TECHNICAL AND ECONOMIC ASSESSMENT OF UTILITY INTERACTIVE PV SYSTEMS FOR DOMESTIC APPLICATIONS IN SOUTH EAST QUEENSLAND

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ABSTRACT

Electric utilities in Australia have been developing policies to stimulate interest and permit the purchase of electricity generated by renewable energy sources such as photovoltaic systems (PV). Studies show that under current conditions, it is technically feasible to introduce small-scale, grid connected, roof-top photovoltaic generation systems with or without battery storage. Economic analysis show that the electricity tariff structure for PV and other renewables requires a major change to allow a reasonable and an acceptable pay-back period if PV is to become an attractive economic investment to private owners. The technical policy developed by the utility should be reviewed to better match the operational characteristics of PV and inverter systems.

Keywords - Grid connected photovoltaic systems, Battery storage, Technical guidelines, Cost analysis.

1. INTRODUCTION

A residential grid connected PV system services the local load and exports excess energy to the electricity authority. Grid-connected PV systems offer several advantages over stand-alone systems including savings on wiring costs due to the capability to use existing wiring in the building, the removal of the need for storage batteries as the grid provides a backup and the possibility of selling surplus energy. PV systems employing batteries may also improve the reliability if loads can be supplied during grid power interruptions. In Australia, individual utilities impose their own regulations on the specifications required for grid interconnection. A national set of guidelines has been developed under the auspices of the Electricity Supply Association of Australia [1] and is available via their web site. The corresponding metering and tariff systems for energy transfer are also set by the utilities.

While studies show that renewable energy generators and in particular PV are technically viable using existing technology, their use in the domestic urban sector has been constrained by economical and organizational barriers. It was shown that there is little or no direct benefit to a utility for accepting PV power [2]. There are additional costs, inconveniences and administration involved which can be seen to outweigh any small financial benefit from buying power at a low price. Furthermore, a marginal loss of system control may be suffered with each additional embedded generator.

The benefits of grid-connected schemes may be seen as expressing concern for the environment, energy credit associated with reductions in fuel consumption [3] and an opportunity to participate and contribute into a new technology. The importance of these benefits should not be discounted, as new methods, from Farmer *et. al.* [4], in measuring the value of distributed photovoltaic generation concluded that there is evidence to prove that non-traditional benefits are measurable and significant.

There have been extensive studies on the economic feasibility of grid-connected PV systems. Davies and Cabraal [5] used net present value analysis as a figure of merit in the least costs analysis of renewable energy projects. Skikos and Machias [6] used net present value, internal rate of return and payback period as models in their fast economic assessment using fuzzy set theory. Gould [7] concluded that PVs are commercially competitive with conventional sources in remote locations, and a continuation of current price and sale trends may make residential rooftop systems commercially competitive in urban areas.

The Southern Electricity Retail Corporation (trading under Energex) is currently active in some early applications of PV. These include solar powered street lights and public amenities blocks. Grid-support is being investigated through a number of projects including "Solar One", a roof top 1.3 kWp system installed on a solar architectural house in the Sunshine Coast north of Brisbane. Other systems include evaluating solar boosted air-conditioning and single residential PV assisted dwellings; with and without battery storage.

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The analyses performed in this paper are based on the payback period and the net present value as these parameters are often required when analyzing an investment decision.

2. TARIFF STRUCTURE

Table 1 gives the domestic tariffs that are in effect for the purchase and sale of electricity to and from 'Energex'. Three tariffs exist: a sliding scale (Tariff 11) used for general light and power, and two tariffs used for off-peak loads (Tariff 31 or Tariff 33). The minimum monthly fee under Tariff 11 is $6.80 which corresponds to a monthly consumption of about 45 kWh. In south east Queensland, the domestic consumption under Tariff 11 ranges from a low 6 kWh/day to more than 16 kWh/day with a typical average consumption of 12 kWh/day. Water heating and few other domestic loads can be directly wired to off peak Tariff 31 or Tariff 33. The average consumption under off-peak tariffs is between 6 and 8 kWh/day.

Table 1. Electricity Tariffs (buy/sell) for Domestic Consumers in South East Queensland.

