Customer and grid impacts of solar, storage and cost reflective tariffs

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***Abstract*— The business environment of distribution networks is changing rapidly. Electricity price rises and technology advances, particularly in distributed energy resources such as solar PV and battery storage, mean that customers have new choices for their energy supply. Adoption of these new technologies, together with more efficient appliances, is leading to changing network utilisation which can contribute to rising electricity prices. Electricity tariffs that are not cost reflective, are also contributing to market distortions. This paper describes the results from an application of cost reflective tariffs with customers that have distributed energy resources within a single Ergon Energy low voltage network.**

***Index Terms*--batteries, distributed power generation, energy management, energy storage, solar energy**

I. Introduction

The business environment of distribution networks is changing rapidly. Electricity price rises and technology advances, particularly in distributed energy resources such as solar photovoltaic (PV) and battery storage, mean that customers have choices for their energy supply. New appliances are likely to be more energy efficient than equivalent older devices, resulting in lower electrical demand. This is leading to changing network utilisation which can contribute to rising electricity prices. Electricity tariffs that are not cost reflective, are also contributing to market distortions. Customers are beginning to turn away from the electricity network as their primary source of electricity supply.

Ergon Energy is a distribution network service provider (DNSP). The company has adopted a corporate strategy of enabling effective electricity markets. This includes the adoption of more cost reflective network tariffs and facilitating the connection of distributed energy resources by our customers. Three power management tools are becoming popular with customers, namely:

1. Power generation: solar PV systems
2. Energy Storage: Battery Energy Storage Systems (BESS)
3. Monitoring and Control: Home Energy Management Systems (HEMS)

PV and BESS can be categorised as distributed energy resources (DER). Understanding the way customers use and interact with DER, is essential for enabling these technologies.

Ergon Energy undertook a detailed investigation into the integration of DER and cost reflective electricity tariffs, with ten residential customers in a single street, all supplied from the same distribution transformer. Solar PV, BESS and HEMS were installed with the customers and three cost reflective tariffs were tested during the project. Impacts to the grid and customers were measured and analysed.

II. Background

A. Distributed Energy Resources

Solar PV and BESS have become popular with customers as a means of reducing grid connected costs and realising the benefits of local renewable energy generation.

1) Solar PV Penetration Levels

Australia is leading the world in uptake of household distributed solar PV systems. A study by the Energy Supply Association of Australia (ESAA), reports Australia (15.2 %) has double the residential solar PV penetration rate of the next highest country (Belgium 7.4 %) [1]. Within the Ergon Energy network solar PV for detached houses is 24.1% penetration, with more than 400 MW of residential solar PV inverter capacity installed. By 2020 it is forecast that there will be up to 800 MW of solar PV connected to Ergon Energy's network.

2) Battery Energy Storage Systems

The number of BESS installations is expected to rapidly increase in the coming years as advised by ESAA [2] and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) [3]. The CSIRO report identifies four key challenges requiring more investigation:

1. The unique Australian climate impacting storage
2. The need to obtain more system performance data
3. Realising benefit for customers and the grid
4. Safety regulations and standards

While penetration levels of BESS are very low, this an appropriate time to undertake real-world investigations across a broad range of potential residential BESS usage scenarios.

Funding for this project was provided by the Queensland Department of Energy and Water Supply.

B. Electricity Tariffs

Electricity tariffs are the price consumers pay for the connection and supply of electricity via their relevant electricity retailer. The tariff is made up of generation, transport and retail charges. The tariff structure varies, but generally speaking the tariff is made up of at least two components:

1. Connection/supply charge ($/day)
2. Usage/energy charge (c/kWh)

Queensland Government uniform tariff policy states that all of Ergon Energy retail customers are on a regulated tariff [4]. This ensures that, regardless of where they live, customers of the same classification pay the same rate. These rates are based on the cost of supply in the competitive southeast Queensland market.

Ergon Energy Network recovers its regulated costs associated with the transport of energy to customers through network tariffs charged to retailers. The majority of Ergon Energy Retail residential customers are on flat rate tariffs, which provide no price signal for the cost to supply electricity.

