ECONOMICS BEHIND DYNAMIC PRICING BENEFITS IN SMART GRIDS

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ABSTRACT

This article shows how inverse demand curves for distribution systems can be built based on the aggregation of information obtained from Smart Grids. These curves provide information regarding demand elasticity, which can be used in the implementation of dynamic pricing schemes. Also, these demand curves are crucial for electricity market equilibrium determination. This article also shows the microeconomic analysis of the implementation of a dynamic pricing program. A study distribution system was modelled in PSS®SINCAL to show the proposed methodology and approach implementation.

INTRODUCTION

Smart Grid technology, specifically Advanced Metering Infrastructure (AMI) and Metering Data Management (MDM) systems, represents a great source of information about customers' behaviour and consumption patterns.

AMI systems generally utilize two-way communication to obtain meter reads, remotely disconnect/reconnect customers and alert utilities of other meter issues, thereby reducing operating costs and wear-and-tear on trucks and equipment. MDM systems facilitate the implementation of AMI, dynamic pricing, and energy conservation as well as the automation of utility distribution operations and maintenance activities. MDM systems serve as a recording system for all meter data, provide real-time access to the data and provide the pricing buckets for dynamic pricing programs. The MDM system also serves as the integration point between the AMI network and the utility's enterprise systems, ensuring the availability of meter data to the rest of the Smart Grid-ready functions.

Historically, utilities have set prices on a flat-rate basis. The flat-rate system, while simple to understand and communicate to customers, does invariably lead to overconsumption of energy during peak periods when the cost to supply the power is at its highest [1]. Numerous studies have, in recent years, documented the pitfalls associated with flat-rate systems, and quantified the benefits associated with more dynamic pricing that varies based on the time of day or cost of power [1] [2] [3] [4]. The flat rate system is based on traditional demand forecasting, which usually requires an enormous amount of information and time to provide accurate results, even so, most demand forecasts can be used only for planning and not for daily operation.

At present, demand curves can be built based on the aggregation of information obtained from Smart Grids. Demand curves are dynamic, they change throughout the day, week, month, etc, and time series analysis might be necessary to identify growth rates, trends and other disruptions. Demand curves provide very important pieces of information about consumers and price, for example, demand-price elasticity.

Dynamic pricing is one among several options for demand response programs which, in general, can be broadly separated into two categories: dispatchable, when demand is reduced according to instructions from a control centre; and non-dispatchable, when demand is reduced according to tariff structures that provide inducements to end-users to manage and "flatten" load shapes (sometimes referred to as "Price-Based Demand Response"). Dynamic price is increasingly being used as the inducement. Dynamic prices are rates that reflect time-varying electricity prices on a day-ahead, hour-ahead or real-time basis [1] [2] [4]. Dynamic pricing can be divided into:

- Time of Use (TOU) pricing: prices are pre-set at different levels for peak and off-peak periods.
- Real Time Pricing (RTP): prices fluctuate hourly to reflect wholesale market (spot or day ahead).
- Critical Peak Pricing (CPP): prices are increased substantially during system peak periods or during declared system emergencies, and are usually reduced slightly at other times.

Dynamic pricing is a more efficient mechanism to harvest demand response megawatts than programmatic, incentive mechanisms [5].

PROPOSED METHODOLOGY AND APPROACH

Information about consumption patterns of customers can be collected through AMI and aggregated and organized by MDM systems. Then, it can be analyzed for the development and implementation of dynamic pricing programs. This kind of research is commonly called customer behaviour studies [6] and is oriented, among other goals, to gather and analyze information on customers' response to different electricity rate levels (price-demand pairs in economics terminology).

As a result of customer behaviour studies, a dynamic pricing plan can be prepared to comply with technical constraints and requirements (for example, system demand of energy, limited generation resources, quality of service, secure system operation under contingencies, etc), and economic goals of utilities (business/financial/process goals) and society (economic welfare) as well. Dynamic pricing programs can actually be used to adjust energy price levels, to establish energy saving policies and to defer system investments, among other benefits [4] [7]. These plans can be revised and updated on a regular basis.

