Impact of Dynamic Pricing in Power System

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Abstract— This paper discusses dynamic pricing, it's benefits, various models used. A detailed sample of California Independent System Operators (ISO) is discussed as a reference to validate the advantages of dynamic pricing concept. It is found that the off-peak prices of all consumer segments are approximately in proportion to their willingness-to pay, but the peak prices are relevant to their willingness-to-pay ratios as well as their willingness-to-pay. The concept of dynamic pricing is proved to be helping in energy management as well as better possible energy utilization.

Keywords- Dynamic pricing, deregulated system, ISO, power system.

I. INTRODUCTION

The term dynamic pricing is used to broadly encompass tariff structures that have one or more elements which are calculated and posted close to the time of applicability. This definition embraces several concepts developed in the pricing literature such as real time (spot) pricing, responsive pricing, taste preference pricing," flexible pricing", and certain forms of "incentive rates", and "economic development rates". The practical motivation for developing dynamic pricing options can perhaps be traced to the unprecedented cost pressures, competitive challenges, and a highly uncertain planning and operating environment that many utilities in their mission to provide an adequate supply of power, reliably, economically. A central component of any strategy for successfully coping with such conditions is flexibility; the ability to quickly respond and adapt to changing circumstances, and market conditions. In the area of resource planning flexibility means developing a resource strategy centred around a portfolio of flexible resource options that can cope with different futures, rather than a resource plan of unit additions. In the area of tariffs and demand management, flexibility means among other things an ability to convey the right signals to consumers that will trigger the desired response. It depicts some typical demand management objectives that utilities may face: peak shaving, valley filling, load shifting, strategic conservation, strategic load growth, and flexible reliability [1].

Many fear dynamic pricing because of the convenience of fixed pricing and the fear of commodity-based pricing. However, it's important to remember that fixed pricing has multiple disadvantages. Economists know that uniform prices cut revenue. Some customers would have paid more than the posted price. Others would have paid less, but still enough to generate a profit and increase sales velocity.

Fixed pricing also raises costs. It takes time and research to determine optimum pricing, especially if a product is new to the marketplace. Pricing based on cost-plus or target models usually doesn't capture process costs. Fixed pricing cannot predict depreciation or accurately incorporate the effect of changing demand. The pricing may be right for a target market, but inappropriate for a customer or channel. Pricing also may not reflect market share, revenue or profit goals adequately.

By contrast, dynamic pricing offers several advantages. By pricing products based on market demand, companies have the potential to enjoy greater profitability on each item. Just because prices can move down with dynamic pricing doesn't mean profits also decline. In this paper type of dynamic pricing used, time of use pricing and load adaptive pricing has been discussed. Poolco model, bilateral model and hybrid model are discussed.

II. BENEFITS OF DYNAMIC PRICING

Reducing peak capacity creates environmental value by reducing required resource use to meet our electricity needs. Thus, dynamic pricing would lead to both environmental benefits and reduced production costs.

1] Ability to offer differentiated "green power" products. A Smart Grid reduces the information costs to retailers and to consumers of offering and choosing green power products. Thus, consumers can have access to retail products that better match their values.

2] Renewable resource interconnection. A Smart Grid facilitates the interconnection of renewable resources and distributed storage that can mitigate some of the intermittency problems associated with generation from renewable resources.

3] Empowering consumers to make "smarter" energy choices. Dynamic pricing is one of the most valuable direct consumer benefits enabled by a Smart Grid. Dynamic pricing makes the value and cost of their energy use transparent to consumers, and it enables consumers to see when cost exceeds value. Dynamic pricing particularly benefits consumers whose consumption is flexible; however, it does not harm the inflexible customer because it reduces the quantity of peak power demanded, thereby reducing average prices paid by inflexible customers. When dynamic pricing reduces peak demand, it also reduces transmission and distribution losses, and associated operating costs.

