ELECTRIC VEHICLES IN A DISTRIBUTED AND INTEGRATED MARKET USING SUSTAINABLE ENERGY AND OPEN NETWORKS

INTRODUCING ELECTRIC VEHICLES INTO THE CURRENT ELECTRICITY MARKETS

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1 EXECUTIVE SUMMARY

This report describes the current Nordic electricity market and addresses the challenges related to a large-scale introduction of electric vehicles.

An electric vehicle (EV) will increase electricity consumption for the typical Danish house by 50-60%. If the charging of many EVs primarily takes place during the peak consumption hours between 17:00 and 19:00, this could possibly cause pressure on the energy system and congestions in the grid. By introducing demand response in connection with EVs, congestion challenges can be met even with a very high penetration of EVs. Demand response can, for example, be based on the electricity market's spot prices.

For the end-user to benefit from demand response an interval meter is needed. Grid companies comprising 50% of all Danish end-users have installed, or will install, new meters within a few years. These meters will be able to record the consumption per hour and thereby make it possible to use price contracts with prices varying per hour (spot prices or critical peak prices), by weekdays/weekends, or day/night (time-of-use).

If EVs are introduced in the spot market, the market set-up is simple and possible today with an interval meter. The retailer can broadcast the electricity prices once a day, and the end-user can make a charging strategy for the hours with known prices (12 to 36 hours ahead). The charging strategy can be a simple clock charging, or the cheapest hours can be selected with a local computer system (home automation system).

If EVs are to participate in both the spot market and the regulating market a few more challenges have to be met. Requirements from the TSO regarding real time measurements of the individual unit and minimum bid size make it difficult for EVs to participate in the regulating power market today. Furthermore, there are some challenges with imbalances related to EVs in the regulating market, as the activation of regulating power at one hour can change the predicted charging at a later hour.

Some of these challenges can be met by introducing a fleet operator to aggregate the consumption of a number of EVs and handle their interaction with the electricity market as one unit.

It should be noted that the design of the market is not fixed. For example, the Danish TSO has sent out a rough draft on changes to the regulating power market in order to activate smaller consumption in the market. However, changes might take some time to implement as the regulating power market today is strictly Nordic; while in the future it may European.

In addition to the wholesale market solutions, there are some challenges in relation to the local grid. Congestions in the local grid have to be taken into account with respect the behaviour of the end-user. This subject is briefly described within this report, but not solved.

2 ELECTRICITY CONSUMPTION BY EVS

2.1 TYPICAL CONSUMPTION OF AN ELECTRIC VEHICLE

The electricity consumption for electric vehicles varies depending on the size, make, model and technology involved. Based on a small-medium sized vehicle it has been estimated that the average new electric vehicle produced within the next five years will consume 130-140 Wh/km (Ea Energy Analyses, 2009). This figure is not based on a single particular vehicle, but instead on a theoretical small-medium sized electric vehicle with current motor, battery, and charger efficiencies.

The average number of km driven yearly via a traditional personal vehicle is 16,600 km (Danmarks Statistik, 2009). Given a value of 135 Wh/km, this represents an annual electricity consumption of 2,240 kWh per vehicle (Ea Energy Analyses, 2009).[1] To put this into perspective, the typical Danish family living in a house currently uses approximately 4,000 kWh per year (Dansk Energi, 2009a).[2] As such, for the average Danish house an additional 2,240 kWh per year represents a 56% increase in annual electricity consumption. Assuming 25% of all personal vehicles are electric, this would correspond to 20-25% of the Danish households owning an EV, and the total electricity consumption from Danish houses would increase by 11-14%.[3]

2.2 POTENTIAL CHALLENGES FOR THE ELECTRICAL GRID DUE TO LARGE NUMBERS OF EVS

What makes EVs different from the majority of other household electrical usage (lights, washing machine, computer, etc) is that the actual use of the electricity (while driving) does not take place at the same time as the consumption (while charging). Subject to driving pattern and the type of electrical charger installation, charging for most EVs is anticipated to take 2 to 8 hours for a full battery. Charging can be realised with standard 1 or 3 phase connections (Dansk Energi, 2009b).

Depending on when charging takes place, this either represents a significant challenge, or an immense opportunity for the electrical power system in Denmark. If a significant amount of Danish households all begin to charge their vehicles immediately after they arrive home from work, this will increase electricity demand during what is typically a peak time. This could be problematic for the electrical power system as a whole. If however, the vast majority of EV users could postpone the charging of their vehicles till late in the evening/very early in the morning, then their vehicles would still be fully charged for the following day and charging would occur at an off-peak time.

[1] It should be noted that estimates regarding EV consumption vary, and in other portions of Edison a figure of 150 Wh/km is utilised.
[2] This figure refers to houses without electric heating.
[3] In 2007 there were 2,068,493 vehicles in Denmark and 2, 6400,000 households, of which 1,451,000 were houses.

2.2.1 MAIN GRID

Based on overall Danish electricity demand, figure 1 illustrates the situation described above. Both graphs present the hourly electricity demand for the day in 2007 that exhibited the highest peak demand hour, namely January 24th. In addition, the graphs also indicate what the hourly demand pattern would look like under three alternative demand response scenarios if 25% of all Danish passenger vehicles were electric. These scenarios are immediate charging, time delayed charging, and market based/fleet operator managed charging, and they are described in greater detail in the following section.

For the sake of simplicity the day has been divided into four charge periods: during the night (23:00 – 06:00), during the day (06:00 – 16:00), directly after coming home from work (16:00-19:00), and evening (19:00 – 23:00). The percentage of charging that will be done during each period has then been allocated for each of the three listed scenarios. Throughout the analysis it is assumed that the average consumption of 2,240kWh per vehicle per year is evenly spread out over each day of the year, therefore implying 6.1 kWh per day. In practice all owners will not charge their vehicles every day, or the same amount each time, however this average figure gives a reasonable approximation, particularly when averaged over a larger number of vehicles. It is assumed that by 2020, the vast majority of Danish homeowners will be able to utilise a 3 phase 16 amp connection. This would allow for 11.0 kWh/h, and as such the 6.1 kWh charge could be completed in just over half an hour (Dansk Energi, 2009b). With respect to the dispersion of the charging in each period, it is assumed that this is spread out evenly over the course of each period. This is of course an oversimplification, because in practice charging is unlikely to be evenly dispersed.

Energinet.dk (2009c) undertook a similar exercise, however Energinet.dk used an increase of electrical consumption by transport figure of 2.6 TWh/year, compared to the 1.2 TWh/year figure in this study (25% EV's). This difference can be explained by the fact that the Energinet.dk study also assumed that 15% of goods transport, and 15% of busses were converted to electric.

2.2.1.1 IMMEDIATE CHARGING

In a situation devoid of demand response tools it is quite likely that the majority of electric vehicle owners will simply plug in their vehicles when they arrive home from work. In this regard, we assume that the vast majority of Danes arrive home from work between 16:00 and 18:30, and given our roughly 30 minute charging timeframe outlined above, this gives us a charging window of 16:00 – 19:00. A small minority can be expected to charge during the day or evening, and a very small group of users would charge in the late evening/early morning. As such, the allocation for the no demand response scenario in this study is defined as 5% charging during the night, 10% during the day, 10% during the evening, and 75% after coming home.

2.2.1.2 TIME DELAYED CHARGING

A simple option to enable shifting of additional electricity demand to off-peak periods is through the implementation of a system where users come home for work, plug in their vehicle, and via a timer, set the vehicle to start charging in the lowest demand and cost hours (typically between 23:00 – 06:00). The advantage of such a device is that it is very low cost, and due to the national hourly demand pattern, a significantly large amount of users could utilise this option and thereby contribute to the smoothing out of daily electrical energy demand. To be effective, such a charging solution would have to ensure that all users did not select the exact same time. In the scenario it is assumed that this is the case, and that the charging is spread out evenly over the 7 hour period. In practice this would not be the case, and this therefore represents one of the drawbacks of time delayed charging. In this scenario 70% are assumed to charge during the night, 10% during the day, 10% during the evening, and 10% would still charge when arriving home from work.

2.2.1.3 MARKET PRICE BASED/FLEET OPERATOR MANAGED CHARGING

The third scenario envisions a situation where price signals or a fleet operator largely dictate the optimal time to charge the electric vehicle. As such, a perfect market price based or fleet operator managed system would both ensure that a large share of charging takes place at the least cost hours, regardless of the time of day, and take into account the charging requirements of other users.

The market price based scenario is predicated upon the assumption that the market can send real time price signals to the vehicle (for example through a retailer), and combined with predetermined criteria from the vehicle owner, the vehicle will then make charging related decisions based on this information. For example, if the electricity price is very low, then a number of users will likely start charging. If too many users begin to charge, this will drive up the price. In the current market design this will be handled in the regulating market, which sends a price signal resulting in the individual vehicles revaluating their charging strategy.

The fleet operator version of the scenario involves the delegation of the charging responsibility to a fleet operator (FO), who offers to handle charging of EV's according to a contractual setup. This is possible because the FO is granted full control of the EV charger. Every time a customer EV is grid connected, the FO will set up a charge plan for charging the EV from current time until estimated off-grid time. The target is to supply the amount of energy corresponding to the contract, which depending on type of contract could for example be 80% charged, or full battery (i.e. 100% charged). The flexibility provided in this scenario can be illustrated as follows: Assume an EV customer comes home at 18:00 and plans to drive at 6:00 the next morning. If the battery has an energy storage capacity of 22 kWh and a 3 phase 16 A charger, it would take less than 2 hours to do a full 0-100% charge. With this EV the FO now has a 12 hour window to do a maximum 2 hours of charging. If the charger was a 1 phase 13 A, the FO would have a 12 hour window to do a maximum 7.5 hours of charging. In either case, the FO has rather good opportunities to place the charging period in an optimal way. The FO could for example place the charging period in such a way that: a) maximizes the expected renewable energy production, or b) minimizes the expected energy cost.

In a Danish context (in the spot market) this scenario would very closely resemble the previous time delayed charging scenario because the lowest cost hours are predominantly between 23:00 and 06:00. In such a scenario 90% of charging is assumed to occur during the night, 5% during the day, 5% during the evening, and no charging during the hours upon arriving home after work as these hours are nearly always those with the highest demand (and therefore associated with high prices). However, these are average figures, and a full demand response system of this type would both capitalise on, and avoid irregularities within this average. As such, this scenario more closely reflects that of the time delayed charging scenario in this theoretical representation, than it would in practice.

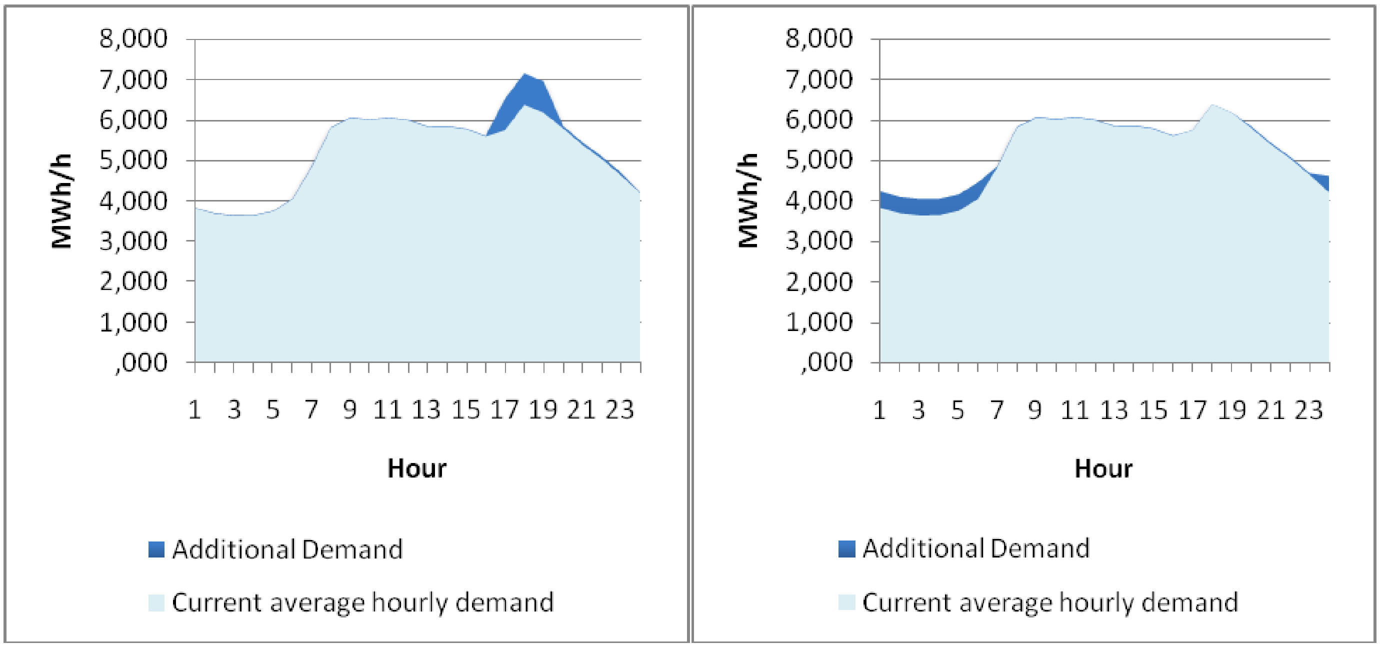

Figure 1: 2007 Peak electricity demands for Denmark. The light blue portions are the hourly demand for January 24th, 2007 (the day in 2007 that had the highest peak hourly demand). Meanwhile, the dark blue portions represent additional demand corresponding to the electrification of 25% of current passenger vehicles. The first graph illustrates the situation without any demand response, and the second with the assumed intelligent automated demand response.