Tariff type and code	Availability	*Monthly charges*
Tariff 11: Purchase of Domestic light and power	Continuous	*15.14 cents/kWh for first 100kWh, 10.29 cents/kWh for next 300kWh, 9.18 cents/kWh for remainder, $6.80 minimum payment*
Tariff 31: Purchase of Super Economy Night Rate	10pm - 7am	*4.25 cents/kWh, $4.25 minimum payment*
Tariff 33: Purchase of Controlled Supply	At least 18 hours	*6.22 cents/kWh, $2.80 minimum payment*
Sale of Energy, Peak/ Off-Peak Rate	peak period 7am - 9pm Mon - Fri	*9.3 cents/kWh in peak period, 3.3 cents/kWh in off peak period*
Sale of Energy, Flat Rate	*Continuous (7 days)*	*5.8 cents/kWh*

Table 1 also gives the tariffs being offered to small producers of electricity in Queensland. The first of these defines a peak and off peak rates, whereas the second offers a flat rate of 5.8 cents/kWh. The period during which 'Energex' normally prefer to receive energy is between 7 am and 9 pm, Monday to Friday. It is noted that the first tariff is complicated to administer; whereas the second tariff is simpler to implement. In the flat-rate tariff, either an additional meter must be installed, or a real-time electronic type, with a minimum of two recording channels, one for each direction of power flow. In the case of the peak/off peak tariff, this requires a meter with channels configured to record the export energy at the specific times and days set by the tariff.

3. GRID-INTERCONNECTION POLICY

Energex may be considered one of the first few utilities in Australia to develop a technical policy on conditions of interconnection for small scale renewable energy generation [8]. A number of other utilities mostly in Queensland adopt the same policy document. The policy proposes specifications required of small scale renewables, as a whole, employing either a rotating machine driven by a prime mover (such as a diesel engine) or a solid state inverter up to a maximum of 30 kVA (3-ph) or 10 kVA (1-ph).

The document gives a brief general guidance to grid interconnection. Apart from the compatibility with system and the additional requirement for protection devices, the policy requires that the owner of the system:

- Pay the cost to supply, install and maintain any export metering equipment.
- Provide all details of calculations of the actual contribution from the owner's system to the fault level at the point of connection. It will be necessary for the owner to bear any costs incurred in respect of fault level control measures.
- Install control equipment to ensure that the level of generation imported or exported is restricted to the mutually agreed power transfer limit.

The implications of a policy for metering using different tariffs for the import and export of electricity do not warrant the additional cost of the meter, installation and testing, or reading the different channels in an electronic meter. The requirement to conduct a fault study for small scale generation may not be necessary if a PV system is the sole generator. Small grid connected PV systems in the range considered for residential dwellings will use standardised, pre-engineered inverters with fixed voltage and frequency trip settings. Inverters which are designed in accordance with applicable codes and requirements may not require additional protection equipment [9]. The costs to install control equipment to limit energy transfer can be seen as an added barrier.

The document does not provide wiring diagrams for the interconnection of the energy source, the batteries or the meters. A list of approved inverters can be obtained from Energex. If the customer wishes to use an inverter that has not been tested, a test should be arranged through Energex.

4. ELECTRICITY PURCHASE AGREEMENT

The "Electricity Purchase Agreement" between 'Energex' and the owner defines the parameters of small scale renewable energy systems, given in Table 2 [10]. The rated parameters may be negotiated with Energex for certain applications. A limit on export energy of 10 kWh per day has been set for "Solar One" project. It would, however, be impossible for a domestic PV system of 1.4 kWp to exceed the maximum energy figure even under bright sunshine.

Table 2. Export Energy Requirements for Small-Scale Generation as of February 1997.

Maximum Rated Capacity of (renewable) source	1.4 kW-peak
Minimum Availability of source	0%
Maximum export energy per day	10 kWh
Maximum voltage variation	240±6%

The maximum power rating of the renewable energy source may be negotiated with Energex before interconnection. The limit on export energy appears to be redundant and implies that excess energy must be eliminated.

5. TECHNICAL GUIDELINES

A set of technical guidelines have been developed by a group of utility, photovoltaic, and inverter industry experts under the auspices of the Electricity Supply Association of Australia (ESAA). The document is meant to be as a guide and should be viewed from a functional perspective, although it is presumed that it may eventually form the basis of an Australian Standard.

The underlying principles of the guidelines are:

1. Uniform implementation by electricity distributors. Electricity distributors will use the guidelines as a basis for formulating their specific requirements.

2. Ensure safety of workers on the distribution system and the integrity of the system.

3. Not restrictive to certain technology.

The guidelines propose specifications required of "energy inverter system" connected to the low voltage distribution, and leave the approval of the inverter to the utility. The performance and safety of the inverters and associated equipment connected to the grid is considered the responsibility of the owner. No wiring diagrams are provided in the guidelines.

