Towards a European Market of Electricity : Spot and Derivatives Trading

by

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Abstract

Deregulation of electricity markets is spreading worldwide at a high speed : it has been completed for some years in Scandinavia and the United Kingdom, is well under way in the United States and being embraced in most continental Western Europe outside France. Germany and the Netherlands are quite deregulated, followed by Spain. Italy is establishing power trading in a competitive environment. This represents a multi-billion spot market that is developing very quickly. And the same pattern of evolution as in the financial markets is being observed, with the growth of a variety of derivative instruments such as forward and Futures contracts swaps, plain-vanilla and exotic options.
The main problem associated with the pricing of those derivatives is that the fundamental financial models were established for stocks and bonds and do not capture the unique features of electricity, in particular the non-storability (except for hydroelectricity), the seasonality and spikes of prices, the difficulties of transportation, (existence of high voltage lines, constraints at the hubs imposed by the Kirchoff laws), not to mention the necessity for the European Community to define clear rules for cross-border electricity transmission.
The goal of this paper is to discuss the main features of electricity spot prices and investigate the pricing issues attached to power options.

Key words : energy markets, electricity spikes, power options.

Section 1 : the European Energy Exchanges and Indexes

The oldest European Energy Exchange is the IPE, which was established in 1980 and already offered in 1981 gas oil Futures contracts. In 1990, were introduced options on gas and oil, then in 1997 natural gas Futures contracts. By any standard, the IPE is today the leading European energy exchange. Providing the desirable properties of operating within an agreed and transparent legal framework, preventing market abuse and ensuring a smooth delivery process, it has acquired a status of Recognized Investment Exchange (RIE).
As far as electricity is concerned, the first Exchange to be established was the Nordpool, in 1993. Right from the start, it benefited from the fact that electricity in Scandinavia is in great part hydroelectricity, hence has the very valuable property of being storable. As we shall see later, the non storability of the other forms of electricity is an important explanatory factor of the spikes as those which were observed in the United States in the ECAR market (Midwestern region close to Chicago) in June 1998 and, at a smaller extent, in the North East during Summer 1999. Obviously, another reason for electricity price spikes is the lack of capacity. Real or strategically organized by major. Today, the Nordpool is a successful exchange, where the electricity players in Europe feel they can place their orders safely.
Three years after the establishment of the Nordpool, the Swep (Swiss Electricity Price Index) started being quoted by Dow Jones on the basis of the transactions taking place in Laufenburg, at the border of Germany and Switzerland.
A fair amount of trading in Europe still uses today the Swep as the reference index but the most two active Exchanges are the Amsterdam Power Exchange (APX) created in early 1999 and the Leipzig Power Exchange (LPX) which was established during Summer 2000 and consolidates today the activities of the LPX and what used to be the European Energy Exchange (EEX) in Francfort. Recently, a structure called Powernext, was built in Paris involving Paris Bourse, Electricité de France and some other major energy structures and spot trading of electricity is starting within the hexagon.
To conclude this paragraph, we may observe that a very small number of indexes and Exchanges would be optimal for continental Western Europe since this would ensure the liquidity required for spot trading and the manipulation-free environment necessary for derivatives trading.

Section 2 : Specificities of Power Markets and Power Price Processes

A. Generalities on power markets

As mentioned earlier, power markets present some unique features :

a) Non-storability of electricity, and hence lack of inventories, requires the development of new approaches to study power markets, both from an economic and financial standpoint.
b) By necessity, these markets are geographically distinct: there are several geographical regions between which moving power is either physically impossible or non-economical, and costly when feasible. This explains why new futures contracts are being created to cover different regions: in the United States, after the COB (California Oregon Border) and PV (Palo Verde, Arizona) contracts introduced in 1996, the NYMEX recently started trading the Cinergy contract (covering Midwestern region) and Entergy contract (Louisiana region). Another contract called PJM, whose delivery point is the border intersect of Pennsylvania, New Jersey and Maryland, has been recently introduced. Such geographical refinement of contracts is similar to the one observed in catastrophic

insurance derivatives (see Geman 1994), first introduced in December 1993 by the Chicago Board of Trade for four regions, then extended to nine distinct regions in the United States. This regional feature derivatives contracts is unknown in the financial markets where an option written on the IBM stock has identical characteristics whether it is traded in New-York or Tokyo.

