MOBILE ENERGY RESOURCES

IN GRIDS OF ELECTRICITY

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ASSESSING IMPACTS FROM EV PRESENCE

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GLOSSARY

TERM	DEFINITION
BDG	Bio Diesel Generators
DC	Dumb Charging
DERs	Distributed Energy Resources
DMS	Demand Side Management
EVs	Electric Vehicles
ICT	Information and Communication Technologies
MG	Micro Grids
PVs	Photovoltaic Systems
RES	Renewable Energy Sources
SC	Smart Charging
SO	System Operator
V2G	Vehicle to Grid
VPP	Virtual Power Plant
WECs	Wind Energy Converter

CONTENTS

1 INTRODUCTION

The share of Renewable Energy Sources (RES) in the European energy mix is expected to increase during the following years, due to the carbon emission reduction targets of several European countries. Recent discussions on the reliability of nuclear power and their stringent necessity for the power supply, Germany for instance decided recently the nuclear phase-out by the end of 2022. A law regulating the gradual withdrawal from nuclear energy until 2022 was officially confirmed by the German government in June 2011 [1]. This decision paves the way for development of new solutions regarding the power supply and as well solutions for reducing the CO2 emissions. The total substitution of nuclear power, having very little CO2 emissions, with coal-fired power plants inevitably lead to increasing CO2 emissions. Therefore new approaches for integrating more RES into existing power systems are needed. The integration of wind energy or solar energy into power systems may cause problems for the secure and reliable operation of power grids [2]-[4]. First, electricity generation from RES and electricity demand do not perfectly occur at the same time. This particularly applies to energy resources which highly depend on unpredictable weather conditions like solar and wind energy. Second, locations with a high potential for installing RES like coast sides are often far away from locations with high electricity demand like industrial centers and areas of high population density. Third, installed RES have often small capacities. This means that power from RES is often injected into the grid at many different points and at a low-voltage level, which makes control of the electrical grid more difficult.

Energy management systems like Smart Grids, Micro Grids (MG) or the adaptation of Virtual Power Plant (VPP) concepts will support the further development of renewable energies. In order to manage fluctuations in power demand and supply from RES, Distributed Energy Resources (DERs) like generators and storage units are aggregated to form a Virtual Power Plant. Electric Vehicles (EVs) can be also considered as storage units. Since EVs characteristics differentiating from other DERs are mobility and duality as they can behave either as controllable loads or as controllable micro-generators. EVs are able to connect at different parts of the grids and still employ the same quality of services. The lack of output controllability and the limited capacity of DERs prevent their direct participation in the electricity markets. The integration of DER units under the VPP concept enables their visibility to the System Operator (SO) and their market participation [5]-[8].

The VPP concept provides an aggregation model that aims to address the challenges associated with the integration of DERs and enable their market participation as one market entity. Supplier/Aggregator (S/A) companies, which are responsible for supplying energy and aggregating generation capacity of their resources [9], can use the VPP concept as a tool for realizing the aggregation of their resources. The VPP concept can provide the opportunity to offset the intermittency of DERs' output, irrespective of the DERs location. This coupling can be done through Information and Communication Technologies (ICT). Thanks to this important feature, a VPP approach represents a potential vehicle to integrate EVs as additional sources.

In this document two different approaches have been studied for using the VPP concept as a way to integrate the EV deployment. One is the point of view of the VPP itself and how to operate the generation and demand resources (including EVs) under its control to efficiently integrate these resources into the system. The other is the point of view of the SO and the impact that the use of VPP will have in the whole electric system. The first one is a local operation approach, while the second one is a system-wide dispatch evaluation.

2 MANAGEMENT OF ELECTRIC VEHICLES UNDER VPP CONCEPT

In electrical power systems, generation and consumption have to be balanced. In the conventional systems, this is mostly done by regulating the output power of large-scale power plants. Future energy systems will also include regulation mechanisms like Demand Side Management (DMS), MG and a large-scale use of electricity storages like aggregated EVs.

The power demand usually shows typical fluctuations between day and night, week days and weekend days as well as seasonal fluctuations for instance in the summer or winter period. Fluctuations in power generation can be caused due to weather conditions as well as technical constraints. Figure 2.1 - shows exemplary the power injection in the East Germany power system. It includes all injected power from power plants as well as injected power from RES which are known to the System Operator (SO) 50Hertz Transmission [10]. Power injections of power plants connected to subordinated distribution systems are partly not available and therefore estimated. However, the fluctuation ranges from about 8 GW up to 18 GW in the peak.

