42 Electricity Economics and Trading

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42.1 Introduction

Like any commodity or good, electrical energy can be bought and sold in an established market place. Hence buying and selling infrastructures are required to enable quantities and prices to be publicised and contracts negotiated between various groups or individuals. The difference between electrical energy and other commodities is the delivery system—rather than delivering by some form of road, rail, air or sea transport, once generated, electricity can only be delivered by wires over a transmission and distribution (T&D) system (see Chapter 39 for details). For such a system to function, at all times the energy input must be equal to the energy taken out plus the system losses (10% or so). This is an added complication for which the consumer has to pay extra to a system operator as well as a charge to the T&D asset owners for use of the system (UoS). In many countries the T&D asset owner is also the system operator, but this need not be so (compare the transporter as a separate entity to the manufacturer, retailer or road owner). Consequently the economics of electricity supply has not only to include the cost of providing a primary fuel (e.g. for gas, coal or oil fired power stations) or even for the provision of renewable energy production (wind generators, solar cells, hydropower, etc.) it must also cover the cost of delivery over a reliable and secure network, right down to each consumer's supply terminals. There are many components to electricity supply chain economics which will be identified in this chapter, finishing with processes for trading in electrical energy markets.

It should be noted that in many developing countries the production and delivery of electricity is still centrally controlled by the government through a state run industry where planning, operation and prices are organised according to the economic and social welfare priorities of the legislature. Until the 1980s this form of electricity supply industry (ESI) control was common in Europe, S. America and Japan but since then many governments have realised that to obtain investment from the financial markets to develop and expand the ESI some 'unbundling' and 'privatisation' of the businesses bound up with electricity production and supply could be beneficial in reducing prices for the consumer through competition and kick-starting new kinds of economic activity. As a result, deregulation and restructuring of the ESI is taking off in many countries where separate utilities have been run as businesses with private investors for many years, but subject to government or state imposed regulation.

42.2 Summary of electricity pricing principles

42.2.1 Economic efficiency

It is obvious that the price of any commodity in a 'free' market will determine the purchase and use of that commodity. With electrical energy, since storage by the consumer is prohibitively expensive, the price per kWh is important but so is the time of day that it occurs. Over a 24 hour period, electricity is usually priced in one hour or half hour 'slots' for prescribed or transacted amounts delineated in kWh. If this amount is exceeded at the end of the slot, a penalty price could be charged for the excess. To calculate the resulting bill the actual energy taken over the time slot must be metered in quantity and time; this requires a modern electronic meter which can be interrogated for all the slots since the last bill was calculated. Such a meter, preferably with a 2-way communication link to the reading and billing agency, is 5 to 6 times the cost of a simple kWh meter as fitted in residential and small business premises. Consequently, time of day pricing is normally only available where the metering costs are justified such as for customers with annual energy bills of £1000 ($1500) or more. Any customer wishing to keep control of business running costs will no doubt be influenced by the time-of-day energy price and adjust energy use accordingly. As an alternative, the limitation of energy use may be delegated to the supplier for a negotiated reduction in tariff, e.g. off-peak night storage heating tariff. The electricity generator will be charging a price for energy to cover the cost of production plus overheads and profit but over a period of time the customer will adjust requirements to minimise total costs, so in the absence of other factors, a balance between generation and consumption will be achieved. This is called a *Pareto* balance named after the 19th century economist, Alfredo Pareto. It is also one definition of *economic efficiency* as sought after by economists with a free market.

Unfortunately, although the market may be efficient it does not follow that everyone using the market is getting good value for money. Some participants may be constrained in their ability to offer lower prices because of their geographical position in respect of the delivery of their goods or alternatively consumers may be paying more for their energy than if they installed and ran their own generator (e.g. a CHP scheme) provided they could find the capital to purchase it. *Social welfare* is an attempt to measure the benefits of having an infrastructure in place which maximises the sum of the monetary benefits accruing to every individual or group (producers and consumers) in the country or state, including any tangible but useful benefits to which a monetary value can be given. A good measure of useful benefits is the willingness to pay, thereby suggesting that the optimal alternatives or *choice* for both parties as brought about by *competition* is desirable. It is at this stage that the government, state or regulator may step in to limit choice so that some societal group (e.g. the poor) is not disadvantaged. This can be done by *subsidy* from government or by *price capping* by a regulator, just two among many possibilities.

42.2.2 Marginal pricing and risk

Any commodity sold in the market place will become dearer as its availability diminishes. Electrical energy is no exception because its price per kWh for a particular period will rise as generators contract to produce more and more energy, starting with the cheapest plant until the most expensive plant is contracted during some periods. If some production capability is not contracted over, say, a season, it can be mothballed or scrapped. Consequently, at any particular time slot not only can the price per kWh available be recorded but also its rate-of-change with total demand. This rate-of-change is called *short-run marginal cost* (SRMC) and indicates the cost of supplying the next kWh of energy. It can be applied to a single generator, a portfolio of generators or to a whole integrated system. In the latter case it is known as *system marginal price* (SMP) or *system lamda* recognising that it is derived from equalising the marginal costs of all part loaded generators by differential calculus. (Note: in a centrally controlled and integrated network such plant would be loaded by the system operator in ascending order of notified or bid prices—the so-called *economic dispatch*.)

