Energy Economics 37 (2013) 182–192

Contents lists available at SciVerse ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

# Investment, firm value, and risk for a system operator balancing energy grids

Engelbert J. Dockner [a], Dénes Kucsera [b], Margarethe Rammerstorfer [a,*]

[a] Institute for Finance, Banking and Insurance, WU Vienna University of Economics and Business, Heiligenstädter Straße 46–48, A, 1190 Vienna, Austria
[b] Institute for Regulatory Economics, WU Vienna University of Economics and Business, Heiligenstädter Straße 46–48, A, 1190 Vienna, Austria

ARTICLE INFO

*Article history:*
Received 21 August 2011
Received in revised form 13 January 2013
Accepted 19 January 2013
Available online 4 February 2013

*JEL classifications:*
G31
G32
L94

*Keywords:*
Balancing energy markets
Grid expansion investments
Value and risk implications of grid balancing

ABSTRACT

With the liberalization of energy markets integrated energy companies have separated into entities that specialize in production and/or transmission of energy. Transmission of energy requires balancing the grid to guarantee system security, which is performed by the (independent) system operator (SO). When the SO faces stochastic demand, grid balancing has sizeable consequences on current and future profits, and hence, on firm value and firm risk. We explore these value and risk consequences with and without an investment option to expand transmission capacity. We show that firm value consists of the value of the transmission capacity in place plus the value of a short put and a short call option that are the result of the SO's balancing actions. Firm risk without investment option is non-linear and determined by the short option positions. It is decreasing with increasing energy demand. The existence of an option to expand transmission capacity increases firm value and firm risk.



## 1. Introduction

The liberalization of energy markets forced integrated energy companies to unbundle and become separate businesses for production, transmission and distribution. While the generation of electricity is entirely determined by the employed technology (e.g. fossil, nuclear and renewable energy), transmission and distribution of energy crucially depends on the capacity of the grid. Prior to deregulation, production, transmission, and distribution of electric energy have been controlled by a single regulated public utility. In this case, the vertically integrated public utility produced and transmitted energy on the basis of maximizing economic surplus subject to regulatory constraints, including service security for customers.[1]

In a deregulated power market, (independent) system operators (SO) transport electricity to locations where it is demanded by using the existing grid capacity. These operating firms are exposed to fluctuating supply and demand. On the supply side fluctuations are caused by production uncertainties arising from wind energy, for example, or they can be triggered by unpredictable political decisions such as the shut-down of nuclear power plants. Demand fluctuations are mainly driven by changing consumer preferences, seasonalities, and the awareness of environmental policies. Some of these fluctuations like seasonalities can easily be predicted, in which case they do not lead to a grid imbalance. However, differences between energy consumed and produced in the system and the majority of stochastic shocks leave the system unbalanced. This is where the SO needs to jump in as imbalances between energy demand and energy supply have to be equilibrated on spot. Given additional technological constraints such as the existence of Ohm's law any SO faces a complex decision problem. The SO not only needs to ensure transmission of electricity by using the grid but also needs to take actions in order to balance the grid and to guarantee the security of the entire power system.[2] Since balanced grids are an important precondition for system security, the regulator's focus has moved towards providing a legal framework and market environment to guarantee this. One possibility to balance the grid is to create a market for balancing power or balancing reserves, i.e., the balancing energy — or reserve market.[3] This market is separated from the spot

* Corresponding author.
*E-mail addresses:* engelbert.dockner@wu.ac.at (E.J. Dockner), denes.kucsera@wu.ac.at (D. Kucsera), margarethe.rammerstorfer@wu.ac.at (M. Rammerstorfer).

[1] There are, however, some doubts about unbundling. The major concern is the ability of the market to deliver timely and sufficient investments that ensure system security. Detailed reservations against unbundling can be found in for example Brunekreeft and Ehlers (2005), Mulder et al. (2005), or from a legal perspective in Pielow and Ehlers (2008).

[2] The grid operator can be a system operator or any other legal type of (firm) operation. For expository convenience, we will in the following denote the balancing firm as SO.

[3] Readers not familiar with the reserve market are referred to for example Rebours and Kirschen (2005) who compare the definition and technical specification of reserve services in Great Britain, PJM (Pennsylvania–New Jersey–Maryland), California, Spain, the Netherlands, Germany, France, Belgium, and the UCTE as a whole. For a detailed survey of the North American market, see e.g. Lusztig et al. (2006).

0140-9883/$ – see front matter 
http://dx.doi.org/10.1016/j.eneco.2013.01.007

market, although, similar products are traded. In a recent article Möller et al. (2011) study the German balancing energy market within the system of the day-ahead and futures market in detail. They determine strategic positions in the balancing energy market and identify corresponding incentives. Moreover, they point out the main difference between these different market segments that rests in the constraints necessary when balancing power. Hence, balancing power gives the SO a certain flexibility that goes along with a price difference when compared to the rigid spot market.

In most countries three different types of energy reserves are distinguished which differ with respect to their flexibilities. Primary reserves are direct reserves that allow to balance the system within a few seconds. The secondary reserves can be used to balance the system within five minutes, while tertiary reserves have to be available within 15 min. Due to the flexibility associated with these different reserves for the system operator, the prices vary, i.e. higher flexibility is more costly. Additional to this, and based on over- or under-balance of supply in the market, positive and negative reserves are distinguished. If supply exceeds demand, i.e. produced energy exceeds energy consumption, the SO could either pay consumers to consume more or pay suppliers to produce less. This is referred to as buying negative balancing power. On the other hand if demand exceeds supply, the SO could either pay consumers to consume less, or pay suppliers to produce more. Consequently, this is referred to as buying positive balancing power.