The combination of a Smart Grid with dynamic pricing, plus product offerings such as renewable (“green”) power, creates the conditions that can finally deliver on the long-awaited promise of energy efficiency, as well as reduced operating costs:

Information transparency and dynamic pricing optimize fuel use and can reduce emissions. The connection between a Smart Grid and dynamic pricing can also create environmental benefits. Dynamic pricing can also contribute to improving environmental quality by enabling customers to shift demand away from peak periods with high prices or by reducing their overall use. This economizing incentive is the source of the conservation benefits of market-based pricing. Conservation brought on by dynamic pricing reduces energy costs and increases energy efficiency. This conservation typically takes two forms -- curtailing consumption (reducing overall use) and shifting use to non-peak hours. Environmental benefits result from using more efficient generators that operate closer to conditions for which they were designed, and reduced transmission and distribution losses[2].

Reduction in long-term investment and higher load factors mean less resource use. The shift away from peak consumption reduces the required investment in generation capacity to satisfy peak period demand. Customers shifting and reducing demand would lead to less required investment and new plant and wires construction, which would also reduce long-run average cost by reducing capital costs. Furthermore, many of those assets are used during only a few peak hours each year, which means that building to meet peak demand requires using many physical and financial resources that sit idle much of the year. In addition to the cost savings from reducing the amount of idle peak capacity, red capture their imaginations. In this case, technological innovation and dynamic retail electricity pricing are at the heart of decentralized coordination in the electric power network proving the system’s load factor via Smart Grid facilitated dynamic pricing and other Smart Grid strategies reduces required investment in distribution infrastructure. Moreover, communication technologies have become less expensive over time, while the costs of planning, siting, and constructing physical infrastructure have increased dramatically. Thus, investments in Smart Grid technologies can achieve many of the same reliability and resource adequacy objectives that traditional physical investments are intended to achieve, and they increasingly do so at lower relative cost.

Digital technologies are increasingly available that reduce the cost of sending prices to people and their devices. Dynamic pricing and the digital technology that enables communication of price information are symbiotic. Dynamic pricing without enabling technology is meaningless; technology without economic signals to which to respond is extremely limited in its ability to coordinate buyers and sellers in a way that optimizes network quality and resource use. (The exception to this claim is a time-of-use contract where the rate structure is known in advance. However, even on such a simple dynamic pricing contract, devices that allow customers to see their consumption and expenditure in real time instead of waiting for their bill can change behavior.

III. TYPES OF DYNAMIC PRICING

A. Time of Use Pricing

Time-of-use (TOU) tariffs have been widely used in electricity supply industry in many countries for about a decade. Pricing approaches in use for these tariffs are mostly based on electricity supply cost of utilities and seldom take the consumer responsiveness to the tariffs into consideration. With the restructuring of the electricity supply industry, responsibility for the power systems is passing from public to private hands and power utilities trend to be run as a profit maximizing business. Moreover at the beginning of the privatization process in many countries, electricity supply cost increased and therefore it becomes important to give consideration to both the cost of providing electricity (production side) and the worth of using electricity (consumption side) in electricity pricing.

The time-of use price is the method that adopting different price for different time of using electricity power, and it provides a more logical strategy under nowadays condition. The electricity companies confirm the time of power peak and power valley, then adopt higher price during the peak time and lower price during the valley time in order to inspirit the consumers adjust their policy on using electricity power. The strategy of time-of-use price can move peak and fill valley of power, abate the complexion of lack of power and raise the society benefit of electricity power. Nowadays electricity price method is based on the supposition that electricity price alters with the demand of power continuously and linearly, and any change of price should lead the adjusting of power demand. Actually the consumers are not always sensitive on the signal of price. The response is rapidly in some area of price and slowly in some other area, which is to say that the real response curve is not a linear curve. So it is must that he imports the analysis of the conception of consumer’s load-move-cost and the theory of demand-price elasticity. Under power market circumstance, if reasonable power price to consumers is determined, consumers can be motivated to take part in innovation of power industry and to adjust modes of power consumption. Thus the objective of making load in a stable level and improving efficiency and stability of power systems can be obtained. As one of power prices to consumers, TOU power is widely applied in many countries. Moreover, it is one of important approaches of DSM and can shift load and reduce cost of consumers' power purchase. However, in TOU power price, power price of flat time period is the base and extraordinary essential. So it is very important to determine a reasonable power price of flat time period. Power price of flat load is determined by average annual power price. Although average annual power price can reflect cost of power generation and level of power using, consumers' load will change after TOU power price is carried out. So it is quite unreasonable to have the annual average power price as power price of flat time period and it is possible that consumers will not accept it [3].