The left portion of figure 1 highlights the fact that if the majority of charging is done shortly after arriving home from work (immediate charging scenario), the introduction of electric vehicles will lead to an increase in peak demand of 12.5% relative to the 2007 peak workday hour. An increase in peak demand does not necessarily threaten the security of supply, but it could imply a more congested transmission grid and higher prices.

The visual representation of the time schedule scenario and market price based/fleet operator managed charging demand response scenarios closely resemble each other, and as such just the latter is included in the right side of figure 1. In scenarios with demand response, overnight demand voids become somewhat filled, and it therefore appears that the Danish electricity production and transmission system can handle a 25% (and much greater) electrification of the Danish passenger vehicle fleet. This conclusion is also predicated on the assumption that the electrical supply system can continue production throughout the night, and will thus benefit from a smoother daily electricity demand.

2.2.2 LOCAL GRID

Figure 1 indicates the impact of demand response tools on the main transmission grid (assuming that additional demand at off peak times can be met). However, the Danish power system is also made up of thousands of 0.4 kW local distribution grids, and particularly during peak hours there have been concerns that these grids may not be able to withstand the addition of large amounts of electric vehicles.

In an effort to replicate the potential impacts on a local grid, a simplified theoretical grid consisting of 100 average Danish houses without electric heating has been created. Depending on how much additional capacity is currently in the local grid, an attempt to quantify how many of these houses could simultaneously charge an electric vehicle in the three different scenarios will be presented.

It is important to note that the following discussion is meant to illustrate potential problems in the local grid. The discussion also illustrates the need for incorporation of signals from the local grid in the charging of the EV. Concrete analysis to survey the actual problems in the grid are made in WP2 of the Edison project.

In terms of which weekday to select, figure 2 reveals that on average the 2007 daily demand for Danish houses without electric heating was very similar for each weekday, with only Monday being slightly different. However this can largely be explained by the fact that in 2007, Jan 1st, Dec 24th, and Dec 31st all were Mondays, and if these days are removed from the dataset the average hourly consumption very closely resembles that of Tuesday through Friday. Figure 2 also highlights the fact that the hourly electricity demand pattern for households is quite similar on weekdays and weekends. The only significant differences being that on weekends Danes tend to wake up a couple of hours later, and there is a higher utilisation during the day as people are at home instead of at work.

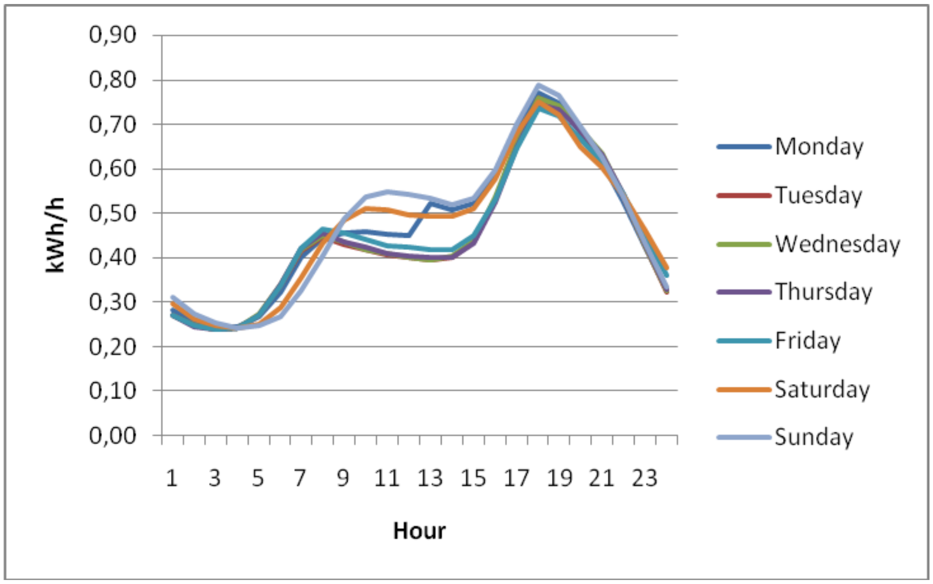

Figure 2: Average hourly demand for Danish households (single family house without electric heating). Data from 2007, Elforbrugspanelerne.

According to (Dansk Energi, 2008), in 2007 the typical Danish house without electric heating had an annual electricity demand of roughly 4,000 kWh. However, to forecast the ability of the local distribution net to handle large amounts of electric vehicles, the task is to look at the effect on the net during the hour with the highest demand. In 2007 (as is often the case), the highest demand hour for average Danish houses without electric heating was December 24th from 16:00-17:00. On average, each Danish house used 1.23 kWh/h of electricity during this hour in 2007, and therefore this figure is used as a starting point to which an estimated amount of unused grid capacity will be added.

Christmas Eve is however not representative of a typical day where people will be charging their vehicles after returning home from work. Therefore, as the basis day the data from the work day with the highest demand hour in houses without electrical heating in 2007 is selected, namely Wednesday January 3rd from 17:00-18:00. In figures 3 and 4 this is represented by the light blue portion. As was the case in figure 1, the dark blue portion in each graph represents the additional electricity demand that is forecasted to occur as the result of charging a certain number of electric vehicles under the three different demand response scenarios. There are thousands of local distribution nets in Denmark and little is known regarding how much unused capacity exists in each net. Relative to the maximum demand hour of 1.23 kWh/h per house in 2007, and indicated by a red line, figure 3 displays a situation where the local grid has 25% higher capacity than the maximal use of 1.23 kWh/h, i.e. 153/h kW for 100 houses, and in figure 4 a situation with 50% higher capacity (184 kWh/h for 100 houses). However, given the abovementioned uncertainty some local grids could fall outside of these boundaries. It should also be noted that average hourly values are used here, and maximum intra hour demand will be higher.

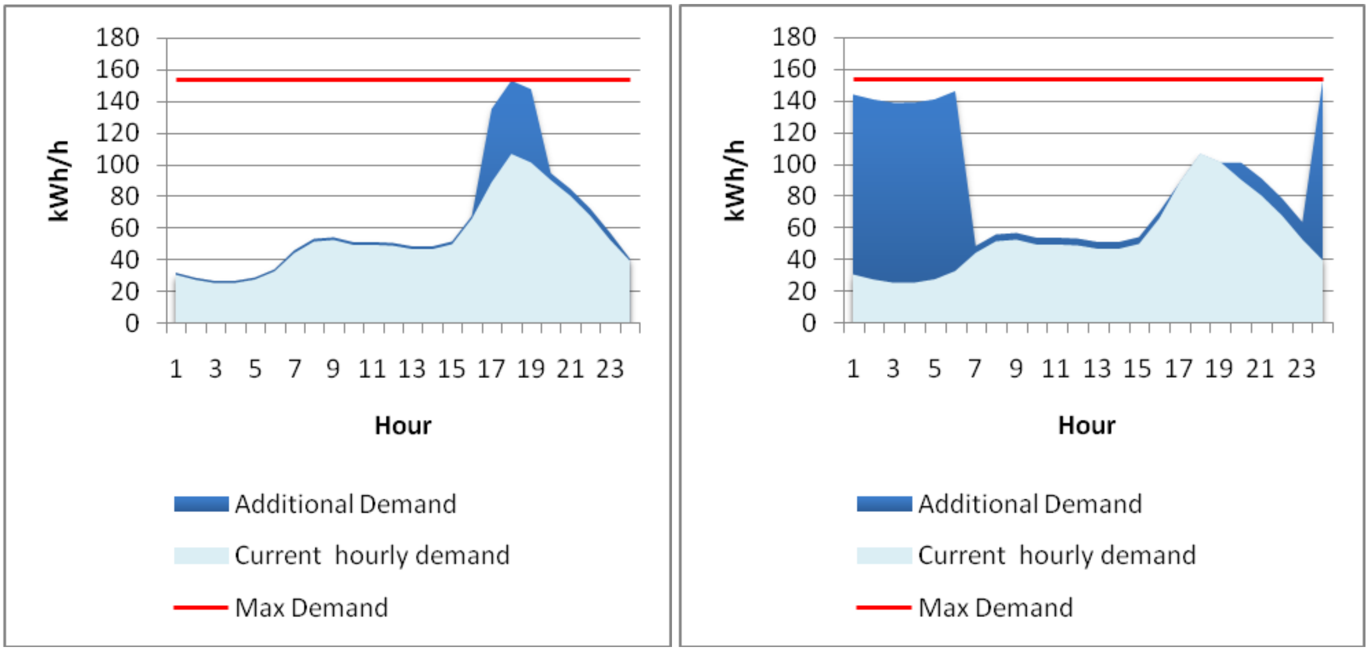

Figure 3: Maximum electric vehicle penetration for a Danish local grid given 25% unused capacity in a situation with maximum demand, under two demand response scenarios. The light blue reflects the average hourly demand on the 2007 workday with the highest single peak demand hour (January 3rd, 2007), the red line represents an additional 25% capacity relative to the maximum average demand hour in 2007 (December 24th, 2007). The dark blue represents the additional electricity demand from the number of electric vehicles that the additional capacity allows room for (this last variable will therefore be different in each of the scenarios).

Without demand response (i.e. immediate charging), the first scenario in figure 3 reveals that with 25% unused capacity a local grid consisting of 100 average Danish houses could accommodate over 30 electric vehicles.[4] The market price based / fleet operator managed charging scenario meanwhile could accommodate 143 electric vehicles. The time delayed charging scenario involving vehicle users simply selecting a time after 23:00 to charge their cars is not shown in the above figure. Theoretically speaking, if in such a scenario it is assumed that users will either through experience, or via signals from local grid operators, disperse their collective charging relatively evenly throughout the night, then the visual representation will closely resemble that of the right panel in figure 3. If however the time schedule scenario leads to a significant amount of users charging at the same time, then the local grid will be able to accommodate far less than 143 electric vehicles.

Figure 4 below presents the same situation as figure 3, with the only difference being that the local grid is now assumed to have 50% unused capacity relative to the highest demand hour in 2007. With this amount of unused capacity a 100 household grid utilising only immediate charging could accommodate 50 electric vehicles. With market price based / fleet operator managed charging in place, this figure is forecasted to rise to 182 vehicles.

[4] This is again based on an average charge of 6.1 kWh per day. If all 30 vehicles in the same neighbourhood were to fully charge their vehicle at the same time the dark blue region would eventually intercept the red line.

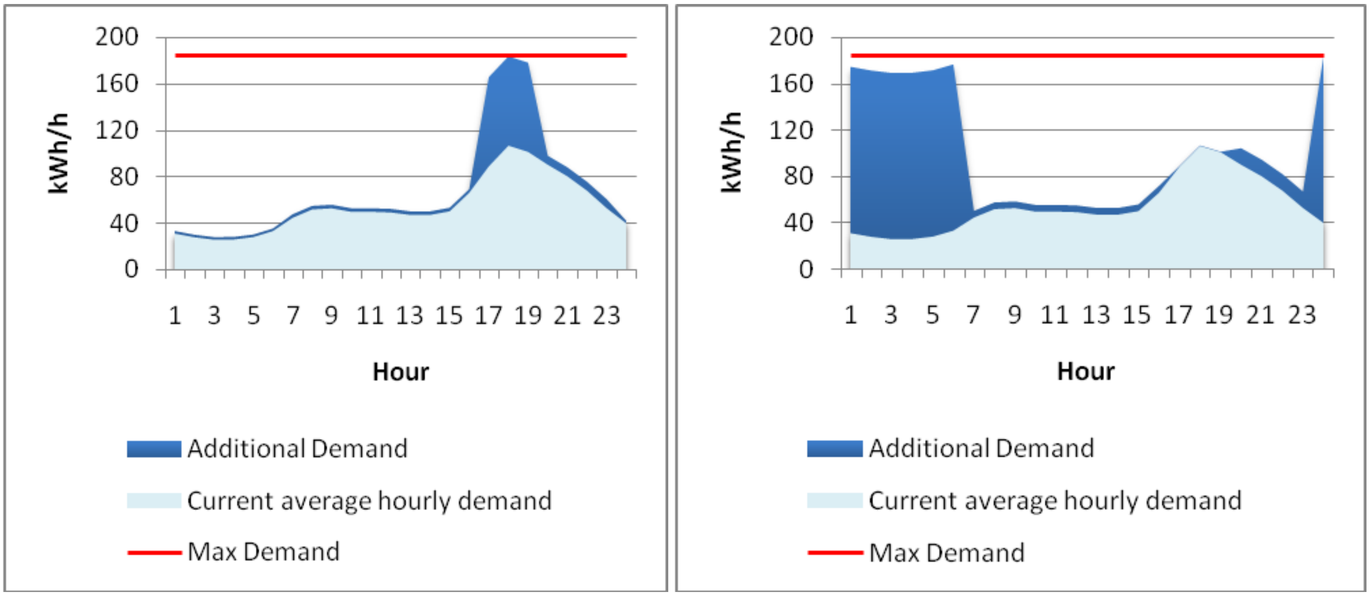

Figure 4: Maximum electric vehicle penetration for a Danish local net given 50% unused capacity under two demand response scenarios. The light blue reflects the hourly demand on the 2007 workday with the highest hourly demand (January 3rd, 2007), the red line represents an additional 50% capacity relative to the maximum demand hour in 2007 (December 24th, 2007). The dark blue represents the additional electricity demand from the number of electric vehicles that the additional capacity allows room for (this last variable will therefore be different in each of the scenarios).

