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Evaluation of using Storage Batteries at Residential Community Level under a new Electricity Pricing Criteria

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Abstract: **over the next decades, the electricity system will face several challenges originating from both supply and demand side. In the UK there is no real time retail market, and hence no real time retail electricity pricing. Therefore domestic electricity consumers in the UK pay electricity prices that do not vary from hour to hour, but are rather some kind of average price. Real time pricing information was identified as a barrier to understanding the effectiveness of various incentives and interventions. The key question is whether we can evaluate energy management, renewable energy and energy storage intervention in the behaviour of customers in real market terms. Currently only behaviour changes with respect to total consumption can be evaluated. Interventions cannot be defined for peak load behaviour. The effectiveness of the introduction of renewable energy is also hard to assess. Therefore, it is hard to justify introducing of energy storage and demand side management at local community level, apart from when following government approved schemes, subsidies, and other initiatives. In this paper, the possibility of using storage batteries at community level has been evaluated using new electricity pricing criteria. PV cells or other embedded could also be studied in a similar way.**

Keywords: **Real Time Pricing, Renewable Energy Intervention, Demand Side Management, Local Community**

I. Introduction

The restructuring of power markets has been ongoing in various countries around the world, including the UK, over the last two decades. Since the early 1990's the UK's electricity industry has changed from a government controlled monopoly to a competitive market in order to deliver a lower cost to the consumers, giving consumers the choice to select their energy supplier [1]. In the process a commodity market for wholesale electricity transactions was established. The balancing mechanism market is through the National Grid Company (NGC). The National Grid Company (NGC) will accept offers and bids for electricity close to real time to maintain energy balance, and also to deal with other operational constraints of the transmission system. The balancing mechanism allows electricity companies and traders to submit offers to sell energy (by increasing generation or decreasing consumption) to the system. These participants can also submit bids to buy energy (by decreasing generation or increasing consumption) from the system, at a price of the company's choosing. The National Grid Company will take the lowest priced offers and accept the highest priced bids [2]. The imbalance prices, the system buy price (SBP) and system sell price (SSP), applied to imbalances, are derived largely as the weighted average prices of these accepted balancing mechanism offers and bids.

In recent years, there has been greater worldwide attention towards energy storage in order to reduce the perceived risks related with higher penetration of renewable generation (e.g. not available on demand).

Households will plug in their storage elements at night when electricity is cheap, then plug-in during the day when energy cost is expensive and sell that surplus power at a profit. Many storage elements could be used, like batteries, capacitors or electric vehicles (EV).

The need for storage elements and their use in a power system has long been discussed. An overview of the different storage technologies and their use has been presented in [3-6].

In this paper, the evaluation of the possible use of storage batteries at community level under new electricity pricing criteria has been presented. This paper aims to use the results previously developed by the author in [7, 8].

II. System Buy Price

System Buy Price (SBP) is the price at which retailers settle the deficit in electricity by buying electricity from suppliers to meet the demands of their customers. It is possible to use the System Buy Price (SBP) as an indicator of electricity real price.

The SBP prices have been plotted against national demand to give an indication of the way prices rise as demand comes close to the fundamental limits of supply capacity (Figure 1). The data was taken from the National Grid website [2,9]. In order to model this further, a per unit system is developed.

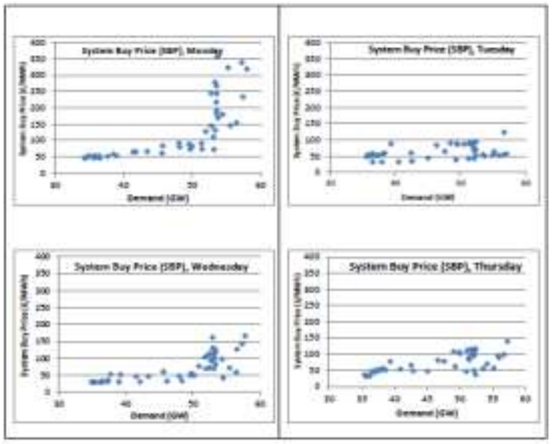

Figure 1. System Buy Price vs. demand

III. Price Model

When overlaid the system buy prices data for January, February and March (as shown in Figure 2), the whole data sets are not visually discernible. It can be seen that the supply capacity is in the range of about 55 to 58 GW, and that there is a considerable knee in the curve at around the 52GW, £100/MWh region. Also, there is a spread in price points for demand between 40 and 58 GW**.**

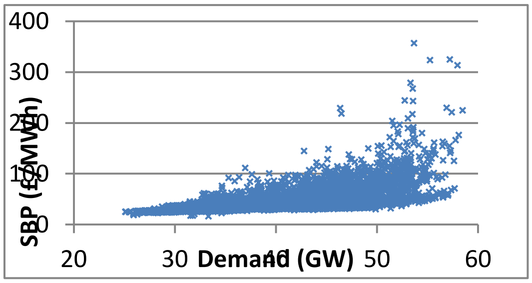

Figure 2. System Buy Price Vs. Demand (Data Combined)

Figure 2 is not useful in this form, therefore it was decided to use the quartiles as an indicator of range of prices. Each quartile is treated as a separate data. The first or bottom quartile represents the lowest price data , the second quartile or median represents the median price, and the third or upper quartile represents the highest price The computer statistical package software MINITAB has been used to get the fitted regression equation. The electricity price curves are of the form:

$$price = a + be^{cd} \qquad (1)$$

Where price is the fitted quartile electricity price in p.u and d is the instantaneous national demand in p.u at that day. The resultant electricity price curves, shown as a function of demand, can be seen in Figure 3.