According to problems in existing research, a new determination approach of power price of flat time period is studied. Determination of TOU power price is studied based on this determination method of power price of flat time period.

B. Load Adaptive Pricing

The electric utilities in the United States face the peak_load problem. This problem arises because traditionally, the utilities are required to supply their customers instantaneously with whatever amount of power they wish to purchase at whatever time they desire, with pre-specified prices which are independent of the time of consumption. In exercising their preferences, customers have evolved electric power use patterns which vary not only periodically over the day, week, and year also depend significantly on some random elements such as weather, for example: with few exceptions, all system peaks in the U.S. are caused principally by air conditioning (summer peak) and space heating (winter peak). Thus the utility must meet the demand due to a fluctuating load instantaneously. Incurring idle capacity cost, while capacity expansions require a fairly long gestation period. Most utilities use additional peaking generators (which have low capital cost to offset their idle time, but high running cost) to satisfy the excess loads during the short duration peak periods. The unit cost of electricity production during the peak period is thus higher than that in the off-peak periods [4].

In recent years the high cost of electricity production, especially during peaks, and the concern for future energy resources have led utilities and regulatory agencies to move to policies that encourage conservation and more efficient use of production capacity. Toward these ends, the utility may either negotiate for direct control of some of the customer loads as with industrial users and/or design some forms of incentive rate structures which may be time-dependent, **as** an indirect way to influence some of the customer loads. The latter is a variable pricing scheme for electricity consumption. The peak load pricing scheme is a familiar example. In peak load pricing. a cycle (usually a day, a week, or a year) is divided into several period (a period may range from several hours to seasons). The price of electricity in each period reflects the estimated production costs for that period, and is required to be announced prior to the beginning of operation. From a game theoretic point of view, the utility company plays the role of a leader. and customers play roles of followers in the variable pricing framework. For a given pricing strategy, each customer determines his optimal consumption strategy which is reflected in the demand curve. The utility company foresees these reactions and decides the optimal pricing strategy. Thus. pricing problems are actually Stackelberg games. However, in peak load pricing, the utility company is not a “powerful” leader. On the other hand it needs to announce all the time-dependent prices prior to the beginning of operation. After which it is expected to persist without change for many cycles. (In the parlance of control theory, this is called open-loop control.) Price cannot respond to “real-time” loads caused by random events such as weather and outage under this setup. On the other hand the utility company bears almost all the burden concerning system operation, planning, integrity, and environmental impact. Customers are, in general, not supplied with any system demand/supply information. It will not be very effective for the utility company to induce a particular behavior on the part of customers without providing them with some kind of demand/supply information. In recognizing the limit of the peak load pricing formulation and the persuasive breakthrough of microelectronic technology, we foresee a new pricing philosophy emerging in which supply and demand respond to each other through prices and consumptions. We call it load adaptive pricing. In load adaptive pricing, the utility company does not announce prices for all cycles prior to the beginning of operation. On the contrary, it announces the strategy of pricing, i.e., the rules for how the prices will be determined. The exact price for each period is calculated at the beginning of that period according to the announced strategy and based on previous consumptions and realizations of random events. Supply and demand thus respond to each other through prices and consumption, and the prices are made to adapt to the load.

IV. RECONSTRUCTING MODELS

A. Poolco Model

A Poolco is defined as a centralized marketplace that clears the market for buyers and sellers where electric power sellers/buyers submit bids and prices into the pool for the amounts of energy that they are willing to sell/buy. The ISO or similar entities (e.g. PX) will forecast the demand for the following day and receive bids that will satisfy the demand at the lowest cost and prices for electricity on the basis of the most expensive generator in operation (marginal generator). On the other hand, in the second model, bilateral trades are negotiable and terms and conditions of contracts are set by traders without interference with system operators.