It is interesting to note the doubling of the unused capacity does not result in the doubling of the amount of electric vehicles that can be accommodated by the local grid. This is because the unused capacity is set in relation to the hour in 2007 that had the highest demand (December 24th, from 16:00-17:00), while the current average hourly demand is in relation to the workday that had the hour with the highest hourly demand (Wednesday January 3rd from 17:00-18:00).

Figures 3 and 4 highlight the fact that a significant amount of electric vehicles can be integrated into the local grid if a) there is at least 25% unused capacity in the distribution grid, and b) the demand response tools are successful in spreading the charging out during the night period.

Figures 3 and 4 attempted to demonstrate the amount of electric vehicles a local grid could accommodate given a fixed amount of unused capacity. Another way of approaching this involves holding the amount of electric vehicles fixed, and then forecasting how much unused capacity would be required to accommodate this amount of electric vehicles. This situation is reflected in figure 5, which demonstrates the amount of unused capacity in the local grid that is required to accommodate a 25% electrification of personal vehicles within a local grid. The left side of figure 5 shows a situation where 75% of electric vehicle owners begin to charge their vehicles directly after arriving home from work (immediate charging). In such a situation, if 25% of personal vehicles were to be electric, the local grid would require at least 18% unused grid capacity to cope with this additional demand.[5] The right side of figure 5 on the other hand reveals that if effective demand response tools are in place (market price based / fleet operator managed charging), a 25% electrification of the personal vehicle fleet would not require the utilisation of any unused capacity. In fact, during the busiest hour on a work day, relative to Christmas Eve there would on average be 13% unused capacity in the local grid.

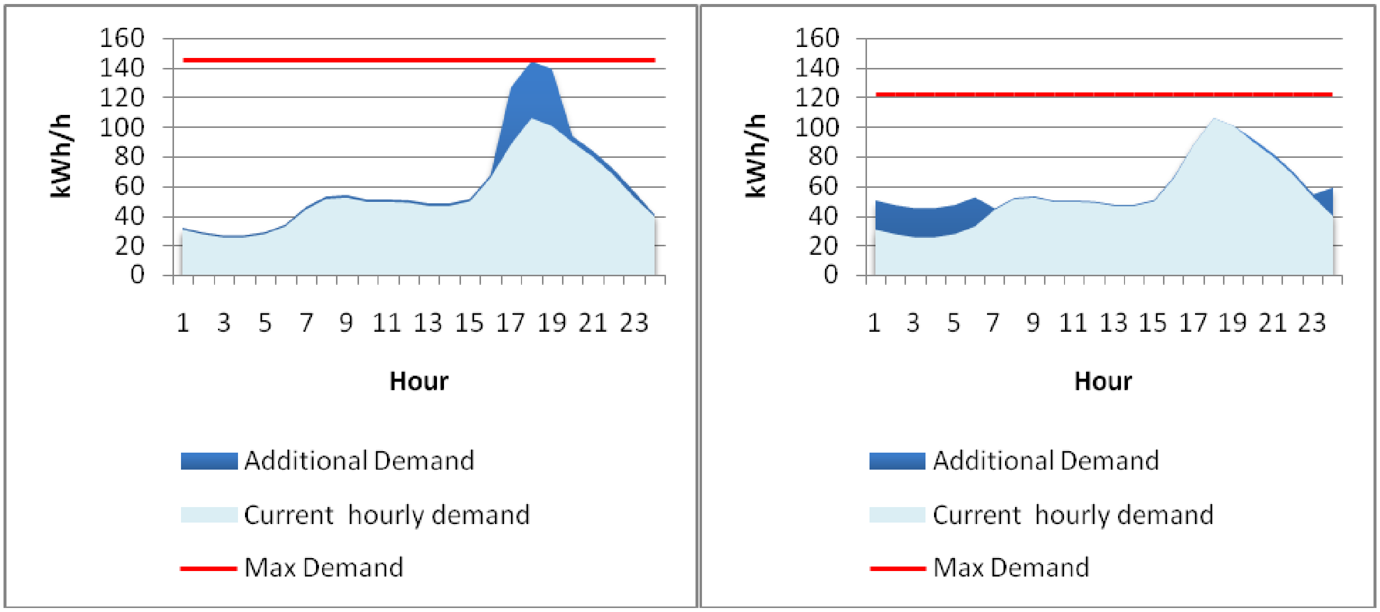

Figure 5: Amount of unused capacity in the local grids required to support the electrification of 25% of the Danish personal vehicle fleet under a) a scenario with immediate charging, and b) a scenario with effective demand response (market price based / fleet operator managed charging). The light blue reflects the average hourly demand on the 2007 workday with the highest average hourly demand (January 3rd, 2007), and the red line represents % capacity relative to the maximum average demand hour in 2007 (December 24th, 2007). The dark blue represents the additional electricity demand based on the electrification of 25% of the Danish personal vehicle fleet.

In the above discussion, the demand response scenarios, whether they involved time delayed charging or intelligent automated demand response (market price based/fleet operator managed charging), both assumed that the additional demand would be evenly spread out over the selected time periods. In practice, the signal that these tools will be responding to will most likely be the market price for electricity within a given hour. In the time delayed demand response situation this could be problematic if the majority of users come to the conclusion that the same one or two hours are usually the cheapest, and therefore set their vehicles to charge at this time. This would result in a situation where local grid capacity in many areas would likely be breached. As such, to be effective, any time delayed demand response demand tool will also have to be able to take into account local grid conditions, whether it be via allocating particular charging hours to customers, or setting a limit on the rate of charge. The same applies to intelligent automated demand response, as an effective technology of this type should

[5] This scenario is again based on unused capacity linked to December 24th, 2007, from 16:00-17:00, and demand equal to that of Wednesday January 3rd, 2007 from 17:00-18:00.

not only be able to react to market signals, but also coordinate the charging needs of other users to ensure that the collective charging is done in an optimal fashion.

Figure 6 reflects a situation where there is a combination of both extremely effective price signals, and complete consideration for the local grid conditions. It assumes 25% unused capacity in a local grid with 100 average Danish houses. It is a highly theoretical situation where the 153 kWh/h level is maintained throughout the day. In such a situation it would be possible to accommodate 386 electric vehicles in the local grid. While likely not a realistic practical situation at any point in the near future, this scenario does highlight the potential for utilisation of the current local power grid without any significant expansion, particularly if the demand load can be perfectly spread out over the course of 24 hours.

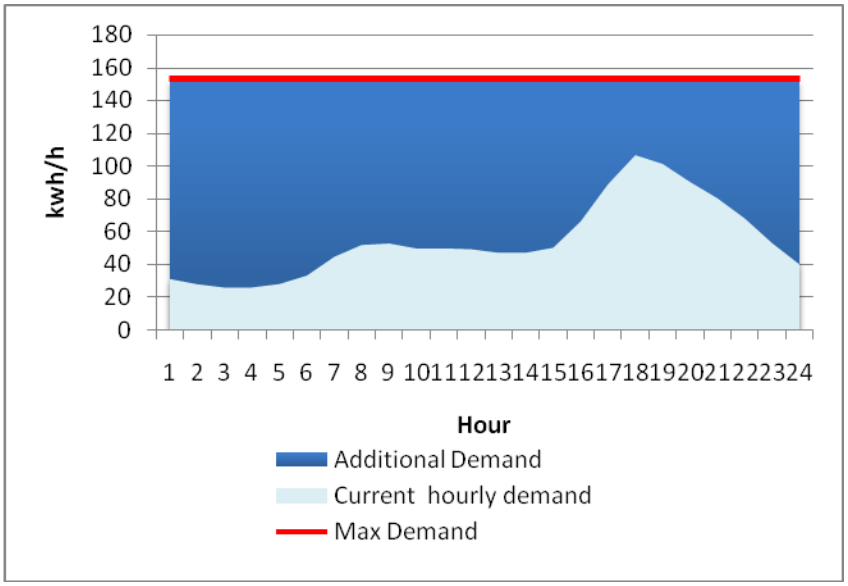

Figure 6: Maximum electric vehicle penetration via optimal utilisation of the local grid given 25% unused capacity. The light blue reflects the average hourly demand on the 2007 workday with the highest average peak demand hour (January 3rd, 2007), the red line represents an additional 25% capacity relative to the maximum average demand hour in 2007 (December 24th, 2007). The dark blue represents the additional electricity demand based on the electrification of 386 vehicles in a 100 house theoretical local grid.

2.3 SUMMARY

Based on simplified scenarios, a theoretical study of the increased load on the electricity system has been carried out. With 25% personal electric vehicle penetration, overall peak consumption is anticipated to increase by 12.5%.

For local grids, if only 18% surplus capacity exists in the grid - relative to the average maximum demand hour in 2007 (December 24th, 2007), 25% electric personal vehicle penetration could be supplied on a workday with the highest average hourly demand, even if the majority of users charged their vehicles when they arrived home from work.

Little available information exists about surplus capacity in local grids. In some cases capacity may be fully utilised, in others capacity limits may be close, while still others may have substantial amounts of excess capacity. In any case, an increase in electrical consumption will move the electrical demand closer to the capacity of the local grids.

If demand response tools are put into place, both the local and national grids can accommodate significant electric vehicle penetration without additional grid capacity. However, to be most effective, these demand tools must be able to take market, local grid conditions, and other electric vehicles needs into account. Amongst other things, a concrete analysis of grid congestion is undertaken in WP2 of the Edison project.

3 MARKET ACTORS

In this chapter an introduction to the electricity market actors is given. A description of actors is relevant in relation to the electricity demand, e.g. charging of EVs. Further introduction to the electricity market can be found in 'Arbejdsgruppen vedrørende udvikling af salgsprodukter på elmarkedet', der understøtter det intelligente elforbrug (2009), and in chapter 4 of WP4 under the Ecogrid study (Energinet.dk, 2009a).

3.1.1 ELECTRICITY CONSUMER – INDIVIDUAL VEHICLE OWNER

The individual vehicle owner can be an ordinary consumer in the electricity market. The EV can be regarded as a new type of consumption in line with other household consumptions such as electrical heating, washing machines, etc. Since 2003 the Danish consumer could freely choose their electricity supplier. From January 1st, 2010 the maximum binding period for a contract between consumer and supplier became six months (LOV nr. 451 af 09/06/2004). The unique thing about the EV is that the consumption (the charging) takes place when the owner is not using the vehicle, implying that the battery allows a greater flexibility in the demand for electricity, thereby giving an opportunity to introduce demand response. The term 'demand response' refers to the fact that vehicle owners adjust their consumption according to the electricity prices.

2009 Study of demand response

A study of demand response in private households with electrical heating in 2009 showed that there are challenges related to the consumers' ability and willingness to act flexibly. It was difficult to 'activate' end-users to adapt their electricity demand to the fluctuating prices without some level of automation. Price signals via e-mail and SMS were not effective in activating demand response in relation to electric heating. With automation the project demonstrated that it was possible to adjust demand without any changes in comfort (DI-Energibranchen, 2009)

The economic benefit of delaying charging is often modest. With a typical difference between the highest and lowest spot price per day of 0.30 DKK/kWh the average cost savings for an electric vehicle would be less than 2 DKK per day.

For the end-user to benefit from demand response an interval meter is needed. Grid companies comprising 50% of all Danish end-users have installed, or will install, new meters within a few years. These meters will be able to read the consumption per hour (or more frequently), and thereby make it possible to use price contracts with prices varying per hour (spot prices), by weekdays/weekends or day/night.

Without an interval meter the end-user is part of a profiling system (*skabelonkunde)* that prevents any economic motivation for demand response.

3.1.2 DSO/GRID COMPANY

Grid companies (distribution system operators, DSOs) operate the distribution grid and are thereby responsible for the supply security through the delivery of power to the customers. In Denmark all grid companies are obligated to ensure that meters are installed and read at all end users. Thus it is the local grid company who is responsible if interval meters are to be installed.

Grid companies are closely regulated monopolies. They must be legally and management independent from other companies, e.g. commercial companies such as generators (see below). The grid companies are benchmarked and the tariffs are controlled by the regulator.

3.1.3 RETAILER

The retailer acts as a link between the power market and the consumer. The retailer communicates the consumers demand to the power market, purchases electricity from the power market and resells it to the various consumers. Electricity can be bought on the Nord Pool power exchange or directly from a local generator.

