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ECONOMICS OF ENERGY STORAGE

An analysis of the administrative consequences of electricity storage

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Acknowledgement/Preface

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Abstract

This report discusses the administrative aspects connected to the introduction of electricity storage in the energy system. First, the macro-economic aspects of utilizing storage facilities are discussed, and the possible benefits of storage in the electricity system are summarized. Next, the discussion focuses on the administrative aspects. In particular, the regulation system of the Dutch electricity market is reviewed, paying particular attention to the market design in connection with Distribution Network Operators. A number of relevant aspects are discussed, such as the incentives for the Operators to optimize network performance, as well as the means available to the Operators to stimulate third parties to do so. Finally, the perspectives for storage operators to enter directly on the different power markets are treated. Generally, one can conclude that the administrative aspects for storage facilities leave room for improvement.

CONTENTS

LIST OF ABBREVIATIONS

DG	Distributed Generation
DNO	Distribution Network Operator
DTe	Dienst uitvoering en toezicht energie
MC	Marginal Cost
OTC	Over The Counter
TSO	Transmission System Operator

SUMMARY

This report illustrates important aspects in the economics of electricity storage systems. It does so by describing the supply and demand side of the technology and by analyzing the impact of the network regulation and the wholesale market design.

First, the economics of electricity storage systems are analyzed. The short-term marginal costs as well as the various services electricity storage systems can provide are discussed. The different services generate value in the electricity system. The most central of these services is the inter-temporal arbitrage - also considered as peak-shaving - where the storage device is used to transform cheap electricity from low price periods (e.g. off-peak) into more expensive electricity by selling it during high price periods (e.g. peak). However, energy storage systems can also provide other services. The values of these services depend on their demand levels and, indirectly, from the existence of substitute technologies that can also provide the considered services.

The influences of regulation on the development of the implementation of electricity storage systems are exerted in a number of ways. First of all, the incentives as provided by the current regulation system (2000-2004) are discussed. This price-cap regulation system, focusing on (short term) cost reduction does not give positive incentives to risk-bearing innovations with long payback times. Furthermore, the regulation system does not reward the positive effects storage systems can have on the quality of electricity supply. Concluding, it is argued that the strict Dutch regulatory framework might be revised in order to create a larger playing field for Distribution Network Operators (DNO's).

The regulatory system in the second period (2005-2007) will consist of a yardstick system extended with quality regulation. The new system could offer incentives to implement storage systems as higher network reliability is financially rewarded. Power quality, another benefit of the implementation of storage systems, will still not be rewarded.

Third topic analyzed is the influence of regulation concerning connection and transport costs on Distributed Generation. This regulation offers positive as well as negative incentives for electricity storage. Charging only shallow costs for small connections and the exemption from having to pay LUP[1] offers positive incentives for DG and electricity storage. The Cascade system and the fact that DG is not rewarded for causing less network losses offers negative incentives for DG and electricity storage.

The report ends with a discussion of the current market access for storage systems. Although there is no principal barrier to two of the three markets, none of the markets have been very attractive to small-scale parties. For the day-ahead APX market, the main barrier has been the high costs for entering the market. Recently, the tariffs have been reduced, but it remains to be seen whether this suffices to facilitate small parties to enter the market. For the Over-the Counter market, deteriorating market conditions form the major obstacle. The third market, the balancing market, as yet is entirely closed to small-scale parties.

[1] As of 1 July 2004 the LUP will be set at nil.

1. INTRODUCTION

An ongoing transformation is taking place in the electricity markets across the European Union. Driven by a common European framework, while competition is being introduced in the production and supply sectors, new regulatory systems are being introduced to regulate the transmission and distribution sectors of the electricity markets. In addition, due to technological developments, environmental targets and security of supply issues, the amount of intermittent renewable energy sources such as wind energy and maybe in the long run photo-voltaics are expected to increase significantly. In this new playing field, the market value (profitability) of electricity storage systems is receiving an increasing attention.

