage load moderation by set of loads (in this case 75% of load above the average load) from peak to off-peak periods.

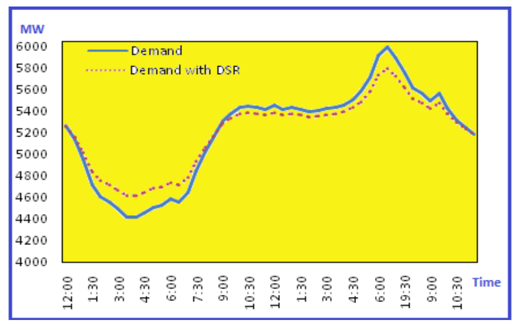

Figure 7. The impact of implementing DSR Program in Queensland on 23rd April 2011

Fig. 8 illustrate the technique is enabling consumers to remove 6.1 TWh/year from a total of 52.324 TWh/year in Queensland if users are prepared to curtail own loads at any regional reference prices above $50/MWh; In case users choose to curtail loads at $40/MWh, the savings are 12 TWh/year; and $30/MWh curtailment at 25 TWh/year, $20/MWh curtailment at 44 TWh/year.

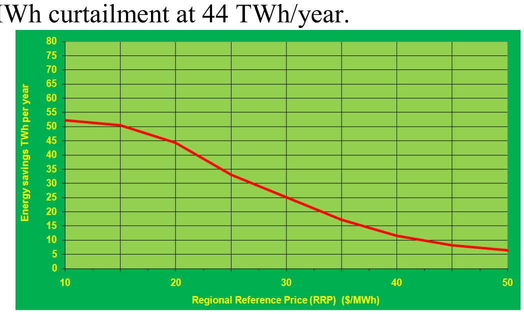

Fig. 8. Achievable energy savings by curtailing energy demand over a certain energy price in Queensland.

Fig. 9 depicts the case where coordinated strategies are able to lead consumers to defer loads from times of peak-demand to times of low-demands. Such a procedure shall help flatten the total energy demand to meet a constant average of 5957 MW for Queensland, achieving considerable improvement in the system utilization and thus in the whole system economics. In such a procedure the technique enables deferring 3.175 TWh/year from peak to off-peak times.

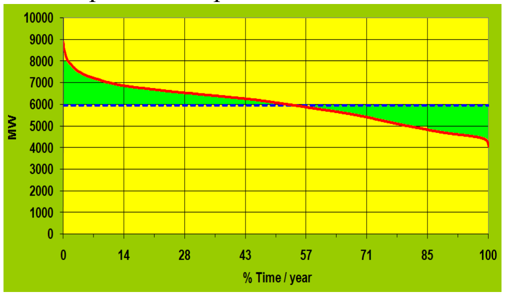

Fig. 9. Occurrence and average electrical energy demand in Queensland

Fig. 10 depicts the possibility to utilize 25.558 TWh/year of electrical capacity, mainly of peak-load power stations, otherwise not used full time. The procedure helps enhancing the utilization of present electrical power stations to approach a plant capacity factor close to the unity, achieving thus an optimal use of power plants.

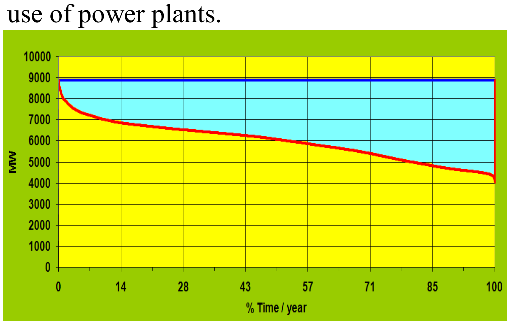

Fig. 10. Electrical energy demand Queensland accommodating electrical vehicles

VIII. Conclusion

The proposed DSR scheme aimed to develop an integrated energy scheme that enables electricity consumers to gain automated control on their energy consumption and optimized use of renewable energy resources and electrical vehicles. The proposed scheme is securing financial and energy savings to consumers. The scheme is helping engaging consumers to be participating in solving peak demand conditions on the electrical network in Australian States covered by the Australian Energy Management Operator (AEMO) and other electricity markets under similar operating conditions.

IX. Acknowledgment

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XI. Biographies

Marwan Marwan received the B.Eng degree from Hasanuddin University Makassar Indonesia and the M.Eng degree from Queensland University of Technology (QUT) Brisbane Australia, in 2000 and 2006, respectively, all in electrical power engineering. He has been a lecturer with the State Polytechnic of Ujung Pandang Makassar Indonesia in Energy Conversion Department since 2001. Presently, Marwan is pursuing his Ph.D degree with the Queensland University of Technology (QUT) Brisbane Australia.
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