Some retailers are also load balance responsible (LBR), and in some cases several retailers use a common load balance responsible. Currently 11 companies in Denmark act as load balance responsible for demand (www.energinet.dk). The main task of the balance responsible is to make a plan of the consumption and production for the upcoming day.

In case of imbalances (deviations from the plan) the balance responsible has to pay for imbalances to the TSO, Energinet.dk. In some situations it is costly to have imbalances, and average costs of imbalances are 5 øre/kWh (1/1 – 1/12 2009, West and East Denmark).

The balance responsible can be active on the regulating power market and submit bids related to up and down regulation to Energinet.dk. Today electric boilers in the district heating system are the only type of Danish demand that is active in the regulating power market.

3.1.4 GENERATOR

The electricity generator produces power to the electricity system. The generators bid in with their expected power production on the Nordpool Spot market every day for the upcoming day.

Some generators are production balance responsible (PBR) and are thus responsible for balancing the actual production according to the planned production.

3.1.5 FLEET OPERATORS

A fleet operator is defined as an actor that operates a number of EVs in their interaction with the power system, but is not necessarily the owner of the EVs. The fleet operator can either be an independent actor, or it can be the retailer. By pooling the EVs under a common operator they can act together like a larger consumer. The fleet operator can manage the charging of the individual EVs, i.e. automate the charging and provide other services to the EVs.

The fleet operator has a contractual agreement with the EV owner that describes the conditions for charging, level of control, payment, etc.

3.1.6 TSO

The Transmission System Operator (TSO) is responsible for the overall security of supply and to ensure a well-functioning electricity market by maintaining the electrical balance in the power system, and by developing market rules. The Nordic TSO's own the Nord Pool power exchange.

3.1.7 NORD POOL

Nord pool manages the Nordic power exchange, which includes the physical trade in the two markets Elspot and Elbas and the financial markets (see next chapter).

Figure 7 on the following page illustrates the market actor set-up with the actors as described above. Data for the consumer's electricity consumption is recorded in the meter and sent to the DSO. After consolidation of data, they are sent to the TSO and load balance responsible.

The consumer enters a contract with a retailer (or with a fleet operator). Each retailer refers to a load balance responsible. The load balance responsible sends a plan for the next day's electricity demand to the TSO. The electricity can be bought from the power exchange Nord Pool. If the actual generation or consumption differs from the scheduled plan the difference is bought or sold from the TSO as unbalances.

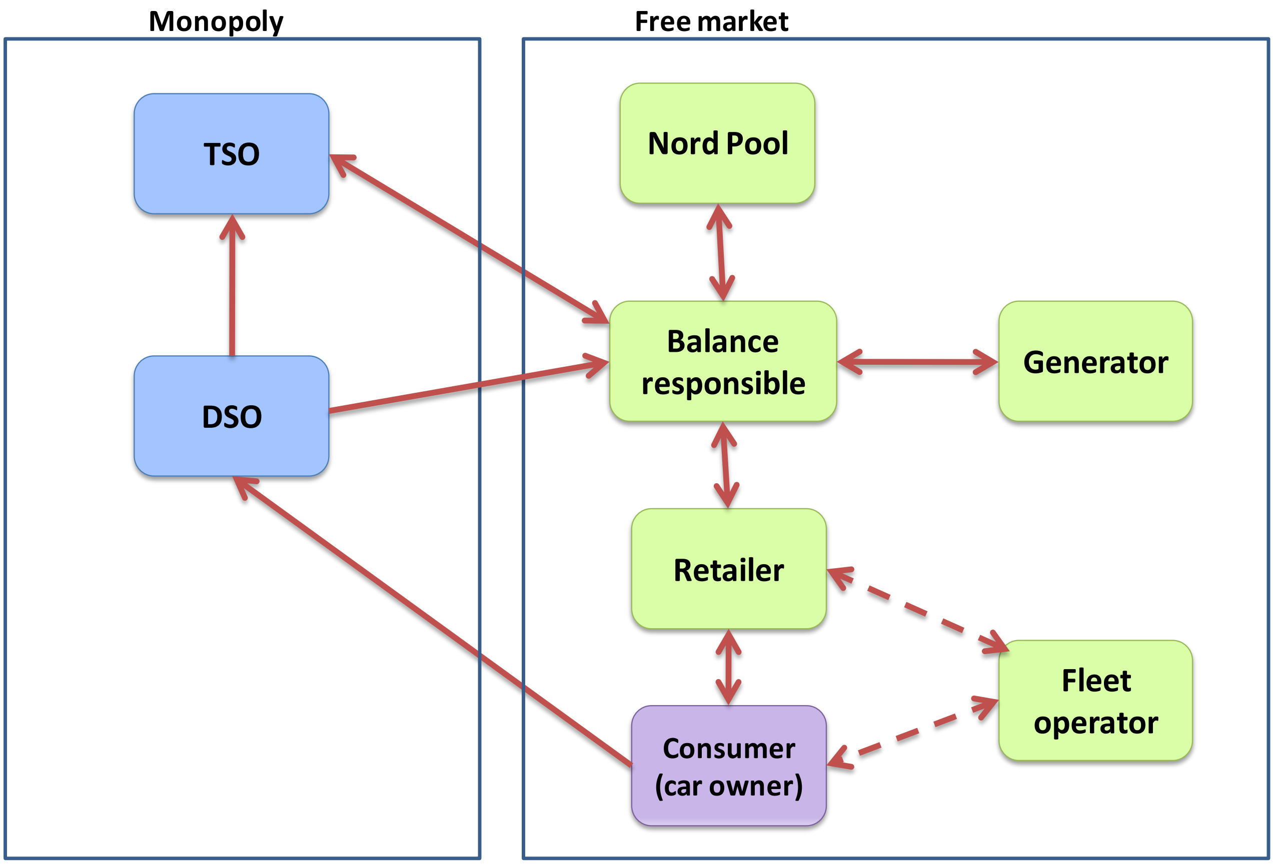

Figure 7: Simplified illustration of the interaction between the market actors in the Nordic power system.

4 ELECTRICITY MARKETS

The current Nordic electricity market consists of a number of specific underlying markets based on a timeline for the bidding offers. Figure 7 illustrates the major components of this market.

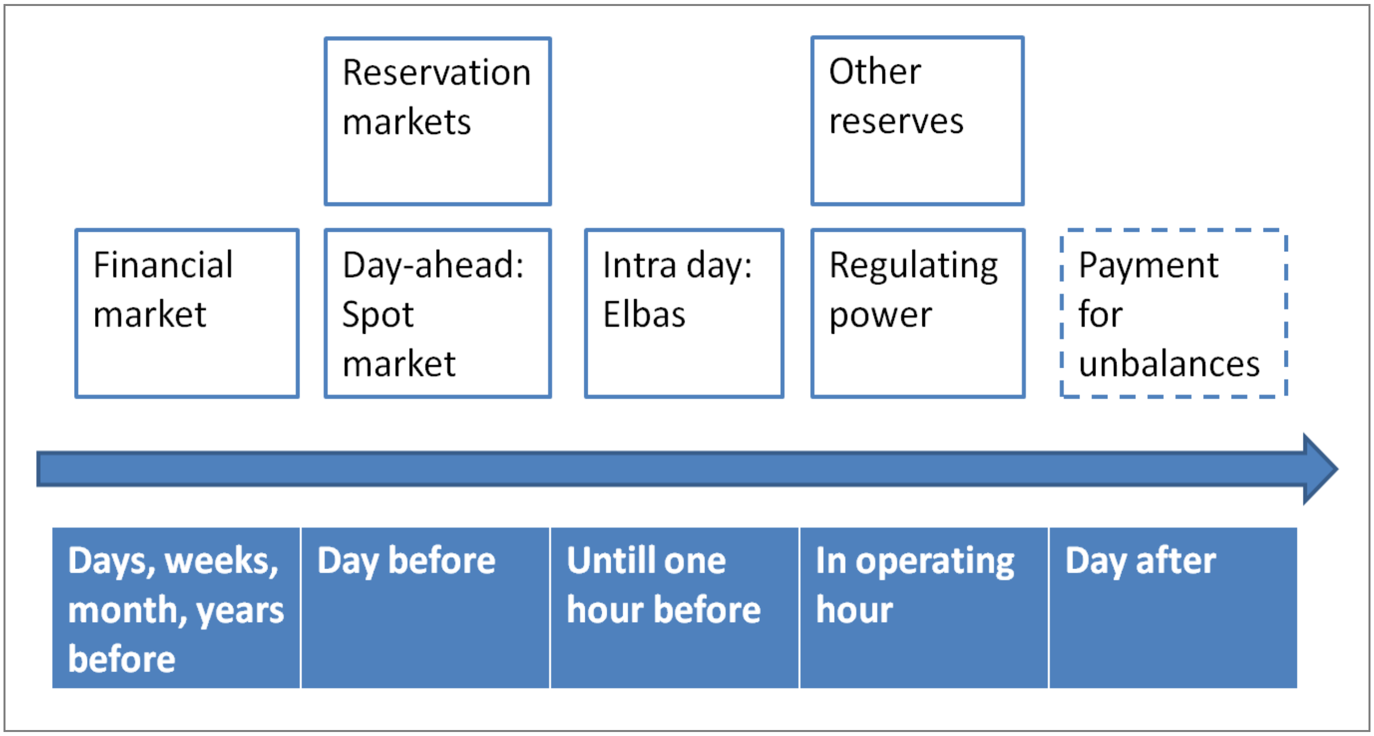

Figure 8: Different markets for different time regimes – the Nordic set-up. The reservation markets include reservation of resources for the regulating power market.

It should be noted that the Nordic electricity markets are constantly developing. The development in the Nordic system and in Europe as a whole is towards one European cross-border market. This means that unless changes are in the direction of the common European setup, dramatic changes are not realistic in the short term. This setup is defined in groups managed by the European regulators, ERGEG. All the Nordic markets are geared towards a European setup, in large part because in many circumstances it was the Nordic market setup that has been the basis for the broader European setup.

4.1 THE SPOT MARKET AND THE FINANCIAL MARKET

The central Nordic energy market is the spot market (Nord Pool Spot) where a daily competitive auction establishes a price for each hour of the next day. The trading horizon is 12- 36 hours ahead and is done in the context of the next day's 24 hour period. The system price and the area prices are calculated after all participants bids have been received before gate closure at 12:00. Participants' bids consist of price and an hourly volume in a certain bidding area. Retailers bid in with expected consumption while the generators bid in with their production capacity and their associated production costs. Different types of bids exist, e.g. a bid for a specific hour or in block bids, which exist in several variations. The price is determined as the intersection between the aggregated curves for demand and supply for each hour – taking the restriction imposed by transmission lines into account. Figure 8 illustrates the formation of the system price on the spot market as a price intersection between the purchase and sale of electricity.

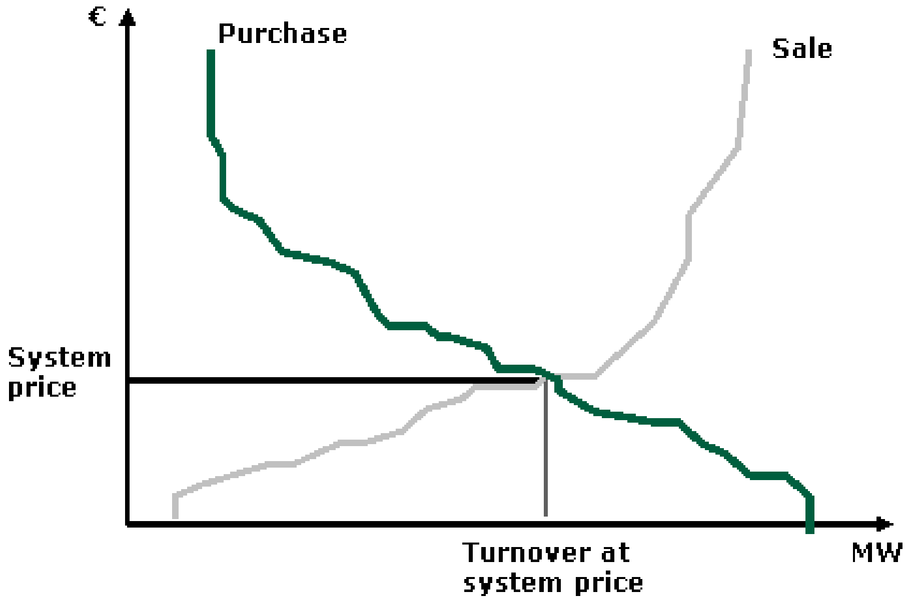

Figure 9: The formation of the system price for electricity on the Nord Pool Spot market. (www.nordpoolspot.com)

The financial market is a commercial market, where price securing contracts are traded. The financial markets trade futures and other derivatives that are settled against future spot prices; it is possible to enter a future contract involving for example 100 MW next year. Most liquidity is related to financial contracts targeting the *System Price.* The System Price is an artificial price that would be the result, if no congestion exists. Financial contracts manage risks and are essential for the market participants in the absence of long-term physical contractual markets.