It is against this background of increasing intermittent supply in an increasing liberalizing market that a project has been formulated in which the technological, economical, social, and administrative consequences of large-scale electricity storage is investigated. The project is part of the PRogramma Elektriciteitsnetwerk GebruikersOnderzoek (PREGO), a program aimed at consolidating and extending the knowledge about the electricity infrastructure, in particular in the liberalized market.

This report focuses on the administrative consequences of introducing large-scale electricity storage in the electricity net. It first qualitatively describes the supply and demand functions of the energy storage systems, illustrating a typical marginal cost function and emphasizing on the potential values of these technologies. Later, the influence of the network regulation system and market design of the wholesale electricity market on the economics of storage systems is analyzed.

2. ECONOMICS OF ENERGY STORAGE SYSTEMS

According to basic economic literature, the feasibility or profitability of a project depends on whether the expected income can cover the long-run marginal costs of the project. For the sake of the analysis, the economics of storage systems will be divided into supply and demand side issues. It is difficult to quantitatively illustrate the supply and demand curves because:

- As many electricity storage systems are infant technologies, and currently not competitive, costs are expected to reduce with time. It can therefore be argued that a static analysis could actually provide low added value.
- Other marginal costs inputs are very uncertain, such as electricity price.
- Incomes of storage facilities, as later explained, depend on many variables.

For the above reasons, the description is limited to a qualitative characterization of the supply and demand functions of the energy storage systems.

Supply side

As mentioned above, in the long run the feasibility or profitability of projects depends on the expected income covering the long-run marginal costs of production (LRMC). In the long run no costs are fixed and therefore all costs are included in the LRMC, also investment costs. However, in the short-term, production decisions of storage systems depend on whether the marginal costs are lower than the marginal income - fixed costs are considered as sunk costs. The (short-term) marginal cost (MC) function of the storage activity could be defined as:

MC = PP + EL + O&M

Where the MC of storage devices depend on the purchase price (PP) of electricity, the electricity losses (EL) caused by operating the device and the operational and maintenance (O&M) costs raised. Marginal costs vary depending on the specific technology and geographic location. For an electricity storage system connected to the grid, reasonably, the purchase of electricity would be done during off-peak periods, when its price is relatively low. Electricity losses are caused by inefficiencies in the system, i.e. the difference between the electricity imported and the electricity exported to and from the storage facility.

Demand side

Electricity storage systems can provide different services that generate value in the electricity system. These services depend on whether the storage facility is connected on or off grid (see Table 2.1). The first to come to mind would be the inter-temporal arbitrage - also considered as peak shaving - where the storage device buys power during low price periods (e.g. off-peak) and sells it during high price periods (e.g. peak). Roughly, it is profitable to utilize the storage facilities if the marginal costs of production are lower than the price differential between the two periods.

Nonetheless, energy storage systems can provide other services than the above mentioned. The values of these services depend on their demand levels and, indirectly, on the existence of substitute technologies that can also provide the considered services. As an example of the latter, ‘balancing’ the electricity supply system can be provided by electricity storage systems, but also by thermal power generators. In the case competitive technologies are cheaper than storage systems, they would set the price for that service, and consequently would not allow for storage facilities to cover their costs.

Table 2.1 *Added value of storage of electricity in the case of on-grid and off-grid*

	On-grid	Off-grid
Inter-temporal arbitrage	×	
Balancing of the system	×	
Grid losses avoidance	×	
Grid investment avoidance/deferral	×	
Reserve capacity - emergency supply	×	×
Voltage/frequency support	×	
Black start	×	
Seasonal/day-night renewable (D G) energy storage	×	×
Uninterruptible Power Supply (UPS)	×	×
Power Quality Management	×	

It is important to note that for some values - for instance grid losses - these can also be negative. Furthermore, it is crucial to differentiate between short-term and long-term values. For example, although currently marginal, due to the expected increase in the share of wind energy in the EU, power quality management for wind farms can become an important market niche for storage facilities in the longer-term.