A dynamic pricing scheme will provide customers with real-time pricing information, which they receive through advanced metering devices with two-way communication capability, and which they can act upon [4] [8]. Also, internet web portals can provide this kind of information [3] [8]. End-user decisions on energy management can be manually implemented, and automatically as well, with the use of smart home appliances [3] [8] [9].

The information to develop and establish dynamic pricing schemes changes continuously while it is received and managed by MDM systems. This information can be automatically organized and analyzed to update dynamic pricing schemes based on pre-defined procedures. If this kind of intelligent decision-making system is not available, information can still be extracted from MDM systems to conduct or update external customer behaviour studies.

Once the data is extracted from MDM systems and is conveniently arranged, the first element that should be analyzed is the price elasticity of demand E_d which gives the percentage change in quantity demanded in response to a one percent change in price [10]:

$$E_d = \frac{\Delta Q_d \,/\, Q_d}{\Delta P / P} \tag{1}$$

In this paper, Q_d is the energy demand (MWh), and P is the electricity rate (US$/KWh). The price elasticity of demand can also be defined in terms of partial differential calculus:

$$E_{q,p} = \frac{\partial \log Q_d(P)}{\partial \log P} \tag{2}$$

The price elasticity of demand is negative by definition and sign is usually omitted. If it is less than 1, it is said demand is inelastic, while if it is greater than 1, it is said demand is elastic. Study of the elasticity of demand will help with the identification of those energy price intervals where energy saving policies based on dynamic pricing can be more or less effective. From (2), it is clear that elasticity may change along the demand curve.

Utility revenues are defined as energy demanded multiplied by the respective electricity rate, as follows [10]:

$$R = Q'_d \times P \tag{3}$$

Given P_1 and P_2 as two (2) electricity rate values, and $Q_d(P_1)$ and $Q_d(P_2)$ as their respective demanded energy at equilibrium, then:

$$R_1 = Q_d(P_1) \times P_1 \,,\; R_2 = Q_d(P_2) \times P_2 \tag{4}$$

If P_1 and P_2 are in a price range where demand is elastic and $P_1 > P_2$ then it is clear that $R_1 < R_2$.

When elasticity information is available, utilities can send adequate signals to customers, as part of a demand-response program [11] as shown in Figure 1.

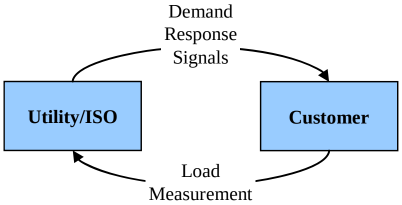

Figure 1 – Interactions with Demand Response Resources (Customers)

Also, demand-supply partial equilibrium can be studied to determine how the utility, energy sector or society benefits from electricity rates and dynamic pricing. The benefit can be studied from the point of view of utilities or customers, independently of the level of competition on the electricity market. Governments, groups of influence and/or other agents can regulate or influence electricity rates to increase the social welfare. They can do this directly, by imposing legislation to force rates to be low, or indirectly, by delivering better public services funded by incremental taxes paid by utilities when rates are high.

Partial equilibrium (Q^*, P^*) on a perfectly competitive market is reached when marginal cost MC, which is a function of energy demand Q, equals market price or electricity rate P, as indicated in the following expression:

$$MC(Q^*) = P^* \tag{5}$$

On monopolistic market, demanded energy at equilibrium (Q^*) is reached when marginal cost MC equals marginal revenues MR (derived from demand curve), while equilibrium price (P^*) is taken from demand curve D when demanded energy is (Q^*) [10]:

$$MR(Q^*) = MC(Q^*) \,,\; D(Q^*) = P^* \tag{6}$$

Other markets with intermediate levels of competition, e.g. oligopolistic markets, can also be studied based on information provided on price elasticity and demand curves.