5.1 Standard Requirements

The document makes reference to several Australian standards relating to the interconnection and the design and safety requirements of grid interface inverters. These are: AS1044: Electromagnetic interference, AS1931: High voltage test techniques, AS2279: Disturbances in mains supply, AS2481: Relays, AS3000: Wiring rules, AS3100/AS3300: Approval and test specifications of electrical appliances.

5.2 Testing For Compliance With Guidelines

The guidelines specify the following type testing for compliance testing for an inverter for approval:

- Power factor: range 0.8 lagging to 0.95 leading for outputs from 20% to 100% of rated VA; 0.6 lagging to 0.9 leading for outputs from 5% to 20% of rated VA. (utility may require a specific power factor).

- Automatic reconnection: only occur when grid voltage is within 200 V and 270 V phase-to-neutral and frequency range within FreqMIN (48 to 50 Hz) to FreqMAX (50 to 52 Hz). These conditions must be maintained for a minimum of 1 minute.

- Anti-islanding protection: comprising two tests:
    - Over / under frequency and voltage trip settings: the voltage and frequency trip settings are specified under automatic reconnection. The time to trip must be verified to be less than 2 seconds.

    - Tests under actual grid trip conditions: the inverter output terminals will be connected to a resistive load and a switch placed between the load and the grid. System testing (9 in all) is carried out under 3 loading conditions: open circuit, load match, and 10% above load match; and 3 inverter output levels: 10%, 50% and 100%. The tests will record the inverter output voltage and frequency from at least 2 cycles before the switch is opened until the inverter protection system operates and isolates itself from the grid. The time from the switch opening until the protection isolation occurs must be within 2 seconds.

- Harmonics: must be less than the values listed in table 3.
- High frequency noise: according to AS1044.
- Voltage flicker: according to AS2279 P4 S6.
- Impulse protection: must withstand standard lightning impulse of 0.5 Joule, 5 kV, 1.2/50 waveform to AS1931.1 P1.
- High frequency disturbance tests: according to AS2481.
- DC injection: according to AS3300 for continuously energised appliances.
- Insulation tests: according to AS3100.
- Earthing test: according to AS3100.

Table 3. Harmonic ratio limits for voltage and current source inverters (fundamental=100%).

Harmonic	Voltage	Current
3rd	2.7%	3.6%
5th	1.2%	1.6%
7th	0.9%	1.2%
9th	0.6%	0.8%
Even 2nd-10th	0.6%	0.8%
11th-40th	0.3%	0.4%
Total Harmonic Distortion	< 3%	< 4%

A number of tasks are left to individual utilities. These include:

- *Testing and approval of inverter*
- Arrangement of maintenance and routine testing
- Metering scheme and revenue agreement

6. ECONOMIC STUDY

Figure 1 shows a typical average domestic load (not including off peak supply) in south-east Queensland extrapolated from [11]. The curve has a cumulative daily load close to 12 kWh. The figure also shows the output of a 1.5 kWac PV-inverter system on a clear sky day.

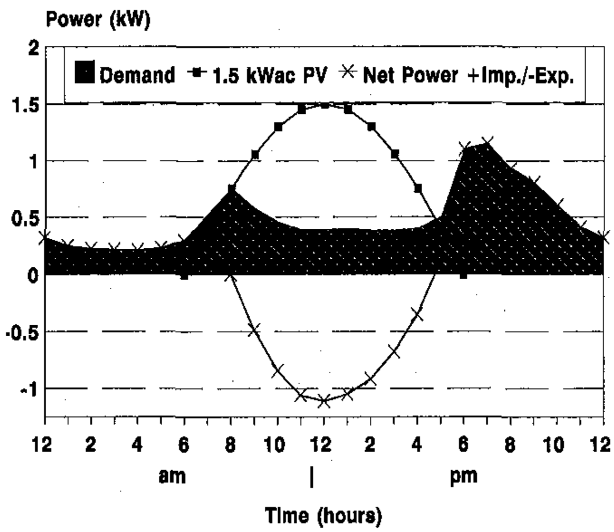

Fig. 1. Typical average domestic load (Energex).