These values can be distinguished between energy-related values and network-related values. Examples of the first are the inter-temporal arbitrage and the balancing of the system. An example of the second is grid investment avoidance. In all cases market design and economic regulation have the responsibility to recognize, and introduce appropriate mechanisms to put a monetary value to these values. However, as the next section shows, the current Dutch regulatory framework does not recognize a number of these values.

3. NETWORK REGULATION AND MARKET ACCES

The profitability of electricity storage systems not only depends on the costs of the device but also on the market opportunities, i.e. the income generated with the device. Storage facilities can provide a number of services - illustrated in the previous section - to the electricity system. Via regulation and market design, the services provided should be recognized and, if utilized, rewarded. This analysis aims specifically at illustrating regulatory and market circumstances for electricity storage systems on an intermediate term, of the order of 10 years. Within this period small-scale storage systems are considered to be the most promising systems for the Dutch electricity sector, as these are developing in a niche market[2]. Therefore, this research will be limited to the small-scale systems.

In the following, first the regulation system used to supervise the Distribution Network Operators (DNO's) will be discussed. In particular, the influence of this system on the development of electricity storage will be analyzed. The analysis will pay attention to both the current regulation system (2000-2004) as well as the system for the second regulatory period (2005-2007). Next, it is discussed whether the regulation concerning connection and transport costs offers incentives to implement storage systems. Small-scale storage systems resemble distributed generation systems regarding the regulation concerning connection and transportation costs (Stortelder, 2003). Because of these identical characteristics in Paragraph 3.3 small-scale storage systems will be considered as Distributed Generation (DG). The last factor that will be analyzed is the market access of storage capacity.

3.1 The current network regulation system (2000-2004)

In the last years, regulation of distribution networks evolved from a rate-of-return to an incentive based regulation system in order to promote efficiency in the sector (Jamasb, Pollitt, 2000). In other words, consistent with the developments in the production and supply sectors, incentive regulation aims at stimulating competitive forces in the distribution sector. In the Netherlands a price-cap system, implemented in the first regulatory period (2000-2004), and the yardstick system, to be implemented in the second regulatory period (2005-2007), stimulates competitive forces that promote efficiency via tariff reductions. As indicated in the formula below, which illustrates the basic principles of the price-cap system, the tariff reductions per year depend on the x-factor (x_t) and the inflation index (cpi).

$$P_t = \left(1 + \frac{cpi - x_t}{100}\right) P_{t-1}$$

The x-factor is the discount to promote an efficient operation by network firms and is based on the benchmarking of the operational and capital expenditures between the different DNO's (DTe, 2002).

Innovation

The current price-cap regulation system focuses very much on the reduction of costs, not giving any financial incentives to improve the quality of the network (DTe has only set minimal requirements regarding quality aspects). The fact that the current regulation system does not include a rewarding system to improve the network quality has as consequence that these services

[2] 'On the time-scale under consideration, the niche market will be defined by relatively small-scale wind farms, where storage may limit the network extension. Thus, the scale of the wind farm limits the application of storage. As the systems can develop in the niche market, they may eventually break through into the electricity system as full-scale alternatives for new (conventional) generation systems.

offered by a storage system do not contribute to a positive outcome of the cost-benefit analysis. Not valuing these benefits makes that the regulation system offers negative incentives to implement storage systems.

Besides improving the quality of the network, the postponement of investments in grid capacity is another important application of storage systems. When demand for the load of a certain grid part exceeds grid capacity, the DNO can decide to invest in the installation of extra capacity. In some cases installing a storage system could also solve the capacity shortage. A storage system can shave peaks of the transport capacity demands, which leads to a more efficient use of the network capacity. When the implementation of storage systems would be the most cost effective option to meet the increased transportation demands, the current regulation system would stimulate the investments in storage capacity. Often however the introduction of innovating techniques first enhances (high) investments in research and development, which only after a while could, perhaps, result in lower operational costs. This could make DNO's choose to invest in traditional grid expansion rather than in innovating storage systems. The price-cap regulation system, focusing on (short term) cost reduction does not give positive incentives to risk-bearing innovations with long payback times. This makes that within the current regulation system investments in storage systems are not stimulated.