C. Ergon Energy

Ergon Energy is a state government-owned corporation responsible for distribution of electricity to 97 % of Queensland and the Torres Strait, Australia. The supply region is characterised as being large, over 1 million square kilometres and sparsely populated, only around 720 000 customers. This makes it one of the lowest density networks in Australia. The combination of a sparse network and high PV penetration is anticipated to result in over $80 million in capital and operational expenditure between 2015 and 2020 in order to address LV overvoltage issues [5].

III. Hosting Ability of Distribution Networks

Highlighted by the rapid uptake of PV by households, distribution networks and numerous studies have identified a number of power quality issues attributed to DER, namely overvoltage and phase unbalancing, as well as capacity overloading and disruption to protection schemes [6] [7] [8]. However, DER can also be a lower cost alternative to traditional network solutions for managing capacity constraints and outage response, using a range of delivery models on either the network- or customer-side of the meter [9]. DNSPs have previously analysed the ability of representative distribution networks to facilitate the connection of customer-side DER, by considering the contribution of exported energy on overvoltage. With a 100 % penetration of solar PV exporting during the middle of the day (when residential load is at its lowest), only 1.5–3.4 kVA can be supported per customer on a typical LV network. This capacity can increase to 2.1–5 kVA per customer, by actively managing the voltage at customer's premises, with reactive power control [10] [11]. It is important to highlight that these capacities are the exported power and not the generated power. This flags the opportunity for either controlled self-consumption (home load control, or battery charging), or curtailing generation to further avoid overvoltage in larger systems. While generation curtailment is already a standard option for connecting DER to the network in Australia [12], controlled self-consumption is currently not widely used, beyond historic residential load shedding schemes.

Customers as well as DNSPs can derive value through controlling DER, as well as large household loads such as hot water systems and pool pumps. This is achieved through suitable price structures, using shifting Time of Use signals to the DER or home energy management system controller. By having an active price signal, as opposed to a generic time/season based one that applies to all customers, DNSPs can avoid coincidental charging/discharging of batteries and creating new peaks. While this approach requires an ability to send the signal from the network to the customer, it is able to be operated through existing load control arrangements, as well as modern internet approaches as well.

IV. Field Trial

The field trial tested the integration of DER with cost reflective tariffs in a simulated real world environment with ten customers connected to the same 11000/415 V distribution transformer. The DER equipment was installed on the customers' side of the meter and three different cost reflected tariffs were tested throughout the year. Shadow tariffs were used to simulate the tariff change with the customer, without their official tariff arrangements changing. The customers were provided with a small financial incentive to reduce their peak time energy use.

A. Field Trial Details

Figure 1 shows a simplified electrical connection diagram for the field trial site. The site has a 100 kVA distribution transformer supplying a total of fourteen customers. Ten of these participated in the field trial. The field trial participants had a mix of single phase and multiphase connections and all except one had a solar PV system. Sites S01, S10, S12 and S14 did not participate in the field trial.

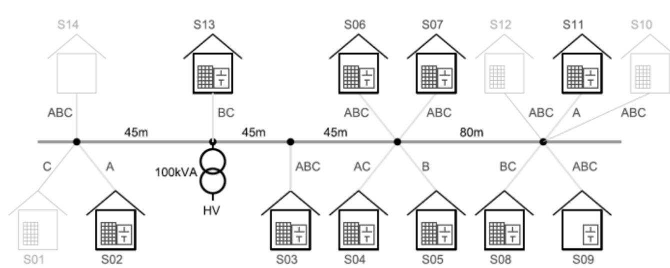

Figure 1. Electrical connection diagram of field trial site

TABLE I. CUSTOMER DER EQUIPMENT DETAILS

Site No.	No. of Phase	DER Phase	Solar PV Size	BESS Rating	BESS usable Energy
S02	1	A	2.4 kW	3 kW, 10 kWh	7 kWh
S03	3	A	4.6 kW	5 kW, 20 kWh	14 kWh
S04	2	A,C	5.0 kW	3 kW, 10 kWh	14 kWh
S05	1	B	4.5 kW	6 kW, 12 kWh	9 kWh
S06	3	A	3.0 kW	5 kW, 20 kWh	14 kWh
S07	3	A	4.9 kW	7.5 kW, 16 kWh	6.4 kWh
S08	2	B	4.9 kW	7.5 kW, 16 kWh	6.4 kWh
S09	3	B	nil	5 kW, 20 kWh	14 kWh
S11	1	A	2.8 kW	3 kW, 10 kWh	7 kWh
S13	2	B	4.9 kW	5 kW, 20 kWh	14 kWh