The Poolco model is comprised of competitive power providers as obligatory members of an independently owned regional power pool, vertically integrated distribution companies, vertically integrated transmission companies and a single and separate entity responsible for: establishing bidding procedures, scheduling and dispatching generation resources, acquiring necessary ancillary services to assure system reliability, administering the settlements process and ensuring non-discriminatory access to the transmission grid. Poolco does not own any generation or transmission components and centrally dispatches all generating units within the service jurisdiction of the pool. Poolco controls the maintenance of transmission grid and encourages an efficient operation by assessing non-discriminatory fees to generators and distributors to cover its operating expenses.

In a Poolco, sellers and buyers submit their bids to inject power into and out of the pool. Sellers compete for the right to inject power into the grid, not for specific customers. If a power provider bids too high, it may not be able to sell power. On the other hand, buyers compete for buying power and if their bids are too low, they may not be getting any power. In this market, low cost generators would essentially be rewarded. Power pools would implement the economic dispatch and produce a single (spot) price for electricity, giving participants a clear signal for consumption and investment decisions. Winning bidders are paid i. e spot price that is equal to the highest bid of the winner. Since the spot price may exceed the actual running of selected bidders, bidders are encouraged to expand their market share which will force high cost generators to exit the market. Market dynamics will drive the spot price a competitive level that is equal to the marginal cost of most efficient firms. Figures 1and 2 show the idea of price signals and their impact on consumption behavior. Let’s assume that an Industrial Customer (Indus consumption pattern in a vertically integrated electric industry, in a certain day, would look like that shown in Figure l. In this figure, the price of electricity in C/KW is fixed, and the Industco has no incentives to change its consumption pattern. While in a competition-based market, when the lndustco receives a real time price signal, it could change its consumption pattern in response to the price (See Figure 2. In Figure 2, the Industco reduces its usage at times high prices. As the price jumps from 6C/kWh 5 a.m. to 8C/kWh 9 a.m. the Industco starts decreasing its consumption. As the price continues to increase from 8C/KWh at 9 a.m. to 16C/KWh at 6 p.m. the Industco continues decreasing its consumption. When the price decreases after 6 p.m. the Industco increases its usage of electricity. The consumption response to price could reduce the need for maintaining expensive generating facilities that are rarely used, and enhance the real-time reliability by not letting the consumption to exceed supply [5].