As an illustration of the importance of this issue, the English regulator has recently put forward two different regulatory mechanisms that could promote innovation - Innovation Funding Incentive and Registered Power Zones are currently being discussed among stakeholders (OFGEM, 2003). Innovation Funding Incentive is aimed at facilitating funds spent on R&D by DNO's. As operational expenditures of distribution firms come under great pressure from the incentive regulation in place, Innovation Funding Incentive would provide specific funding to demonstration phases of certain projects. Registered Power Zones are intended to offer DNO's a sufficient incentive to encourage them to pursue network projects with higher risk profiles. As a result, a financial incentive would be provided to balance the DNO's risk/reward position.

Strict separation of activities

To be able to introduce competition in some stages of the electricity chain, the different activities within the chain first are unbundled. The distributed networks, still owned by the utility companies, have to be heavily regulated in order to guarantee a level playing field for all electricity supply companies. Compared to other systems in Europe, Dutch regulation and legislation give high priority to the stimulation of competition by imposing strict rules concerning the separation of activities. Since the activities in the electricity chain highly depend on one another, this strict separation generally has negative consequences for technical optimization. An example of the disadvantages of the rigid regulatory framework is the following.

Due to the unbundling of the sectors, long-term cost minimization policies through integrated resource planning can no longer be undertaken. As decisions for the building of new generation are detached from the managers of the grid, DNO's face constraints in determining how and where infrastructure developments should take place in the most efficient way. In order to provide incentives to network and storage operators to exploit the values storage facilities provide DNO's should be given a certain level of flexibility. Locational signals, which can be provided through market prices or through network regulation, are a way to provide this flexibility. However, under the current Dutch regulation no locational signals are provided. In other words, no price or payment incentives are given to producers who locate their generation or storage capacity in places where it's most convenient to the distribution company or network operator.

An important consequence of the strict regulation and legislation is the prohibition for DNO's to exploit any activities that compete with market activities. This is laid down in the Electricity Act 1998. As a consequence of the Act, current regulation forbids network managers to store electricity during off peak hours and subsequently use this during peak hours, or use electricity storage to balance the electricity system. What is more, regulation does not supply DNO's with means to stimulate market parties to invest in storage systems. Given the advantages the implementation of storage systems could offer for technical optimization, it could be argued that regulatory constraints should be eased sufficiently to enable such a technological optimization by the DNO's.

3.2 The second period network regulation system (2005-2007)

In 2005 the Dutch Regulator (DTe) will introduce a new regulation system. In the system, based on a yardstick system, the tariffs are determined based on the average productivity changes of the sector. In other words, the performance of the DNO's will be benchmarked against the performance of the whole sector and not against an efficient benchmark like in the current price cap-system. Companies that do better than the sector average will receive extra benefits. Conversely, DNO's that do worse than the sector average will see their benefits reduced. In order to ensure that the efficiency improvements are not made at the expense of the reliability of the network, DTe will extend the system of yardstick competition to include quality regulation.

Under the new system, tariffs will be also determined based on a reliability and quality standard set by DTe. An individual network company may achieve a profit if it outperforms the standard, but a loss if it performs poorly relative to the standard. Initially the standard will be determined for each network company separately and will be adjusted annually by the same factor that applies to all companies thereafter. The customer's preferences with regard to reliability will have an important place in this quality regulation system (Newbery et al., 2003).

Within the new regulation system the DTe makes a distinction between 3 dimensions of quality:
- reliability
- power quality
- commercial quality.