c) The market for power options, like the credit market, is not really complete in the sense of Arrow-Debreu since hedging portfolios do not exist or are at least very difficult to identify, in particular for the daily options. Owning the production capacity in the delivery location or both the production and the transmission right to this point is for now the only way of covering a short position, i.e., a position where the option has been sold.

B. Characteristics of Electricity Price Processes

As far as electricity price processes are concerned, they exhibit a number of intrinsic features, unique in comparison with financial assets such as stocks and bonds, but also unique in comparison with other every commodities such as oil and gas. The most important properties one should keep in mind before entering electricity market are the following :

a) seasonality, related to cyclical fluctuations of demand by time in the day, week and year.
b) Mean-reversion of the price process towards a level that may be viewed as the marginal generation cost, hence evolves stochastically over time. This property is shared by most other commodities, including agricultural. It has been discussed by many authors in the framework of energy commodities : Pindyck (1999) analyzes a 127-year period for crude oil and bituminous coal and a 75-year period for natural gas and concludes that prices exhibit mean-reversion towards a stochastically fluctuating trend line. Eydeland-Geman (1999) show the same property for electricity prices when analyzing several regions of the United States.
c) Substantial price differences are observed in different regions, and this is obviously another feature electricity prices do not share with financial assets. These differences result from varying capacity generation across regions as well as transmission network into a region. Conversely, one may view a transmission facility as a locational spread option and price it using the methodology of real options (see Geman 2000).
d) Like the mean price of electricity, the volatility of electricity varies within the day and the year as fluctuations in demand move prices to the upper part of the power stock function (see Graphs 1 and 2).
e) Lastly, another key feature of electricity prices is the presence of dramatic price changes, materialized by spikes in trajectories, i.e., sudden upward jumps shortly followed by a rapid reversion to normal levels. As of today, the most famous spike ever observed was in the ECAR region (region covering several Midwestern states of the U.S.) during June 1998, the outage of a nuclear plant hit by a tornadoe and transmission problems for hydroelectricity coming from Canada sent electricity prices to several thousand dollars.

These spikes are the reason why peakers- modern gas turbines which can be turned on quite rapidly- started being built by power marketers and energy companies wishing to take advantage of these few days when power prices are so high that they provide the revenues of the whole year. Conversely, these spikes are a major subject of concern in the risk-management of utilities which have been used to address the issue of *volume risk* but face also today the new problem of *price risk*, with the possibility of enormous short-term price fluctuations.

Section 3 : Energy Options

In order to introduce a pricing methodology for power options, it is useful to first discuss the valuation methods used for other commodities, particularly energy commodities. In the next paragraph we review the current approach to commodity option valuation, for both standard and Asian options, i.e., options whose payout at maturity is related to the average of spot prices observed during the lifetime [0, T] (or a subinterval) of the option (let us observe that weather derivatives, which are becoming increasingly popular among power traders and in the whole economy, most frequently have Asian-type payoffs).

Commodities and Convenience Yield

The notion of convenience yield was introduced by the economists Kaldor and Working who, among important topics, studied the theory of storage. In the context of commodities, the convenience yield captures the benefit from owning a commodity minus the cost of storing it. Brennan and Schwartz in their pioneering research (1985) incorporated the convenience yield in the valuation of commodity derivatives and established in particular that the relationship prevailing between the spot price $S(t)$ and the future price $F(t,T)$ of a contract of maturity T is

$$F(t,T) = S(t)e^{(r-y)(T-t)}$$

where r, the risk-free rate, and y, the convenience yield attached to the commodity, are assumed to be non stochastic. This remarkable relationship has a number of fundamental consequences :