In order to handle grid congestions the Nordic exchange area is divided into bidding areas. The bidding areas are consistent with the geographical area of each of the TSOs. Denmark is however divided into two bidding areas, East and West (DK2 and DK1). The same goes for the Norwegian grid that is usually divided into two bidding areas. Participants must make their bids according to where their production or consumption is physically located in the Nordic grid areas. In this way the transmission capacity between the different bidding areas is implicitly auctioned via the area spot price calculation. Thus, whenever there are grid congestions, different price areas are formed. The participants' bids in the bidding areas on each side of the congestion are aggregated into supply and demand curves in the same way that the System price is calculated. Figure 9 illustrates the formation of the area prices.

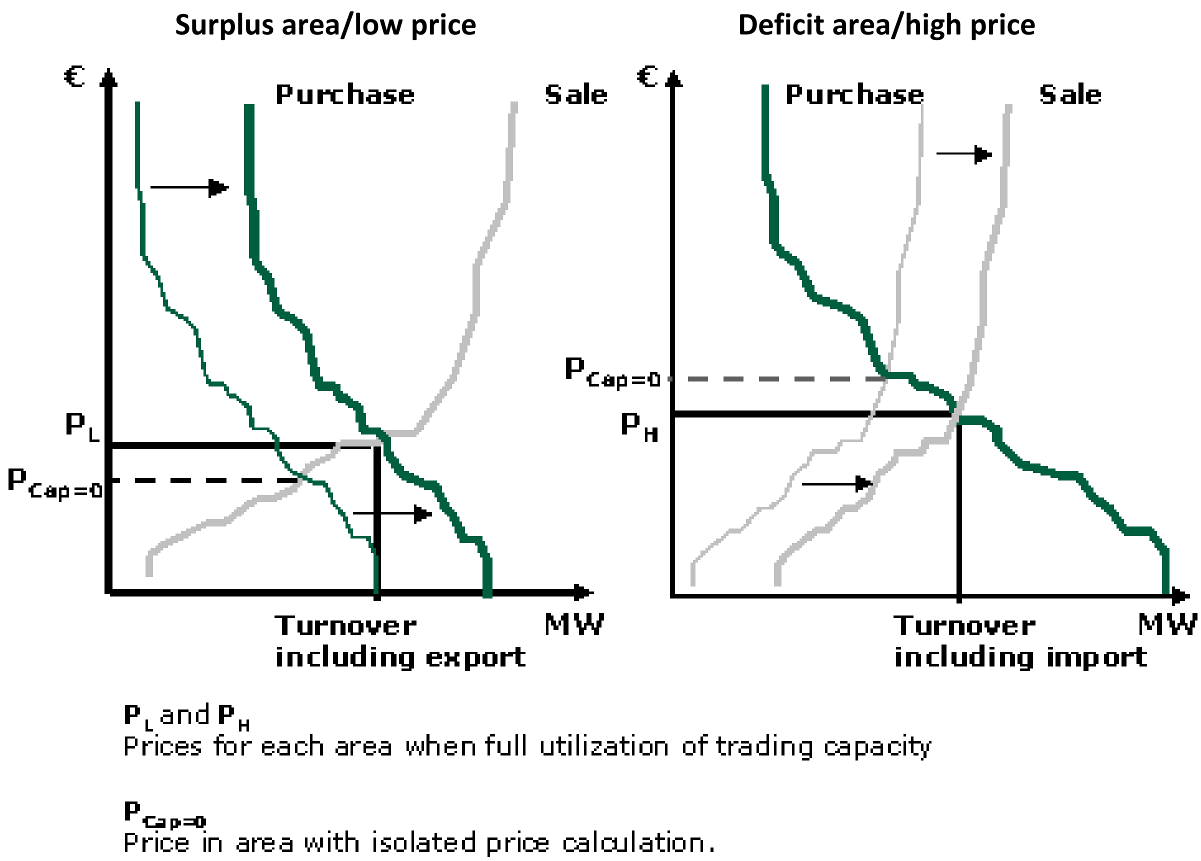

Figure 10: The formation of the area prices for electricity on the Nord Pool Spot market. (www.nordpoolspot.com)

As illustrated in figure 10, a volume corresponding to the trading capacity on the constrained connection is added as a price independent purchase in the surplus area (export), and as a price independent sale in the deficit area (import). In the deficit area the import will lead to a parallel shift of the supply curve, while in the surplus area the additional purchase will lead to parallel shift of the demand curve.

By increasing the price in the deficit area, the participants in this area will sell more and purchase less electricity, while in the surplus area a lower price will lead to more purchase and less sale. The area price calculation is repeated so that the capacity between the high price area and the low price area is utilized to the maximum. Each TSO area may contain one or more price areas depending on where the grid congestions are from hour to hour, thus the constellation of price areas may change every hour.

In situations where the power flows between the bidding areas are within the limits set by the TSOs (that is when no congestions exist) the System Price is the price for all price areas.

4.1.1 DEVIATIONS CAN BE HANDLED IN THE ELBAS MARKET

Given that the time from fixing of the price, and the plans for demand and generation in the spot market to the actual delivery hours is up to 36 hours, deviations can occur. Deviations can come from e.g. unforeseen changes in demand, tripping of generation or transmission lines, or from incomplete prognoses for wind power generation. Such deviations can be compensated during the operational day by hourly contracts in the Elbas market up till one hour before the operating hour. However, the liquidity in this market today is limited. Currently, the average Elbas trade in the Nordic area is only 200 MW, although this trade has seen an increasing trend (Togeby et al., 2009).

4.2 THE REGULATING POWER MARKET

In order to have stability in the Nordic electricity system different criteria must be met at all times (Nordel, 2006):

- The frequency of the synchronous system must be between 49.9 and 50.1 Hz,
- The time deviation of the synchronization shall be within the range [-30s, 30s]. Time deviation is found by integrating the frequency deviation from 50 Hz,
- The requirement in RG Continental Europe that every control area has to keep its own balance,[6]
- The transmission capacity must not be exceeded at any line.

These criteria are set by the TSO associations. Before July of 2009 the TSO Association Nordel managed the synchronous area comprised by Norway, Sweden, Finland and Eastern Denmark (DK2) while UCTE managed the Central European synchronous area, including Western Denmark (DK1). As of July 2009 the 6 European TSO associations have merged into ESTO-E, covering all of Europe. The electricity system is still divided into the same synchronous areas, now called Regional Groups (RG). Thus Eastern Denmark is a part of the RG Nordic, and Western Denmark is a part of the RG Continental Europe.

In the hour of operation, several types of reserves ensure stability of the system. The reserves can be grouped into automatic and manual reserves. The system criteria are initially managed by the automatic reserves.

To anticipate excessive use of automatic reserves and in order to re-establish the availability of these, regulating power is utilised. Regulating power is a manual reserve. It is defined as increased or decreased generation that can be fully activated within 15 minutes. Regulating power can also be demand that is increased or decreased. Activation can start at any time and the duration can vary.

In the Nordic countries there is a common regulating market managed by the TSOs with a common merit order bidding list. The balance responsibles (for demand or generation) make bids consisting of amount (MW) and price (DKK/MWh). All bids for delivering regulating power are collected in the common Nordic NOIS-list and are sorted in a list with increasing prices for up-

[6] Western Denmark has a special requirement within the RG Continental Europe keeping its own balance in Jutland.

regulation (above spot price), and decreasing prices for down-regulation (below spot price). Taking into consideration the potential congestions in the transmission system, the TSO manages the activation of the cheapest regulating power.

In a supplement to this, Denmark and Finland also have reservation markets.[7] Resources can receive a payment for being present in the regulating power market. A similar system exists in Norway (RKOM), which is only active during the winter period.

There is an interaction between the spot market and the regulating power market, and the reservation market is used to attract sufficient resources to the regulating power market. For example, with high spot prices it is so attractive to produce for the spot market that a high reservation price is needed to maintain capacity for up-regulation in the regulating power market – and visa verse for low spot prices. The reservation price is established based on the amount needed by the TSO and bids from potential suppliers.

The payments for activating regulating power are passed on to the balance responsible after the day of operation.

Participation in the regulating power market requires that certain elements can be fulfilled. In the case of EVs the most important preconditions are:

- Minimum bid size is 10 MW
- Requirement of real time measurement

The minimum bid cannot be met by the individual EV owner. Hence, if the EV's are to participate in the regulating market this precondition either has to be moderated or the EV's must be monitored more closely, for example aggregated by a fleet operator or balance responsible. The requirement for real time measurements will be very costly to fulfil, and it can be argued that other methods, such as statistical methods, are more relevant in relation to thousands of small units.

4.3 THE FUTURE DEVELOPMENT OF THE REGULATING POWER MARKET

With the intense focus on climate challenges, renewable energy becomes an important tool for reducing emissions from fossil fuels. In Denmark, 800 MW of new offshore wind turbines will be built by 2012. When wind power capacity is expanded, more regulating power will likely be needed due to the limited or imperfect predictability of wind power. Togeby et al (2009) describes the structure of prognoses error in wind power forecasts. It was found that the largest errors occur when medium wind speeds are expected.

[7] http://www.fingrid.fi/portal/in_english/services/balance_services/regulating_power_market/

More wind power is expected to increase the need for regulating power, and thus, more focus will be in the regulating power market. The focus will also be on including more sources.

If small consumption, as in the case of EV's, should be activated in the regulating power market, then the preconditions involving the minimum bid size and the requirement of real time measurement should be carefully investigated.

In May of 2010, the Danish TSO, Energinet.dk, with that purpose in mind, introduced draft thoughts of how small consumption units can be activated in the regulating power market. They suggest publishing a regulating price in the hour of operation to be used only for small consumption. The published price will be the price of the last taken bid from the bidding list (from the more traditional regulating resources). This suggestion will give the possibility to send a price signal to the EV – from both the spot market and from the regulating power market. This case is handled in "contract structure 2" in chapter 7.

It should be noted that this it is a suggestion that the Danish TSO will raise with the rest of the Nordic TSO's as the regulating power market is a shared Nordic market.

5 THE ELECTRICITY PRICE

5.1 THE COMPOSITION OF THE END-USER PRICE

In the context of individual EV charging it is important that the end-user price is broadcasted to the consumers, and that the end-user price is composed in a way that the consumers will in practise react to the price. In the case of a fleet operator subscription, the individual EV has no use for the end user price, as it is optimized by the fleet operator or fixed by contractual terms.

The wholesale price (the spot price) is a part of the end-user price, which also includes taxes, network payments, etc. As shown in figure 11, the end-user price consists of several parts: **Market electricity** (20%) is the commercial part of the electricity, that is, the electricity traded on the spot market. **Transport** (12%) covers the costs of transport of electricity from the production unit to the end-user and includes grid tariffs to the TSO and the DSO. **Public service obligations** (8%) are legal obligations paid by all consumers for subsidies for wind energy and CHPs and research and development. **Taxes** (40%) are fixed proportionally to the amount of kWh consumed by the end-user and covers CO2 taxes, electricity taxes, distribution taxes and electrical heating taxes. Finally, the costumers pay **VAT** on the total electricity bill. For companies the tax is much lower than it is for households.

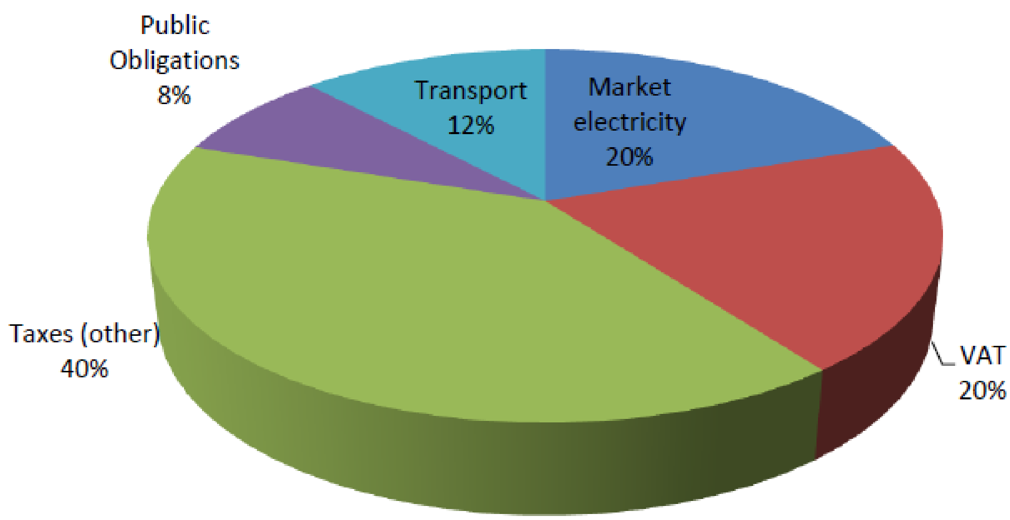

Figure 11: The composition of the electricity price for households. Note that the market electricity, which is the electricity that is traded on the spot market, only amounts to 20% of the electricity price. Dansk Energi (2009a).