Reliability relates to the degree to which buyers can be supplied without interruption. This provides a stimulus for the network company to install sufficient capacity. Even though the network has sufficient installed capacity, the supply to a buyer may nevertheless be interrupted in practice as a result of the malfunctioning of the network. This also affects the network company's performance regarding the reliability criterion. Power quality (or voltage quality) is a term, which refers to the disturbance of the ideal sinusoidal curve of alternating current. This relates, for instance, to the voltage level, frequency and symmetry of phases. In addition to the physical supply of electricity, the network company also maintains a commercial relationship with its customer. This relates to the contact that takes place between a network company and a buyer (in writing, by telephone or in person).

The system for the second regulatory period will only include the reliability dimension regarding quality control. Given the different factors that affect reliability performance as defined by the DTe, electricity storage systems could contribute to reliability and therefore generate higher benefits. Small-scale storage systems like batteries and flow batteries can be brought into action within seconds and reduce interruption of supply. Network companies will look for the most cost effective way to reach their optimal level of reliability. If the cost level of storage systems is competitive with other options to improve reliability, the new regulatory system offers great incentives to investment in storage systems.

The implementation of storage systems can also contribute to improving the second identified dimension of quality, that of power quality. In combination with advanced power electronics storage systems can reduce harmonic distortions, and eliminate voltage sags and surges (Electricity storage, 2003). Restricting the regulation to only rewarding the reliability of networks leaves the value storage systems have regarding power quality un-rewarded. In this respect the regulatory system does not give positive incentives to the implementation of storage systems.

In the previous paragraph the lack of regulation to stimulate risk-bearing innovations under the current regulatory system was identified. As does the price cap system, the system introduced in the second regulation period will fail to provide sufficient stimulating measures to specifically counterweight the negative incentives for innovation. Thus, the inability of the network operators to provide “locational signals” will keep the network manager from managing the network in a more technically optimal way. This holds both in the first as well as in the second regulation period.

3.3 The role of connection and transport regulation in promoting DG

Small-scale storage systems resemble distributed generation systems regarding the regulation concerning connection and transportation costs (Stortelder, 2003). In this paragraph an analysis will be made to see whether this regulation gives positive or negative incentives to distributed generation and small-scale storage systems.

Connection costs

In the Netherlands connection charges depend on the type of connection. Connection charges until 10 MVA are shallow, regulated and averaged. Shallow refers to connection charges that only pay for capital and maintenance costs of the connection itself but are not charged directly for other costs incurred by the network operators. In other words, the party connected to the grid does not pay possible adjustments, reinforcements and upgrades beyond the point of connection, which may be necessary to facilitate the integration of the generator into the grid. These indirect costs of grid adjustments, depending on the situation, can or cannot be passed on to consumers through the use of the system tariff.

Connections charges larger than 10 MVA are negotiated and deep. Deep is referred to connection charges that cover all costs raised by connecting to the grid. They include the direct costs of connecting to the grid and all indirect costs raised inside the grid. Charges are determined through negotiation processes between users and the DNO’s. Small-scale storage facilities fall under the first category. As deep connection costs can pose a significant financial barrier to small-scale store systems, this benefits the deployment of these technologies.

Transportation costs

Transport costs can be divided into two parts: transport dependent costs and transport independent costs. The largest part of the transport dependent costs is passed on to the consumers. A small part however (25%) is passed on to the producers. This is called the Landelijk Uniform Producenten tarief (LUP)[3]. Only producers connected to the 110 kV grid and higher pay the LUP. This regulation promotes the implementation of DG because DG producers are connected to the grid at lower voltage levels and therefore don’t have to pay the LUP.

The transportation costs paid by the consumers are determined by means of the Cascade system. Within this system, costs are accounted based on the voltage level on which the consumed electricity is fed into the grid. Electricity fed into the grid on a low voltage level is charged a share of the costs of higher voltage levels. In general however, DG is connected to the same voltage level as the consumers and thus reduces the usage of the higher voltage levels. Furthermore, as the location of DG in general is closer to the consumer, DG causes less grid losses compared to central production. Neither these cost reducing effects are recognized by the regulatory system, be it the capacity saving effect on the level of higher voltage networks, or the avoidance of grid losses by the close proximity of generation and consumption.