STUDY CASE

The study case system used to show the proposed methodology and approach implementation is shown in Figure 2. In this figure the four main feeders are identified with different colours.

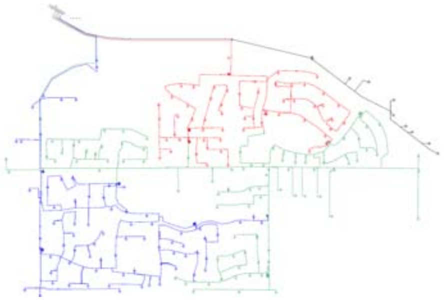

Figure 2 – Study Case System

This system was modelled in PSS®SINCAL, which allows the handling of periodic data (daily, monthly, etc) of loads, generator units, etc. The system and data considered are based on a real system and typical system behaviour.

Figure 3 shows how load information aggregation for each feeder can be modelled and accessed in PSS®SINCAL. Individual feeders can be studied separately, if necessary.

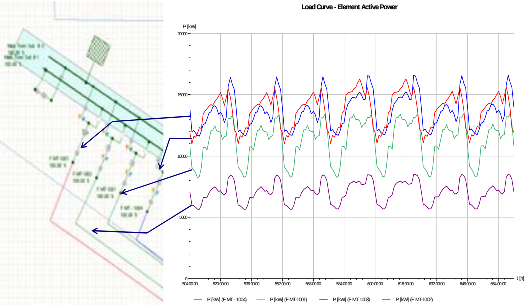

Figure 3 – Load Profile by Feeder

EXAMPLE OF METHODOLOGY IMPLEMENTATION AND RESULTS

For the study case, the implementation of a CPP program is desired for peak-shaving purpose. As mentioned above, a system's demand curve is dynamic and it always changes. Figure 4 shows 100 points corresponding to energy rate-demand pairs under a peak load case. Just as reference, this peak load occurs on 7:00 p.m. weekdays, during spring and summer seasons.

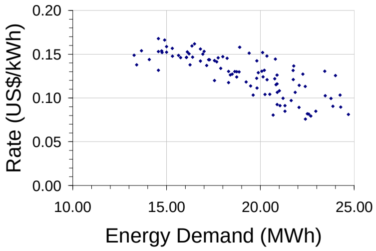

Figure 4 – Energy Rate – Demand System Data

As proposed, the first thing we calculated was the elasticity of demand for our system. Figure 5 shows graphically the elasticity calculation based on (2), which yields a result of 0.58. That is, the collected set of data shows that demand is inelastic.

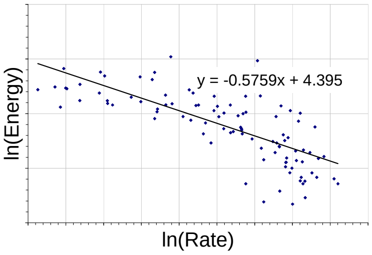

Figure 5 – Demand Elasticity Calculation over Entire Rate Range

Since the demand is inelastic, CPP program implementation would increase the utility's revenues, independently of rate level. However, Figure 6 shows the same graphical result for the elasticity calculation, when the electricity rate is below 0.12 US$/kWh. As observed, the demand in this interval is highly inelastic (0.30), as expected.

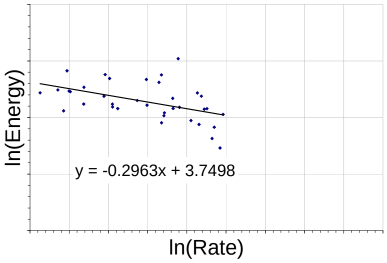

Figure 6 – Demand Elasticity Calculation below 0.12 US$/kWh

However, Figure 7 shows the elasticity calculation when the electricity rate is above 0.12 US$/kWh. As can be seen, demand in this interval is elastic (1.10), which indicates that a CPP program would decrease the utility's revenues when price is increased above 0.12 US$/kWh (further analysis shows this value might be approximately 0.126 US$/kWh).