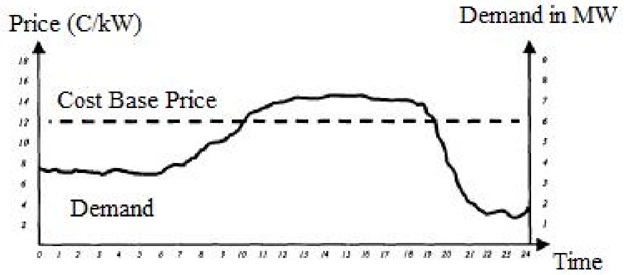

Fig-1 Behaviour of Demand in a Vertical Integrated Power Market

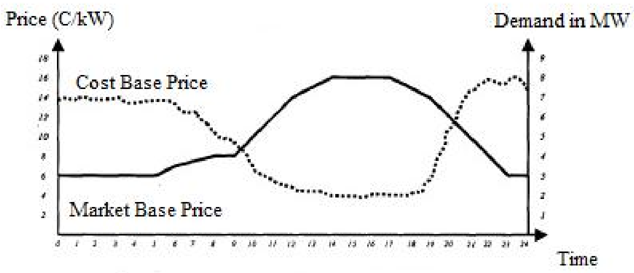

Fig-2 Responce of a Demand to Price Signals

B. Bilateral Model

The second model, which is based on bilateral contracts, may also be referred to as Direct Access Model. As the name implies, customers are free to contract directly (bilaterally) with power generating companies. By establishing an appropriate access and pricing standards, customers transfer purchased power as restricted to the power transmission and distribution over utility wires. Under this model, a single centrally dispatched regional power pool is not obligatory as under the first model. The Bilateral Contract model has two main characteristics that would distinguish it from the Pool Co model. These two characteristics are: The ISO's role is more limited; and buyers and sellers could negotiate directly in the marketplace. In this model, small customers' aggregation is essential to ensure that they would benefit from competition. This model permits direct contracts between customers and generators without entering into pooling arrangements. By establishing non-discriminatory access and pricing rules for transmission and distribution systems, direct sales of power over a utility's transmission and distribution systems are guaranteed. Wholesale suppliers would pay transmission charges to a transmission company to acquire access to the transmission grid and pays similar charges to a distribution company to acquire access to the local distribution grid. In this model, a distribution company may function as an aggregator for a large number of retail customers in supplying a long-term capacity. Also, the generation portion of a former integrated utility may function as a supplier or other independent generating companies, and transmission system would serve as a common carrier to contracted parties that would permit mutual benefits and customer's choice. Any two contracted parties would agree on contract terms such as price, quantity and locations, and generation providers would inform the ISO on how its hourly generators would be dispatched. The ISO would make sure that sufficient resources are available to finalize the transactions and maintain the system reliability. To maintain reliability in real time, the suppliers would supply incremental and detrimental energy bids to prevent transmission flow congestion. Here, a cost-based transmission pricing would provide a non-discriminatory access to transmission and distribution systems. As long as the power network is not constrained, this pricing scheme is perfect, but as constraints arise, pricing procedures would be necessary. To predict possible constraints, load flow models are used by considering various generating units and transmission lines. In addition to predicting constraints, these models could determine power flow contributions of individual generators to constrained flows as well as transfer capabilities of transmission and distribution systems. The users who value scarce facilities the most are those who acquire it, where us is cost-based and would motivate users to value it high through their bids. System users who lose in the bidding process would have to find other power providers to supply their loads or modify their load profiles

C. Hybrid Model

The hybrid model combines various features of the previous two models. The hybrid model differs from the Poolco model as utilizing the PX is not obligatory and customers are allowed to sign bilateral contracts and choose suppliers from the pool. The pool would serve all participants (buyers and sellers) who choose not to sign bilateral contracts. The California model is an example of the hybrid model. This structure has advantages over a mandatory pool as it provides end-users with the maximum flexibility to purchase from either the pool or directly from suppliers. A customer who would choose a PX option with CFDs could acquire the economic equivalent of bilateral contracts.

As in the PoolCo case, if generators opt to compete through the pool, they would submit competitive bids to the PX. All bilateral contracts would be scheduled to meet their loads unless they would constrain transmission lines. Loads not provided bilaterally would be supplied by an economic dispatch of generating units through bids in the pool. The existence of the pool can efficiently identify individual customer's energy requirements and simplify the balancing process of energy supply. The hybrid model would enable market participants to choose between the two options based on provided prices and services [6].

The hybrid model is very costly to set up because of separate entities required for operating the PX and the transmission system.

V. ELECTRIC UTILITY MARKETS IN UNITED STATES CALIFORNIA MARKETS

California was the first state in the United States to offer large-scale retail choices and a competitive generation market. The California ISO was created in 1996, and has the second largest control area in the U.S. and the fifth largest in the world. The California ISO is a non-profit association which performs functions similar to those of a tight power pool. The ISO uses a computerized centre to send commands through long and high-voltage lines that deliver electricity in California and between Mexico and neighboring states. The main players that compose the California market structure include the ISO (provides grid dispatch and transmission access services), and Scheduling Coordinators (SCs which submit balanced schedules to the ISO), Power Exchange (PX which creates a spot market for electricity, schedules and settles trades in its markets), Utility Distribution Companies(UDCs which distribute or deliver electricity), Retail Marketers that include Electricity Service Providers (ESPs which provide competitive energy services), Customers (which acquire and consumer electricity)and Generators (generates electric power)

A PX considered as an SC but with limited capabilities, as discussed in this chapter. In the California market, major Investor-Owned Utilities (IOUs) must bid their generation through the PX (obligatory). The transmission grid is owned by IOUs but operated by the ISO. This proposal has three markets, which are Day-Ahead Market, Hour-Ahead Market and Real-time (Balancing) Market. In these markets, energy, supplementary energy and ancillary services are traded. Ancillary services include spinning and non-spinning reserves, replacement reserves, regulation, and reactive power and black start capability [7-9]. Interactions among different entities in California are shown in Figure3