In practice the SRMC, if charged, although more than the average cost of generation, will not bring in sufficient revenue to cover the repayments on the invested or asset cost to enable producers to survive and make a reasonable profit. When these necessary repayment costs are included in the price per kWh, they are called *long run marginal costs* (LRMC). If sufficient revenues are to be made to include LRMC, economic theory requires that over several years SRMC and LRMC should be equal for profit maximisation. However, the usual case is that SRMC is less than LRMC requiring that the producer or supplier must charge a 'supplement' to cover the capital repayment cost of installed plant and any new plant—this supplement is known as *revenue reconciliation*. In market trading it is expected that the seller will include a *mark-up* in the negotiated price to enable the business to continue. The mark-up is a matter of judgement depending upon competition in the market and is part of the *risk taking* strategy adopted by the business. There is a wealth of economic literature and many useful theories such as Ramsey pricing, inverse elasticity rule, benefit maximisation etc. which businesses indulging in markets should take on board. (see Hunt & Shuttleworth, 1996, Schweppe *et al.*, 1989).

42.2.3 Delivery charging

With physical commodities such as grain, coal, packaged goods etc. a haulier or transporter is engaged at a contract price to carry out delivery to the customer. Who pays for the delivery is a matter for the contract to specify. With electrical energy there are several complications to take into account, the most important being the *instantaneous* nature of electricity and the need for the existence of a continuous wire path between generators and consumers. A further complication is that as the power system network (at least as far as transmission is involved) is a *meshed* system there is no defined path between a producer and a consumer. Consequently, any delivery charge (known as *use-of-system* charge) in all fairness must depend upon some measure of quantity, based on the provision of installed plant and circuits with adequate capacity and the 'wear & tear' on the system due to the flow of power through the wires. The only reason for system equipment, including overhead lines, cables and transformers, to deteriorate and require maintenance or replacement is that the power flow involves some heating due to losses, the raised temperature thereby causing faster deterioration of insulation than if no heating occurred. Over the power system as a whole, the owners and operators require to recover their costs in an equitable manner. This is done by a use-of-system (UoS) charge agreed with the regulator as competitive delivery systems are unlikely and delivery is a monopoly business.

It is usual for the power network to be split between various owners through which power flows by a path determined by basic electrical laws from the generator to the consumer. Each owner will expect to recover the cost of installing and maintaining equipment (amortised over say 20 years) and for controlling the flows, including voltage control at all parts of the owned network. This requires metering at input and output points such that the delivery charge can be apportioned dependent upon the chosen or agreed rate. Suffice to say, there are a number of established methods for charging based on capacity (kW) and metered energy (kWh), the main requirement being the recovery of sufficient monies to keep the utility owner in business or to satisfy any governmental or regulatory target set for rate-of-return on the service. Details of UoS charging methods can be found in Schweppe, *et al.* 1989 or Weedy & Cory, 1998.

42.3 Electricity markets

A commodity market is where buyers and sellers can negotiate a contract for a designated 'block' of electrical energy. It also enables everyone trading in the market to 'discover' the price that other traders are paying or are prepared to offer their blocks of energy so that an auction can be conducted under established rules. An electricity market has effectively only one commodity on offer but its price is very dependent on the period over which it has to be delivered. This is because the price of electricity is higher at peak times than at other periods of the day, week or season (see Chapter 39 on Planning). In the market through negotiation, contracts can be drawn up with the usual penalties for non-delivery etc. under market rules. The market must be efficiently organised and include mechanisms for collecting revenues due under the contracts and any penalties for non-compliance. This can be a complicated procedure, often requiring legislation to enforce the rules and to deal with disputes.

One of the most difficult features markets need to enforce is that of preventing particular traders setting prices because they have monopoly or near monopoly power due to their size or the lack of effective competition. Also they must police the traders to ensure that collusion on price is outlawed. If natural monopolies exist e.g. in transmission and distribution, then a regulator is appointed to control prices that can be charged. In many cases the same market may deal with a number of different businesses such as generators (producers), shippers (transporters) and suppliers (retailers) to end users. In electricity the markets are now used to dealing with four types of traders, namely generators (single or multiple utilities), transmitters (usually high voltage transmission companies), distributors (lower voltage) and suppliers (retailers to the individual consumer, factory, commercial building, etc.). Up to now, transmitters and distributors have been thought of as natural monopolies implying that other shippers would find it too expensive to offer an alternative means of delivery, but with the growth of small embedded generators who might find it worthwhile to construct their own local distribution network, this natural monopoly could be gradually eroded.