TABLE II. BESS DETAILS

	BYD	SP PRO	Sunverge	ZEN Energy
Field Trial Quantity	4	2	1	4
Model	DESS P03B10-C00-A	MG016048-S6	SIS-6048-X	Freedom Powerbank
Power Rating	3 kW	7.5 kW	6 kW	5 kW
Energy Rating Total	10 kWh	16 kWh	12 kWh	20 kWh
Energy Rating Useable	7 kWh	6.4 kWh	9 kWh	14 kWh
Battery Chemistry	Lithium Ion LFP	Lead Acid	Lithium Polymer NMC	Lithium Ion LFP
Battery System Voltage	48 V	48 V	48 V	48 V

Table 1 has the solar PV and BESS details for each of the field trial participants. In addition to the DER, all sites had a HEMS installed. The HEMS were used as energy monitors, as they were not able to communicate with any of the solar PV or BESS units. The solar PV systems array sizes ranged from 2.4–5.0 kW.

TABLE III. TIME OF USE TARIFF DETAILS

Name	Time	Volume Charge ($/kWh)	Fixed Charge ($/day)
Off Peak	00:00-15:00	0.20	1.15
Shoulder	15:00-16:30	0.35	
Peak	16:30-21:00	0.70	
Shoulder	21:00-21:30	0.35	
Off Peak	21:30-24:00	0.20	

Table 2 details the four BESS makes used during the field trial. The BESS units were complete systems and included energy storage, battery management system and ac inverter. Only the Sunverge system had dc coupled solar PV, all others had ac coupled solar PV. Only one of the four makes of systems utilised gel lead acid batteries, all others were a type of Lithium. The usable energy capacity ranged from 6.4 kWh to 14 kWh.

The DER was connected into the switchboard on the customers' side of the meter. The switchboard circuits were split into three groups:

1. Essential: light and power circuits, power is supplied from grid, solar PV or battery storage
2. Non-essential: cooking, shed power, power is supplied from grid only
3. Controlled: hot water, air conditioning, pool pumps, bore pumps, power is supplied from grid only via economy tariff

The essential circuits could utilise power from the grid, solar PV or battery storage and this choice was determined by the BESS. The BESS control algorithms were proprietary to each vendor and in general all were less sophisticated than desired or expected.

B. Tariff Testing

The field trial tested three tariffs with customers in a shadow environment and hence actual costs were not incurred, but a small financial incentive provided motivation to change behaviour based on the tariff details. The three tariffs tested were: Time of Use (TOU), Capacity (CAP) and Time of Use Demand (TOUD). Each tariff test was conducted for two weeks, but the three testing periods occurred over a six month period, hence there are results that are influenced by changes in weather. TOU testing occurred in June (winter), CAP occurred in August (winter), TOUD occurred in December (summer) and September (spring) was used a control period. Customers were given the specific tariff details the week prior to testing and then notified again on the morning the testing commenced.

Table 3 shows the details of the TOU tariff, where there are different prices for energy based on threes time periods, off peak, shoulder and peak. There is also a daily fixed charge.

TABLE IV. CAPACITY TARIFF DETAILS

Demand	Description	Volume Charge ($/kWh)	Fixed Charge ($/day)
0 < 2 kW	Zero to less than 2 kW	0.20	1.15
2 < 4 kW	2 kW to less than 4 kW	0.35	
> 4 kW	4 kW and greater	0.70	

TABLE V. TIME OF USE DEMAND TARIFF DETAILS

Name	Time	Demand Charge ($/kW/day)	Volume Charge ($/kWh)	Fixed Charge ($/day)
Peak Demand	15:00-21:30	1.67	0.13	0.76