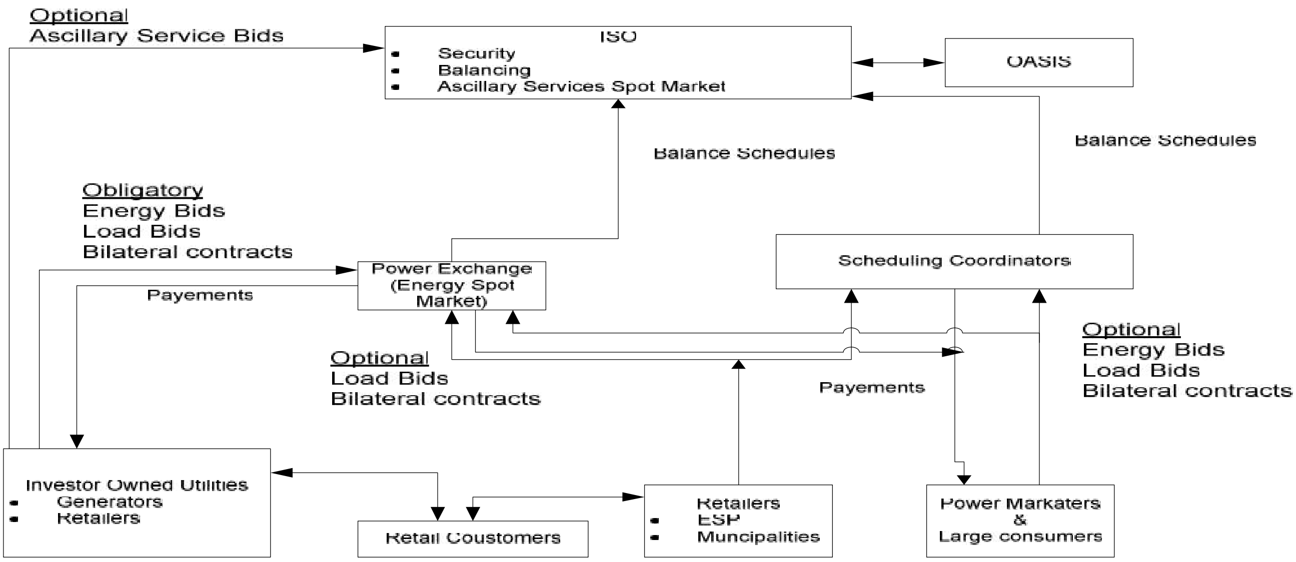

Fig-3 Interaction between ISO and other entities.

1] INDEPENDENT SYSTEM OPERATOR: The primary component that is considered as the nerve of the California market is the ISO. The ISO, concerned with the reliability of the transmission grid, balances the operation of transmission grid in real-time. The real-time market is operated by the ISO which uses ancillary services bids and supplemental energy bids submitted through PX and SCs. The ISO also determines the real-time market price after the fac .1.2 Generation. The second component is the generation sector. Non-investor-owned and independent power producers2 (or generating companies) could either bid their power into the PX or schedule it through another SC. Generating companies could bid ancillary services through the PX or another SC into the ISO, and as stated in this model, are obligated to respond to instructions issued by the ISO and SCs.

2] POWER EXCHANGE: The second component is the PX . The PX represents the energy spot market where day-ahead and hour-ahead market clearing prices are determined. The PX is a non-profit corporation that is open to all suppliers, provides an efficient and competitive auction and facilitates short-term pool electricity transactions. The PX performs competitive trading in the forward day ahead and hour-ahead markets (auctions). In these auctions, participants of the PX submit demand and generation bids based on prices and

quantities, and the PX determines the MCP at which energy is traded, as dt (ex-post price) based on actual metered data. As

an SC, the PX submits balanced demand and supply schedules for successful bidders to the ISO, and performs settlement4 functions with the ISO as well as the PX participants such as UDCs, marketers and aggregators (non-utility retailers) and other SCs. In addition to these functions, the PX submits ancillary service bids to the ISO for maintaining the system reliability, adjustment bids (i.e., Dec/inc bids are used to relieve or eliminate congestion on transmission grid) and supplemental energy bids, which are used by the ISO to match loads and resources on a real-time basis.