a) It establishes that the spot price observed at date t and the forward price prevailing at that date for delivery at time T (T > t) cannot take arbitrary values with respect to each other. In fact, if the assumption of constant interest rates and convenience yield is correct, the knowledge of the spot price allows to derive the whole *forward curve* (let us observe - and this is a subtle point whose discussion is beyond the scope of this paper - , that the assumption of constant interest rates implies the equality between forward and Futures prices. This assumption will be made throughout the article).
b) It allows, when one has sold an option, to build the hedging portfolio by using indifferently the spot or a forward contract particularly liquid at a given point in time.
c) It leads to interpreting the convenience yield as a continuous dividend payment made to the owner of the commodity. Hence, under the additional assumption that the price of the underlying commodity is driven by a geometric Brownian motion, Merton's (1973) formula for options on dividend-paying stocks provides the price of a plain vanilla call option written on a commodity such as gas or oil

$$C(t) = S(t)e^{-y(T-t)}N(d_1) - ke^{-r(T-t)}N(d_2)$$

where

- $S(t)$ is the current spote price

- $d_1 = \dfrac{\ln\left(\dfrac{S(t)e^{-y(T-t)}}{ke^{-r(T-t)}}\right) + \dfrac{1}{2}\sigma^2(T-t)}{\sigma\sqrt{T-t}}$

- $d_2 = d_1 - \sigma\sqrt{T-t}$

This setting where the uncertainty of the economy is represented by a single Brownian motion implies the unicity of the price not only for plain-vanilla options but also for exotic options ; the latter case only involves solving mathematical technicalities . For instance, Asian options which represent today a big percentage of the total number of options written on oil or oil spreads (because of the duration of oil extraction and transportation, most indices on oil are defined as arithmetic averages) are becoming popular in electricity, in particular because of the Summer 1998 events . The averaging effect allows to smooth out the spikes in prices and keep the average cost of electricity over a given time period as the underlying source of risk in the option. It is well-known that the valuation of Asian options is a difficult problem and several approximations for the call price have been offered in the literature. Geman-Yor (1993) were able, using stochastic time changes and Bessel processes, to provide the Laplace transform of the exact price of the Asian option. Eydeland-Geman (1995) inverted this Laplace transform and showed the superiority of this approach over Monte Carlo simulations, in particular in terms of hedging accuracy. These results were established under the general assumptions of constant dividend payments for stocks or convenience yield for commodities.

As was mentioned before, the main difficulty in valuation of power options is due to the fact that electricity (except for hydroelectricity) cannot be stored practically, which creates major obstacles for extending the notion of convenience yield to power:

a) By definition, the convenience yield is the difference between two quantities: the positive return from owning the commodity for delivery and the cost of storage. Because of the impossibility of storing power, these two quantities cannot be specified.

b) The non-storability of electricity also leads to the breakdown of the relationship which prevails at equilibrium between spot and future prices on stocks, equity indices, currencies, etc. The “no arbitrage” argument used to establish the cash and carry relation is not valid in the case of power, since it requires that the underlying instrument be bought at time *t* and held until the expiration of the futures contract.

One way to avoid the problems described above and to extend to power derivatives the hedging strategy explicit in the Black-Scholes-Merton formula, is to restrict ourselves to options written on forward and future contracts ; in practice, these options are much more liquid (in OTC transactions in the Nordpool for instance) for two sets of reasons – obviously related – but not identical :

(i) the existence of a pricing formula, namely the Black (1976) formula for options written on Futures, whose use is (more or less) legitimate since the behavior of electricity Future prices is less extreme than the one of the spot price itself. This formula, which resembles the Merton formula seen above, is the following :

$$C(t) = e^{-r(T-t)}\left[F^{T_1}(t)\, N(d_1) - k\, N(d_2)\right]$$

where
- T_1 is the maturity of the Future contract (greater than T, maturity of the option)
- $F^{T1}(t)$ is the current price of the Future contract

- $$d_1 = \frac{\ln\left(\frac{F^{T1}(t)}{k}\right) + \frac{1}{2}\sigma^2(T-t)}{\sigma\sqrt{T-t}}$$

- $$d_2 = d_1 - \sigma\sqrt{T-t}$$

(ii) the hedging instrument exists, is liquid and does not raise any storage difficulty since it is “paper”, namely the underlying Future contract.