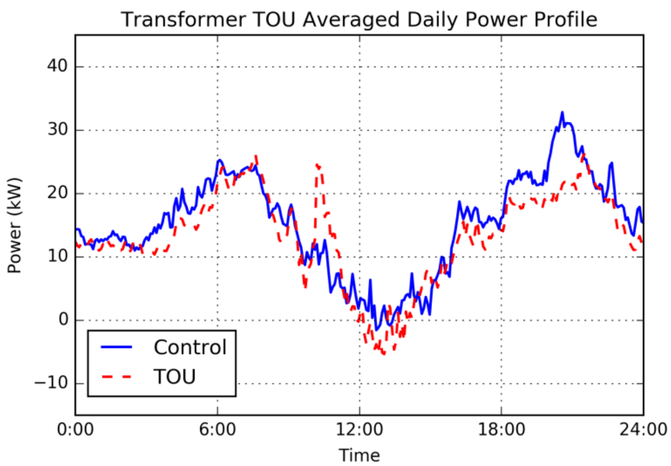

Figure 2. TOU tariff testing power profile

Table 4 shows the details of the CAP tariff, were there are three different prices for all daily energy, based on the maximum demand for the day. There is also a daily fixed charge.

Table 5 shows the details of the TOUD tariff. This tariff has three components: demand (kW), energy (kWh) and fixed cost ($) for calculating the daily charges. The demand charge is the maximum demand (kW) during the time period of 15:00-21:30 each day. The energy charge is for all energy consumed during the day and the fixed charge is a daily connection charge.

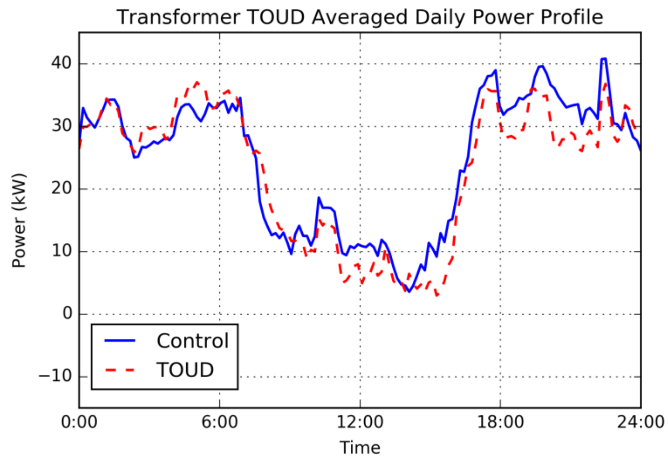

Figure 3. TOUD tariff test power profile

V. DISCUSSION

A. Grid Impacts

BESS offers potential benefit for DNSP, to avoid capacity constraints and maintain power quality boundaries on their distribution networks. The field trial tested if cost reflective tariffs alone worked well enough to achieve a benefit to the network and customers.

Analysis was conducted at the distribution transformer, to review the change in demand during the tariff testing. Load profiles were produced from the two weeks prior to and two weeks during tariff testing. The data was averaged from 10 minute interval measurements, to obtain a single load profile for the test period and control period.

Figure 2 shows that the TOU tariff reduced demand during the evening peak time, compared to the control period. Peak time power reduction was approximately 10 kW or roughly 30%. However, four of the BESS were incorrectly set to charge from the grid, instead of from solar PV, at 10:30, which caused a large increase in demand. This demonstrates that incorrect or unintentional programing has the potential to add significant load to the network at undesirable times.

Figure 3 shows that the TOUD tariff did not consistently reduce demand during the evening peak compared to the control period. There are times when the TOUD profile is 10-20 % less in the evening, however results are not consistent. This may be due to cooking or air conditioning loads switching on (both not supplied by BESS). This suggests an integrated energy management system is needed if consistent and reliable demand reduction is to be achieved.