3] SCHEDULING CORDINATOR: The third component is the group of SCs. The concept of SC is seen as adding a new dimension to competition in power markets by arranging trading between generators and customers. SC plays as intermediary between the ISO, retailers and customers. Each SC submits balanced schedules and provides settlement ready data to the ISO. Each SC maintains a year-round, 24-hour scheduling centre and provides non-emergency operating instructions to generators and retailers. Each SC provides the ISO with its customers' demand, supply schedule and transmission uses, and the ISO runs the information thorough a computer program to check for transmission congestions. If no congestion exists, the ISO will send an approval signal to the SC, otherwise, the SC will be advised to sell, buy or trade power to resolve the situation. In this process, the ISO may provide suggested alternatives to the SC for removing the congestion [10-12].

4] UDCs, RETAILORS & CUSTOMERS: The fourth component is the group of UDCs such as PG&E, SCE and SDG&E which provide distribution services to all electric customers and retailers within their service territories. Distribution services provided by UDCs are composed of metering of delivered energy and billing. Billing would account for consumed electricity and the use of transmission and distribution systems. When UDCs purchase bulk power for their customers, it should be obtained from the PX (the only option). In addition, UDCs may offer bundled energy tariffs to retailers in their territories. Bundled tariffs include meter reading and usage measurement services to other energy service providers 2.1.6 Day-Ahead and Hour-Ahead Markets. As mentioned before, the PX manages day-ahead and hour-ahead markets. In the day-ahead market, participants would bid supply and demand for the next day's 24 hours. This market starts at 6:00 a.m. and closes at 1:00 p.m. of the day ahead of the trading day. When the market closes, the ISO announces the final day-ahead schedules. In this market, a participant may trade and schedule for the next-day delivery, each trade would be subject to mutual payment agreements between the PX and its market participants, and settlements would be based on schedules provided within three days after each trading day. Once the participants submit bids to the PX, the PX verifies them by ensuring that the content of a bid, such as the bid format, complies with the PX requirements. For verified bids, the PX determines MCP based on participants' supply/demand bids for each hour of the 24-hour scheduling day, as shown in Figure 1.7. Participants' bids, initially submitted into the day-ahead market auction, are considered as portfolio bids, i.e., will not be referred to any particular unit or physical scheduling planet. The portfolio bids accepted by the PX will then be split into generation unit schedules and submitted to the ISO along with adjustment bids and ancillary service bids. Adjustment bids are used for congestion considerations. After this stage and based on all unit-specific supply bids and location-specific demand bids, the ISO determines whether there are any transmission congestions, and in the case of congestion, the ISO uses adjustment bids to submit an adjusted schedule to SCs (including PX). This process would create adjusted schedules and transmission usage, and the PX and other SCs either revise their schedules or accept the adjusted schedules and any charges calculated by the ISO. The schedules are then passed on to the ISO as final schedules. In the hour-ahead market, participants perform a similar bidding process as the day-ahead market, where the hour-ahead market begins two hours before the hour of operation. This market provides a means for participants to buy and sell so as to adjust their day-ahead commitments based on information closer to the transaction hour schedules for minimizing real-time imbalances. In this market, bids are unit specific and MCP is determined the same way as the day-ahead market. Once the market is closed, the PX would declare the price and traded quantities to participants.

VI. CONCLUSION

In this paper it is concluded that dynamic pricing in power system is more beneficial than the pricing based on economic aspects only. The off-peak pricing of all the consumer sectors are proportional to their shortage cost. The peak pricing are dependent on their shortage cost ratio as well as their shortage cost. California ISO model has been used for reference, but this model can be used in developing countries like India also. This will help in better management of energy and optimum utilization with clean environment.

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