Power Options

As discussed above, the first category of options consists of calendar year and monthly physical options. The monthly options roughly follow the specifications of the electricity Futures contracts which were introduced on the New York Mercantile Exchange in March 1996. The exercise at the end of July of the August 2002 denominated call option allows the buyer to receive power (in a given location, defined in the option contract) during all business days (5 or 6 days a week, depending on the specification) of the month of August, 16 hours a day in most cases, from 6 a.m to 10 p.m prevailing time (on-peak hours), of a given number of megawatthours at the price *k*, called strike price of the option. We can observe that the buyer of the option, holding the right of purchasing electricity for a fixed amount k is protected against a rise in electricity prices during the lifetime of the option (recently, airlines and industrial companies which had bought options on oil or fuel fared much better than the ones which were fully exposed to the sharp price rise).
A second category of power options is comprised of daily options. These options are specified for a given period of time (year, season, particular month, etc) and can be exercised every day during this period. For example, the owner of the January 2001 daily call option can issue, if she so chooses, an advance notice on January 11 to receive a specified volume of electricity on January 12 during the on-peak hours, paying a price *k* per megawatthour. Daily options, are not very liquid and are difficult to manage. (We note that although Asian, swing and other volumetric options involve daily options related issues, they raise additional constraints and complexities whose precise discussion is beyond the scope of this paper). Lastly, there are hourly options, designed to have access to power during specified blocks of hours (one, four, eight). As of now, the market for these options is thin.

As mentioned earlier, there were several days in June 1998 when the spot price was above $2,000 per megawatthour, and in the range of seven thousand dollars for some hours, up from $25 a few weeks before (see Figs. 1, 2 and 3 for price and volatility data observed in ECAR - East Center Area Reliability Coordination Agreement - , region covering several Midwestern states). Sellers of calls, even deep out-of-the money calls with a strike price k of $1,000, incurred severe losses. In the Spring of 1998, these options were selling for 50 cents per megawatthour, probably because $300 per megawatthour was the highest spot price of power registered during the year 1997. A year later, their price was multiplied by a huge factor.

As of today, financially settled power options are gaining popularity worlwide (we can observe that the futures contracts just created on the Leipzig Exchange are also financially settled). The daily ones exhibit a 10 - 50% higher volatility than physically settled daily options. In order to not complicate issues further, we will restrict our attention in this paper to the physically settled options : at maturity T, the buyer may - if he so chooses- get delivery of electricity at a price k per megawatthour.

The case of daily options

If the market of daily futures existed, the hedging of daily options would not be different from that of monthly options and the approach described above would be applicable. However, most markets – except perhaps for the Nordpool - do not have liquid daily forward or futures contracts, and therefore, we are forced to use an imperfect and sometimes dangerous surrogate of this daily futures contract in the form of the *balance of the month* contract. The balance of the month price is the price of power delivered every day from today until the end of the current month. Going one step further and assuming a strong correlation between this balance of the month and the spot price, we now can allow ourselves to model the spot price evolution in order to derive, in a standard way, the option price from the spot price dynamics. The balance of the month becomes the traded hedging instrument as opposed to the non storable spot. The main problems that one faces while modeling spot dynamics are the difficult issues of matching fat tails of marginal and conditional distributions and the spikes in spot prices. There are a number of techniques addressing these issues; below, we describe two models that appear to us most relevant.

a) The first one is a diffusion process with stochastic volatility, namely

$$dS_t = \mu_1(t, S_t)dt + \sigma(t)S_t dW_t^1$$

(3)

$$d\sum_t = \mu_2(t, \sum_t)dt + y(t, \sum_t)dW_t^2$$

where $\sum_t = [\sigma(t)]^2$, $W^1(t)$ and $W^2(t)$ are two Brownian motions, with a correlation coefficient $\rho(t)$, and the terms $\mu_1(t, S_t)$ and $\mu_2(t, \Sigma_t)$ may account for some mean reversion either in the spot prices or in the spot price volatility.