The resultant fitted equations for high, medium and low electricity price curves are shown in Equations 2, 3 and 4 respectively. The determination coefficients for the three quartiles are 0.96, 0.96 and 0.93 respectively.

$$P_{high} = 0.3365 + 1.565 \times 10^{-3} e^{5.502d} \qquad (2)$$

$$P_{medium} = 0.3282 + 1.4523 \times 10^{-4} e^{7.175d} \qquad (3)$$

$$P_{low} = 0.108e^{1.47d} \qquad (4)$$

These equations are only valid for the demand data ranging from about 0.6 pu to 1.3 pu. The constant (a) could probably represent the minimum cost of electricity produced, b is a scaling factor and c represents the rate of change of pricing.

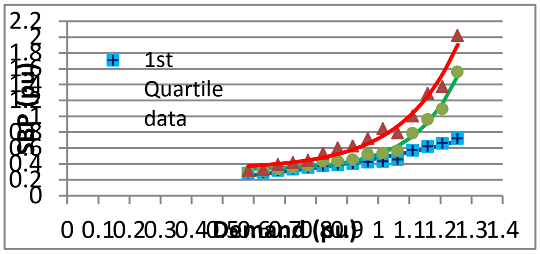

Figure 3. System Buy Price Vs. Demand (Data Combined)

The gap between the curves at high demand shows the potential for the market. The curve also shows that at high demand the cost is a significant; up to 2 pu, whereas it can possibly be as good as 0.8 pu. The median curve also indicates that at peak level of demand the price is about 1.5 pu. Structurally, this indicates that for generators it would cost more to invest in additional generation, as this indicates infrastructure costs in future. For planners, this indicates opportunities via understanding of peak load pricing which is based on real data. Moreover, the margin of cost benefit to a local planner can be quantified in financial terms. The base value may change but as the comparison in pu the analysis will still be the same. Updated curves can always be obtained for planners.

The fitted price curves are used in the following section to forecast the half-hourly SBP which were considered as a measure of system price in order to investigate its effect on community electricity cost.

IV. Community Electricity Cost under the new Pricing Criteria

In this section we are looking at the community electricity cost using the three price curves. The generated load profile for the local community of 400 households previously developed by the authors in [7, 8] has been used.The cost of one day (Tuesday) under the three price curves is shown in Figure 4. It can be seen that the community demand is higher at 21:00 but the cost is higher at 18:00. The cost variation at peak is ranging from 1.5 pu to 3.5 pu.

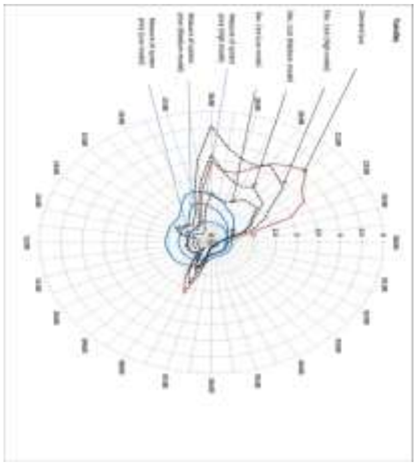

Figure 4. Electricity Cost under Three Price Model Options

It can be seen that the cost was about 1.5 pu at 18:00 for the low model, 2.4 pu at 18:00 for the medium model, and about 3.5 pu at 18:00 for the high model**.** From the Figure, it can be seen that the load pattern is not correlated with the price pattern, where maximum consumption periods do not coincide with periods of high price. The electricity cost at 18:00 is about 3.5 pu with demand of about 2.5 pu. This is higher than it is at 21:00 where the cost is about 2.5 pu with demand of 3.1pu.

V. Storage Battery Payback Period

In this section, we are looking to evaluate the benefits of electricity storage at community level. Community savings using three possible electricity prices will be calculated with a battery storage system. Furthermore, we estimate the battery payback time under the three price curves (Figure 4).

In Figure 4 the cost curves are shown. The highest cost occurs at 18:00. The community load at 18:00 is about 2.5 pu. The price at peak is 1.45 pu and about 0.45 pu at night for the worst case scenario. For the most likely case, the price at peak is 1.0 pu and about 0.3 pu at night. For the best case, the price at peak is 0.64 pu and about 0.3 pu at night. These prices are summarized in Table I.