Adjusting the various elements of the electricity price may result in having an electricity price that has enough variations (large differences between low prices and high prices) to make it attractive for consumers to react to price fluctuations, i.e. to become flexible.

Figure 12 shows the spot prices for electricity on January 5th 2009. As can be observed from the figure, the price peaks follow the patterns of the consumption figures shown in chapter 2.

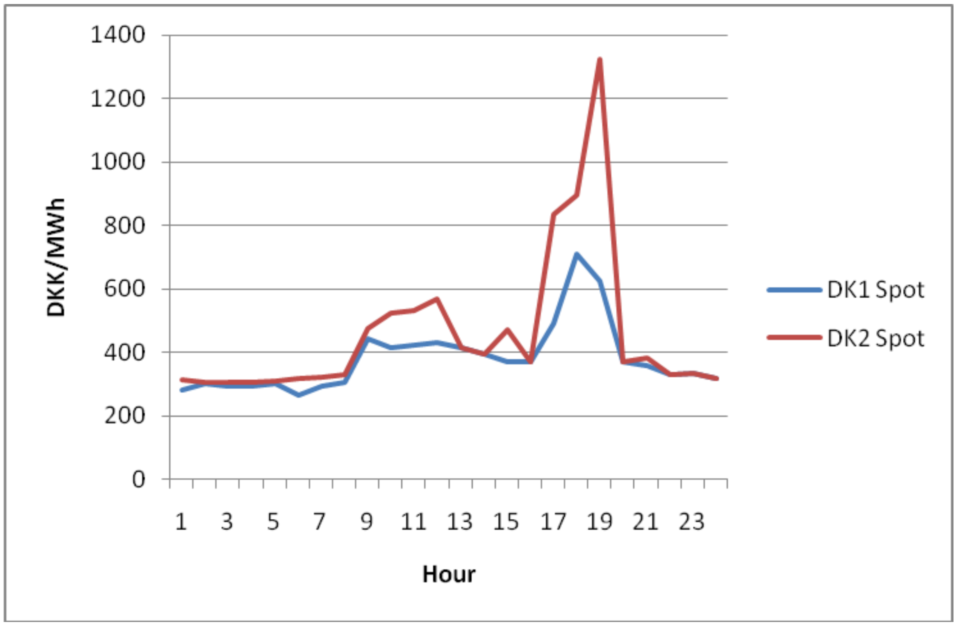

Figure 12: Spot prices in DKK/MWh for Eastern and Western Denmark on January 5th, 2009. Energinet.dk (2009b).

This particular day represents a high variation between high and low prices. When an end-user buys electricity from a retailer, the balancing costs (to cover the cost of regulating power) are typically included as a fixed addition to the spot price (in the order of 10-20 DKK/MWh). Examples of the regulating power prices for the same day are shown in Figure 13 on the following page.

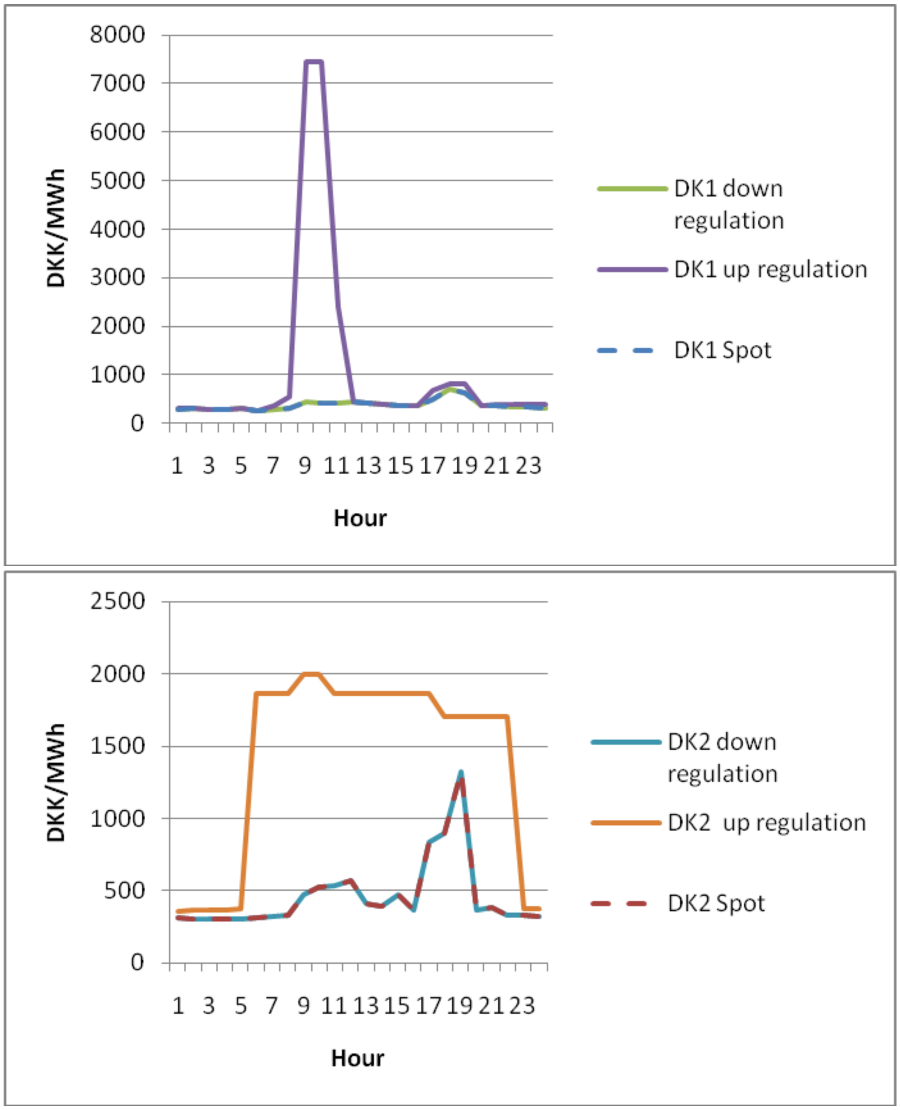

Figure 13: Examples of regulating power prices. 5. January 2009. This day had no down regulation.

5.2 FIXED TARIFFS FOR LOSSES

The losses are in the order of 1% in the transmission grid and 6% in the distribution grid. Today the costs of losses are covered by tariffs to the TSO and the DSO. These tariffs appear in the form of a fixed value per kWh. The tariffs do not reflect the actual price of electricity or the level of losses in the actual hour.

Ideal tariffs for losses should show the *marginal losses* at any given time. Marginal losses are, e.g., the losses an extra electricity demand gives rise to. It can be noted that the marginal losses in practice can vary from -5% to 20% depending on the flow in the grid and the presence of local generation. Negative marginal losses can exist if an extra demand results in less transport, e.g. in cases with export for distribution to transmission grids. Due to the fact that losses are related to the square of the flow in distribution lines, the marginal loss is typically twice the average loss. This results in the highly varying marginal losses. The Danish Energy Agency is preparing a report about dynamic tariffs scheduled for release in June of 2010.

5.3 TRANSPORT AND LOCAL CONGESTIONS

Today **local congestion** is managed by expanding or reinforcing the grid. Each consumer has an installation with a certain maximum power rating; however the grid is designed in a way that takes into account the low coincidence factor between different users. A user may in some situations consume power close to the maximum allowed value, but this is only seldom and not necessarily closely correlated to other users' consumption. In this way the distribution grid is efficiently designed – but it will not be able to deliver the requested power, if a high fraction of the end-users utilise their allowed consumption at the same time. This topic was addressed related to EV charging in chapter 2.

5.4 TAXES

Taxes on electricity used by households are very high in Denmark. Today all taxes are a fixed value per kWh, and only the VAT is a percentage (25%) of the price. The Danish Energy Agency is currently studying dynamic tariffs and The Ministry of Taxation is studying the possibilities of using dynamic taxes in order to help the integration of wind power. Both reports are due for release in June of 2010.

5.5 FUTURE TARIFF POSSIBILITIES

Dynamic tariffs could be used to balance the optimal response to congestion in the distribution grid. Ideally this can be done as an auctioning of the available capacity (in a future with a high penetration of computers and communication), or in a simplified way with time-of-use tariffs. With dynamic tariffs the end-users may adapt their consumption to the varying electricity costs (defined as the sum of energy and transport). This could be via automatic demand response such as air-conditioners, electric heating, heat pumps or charging of electric vehicles. The tariffs for managing congestions in the distribution system could be in the form of critical-peak-pricing (see next section) – so a high price is only used in critical situations.

6 ELECTRICITY SALES PRODUCTS TO ENCOURAGE DEMAND RESPONSE

The end-users' payment for electricity is defined by the contract between end-user and retailer. The different price models presented in this chapter are of relevance to all types of electricity consumption within the households and not only to that of EV's.

All Danish households have a contract that defines the cost of electricity as a fixed value for each kWh used. Often the price is defined for each quarter of a year. This is the case for the majority of end-users that are supplied through the default supply company (*forsyningspligtselskab*).[8] If the end-user has decided to utilise another retailer, the price can be fixed for a maximum period of six months. In general the end-users demand on an hourly time scale is defined by a profile with no communication to the household. As a consequence of this, any demand response reaction cannot be measured and will not be rewarded due to the type of contract. The profile is defined by the grid company (DSO) as the consumption by all end-users without an interval meter. The term 'interval metering' refers to online measurement of the electricity consumption on an hourly basis (or more often).

In all these cases the cost of electricity is not related to the time it is consumed, and no economic motivation exists for demand response. If all households are given an interval meter, more advanced contracts will be possible. With a meter that can be read remotely, the electricity consumption can be recorded daily, or as hourly values.

In the report "Det intelligente elforbrug – Salgsprodukter på elmarkedet"[9] several potential price contracts that can motivate demand response are described (Arbejdsgruppen vedrørende udvikling af salgsprodukter på elmarkedet, der understøtter det intelligente elforbrug, 2009). The different types of products presented in the report are listed and described below, starting with the most simple contract with a fixed price and no intelligence, followed by more complicated contracts including price flexibility. Most products make use of interval metering. It is important to note that if these various products are offered to the consumers, it is unlikely that all costumers will choose to enter the same type of contract. The electricity consumption will most likely disperse over different products and combinations.

6.1 FIXED PRICE

The consumers consume electricity whenever it is needed via a fixed price contract. A fixed price contract is decoupled from the actual hourly price fluctuations. This is the situation for the majority of the Danish households today. As of January 1st,

[8] In the project 'Investigating demand response from households with electric heating', it was found that the default supplier was significantly more expensive than the spot price. This was evaluated over 16 quarters. The reasoning is that the default supplier is closely regulated and most are allowed to charge prices corresponding to the use of a financial contract – at the close of each quarter. This "mechanical" use of a financial contract, which includes the use of financial contracts when the spot price is high, resulted in an over-price compared to the raw spot price. Optimal use of financial contracts can potentially give lower costs than the raw spot price (DI-Energibranchen, 2009).

[9] In English "The intelligent electricity demand – Electricity market sales products".

2010 consumers can only enter into a binding contract for a maximum period of six months. In the case of fixed price contracts there is no need for on-line communication, interval metering, etc. This set-up is called instant charging. The fixed price scenario does not support any demand response. As described in chapter 2, it carries the highest risk concerning grid congestions.

6.2 TIME-OF USE PRODUCTS

A very simple price product could be a price with two time regimes: A low price in weekends and nights, and a higher price in other hours. The time periods can be defined by the individual retailers. The end-user is able to react to such a simple tariff, for example by utilising a timer device.

Different retailers may offer various time-of-use tariffs, e.g. with 2 or 3 regimes and with different definitions of time frames. Due to the fact that different retailers can choose individual definitions of the time frames, no negative impact needs to be related to a common increase of the load. However, if a large number of retailers would choose to offer the consumers the same time periods in their time-of-use contract, there could be a problem in the local grid with a large number of customers activating their consumption at the same time, namely the first hour of the cheapest period. Thus a variation in the retailers' definitions of time frames is preferable.

Examination of the spot price indicates that time-of-use products may prove to be efficient. Take for example the average spot price in weekends and nights (from 22:00 to 07:00) that is 229 DKK/MWh, while on workdays it is 332 DKK/MWh – a price difference of 45%.[10]

The time-of-use-tariff defines periods of high and low prices independent of the actual prices. In this way a time-of-use-tariff averages out many of the extreme price variations. It is a simple tool that can provide better utilization of the power system. However, it does not support any demand response.

6.3 CRITICAL PEAK PRICING

The time-of-use-tariff may lead to a general shift in demand – but is not specifically targeted at the seldom extreme prices. A retailer may choose to use a critical-peak-price in order to target unusually high or low prices.

A critical-peak-price can be a fixed price combined with a high and a low price that can be activated, i.e. with a days notice. A price-product could thus be 300 DKK/MWh in all hours except for 50 low price hours per year and 50 high price hours per year – all announced the day before.

[10] Data from West Denmark (DK1) – 1.1.2002 to 19.1.2009

The French Tempo tariff is one example of this type of tariff.[11] Figure 14 displays a simplified critical peak price.