Stochastic volatility is certainly necessary if we want a diffusion representation to be compatible with the extreme spikes as well as the leptokurstosicity displayed by distribution of realized power prices. However, stochastic volatility puts us in a situation of "incomplete markets" since we only have one instrument, the spot power (or rather its surrogate) to hedge the option. Hence the valuation formula for the call,

$C(t) = E_Q\left[\max(S_T - k, 0)e^{-r(T-t)}\right]$, where r is the risk-free rate, S_T is the spot price at maturity as defined by equations (3), and Q is the risk-adjusted probability measure, would require the existence of a volatility-related instrument (for example, a liquid at-the-money option) that could be viewed as a *primitive* security and complete the market.

b) A second model offers interesting features. As extreme temperatures, and hence, an extreme power demand, happen to coincide with outages in power generation and/or transmission, the spikes in electricity spot prices can be advantageously represented by incorporating jumps in the model (Geman and Yor, 1997, analyze an example of this type leading to completeness of the insurance derivatives market). A classical jump-diffusion model is the one proposed by Merton (1976)

$$dS_t = \mu S_t dt + \sigma S_t dW_t + US_t dN_t$$

where

- μ and σ are constant ($\sigma > 0$)
- *(W_t)* is a Brownian motion representing the randomness in the diffusion part
- *(N_t)* is a Poisson process whose intensity λ characterizes the frequency of occurrence of the jumps

- *U* is a real-valued random variable, for instance normal, which represents the direction and magnitude of the jump.

c) More general Lévy processes such as the ones recently used for equity derivatives (see Geman 2002) will be investigated for electricity prices in subsequent research.

Real Options and Power Asset Valuation

Coming back to power derivatives, we have seen that the safest way to hedge daily power options is to own or lease a power plant. Conversely, operating a merchant power plant is financially equivalent to owning a portfolio of daily spark spread options, i.e., options to exchange gas for electricity when beneficiary. Indeed, on any given day one should run a power plant only if the market price is higher than the cost of fuel plus variable operating costs. The net profit from this operating strategy is therefore :

$$\Pi = \max \left(\text{Price}_{\text{Power}} - \frac{\text{Heat rate}}{1{,}000} \text{Price}_{\text{fuel}} - \text{Variable costs}, 0 \right)$$

where Heat rate is a plant-dependent scaling constant introduced to express power and fuel prices in the same units (Heat rate is classically defined as the amount of British thermal units needed to generate one kilowatt hour of electricity). The above expression is also the payout of the call option on the spread between power and fuel (spark spread), with variable costs being the strike of this call option. Owning the power plant is hence financially equivalent to owning a portfolio of spark spread options over the lifetime of the plant..

If the set of daily options we want to analyze matches this portfolio exactly, then its price should equal the value of the plant that may be obtained from economic fundamentals. This approach in terms of real options is an alternative to the method of discounted cashflows used in corporate finance to value projects and investments. In practice, both viewpoints must be analyzed in the process of decision-making for the purchase of a power plant. More generally, power traders are now used to arbitraging the real options embedded in the business such as technology arbitrage : heat rates, fuel switching, response time ; transmission/transportation arbitrage or commodity arbitrage between gas, coal or hydro.

Conclusion

Some issues related to modelling power prices and derivatives pricing were addressed in this paper. Obviously, a more complete picture should incorporate the possible discontinuities due to power plants shutdowns, transmission congestion, changes in environmental policies (in particular regarding emission control) and development of new technologies to produce electricity. At the level of regulation, many issues remain to be resolved in Europe in order to create a unified transmission network.

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