In this paper we model a SO with a given transmission capacity who faces stochastic demand that follows a diffusion process. The SO is required to balance the grid at any time demand deviates from existing capacity levels. If demand deviates from existing transmission capacity by more than a given percentage the SO has to step in and either buy or sell balancing power in the balancing energy market.[4] The system balancing transactions make up the short-run decisions of the SO. Since these actions are costly, it is in the interest of the SO to avoid any grid imbalance. In the long-run, as demand continuously grows and capacity constraints are more frequently binding (grid is continuously imbalanced), it is in the interest of the SO to invest into grid expansion. We use a real option approach to analyze optimal investment decisions in grid expansion and determine its implications on firm value and firm risk. We contrast the long-run value and risk dynamics associated with grid investments with the short-run dynamics resulting from grid balancing. We find that balancing the grid results in a firm value that is the sum of the present value of profits generated by the existing transmission capacity in place plus a short position in a put and a short position in a call option. The short put and the short call options are the consequence of the SO's need to balance the grid. If demand falls below a critical threshold so that the transmission system is imbalanced, grid balancing requires that the SO jumps in and buys positive balancing power. As a consequence the SO needs to pay an extra cost that is higher the larger the demand deviation from the balanced grid is. These extra costs correspond to a short put option with energy demand being the underlying asset and the balanced grid level (i.e. the existing transmission capacity limit) as the exercise price. If, on the contrary, demand exceeds the upper threshold, the SO has to react again and buy negative balancing power at a premium price. Excess demand results in an increase of costs for the SO that is higher the larger the deviation from the grid balance is. This corresponds to a short call option, with demand being the underlying asset and the balancing level being the exercise price. Hence, the value of an SO that primarily balances the grid is identical to the sum of the value of the grid capacity in place, the value of a short call and the value of a short put option. As the combination of a short call with a short put option on the same underlying asset with different strike prices is referred to as a short strangle, the value of the SO corresponds to the value of the existing grid capacity plus the value of a short strangle. While the existing grid capacity in place results in a constant firm beta and hence constant systematic risk, the short strangle introduces non-linearities into the risk dynamics of the SO.[5] Overall, we find that risk for the SO is primarily driven by the short option positions, and is higher the smaller the energy demand is. In case the SO has a growth option to expand grid capacity we find that both, the firm value and its risk, increase.

Analyzing transmission investments is not new and has been studied by Ramanathan and Varadan (2006), for example. They develop a real options model that is solved using binomial tree valuation and point to all possible economic trade-offs, present in such a framework. Boyle et al. (2006) evaluate the use of a real options framework in order to shed light on the investment test proposed by the regulator in New Zealand. The paper by Saphores et al. (2004) analyzes an investment decision under the assumption that the firm must undergo a costly and time-consuming regulatory process prior to making the investment. They show that these constraints severely influence the timing decision when to invest and can lead to early exercise of the investment option. Borenstein et al. (2000) study the competitive effects of transmission capacity. Their model predicts that the level of transmission capacity does neither have an impact on competition nor on the actual electricity that flows on the transmission line in equilibrium. Although many of these papers use a real options approach to derive optimal investment decisions for transmission capacity, none looks at the value and risk implications. The main contribution of this paper is to fill this gap.

Our paper is organized as follows. In Section 2, we present the model and discuss its assumptions. Section 3 studies value and risk consequences of grid balancing when the SO does not have an expansion option. Section 4 introduces a growth option into the model and derives its value and risk implications. Using numerical techniques, we derive the optimal value function, the dynamic firm betas and comparative statics in Section 5. Finally, Section 6 draws together the main findings and concludes.

## 2. The model

We consider a SO, who sells transmission capacities and has the duty to balance the network. The SO operates with a given fixed capacity, denoted by $K_0$, which is irreversible and cannot be employed in alternative uses. The SO faces stochastic demand for transmission services. The demand level at time $t$ is denoted by $X_t$ and is assumed to follow a stochastic process specified as a Geometric Brownian Motion (GBM).

$$dX_t = \mu X_t dt + \sigma X_t dw_t, \tag{1}$$

where $\mu$ is the constant growth rate of demand, $\sigma > 0$ is the constant volatility per unit of time, and $dw_t$ is a standard Wiener process. In principle, the growth rate of demand can take either positive or negative values. In the existing application, we restrict it to be non-negative $\mu \geq 0$. Hence, the expected demand for transmission services either grows exponentially over time or fluctuates randomly around zero. It is well established in energy research that energy demand is characterized by a significant trend (demand grows over time), a strong seasonality (energy demand varies over the seasons), and a stochastic component. Both the trend as well as the seasonality can accurately be forecasted, while by definition the unexpected noise cannot. Hence, trend and seasonality do not generate the considered grid

[4] Depending on the type of ownership of SO profits and losses are distributed differently in European networks. As pointed out in the paper by Pielow and Ehlers (2008), the system operator in the Netherlands is the economic owner of the network and hence can claim all profits, but is also responsible for all losses of the network.

[5] The beta of a company is a measure of its non-diversifiable (systematic) risk triggered by the single market risk factor. It is defined as the ratio of the covariance of the firm's equity returns $r_i$ and the market returns $r_M$, and the variance of the market ($\sigma_M$), i.e. $\beta_i = \frac{Cov(r_i, r_M)}{\sigma_M^2}$.