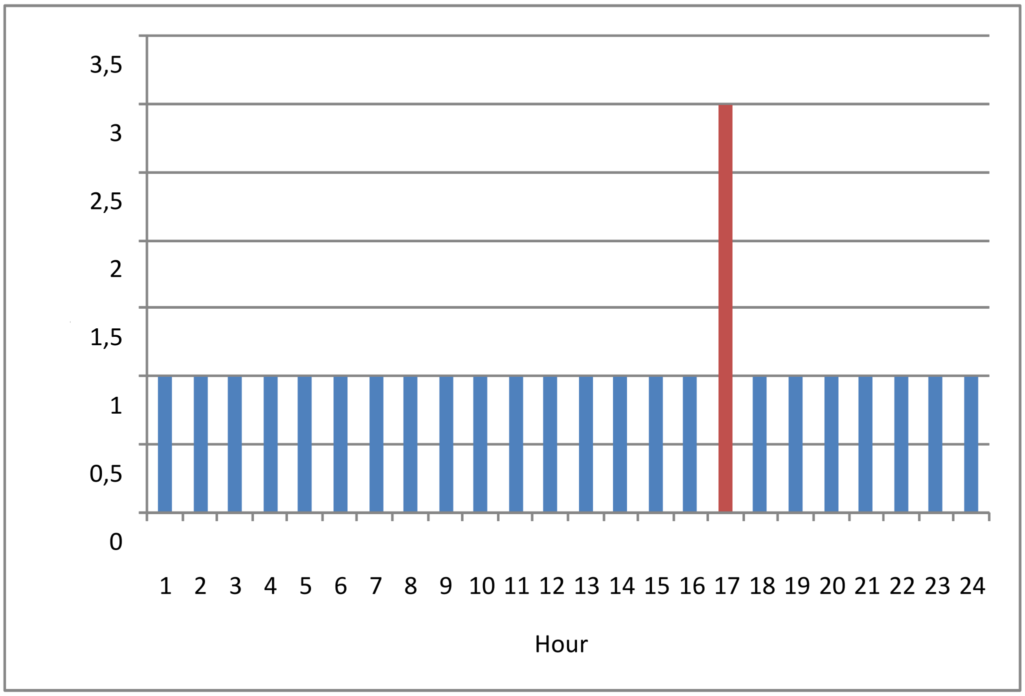

Figure 14: Theoretical example of a critical peak pricing (CPP): A constant price combined with a high price that is only activated when needed. One day notice can be given. Often a maximum number of expensive hours are promised.

As was the case with the time-of-use tariff described above, it is important to note that each individual retailer can choose its own definition for the criteria of the critical peak prices. In this way a situation can be prevented where all costumers start consuming directly after the critical peak hour, and thereby creating a new peak.

This product demands a higher level of communication compared to the time-of-use tariff. Nevertheless, the critical peak price will enable some degree of demand response around the hours where the high peak price is scheduled.

6.4 SPOT PRICE

The most detailed/advanced contracts include price signals for every hour and imply broadcasting of the spot price. With a spot price (or a day-ahead price) the end-user pays the actual price for electricity in each hour. An interval meter keeps track of the actual hourly consumption. The price is published at 13:00-14:00 the day before, for each hour of the day. The end-user in

[11] http://www.edf-bleuciel.fr

this scenario is motivated to move the electricity consumption from expensive hours to less expensive hours. Typical spot prices are in the in the order of 0.04 €/kWh, but can be zero (and from November 30th, 2009 even negative, with a lower limit of -0.20 €/kWh). Prices around 0.20 €/kWh also occur.

The end-user can react to the general pattern in the prices (e.g. lower at nights) or can react to the actual values. In order to react to actual values, automation solutions should be used, e.g. as demonstrated in the projects with spot prices for households with electric heating (DI-Energibranchen, 2009). An alternative is to inform the end-user when extreme prices occur. If this takes place a few times per year the end-user can manually adjust the consumption.

Figure 15 shows an example of a spot price communicated to the customers in the demonstration project (DI-Energibranchen, 2009). The red hours reflects high electricity prices while the green hours reflects low prices (relative to the average price in yellow).

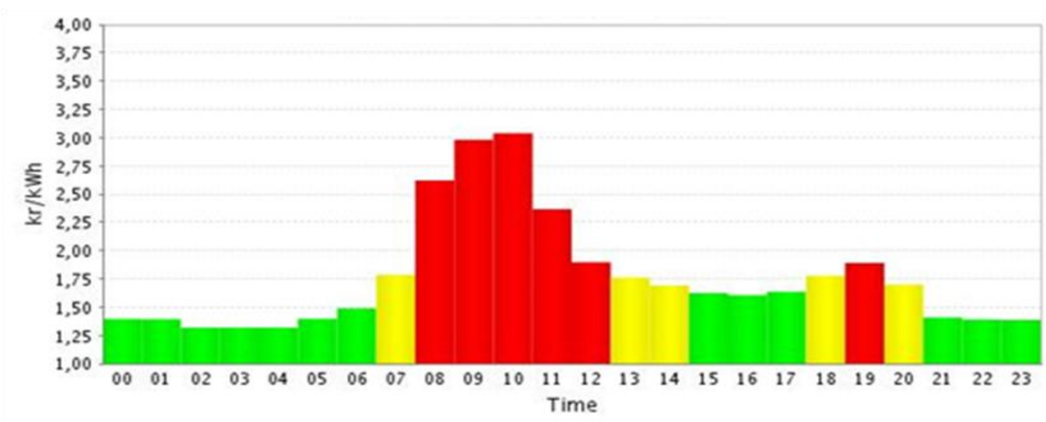

Figure 15: Example of a spot price. Red and green are used to highlight high and low prices respectively. The tariff is a spot price for energy added to a constant payment per kWh for transmission and distribution and taxes as described in chapter 5.

A precondition for obtaining some level of demand response in the spot price scenario is a communication system that enables broadcasting of the hourly spot prices for the following day to the consumer.

6.4.1 SPOT PRICE WITH A FINANCIAL CONTRACT

The spot price can be combined with a financial contract. When a contract for e.g. the next half year's electricity is entered as a spot contract, the end-user can at the same time choose to enter into a financial contract. A financial contract guarantees the average spot price. When combining a spot price contract with a financial contract the end-user can combine the best of two worlds; the end-user can benefit from demand response, and at the same time the average spot price is known beforehand. This type of contract is well-known amongst large-scale end-users, such as industrial companies. The financial contracts may optimally be utilised only when prices are low. Since the value of financial contracts is highly influenced by the current spot price, a combination of spot price contracts and financial contracts (when prices are low) may be an optimal purchasing strategy.

This concept may in the future be maintained by the retailer – so the end-user does not need to speculate on when it is optimal to fix the price.

6.4.2 REMOTE CONTROL OF DEMAND

With a spot price, with or without financial contracts, the end-user is in charge of the demand response, e.g. timing of the charging of the electric vehicle.

The end-users can also choose to give the task of optimising the charging to the retailer or a fleet operator. The retailer may offer a simple contract, e.g. with a fixed price – but with a discount compared to the traditional fixed price. Different retailers and fleet operators may offer different types of user interfaces. One retailer or fleet operator may decide the EV charging independent of user needs, while others may give room for some or full user influence. An advantage of this set-up could be that the retailer and fleet operator may reduce the cost of the automation and control systems due to a large volume. However, this setup demands a two-way communication system where the retailer or fleet operator has knowledge of the state of the individual EV, such as driving patterns, charging preferences, state of charge of the battery, etc.

6.5 FUTURE CONTRACT POSSIBILITIES INCLUDING REGULATING POWER MARKET

The retailer can also include regulating power in the pricing in order to take advantage of the high variation in prices in the regulating power market. For end-users with demand that can be controlled, regulating power can reduce the electricity cost, e.g. by dispatching demand to periods with low prices. To be active in the regulating power market the electricity demand can be remotely controlled, or the end-user can receive a dedicated price signal indicating the need of regulating power.

7 EVS IN DIFFERENT MARKET STRUCTURES

In figure 7, the actors in the electricity market were defined. This chapter introduces three possible interactions between the EV and the electricity market, step-by-step, starting with the simplest model for a contract structure between the vehicle owner and the market. The three different charging strategies that were introduced in chapter 2 were:

1) Immediate charging: The vehicle charges whenever the consumer needs it to, regardless of the electricity price.
2) Time delayed charging: The vehicle charges in predefined time periods e.g. during night time. The charging is controlled by a simple timer.
3) Market price based / fleet operator managed charging: The vehicle charges in the cheapest hours, e.g. the three cheapest hours until 07:00 the next morning based on received price signals. An advanced version of this scenario involves introducing a fleet operator to optimise the charging strategies for an aggregated pool of EV's.

All three charging scenarios will fit into all three contract structures except for minor changes in the market rules under the third contract structure, which will be described in the following.

7.1 CONTRACT STRUCTURE 1 – THE CURRENT SPOT MARKET

The EVs can interact with the current spot market without any changes in market rules.

The EV owner with a conventional manual off-line meter must charge at a fixed price as he cannot make use of intelligent charging. With time fluctuating prices in place the end-user can decide to react to these in a simple way, or in a more advanced way.

The EV owner with an interval meter can decide to buy electricity via a type of contract with varying prices. Assuming the introduction of other electricity sales products this could be a simple time-of-use contract (e.g. with low prices at nights and weekends) or a Critical Peak Price contract (e.g. with occasional high and low prices).

More intelligence can be obtained with an interval meter combined with a home automation device reacting to hourly signals as spot prices. This combination gives the opportunity for the EV owner to utilise the fluctuations in the electricity prices and thus obtain more favourable prices. As discussed in chapter 5, the composition of the end-user price can in the future include time variation of tariffs for transport of electricity and taxes to give more time variation in the price.

The following figure illustrates the interaction and communication between the end-user (EV) and the retailer in the electricity market using only spot prices announced every day at 14:00.

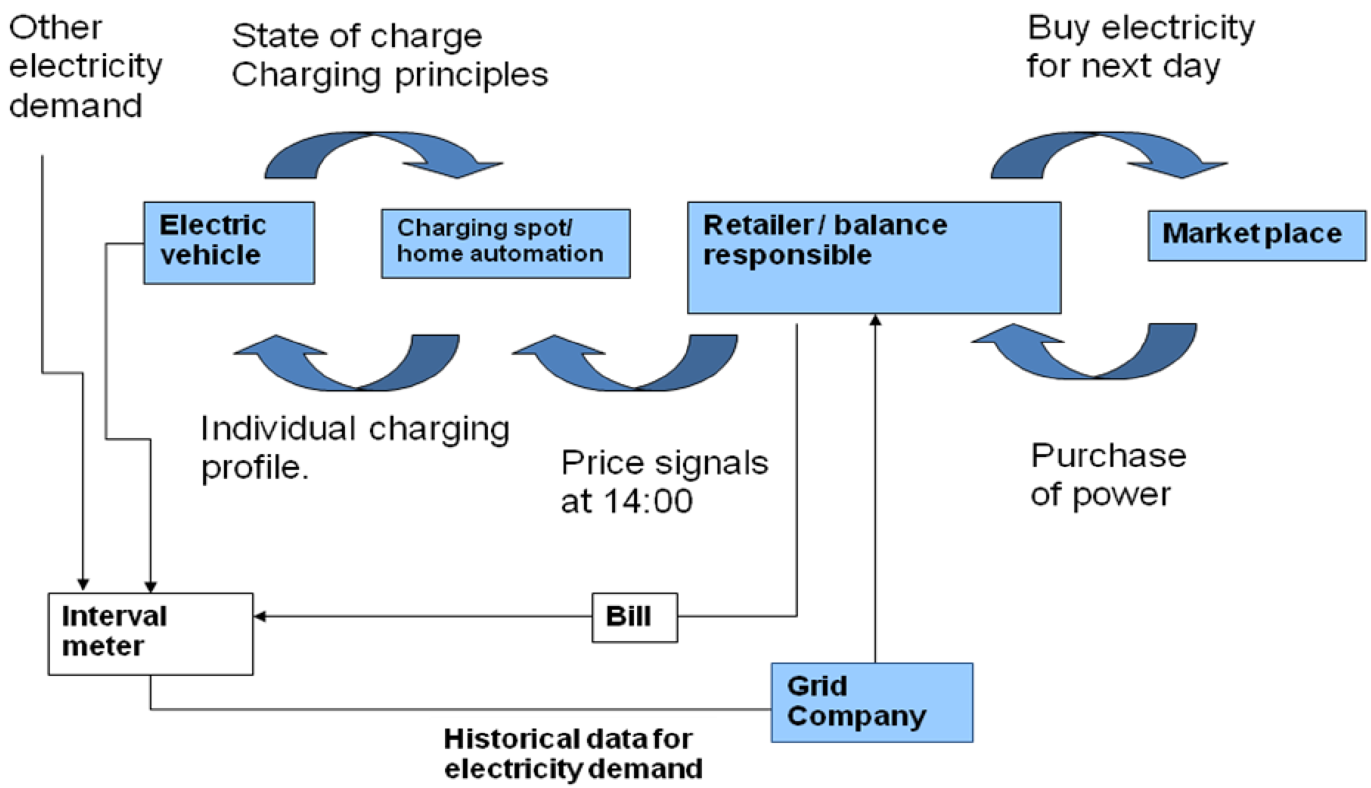

Figure 16: Communication with contract structure 1. Prices are broadcasted from the retailer and received by the household. The only information going from the end-user to the retailer is the historical consumption data. Based on these data the retailer plans for the next day.