Table I. Electricity peak and night prices

Scenario	Peak price (pu)	Night price (pu)
Worst case	1.45	0.45
Most likely case	1.0	0.3
Best case	0.64	0.3

Assuming a standard car battery is being used to supply some of the load at peak periods. A standard car battery may be around 80 Ah at around 12 volts, which is around 1 kWh of electricity.

The battery bank can be sized based on the real demand of the community at the time of high price. The real demand is calculated by multiplying the load in pu by the community base demand as shown in equation 5.

$$\text{Real load} = (\text{load (p.u)} \times \text{Base value of load}) \quad (5)$$
$$= 2.5\,pu \times 75.3kWh = 188.25kWh$$

So we need around two hundred car batteries to store 190 kWh. The physical dimensions are small compared to 400 houses.

Presently, the cost of batteries is about £150 per kilowatt hour of storage. The cost of an inverter to convert battery to mains power is excluded for reasons of simplicity. However, the cost of inverters has fallen significantly over the last few decades. For load of 2.5 pu, the cost of batteries (BC) as a function of energy used will be:

$$\text{BC} = (\text{load} \times \text{Base value of load}) \times \text{cost per kWh} \quad (6)$$

$$= 2.5\,pu \times 75.3kWh \times £150 / kWh = £28237.5$$

The curves in Figure 3 are in pu and represent prices. As they are in pu, if we used the real average electricity tariff price as 1 pu, then we can have a reasonable indication of financial cost/ benefit. Here we use the average electricity tariff for consumers of 13p/kWh [10]. Below is the calculation for cost savings for the three price curves.

For the highest peak price (Worst case for the system), the maximum daily savings of the storage of the system is calculated by subtracting the night charging price from the peak price.

$$\begin{aligned} \text{Cost Savings} &= (\text{Real load}) \times (\text{Price at peak - Price at night}) \\ &= (\text{Real load}) \times (\text{Difference in real prices}) \\ &= 188.25\text{ kWh} \times (1.45 - 0.45)\text{pu} \times £0.13 \\ &= £25/\text{day} \end{aligned}$$

Therefore, the annual cost savings from peak shaving is £8932.

$$SPBP = \frac{\text{Total cost of the system}}{\text{Annual savings}}$$

$$= \frac{28238}{8932} \cong 3\text{ years}$$

Similar calculations provide the cost savings and simple payback period (SPBP) for the most likely price and the lowest peak price. The results are summarised in Table II.

Table II. Annual electricity cost savings & PBP

Scenario	Annual savings	Simple payback period (year)
Worst case	8932	3.16
Most likely case	6253	4.5
Best case	3037	9.3

The storage battery payback times for worst, most likely and best price scenarios, are 3.16, 4.5 and 9.3 years respectively. Therefore, if a true market existed, the planner would be able to predict that the investment would be paid off after three to nine years.

This has been worked out based on the price of electricity at a standard tariff of 13p/kWh. The price could increase over the years as would be expected with increasing fuel price. Therefore, if the battery's life time was longer, then there is a real potential for initiatives in community level battery storage. Furthermore, the cost of batteries should decrease as the technology improves. A standard car battery ought to be used to supply some of the load at peak periods.

VI. Discussion

In the UK there is no real-time retail market, and hence no real-time retail electricity pricing. A criteria has been developed to help developers and planners of local communities to understand the cost of intervention in order to evaluate where the load is when the prices are high. The SBP was suggested to be used as an indicator of electricity real time price.

To better capture the price fluctuations that can occur in real markets, this work took into consideration the diversification in prices the market might have by developing three price curves in Figure 3 using the quartiles of SBP versus national demand. Presenting the data in per unit value allows underlying characteristics of the data sets on different scales to be compared by bringing them to a common scale and makes the analysis easier.

The developed three curves have been used as a tool to evaluate the possibility of using storage batteries at community level as an example. PV cells or other embedded could also be studied in a similar way. The battery simple payback time has been estimated. We used the average electricity price as 1 pu. This can provide a reasonable indication of financial cost/benefit. While the payback period analysis does not take into consideration the time dependent value of money, nor the total accumulated cost or savings over the life of the system, the simple payback period can be applied to determine relative performance among alternatives. Economic calculations can be performed using the life cycle cost (LCC) where consideration of costs over the entire lifetime of the PV system (inflation, tax, and depreciation) can be made.

VII. Conclusion

The conclusions drawn are presented below.

- Presenting the data in per unit value allows underlying characteristics of the data sets to be compared.
- As no real time retail price exists in the UK, the System Buy Price (SBP) has been used as a measure of the real price based on per unit values. In order to better capture the price fluctuations that can occur in real markets, the three curves of Figure 10 have been developed using the quartiles of SBP versus demand.
- As an example of using the tool and system buy pricing, the possibility of using battery storage at community level has been evaluated and battery simple payback has been estimated. The methodology can be applied to other interventions for load shaving.
- It has been shown that battery storage at community level is feasible, provided a real time market or "near real time" market is established.
- The introduction of such an independent retail market at local level to enable electricity transactions between communities with embedded generation capabilities requires further research.

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