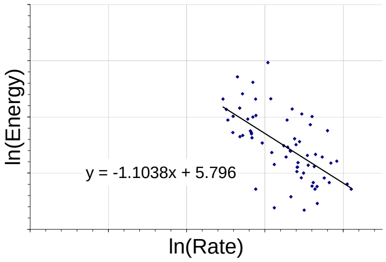

Figure 7 – Demand Elasticity Calculation above 0.12 US$/kWh

Information obtained from demand elasticity calculations can also be used for the construction of a detailed demand curve. In general, demand curves are built assuming unitary elasticity but, since there is a lot of information available from the AMI, it is easy to build/update a more detailed, and accurate, demand curve.

Figure 8 shows a two-section demand curve prepared with the demand elasticity information previously found. The intersection point is 0.126 US$/kWh, and it can be observed that the demand is inelastic when energy price is below 0.126 US$/kWh and elastic above that value.

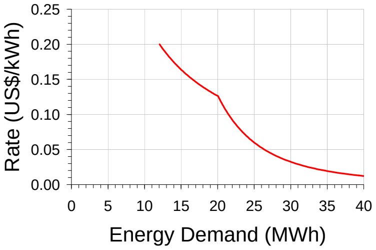

Figure 8 – Demand Curve on System Peak-Load

Considering this demand curve, a wide set of results for partial economic equilibrium (electricity rates and quantities) and recommendations can be issued depending on market structure and level of competition. Industry or utility's average and marginal costs curves should be used in the analysis to properly calculate equilibrium conditions. Here, typical curves were used to show and analyze results.

Figure 9 shows results for both perfectly competitive and monopolistic market conditions. Equilibrium points are identified as A, B and C.

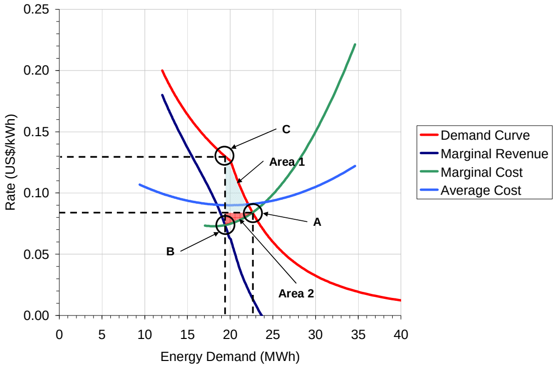

Figure 9 – System Partial Equilibrium Conditions

Point A indicates that equilibrium in a perfectly competitive market corresponds to 22.39 MWh and 0.083 US$/kWh. Points B and C describe the equilibrium for a monopolistic market. Point B indicates that MWh at equilibrium is 19.23 MWh and point C shows that the price at equilibrium is 0.131 US$/kWh.

Two additional results can be observed:

- Comparing the equilibrium points for perfectly competitive and monopolistic markets, and using equation (3), we found the utility revenues on a perfectly competitive market would be 1,858 US$ for every peak load hour, while they would be 2,519 US$ on the monopolistic market.
- Area 1 (blue) and Area 2 (red) in Figure 9 represent losses on consumer and producer surplus, respectively, when there is a monopolistic market instead of a perfectly competitive market. The sum of both areas represents the total welfare loss to the society.

CONCLUDING REMARKS

Demand curves for distribution systems can now be built based on the aggregation of information obtained from Smart Grids. These curves provide information regarding demand elasticity, which can be used in the implementation of dynamic pricing schemes. Also, these demand curves are crucial for electricity market equilibrium determination.

Governments, ISOs, and/or regulatory agents can influence electricity rates by implementing dynamic pricing regulations to increase the level of market competition and/or to reach price-demand equilibrium closer to perfectly competitive solutions and therefore reduce social welfare loss. Also, utilities can use dynamic pricing to increase revenues when electricity prices are in ranges of inelastic demand and/or for peak-saving, energy conservation, etc.

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BIOGRAPHIES

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