7.1.1 ELECTRICITY IS BOUGHT BASED ON HISTORICAL DATA

As illustrated in figure 16, the electricity demand of the household is controlled by an interval meter that delivers historical data about the hourly electricity demand via the grid company to the retailer. These data are based on the EV consumption and other electricity consumptions of the household. A home automation device connected to the EV could deliver information on its state of charge and its predefined charging principles to the charging spot.

With a large number of consumers with EVs, the retailer can forecast the next day's aggregated EV electricity demand based on historical consumption data. This is the current procedure applied for most end-users concerning electricity consumption, including small and large end-users.

Based on historical data for demand for all costumers the retailer communicates the EVs demand (and other electricity demand in the household) to the electricity market for the next day. When the spot market closes and the prices for the next 24 hours are fixed, the retailer delivers signals to the EV charging spot, for example price signals. The EV can now, based on its individual charging strategy, charge according to known prices.

7.1.2 CHARGING STRATEGIES

As mentioned above, all three charging strategies that were introduced in chapter 2 can function in the current spot market with the introduction of an interval meter. The EV's can interact with the current spot market without any changes in market rules either as immediate charging, time delayed charging or market price based / fleet operator managed charging. The fleet operator scenario is further treated under 'contract structure 3'.

The time delayed charging can be based on charging needs and historical prices. One EV owner may set the charging to start at midnight, another at 22:00. This will avoid charging at 17:00-18:00 – the typical time for high prices - and will therefore charge in many of the hours where zero or negative prices can be realised. This simple strategy may be optimal because of the low investment cost related to the automation. However, the strategy will not always target the very lowest prices. With this strategy the end-user may analyse the prices once a year and therefore not need the daily information about next day's prices.

With some kind of home automation in place the EV owner may choose a more advanced strategy. If the retailer communicates the electricity prices for the upcoming 24 hours, the EV owner can choose hours to charge based on predefined needs (e.g. it has to be fully charged by 7 a.m.). The home automation device could automatically choose the cheapest hours within the defined charging period.

The strategy can be designed so that a plan is defined by the home automation based on the consumers predefined needs each time the EV is connected to the charger. Every time the EV is disconnected and connected again, the charging automation will automatically create a new charging strategy based on known electricity prices.

7.2 CONTRACT STRUCTURE 2 - THE SPOT MARKET AND THE REGULATING POWER MARKET

In the above contract structure 1 the EV is reacting to the spot prices only. Relative to a fixed price contract this makes it possible to reduce the costs of charging. However, the costs may be reduced even more if the EVs are exposed to prices reflecting regulating power prices. This is because the price variation for regulating power is larger than for spot prices, and the battery capacity can be utilised to a greater extent. Regulating power is more or less defined as consumption that can be activated within 15 minutes.

This contract structure requires changes of the current rules (see chapter 4 for work in progress to develop the regulating power market to handle small consumption). Three challenges are associated with handling EVs in the regulating market:

- Firstly, it is currently required that suppliers of regulating power must have online-measurements. This would be expensive for a fleet of thousands of EVs. In the following text it is assumed that this requirement is relaxed.
- Secondly, the current requirement of a minimum bid size of 10 MW prevents EVs from participating separately in the regulating power market. Participation would require an aggregation of thousands EVs to reach the 10 MW requirement.

- Lastly, the activating or stopping of charging of EVs due to regulating power will change the expected charging profiles/strategies and thereby alter the reliability of the historical data that the demand bids on the spot market are based upon.

For the EVs to act on the regulating market there needs to be a communication between the retailer and the EV. This communication can be a one-way price signal. The price signal can motivate the EV to alter its charging plan. Charging can be activated or stopped according to price signals from the regulating market. The retailer can predict the effect based on historical data. This set-up is simple and can deliver certain accuracy in the prediction. A more advanced solution is described below in contract structure nr 3.

The following figure illustrates the interaction and communication between the end-user and key actors in the electricity market using the spot prices and the regulating power market. Compared to contract structure 1, price signals are sent to the charging spot/EV at 14:00, and when needed in respect to beneficial bids at the regulating market. Only local control of the EVs is considered in this contract structure.

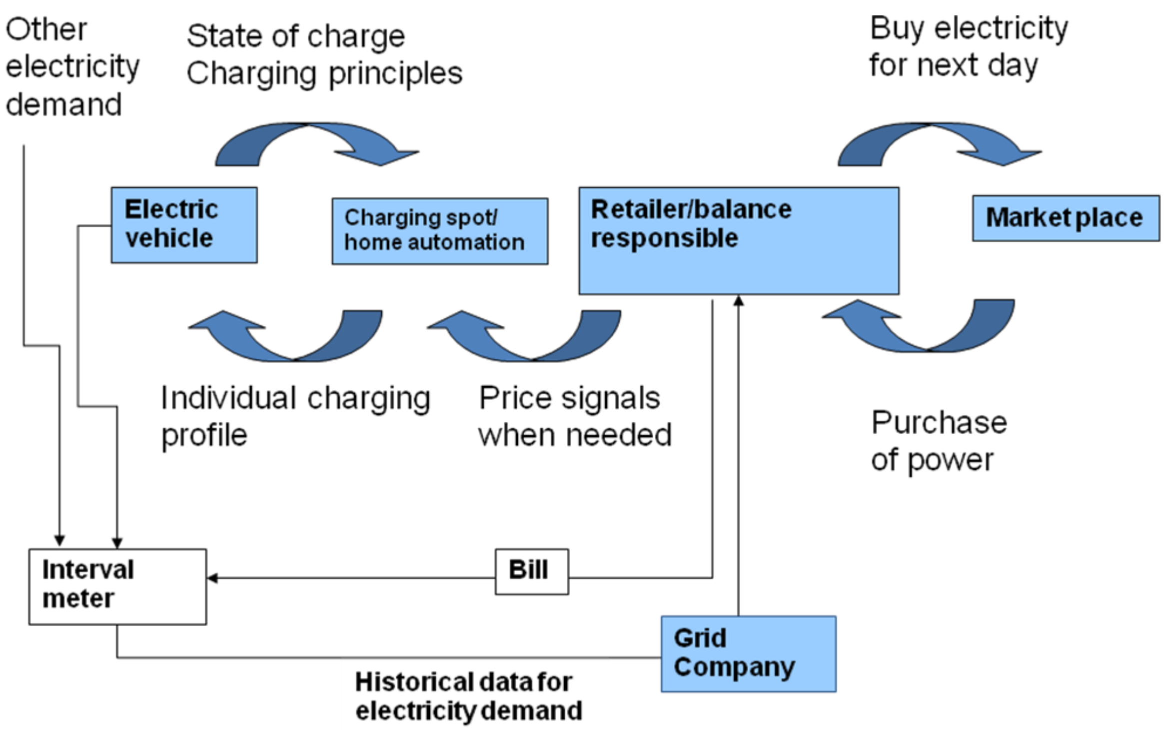

Figure 17: Communication under contract structure 2. The market place is now both the Nord pool spot market and the Energinet.dk regulating power market. The system requires changes in the current market rules.

7.3 CONTRACT STRUCTURE 3: EVS CONTROLLED BY A FLEET OPERATOR

The requirement for predictable results in the regulating power market can be met by introducing more advanced communication equipment with online measurement. In order to be able to prove a given output in the regulating market more information is needed. Within a centralised control system the information flow can be collected, including the status of the EVs, by a fleet operator.

The individual vehicle will need a price signal, whether it comes directly from the electricity retailer, or goes through a fleet operator. In the case of using a fleet operator, the fleet operator will need historical or statistical data on all the EVs under its management: How charged is the individual vehicle right now, is it charging at this very moment, what does the vehicle's driving pattern look like, what are the pre definitions of the vehicle, etc.?

The figure below shows the interaction and communication between the key actors in the spot market and regulating market with the use of a fleet operator.

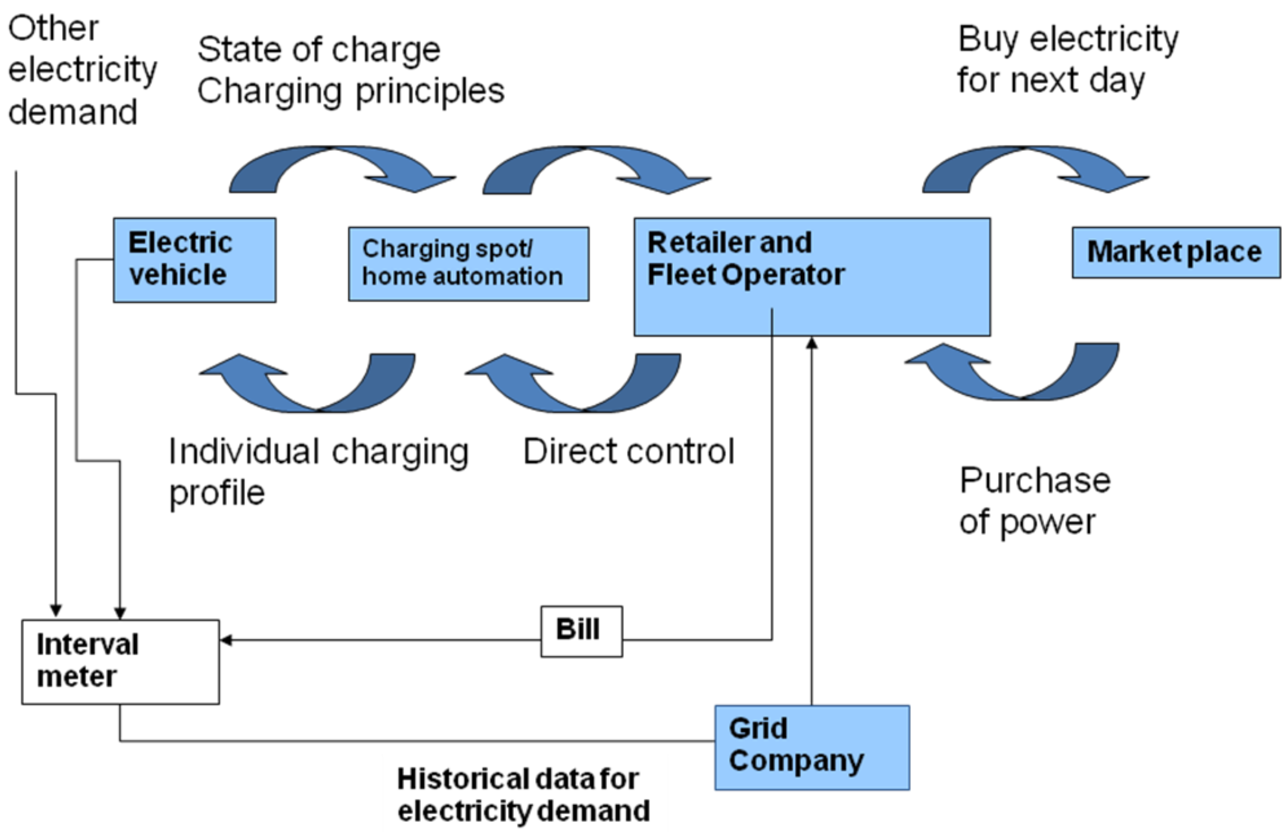

Figure 18: Contract structure 3. The spot market + the regulating market with a fleet operator

The fleet operator makes a bid to the regulating power market. Now real time communication with the EV is needed. The fleet operator will need to know the average consumption, the potential additional consumption, and potential consumption reduction.

7.4 SUMMARY

The advantages and challenges connected to EVs in the different market set-ups are listed below - how suitable local control and central control for example by a fleet operator are with the variable models.

Local control with the individual EV is best suited for contract structure 1 (spot market only), and can be combined with either fixed pricing, Time-Of-Use pricing (TOU), Critical peak pricing (CPP) or spot pricing. This is possible today and the set-up is quite simple as the only requirement is a broadcast of prices once a day.

Central control through a fleet operator is more relevant to the contract structure nr 3, where EVs are operating on the regulating market as well. Contract structures 2 and 3 could imply more attractive prices for the costumer (the EV owner,) but also requires more advanced communication (real time) and is not possible today because of the framework requirements from Energinet.dk.

8 FURTHER WORK

In continuation with the work done within this report, further work will address the following topics:

- Possible and needed changes in the existing regulating power market to ensure EVs participation will be further analysed and discussed with Energinet.dk.
- European perspective and how the markets are developing in Europe.
- Foreign experiences with different market set-ups will be examined and discussed in relation to the possible future market designs mentioned above.
- Future market designs that could support the introduction of electric vehicles will be studied with special attention to real time markets.
- The present work will be extended by taking the vehicle-to-grid (V2G) aspect into account. V2G introduces problems with requirements for unbundling of demand and generation.
- The present work will be extended by taking other reserves and ancillary services into account, e.g. frequency controlled reserve.

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