6.1 Cost Parameters

A number of assumptions have been made for the purpose of the economic analysis of small-scale grid connected PV generators. Several system sizes ranging from 0.5 to 10 kW PV-inverter output were investigated for each of which the cost was calculated using the parameters in Table 4. The parameters are carefully selected to reflect actual market prices in Australia.

Not included in the cost analysis are the possible costs for the calculation of fault level at the feeder which may be required by Energex, or the costs of any other investigations Energex may have to make on behalf of the installation of the system, and must also be paid by the owner.

Table 4. Cost Data of PV and Battery System.

Item	Cost
PV Modules, BOS & installation	$6.50 per Watt
Inverter	$1 per Watt for > 2 kW $2000 for < 2 kW
Battery (3 kWh) & installation	$70 per kWh
Battery minimum SOC	35%
Meter (buy/sell tariff)	$350
Meter (net tariff)	$50
Annual O & M Costs	$0.10 per Watt

6.2 Systems Configurations

Results were obtained for each of the following systems and scenarios:

1. (a) A grid connected PV system with buy / sell metering (selling at Peak/Off-Peak rates), and

   (b) Same system as (a) but using the Flat Rate selling tariff (5.8 cents/kWh).

2. A grid connected PV system with net metering, whereby the net energy is calculated and charged at the same general purchasing tariffs. (This scheme is common in US and many other countries).

3. A *grid interactive battery system*. A 3 kWh battery is charged under Tariff 31 (the cheaper off peak rate) in off peak times and the stored energy is used to supply local load and sell excess energy to the utility in peak times. The resulting costs in this system are calculated using the separate buy / sell tariffs. This system does not employ a PV array.

4. An integrated PV and battery charging system (3 kWh) which uses the buy / sell tariffs.

7. ANALYSIS OF RESULTS

The results for the monthly (30 days) cost of electricity for each PV system size, (as Energex calculates bills on a monthly basis) without and with PV generation under the buy/sell tariff, the continuous tariff and the net tariff schemes are listed in Table 5. The average cost of electricity is presently $41.56 per month per household (12 kWh under Tariff 11).

Note that the values in Table 5 that are in bold, will be affected by Energex minimum monthly payment. For the general domestic lighting and power tariff (Tariff 11) the minimum monthly fee is $6.80.

Table 5. Monthly Electricity Charges.

PV kW	PV & Buy / Sell Tariff	PV & Flat Rate Tariff	PV & Net Tariff
0.5	$30.02	$30.20	$29.76
1	$20.41	$22.21	$17.96
1.5	$11.24	$14.93	**$2.05**
2	**$2.22**	$7.95	**-$15.30**
4	**-$33.10**	**-$18.91**	**-$84.66**
6	**-$68.31**	**-$45.64**	**-$154.04**
8	**-$103.43**	**-$72.28**	**-$223.43**
10	**-$138.53**	**-$98.88**	**-$292.78**

It is shown that the maximum sizes of the PV system in each scenario (columns 3, 4 and 5) in Table 5 before being penalized by the minimum monthly payment are 1.75 kW, 2.05 kW and 1.35 kW. The lowest corresponds to using net metering scheme.

For a system with a battery storage the monthly electricity bill is $38.40 rather than the $41.56 for a home with no energy storage or PV.

7.1 Economic Value of PV Systems

Economic analysis are performed using the non-life cycle technique of simple payback (PBP) period, which does not take into account the time value of money. It does however give an estimate of the time it takes to recover the initial investment. The payback period is given by:

$$\text{PBP} = \frac{\text{Initial Capital Cost}}{\text{Annual Benefits} - \text{Annual O\&M}} \tag{1}$$

Table 6 presents a summary of the results of the payback period for each scenario and each system size, illustrating that under the current conditions only two systems, except the battery charging system alone, will pay themselves back in the expected system lifetime of 25 years. These are the 8 kWac, and 10 kWac systems under the net tariff scheme. It must be noted however that these payback periods do not take into account the $6.80 minimum monthly charges imposed by Energex, which would reduce the yearly savings considerably for the larger systems and hence further increase the payback periods. Table 7 gives a summary of costs and benefits of residential PV systems without battery.

The net present value (NPV), a life-cycle cost analysis method, has been applied and consistent results are obtained. The NPV is given by:

$$\text{NPV} = E_A\left\{\frac{1+f}{d-f}\left[1-\left(\frac{1+f}{1+d}\right)^n\right]\right\} - M_A\left\{\frac{1+j}{d-j}\left[1-\left(\frac{1+j}{1+d}\right)^n\right]\right\} - C_S \tag{2}$$

Table 6. Results of Payback Period Analysis.