TABLE VI. SUMMARY OF DEMAND AND ENERGY CHANGE

Site No.	Daily maximum demand change			Peak time energy use change		
	TOU (%)	***CAP (%)***	***TOUD (%)***	***TOU (%)***	***CAP (%)***	***TOUD (%)***
S02	-20	-5	-5	2	1	21
S03	25	-41	-23	-67	-64	-16
S04	-65	-9	-84	-75	7	-69
S05	28	-32	134	1	-20	-10
S06	30	-7	22	-43	-35	-39
S07	9	-7	15	-39	-5	-32
S08	2	4	34	16	2	11
S09	6	-0	24	-4	2	-51
S11	6	-1	-9	-11	-5	-56
S13	5	-17	-13	-86	-26	-28
All sites						
Mean	2.8	-11.8	9.4	-30.7	-14.4	-27.2
Median	6.3	-7.1	4.5	-25.7	-5.4	-30.2
Std dev	28.2	14.7	55.4	36.6	22.1	29.1

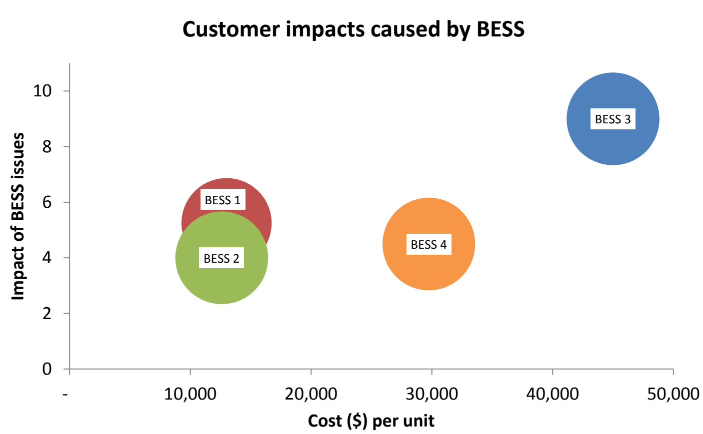

Figure 4. BESS challenges versus cost

Table 6 displays the changes for individual sites. Negative values represent a decrease in load and positive values represent an increase in load compared to the control data. The capacity tariff proved best for demand reduction, as all except for one customer reduced their demand when compared to the regulated tariff. All three tariff tests resulted in reduction of peak time energy use (16:30-21:00).

TABLE VII. COST COMPARISON CHANGE

Site	TOU change (%)	CAP change (%)	TOUD change (%)
S02	-13	-4	27
S03	-1	-30	-12
S04	-25	-4	-63
S05	69	-23	155
S06	-4	94	68
S07	43	-4	41
S08	27	113	50
S09	15	157	2
S11	62	27	30
S13	-23	36	34
All sites			
Avergae	15.0	36.3	33.3
Median	7.1	11.6	32.3
Std Dev	34.5	64.4	56.7

B. Customer Impacts

Over the year-long field trial, only three of the eleven BESS units installed did not require attention. In many of the cases these issues resulted in loss of BESS operation. Resolving issues was often problematic, requiring specialised technical support from other parts of Australia and internationally. Failures in the systems included issues with the inverter, (one inverter was replaced), issues with the battery management system (one was replaced), battery connectivity (one control board was replaced), issues with remote control and monitoring (critical when that is the only way the system can be controlled) and other component failures.

Figure 4 displays challenges versus costs for the BESS. The challenge scale was in regard to negative impact to the customer, where a higher number indicates more trouble or issues. Increased cost did not correlate with a decrease in issues, with the most expensive unit provided some of the greatest challenges and the least expensive unit was the least challenging.

Table 7 displays the change in site specific average daily costs while on the relevant tariffs, compared to the control period. All of the data is for the primary tariff only and does not include any economy tariff data or credit from feed in tariffs.

TOU tariff costs had an average 15 % increase, CAP tariff had a 36 % increase and TOUD had a 33 % average increase compared to the regulated tariff. During testing, five customers would have paid less on TOU and CAP, but only two would with TOUD. The low number of customers that would of paid less during TOUD, could be a combination of three factors: customers burn out, (too many tariff tests being conducted and customers drop into old habits), this test was performed during December and additional load has caused increase in costs, or the TOUD tariff was too complex and customers didn't understand it.

VI. Conclusion

A significant number of challenges and barriers were encountered during the project. Integrating BESS and HEMS technologies into existing electrical installations was problematic. Customers experienced a range of issues that included considerable switchboard modifications, lost HEMS data, power outages and failure of appliances.