Nowadays, everyone expects markets in commodities or services to be run over the internet by established marketeers and the electricity forward market is no exception. Traders can either switch around to various internet sites to discover what prices and trades are available, or they can stay with one market maker if they have a good reason. The internet market is often global in extent although trades between producers and suppliers would need to ensure that delivery could be made and the delivery charge accounted for. Since some markets include other types of energy e.g. gas, oil, coal, bulk shipping across the world or through another country is well established. Delivering electrical energy via another utility's or country's power system (known as 'wheeling') is now becoming possible with the opening up of many grids for third party access under liberalisation rules or legislation.

42.4 Market models

As the ESI in most industrialised countries begins to open up to trading, the 'model' of generation, transmission, distribution and supply moves from a 'vertically' integrated system often with central government control to the separated 'unbundled' system with each part being run as an independent business (see Hunt & Shuttleworth, 1996). In this latter case, economists insist that in a truly competitive market with many buyers and sellers for all time periods, prices for energy and delivery will become based on marginal cost and the most economic means of providing all consumers with electricity will ensue. Unfortunately, as we have seen, transmission and distribution (T&D) are never likely to become fully competitive and, as monopolies, they will have their prices set by a regulator who is required by legislation to set fair prices with a fair return on assets for the owners. With T&D prices added, the market operates with two prices—a generation price and a delivery price for each geographical zone of the power system. The price differential between zones reflects the cost of delivery including payment for losses and service costs for arranging the delivery by the T&D operators. It is implicitly assumed that all trades can be delivered, but if the delivery system is congested (usually on the transmission network) then the system operator can order up (at a price) extra generation to clear or balance the market. The extra cost of this service must be added to the delivery charge in an agreed manner. In some systems it may be possible to buy priority transmission rights, thereby ensuring that at congested times a trade can be completed. In the extreme event that the negotiated energy quantities in a given time slot cannot be delivered, then some form of load shedding is necessary to save the system from collapse. This will certainly incur penalty payments from the supplier to the consumer for lost production or inconvenience, thereby acting as a ceiling on any traded prices. Although most ESIs are now in some transition stage between government controlled vertically integrated operation and a form of generation and supply competition, the final form of the ESI may well take on different features to those expounded here.

42.5 Reactive market

Besides ensuring that trades can be delivered, the system operator (SO) must keep the 'nodes' or 'bus-bars' in the system running within at least ±10% of their designated voltages. This is a tricky job when the power flows through the network can vary by up to 60% during the course of the day. The mechanism for voltage control is through the injection or extraction of volt-ampere reactive (Var) at the main network nodes. Briefly, Var is not real power but is a controlled oscillation of electrical energy between the capacitance and inductance of the network. Any imbalance of Var must be corrected on a local basis through Var producing or absorbing devices, because if Var has to be transmitted over any distance (e.g. 50 km or more) it can produce a considerable voltage change between adjacent nodes, thereby worsening the voltage control problem. Although no net energy is required to produce or absorb Var, it can lead to small extra losses due to the resistance of the network or inherent in the devices it flows through. It can be measured as kVarh by a suitable meter in a similar fashion to kWh and is conventionally considered positive if injected into the network or negative if extracted from the network. A surplus of Var occurs naturally in most networks (consisting of cables, overhead lines and transformers) under light load conditions leading to higher than normal voltages and a deficit of Var occurs under heavily loaded conditions, leading to lower than nominal voltages.

Fortunately, all synchronous generators are designed to run either underexcited or overexcited through control of the rotor currents from the excitation system associated with each generator. When they are overexcited they produce Var (or operate at a lagging power factor in order to satisfy an inductive load); underexcited they have a limited capacity to absorb Var (run at a leading power factor for a predominantly capacitive load). The penalty, as far as the generator plant owner is concerned, is that overexcitation being the more usual of the two running conditions, incurs extra heating of the generator rotor and a drain on the excitation supply, whilst in the long term it causes a more rapid deterioration of the rotor and stator conductors. Both of these considerations require that the plant owner should be compensated based on the net kVarh metered at the generator terminals. At the consumer's terminals, loads normally consist of circuits requiring magnetisation in some form or other e.g. a motor, power supply with input transformer, thereby demanding a lagging current (Var absorbing). The kVarh absorbed can be metered and charged for if there is an economic case to do so, particularly for large 3 ph. loads supplied at high voltage.

However, unlike real power, Var can be locally produced by inserting a capacitor in shunt with the system i.e. in parallel connection to the load. Hence it is considered that a reactive market (£/kVarh) could encourage consumers to reduce their reactive demand, thereby aiding voltage control of the system. In any case, the SO will need to recover any expenditure on kVarh and this would obviously need to come from consumers. Additionally, the transmission & distribution owner could also enter the reactive market by installing compensation devices (known traditionally as power factor correction) at strategic nodes in the system and covering their amortisation costs with a negotiated charge. In most cases, it is expected that the price per kVarh will be of the order of one tenth that of the average kWh energy price.

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