PV Size kW	PBP yrs Sc. 1(a)	PBP yrs Sc. 1(b)	PBP yrs Sc. 2	PBP yrs Sc. 3	PBP yrs Sc. 4
0.5	62	63.5	56.7	14.6	47.7
1	56.5	65.4	45.7	14.6	49.1
1.5	55.6	69.6	35.6	14.6	50.4
2	48.3	63.9	26.5	14.6	44.9
4	60.9	90.4	26.4	14.6	57.9
6	62.3	98.4	25.3	14.6	60.5
8	63.4	103.	24.8	14.6	62
10	64.1	106.	24.5	14.6	62.9

where:

- d = discount / loan interest rate,
- C_S = initial system cost
- f = energy price inflation rate,
- M_A = annual O&M cost
- j = O&M costs inflation rate,
- E_A = annual energy savings.

Table 7. Costs and benefits of PV Systems.

PV kW	System Cost	Monthly Bill	Monthly Savings	Pay-back Period
0.5	$5 300	$29.76	$11.8	56.7
1	$8 550	$17.96	$23.6	45.7
1.5	$11 800	$2.05	$39.5	35.6
2	$15 050	-$15.30	$56.8	26.5
4	$30 050	-$84.66	$126.2	26.4
6	$45 050	-$154.04	$195.6	25.3
8	$60 050	-$223.43	$265.0	24.8
10	$75 050	-$292.78	$334.3	24.5

The study into the economics of residential PV systems reveals that the existing tariff structure in Queensland will make it impossible for an investor to get a return on the investment during the system lifetime. The flat rate yields even lower savings to the home owner. This situation is aggravated by the additional requirement of the metering system and the minimum monthly fees.

The results of the "Solar One" project in which the flat rate was in effect showed that the effective cost of electricity has been 15.14 cents/kWh. Occasionally, the energy imported was below the minimum purchase level so the fixed $6.80 per month was applied. The generated energy would attract 1.71 cents/kWh [12].

Although it has been shown that net metering will not make the investment justifiable at today's prices [13], implementing net metering will sound rather more attractive. The two most important ingredients for price reduction is 'technology push' and 'market pull'. Given the current trend in prices, It is not unrealistic to predict that cost reduction in PV systems and components which makes residential PV systems affordable and economically viable is not expected before 10 to 15 years. The picture must be reassessed if carbon tax on pollutants and other incentives are put in place.

7.2 Sensitivity Analysis

Sensitivity analysis has been performed to investigate the effect of system set-up cost on the pay back period. The results show that a cost reduction of 75% will reduce the PBP to 14 years for the 1 kW system under the net tariff. Larger systems ratings will have lower PBP. A 4 kW system will have the same PBP under a 50% reduction in cost. Systems 4 kW and above will have PBP of about 17 years at 25% reduction in system cost. Under existing tariff even a reduction in cost by 75% will not make the investment economically viable.

The fact of the matter is that the high cost of PV systems, the lack of reward or incentives, and the question of customer affordability to install a residential PV system; especially when electric power already exists at the dwelling, are enough constraints to consider this form of electricity supply. Amongst the average householders, there are many other priorities ahead of residential PV generation to consider. The additional constraints imposed by the existing tariff structure and the technical policy on interconnection are rather redundant. It is therefore important that the utilities take a leadership role by implementing net metering.

8. CONCLUSIONS

The paper presents a discussion into the technical issues related to the grid-connection of residential PV systems. The impact of the electricity tariff structure for renewables on the prospects of widespread penetration of residential PV systems in Queensland is discussed.

It is found that the technical policy on grid-interconnection may have to be amended given the advancements made in the design of synchronous inverters. The limit on energy transfer and the requirement to install equipment to limit the maximum energy is unnecessary and must be lifted.

The metering system must be reassessed given the additional costs associated with the installation and the reading of the export and import energy and of calculating the bill. The revenue agreement must also be changed to permit net metering.

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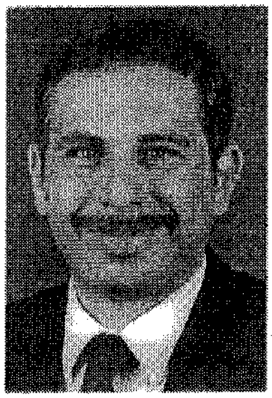
BIOGRAPHY



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