There was a large variation in quality and functionality of the BESS units installed on this project and there were issues with all brands of BESS. Increased cost did not correlate with a decrease in issues. The most expensive unit provided some of the greatest challenges and the least expensive unit was the least challenging but most complex to program. The total house load was not able to be supplied by the BESS and hence only light and power circuits were powered by the BESS, with grid supply the only source for cooking, pumping and cooling loads.

Cost reflective tariffs can provide more accurate price signals for customers for the delivery of energy. Time of Use tariffs are too static and do not always accurately indicate the system or local peak. Time of Use tariffs also encourage daily cycling of BESS, which reduces life of the batteries when there may not be a need to do so. Capacity tariffs provide a good signal to customers in regard to household power limits, but without a suitable control system household load management is almost impossible to achieve. The Time of Use Demand tariff was complex and customers did not understand it or have an energy management system that could automatically avoid costly impacts. None of the tariffs tested formally provided an incentive for the BESS to provide network support if required (i.e. dynamic demand response).

Customers, energy retailers and DNSPs have different drivers and incentives with regard to operating a BESS. Energy utopia is when these stakeholders all achieve their desired outcomes (a Win-Win-Win).

Customers with multiple sources of energy (grid and solar PV), storage (BESS) and an energy management system (HEMS) have all of the tools required to provide the best chance of reducing impact from cost reflective electricity prices. This project has shown that without an effective integrated control system, negative grid and customer impacts cannot be avoided. The most likely scenario for achieving energy utopia is with a local integrated energy management system that can receive data from local and remote sources, make decisions, and control loads, generation and storage to achieve desired outcomes for customers, retailers and DNSPs.

VII. References

[1] Energy Supply Association of Australia, "Renewable Energy in Australia - How do we really compare?," 2015.

[2] Energy Supply Association of Australia, "esaa Technology report," 3 December 2015. [Online]. Available: http://www.energycouncil.com.au/members/esaa_technology_report.

[3] K. Cavanagh, J. K. Ward, S. Behrens, A. I. Bhatt, E. L. Ratnam, E. Oliver and J. Hayward, "Electrical Energy Storage: Technology Overview and Applications," CSIRO, Newcastle, NSW, 2015.

[4] Queensland Competition Authority, "Uniform Tariff Policy & Regional Retail Electricity Price Regulation," 2 February 2015. [Online]. Available: http://www.qca.org.au/getattachment/3085343f-6bc1-41ce-aafc-ddf078f66a51/Final-UTP-Advice.aspx.

[5] Australian Energy Regulator, "Ergon Energy - Determination 2015-2020 - Final Decision," 2015. [Online]. Available: https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/ergon-energy-determination-2015-2020/final-decision.

[6] T. I. Chant, G. M. Shafiullah, A. M. T. Oo and B. E. Harvey, "Impacts of increased photovoltaic panel utilisation on utility grid operations - a case study," in *Innovative Smart Grid Technologies Asia (ISGT)*, Perth, WA, 2011.

[7] P. G. Millers, "The effects of small distributed generation on the electrical distribution network," 4 March 2011. [Online]. Available: http://eprints.usq.edu.au/id/eprint/18555.

[8] Y. Li and P. Wolfs, "Preliminary statistical study of low voltage distribution feeders under a representative HV network in Western Australia," in *21st Australasian Universities Power Engineering Conference (AUPEC)*, Brisbane, Qld, 2011.

[9] G. Celli, E. Ghiani, S. Mocci, F. Pilo and E. Pazzola, "Demand Side Management as a support to distributed generation in active networks," in *18th International Conference and Exhibition on Electricity Distribution (CIRED)*, Turin, Italy, 2005.

[10] AS/NZS 4777.2:2015, "Grid connection of energy systems via inverters - Inverter requirements," Standards Australia, Sydney, NSW, 2015.

[11] D. Condon and D. McPhail, "Voltage regulation of distribution networks using inverter reactive power functionality - Australian utility experience," in *IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Brisbane, Qld, 2015.

[12] Clean Energy Council, "Priorities for inverter energy system connection standards," 12 June 2015. [Online]. Available: http://fpdi.cleanenergycouncil.org.au/reports/inverter-energy-system-connection-standards.html.