[3] As of 1 July 2004 the LUP will be set at nil.

3.4 Market Access

Energy related transactions of electricity storage systems can take place through the markets or intra-firm[4]. The latter occurs when owners of significant amounts of intermittent power generation find it cheaper to solve imbalances by storage facilities rather than by contracting balancing electricity. To recognize and value energy-related services provided by small-scale storage facilities in the case transactions take place through the market, market access must be given to energy delivered by these technologies. In this context market access means:

- network access for selling electricity in the wholesale and retail market,
- access to markets for reserve power, reactive power and balancing markets (ancillary service markets).

The DNO's must provide the technological opportunities for such access. In case the storage operators are not prepared to participate in the markets, an 'active' DNO might be an intermediary between DG operators and the markets. Such participation should be an opportunity for the DNO - and not an obligation. Furthermore, given the current regulation, the role of DNO's can only be very limited, for example to the level where they serve as a broker between storage operators and independent trading companies.

Decentralized trading arrangements were implemented in the Dutch power market when the new Dutch electricity act was put into force in 1998. The day-ahead market in the Amsterdam Power Exchange (APX), the bilateral Over the Counter (OTC) market and TenneT's balancing market, are the three main markets that exist where electricity is currently traded. The first two differ in type of market design, contracts traded, liquidity and transparency. The third is a balancing market designed to handle the deviations between actual demand and projected demand, as well as the under-generation and over-generation due to plant failures.

High transaction and information costs were normally barriers that impeded the participation of DG in the Amsterdam Power Exchange. For example, access fees contribute to transaction costs. Originally, any market party that wanted to trade in the APX had to pay an entrance fee of € 12,500 one time and then € 25,000 per year, which represents a significant sum for small generators. However, since October 9 2003, APX introduced a differentiated membership system to attract smaller participants to the exchange (APX, 2003). It is still unclear whether this new system could facilitate the market access of small-scale storage facilities to the electricity wholesale market.

Another way small-scale storage facilities may sell their energy is through the OTC market. Trading in this market is based on bilateral tailor made transactions. The possibility to continuously trade in this market is an advantage for storage facility operators. However, the deterioration in the market conditions - reduction of liquidity - is a recent characteristic in the OTC market, in particular with lower OTC product offerings, erratic prices, fewer participants and falling volumes (DTe, 2002).

In the Netherlands the Transmission System Operator (TSO) manages the balancing market. This market is used to correct temporal imbalances that arise in the system. Imbalances are solved mainly through two types of electricity - the regulating and reserve power - which vary among the technical specifications of generators that provide them. Although markets exist for these two types of electricity, small-scale facilities are currently barred from this market.

[4] Intra-firm refers to the situation where the storage is exploited by the same company that generates the (temporary) excess of electricity.

4. CONCLUSIONS

The economic prospects of storage systems are determined directly by the marginal cost function. However, a major ingredient into this function is the monetary value connected to additional services that can be provided by storage systems. At present, such monetary valuation of services is hard to give, and as a result the discussion of added values remains on a qualitative level.

In a discussion of added value, administrative aspects - regulation and market design - will play an important role. Both the present Dutch regulation system, using a price-cap regulation, and the future yardstick system provide negative incentives for the implementation of storage, given the fact that the costs of electricity storage are still relatively high. However, as the focus is shifted from pure cost performance in the old system to multiple criteria, some elements in the future system will also provide positive incentives. A similar picture of mixed stimuli for implementation of storage emerges from the regulation of connection and transportation costs. In general, one may argue that a revision of the strict Dutch regulatory framework, creating a larger playing field for DNO's, may lead to increased market opportunities for storage facilities, and indeed for Distributed Generation (DG) in general.

Direct market access for storage facility operators so far has proven to be unsuccessful. This may change in the near future, as the entrance fees of the day-ahead APX have recently been lowered. The other two markets appear not to be accessible, either for practical or for principal reasons.

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