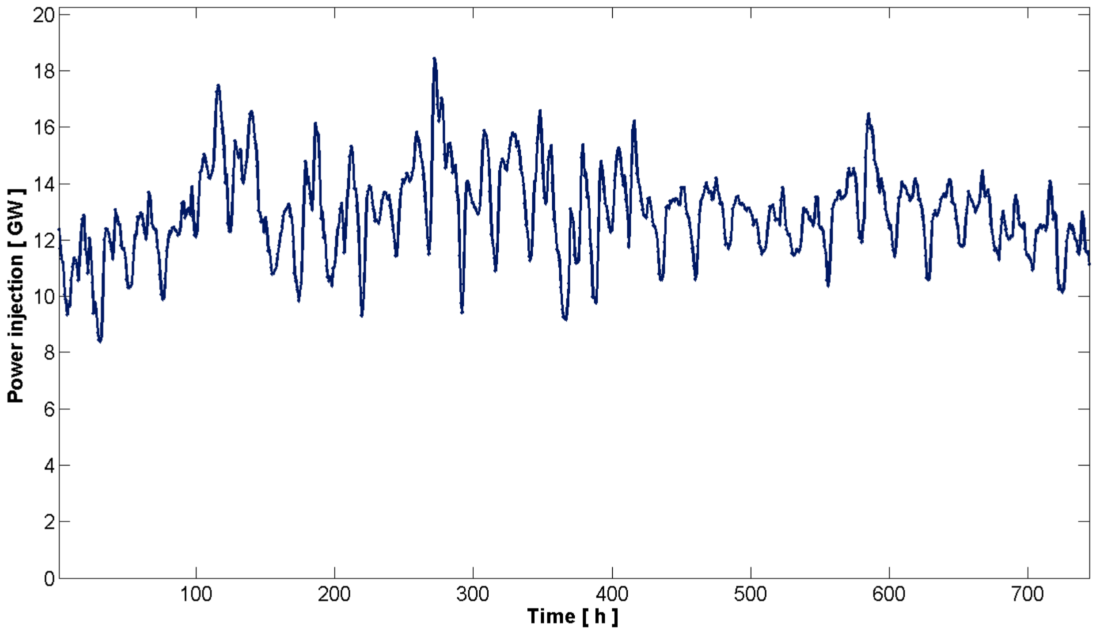

Figure 2.1 - Power injection in East Germany - 50Hertz Transmission area: period under consideration: 01.01.2011 - 31.01.2011

According to the expected power demand a SO establish a schedule for power generation units. The more fluctuating sources inject power to the power system the more challenging it becomes to balance generation and demand. Through the adaption of a VPP concept including energy storage systems like EVs, further expansion of RES can be realized.

As Table 2.2-1 shows the total amount of installed WECs in the 50Hertz area is about 11 GW. This makes almost 40 % of the total installed WECs capacity in whole Germany. The right column is an estimation how much energy can be provided when 1,600 hours per year can be assumed as full load hours. The potential energy generation of the installed WECs in the 50Hertz area is about 17 TWh/a (2010). Compared to the total energy consumption in Germany of 617 TWh/a (2010) those WECs provide almost 3 % of the energy demand.

Table 2.2-1 - Installed capacity of WECs in the 50Hertz area in 2010

German state:	WEC installed capacity [MW]	potential energy ammount [MWh/a]
		1600 full load hours/a
Berlin	2	3.200
Brandenburg	4.401	7.041.600
Hamburg	51	81.600
Mecklenburg-Vorpommern	1.549	2.478.400
Sachsen	943	1.508.800
Sachsen-Anhalt	3.509	5.614.400
Thüringen	754	1.206.400
50 Hertz total	11.209	17.934.400
Germany total (2010)	**27.214**	
Germany energy consumption (2010)		**617.000.000**

Scanario: Integration of EVs in the 50 Hertz area	
Total number of EVs	1.000.000
average km/a	13.000
energy consumption [MWh/100 km]	0,017
Total energy consumption [MWh/a]	**2.210.000**

The mass integration of EVs in European power systems leads to new concepts how to manage those EVs and use their capability for grid operations. The German government plans that about 1,000,000 EVs are in use by the end of 2020. Different analysis for the energy consumption of EVs have been considered compared with that in [11]. In the following simulation, the average energy consumption is assumed to be 0.017MWh/100km. If 1.000.000 EVs can be integrated up to 2020, their potential energy consumption is around 2 TWh/a under the assumption that the average mileages of EV users is around 13,000 km/year. Therefore EVs can potentially lead to further expansion of RES like wind energy and forming a virtual storage system able to balance fluctuations in power systems.

The following section provides a test case where the integration of EVs under a VPP concept can look like. The EVs are considered as an aggregated EV pool. On the basis of the National Development Plan for Electric Mobility [12], 1,000 users with different driving performances were modeled. By a random selection of theses modeled types an EV pool of 10,000 EVs is formed [13],[14].

2.1 Management of Electric Vehicles through a Virtual Power Plant

A VPP aggregates DERs, including generators, loads and storage units. The operation of the DERs can be controlled by the VPP Control Center, to create a desired output or to balance generation and consumption within the power system or participate with its units in the energy market. In this regard, a distinction is made between dispatchable and stochastic generating units. Dispatchable generating units can be Bio Diesel Generators (BDG) whereas stochastic generating units may be Wind Energy Converter (WECs) or Photovoltaic Systems (PVs). According to [9] there are different control mechanisms for operating the DERs: “Direct control” is based on a “top-down” approach, with the VPP Control Center making all decisions and interacting directly with the DERs. In “hierarchical control”, DERs are aggregated and decision-making takes place in layers. In “Distributed Control”, the VPP Control Center gives price incentives to the DERs who are able to make independent decisions.

Technologies for electricity storage include, for example, Compressed Air Energy Storage (CAES), pumped storage, flywheels, hydrogen storage and batteries. CAES and pumped storage are not suitable for this case, due to their geological requirements. Large-scale hydrogen storage could be an interesting option in the future, but still is in an early stage of development today. A lot of battery storage technologies, on the other hand, are already technically mature. Advantage of batteries is their geographical flexibility. However, investment costs are usually very high [15]. EVs with their batteries can be operated in three different modes: Dumb Charging (DC), Smart Charging (SC) and Vehicle to Grid (V2G) [9]. In the DC-mode EVs are connected to the grid and charged up to the desired State of Charge (SOC). In the SC-mode charging can be scheduled according to technical or economic constraints. In the V2G-mode EVs inject a certain amount of power into the grid in order to face a temporary electricity shortage. The storage capacity represented by each individual EV mainly depends on its owner's preferences and constraints like operational profile, risk behavior or financial objectives.

Since a VPP aggregates its units it is able to represent smaller DERs to the energy market, for instance the Day-ahead and the Intraday Market. During Day-ahead auctions, electricity is traded for delivering electricity for each hour of the following day, whereas on the Intraday market, electricity can be traded until 45 minutes before the delivery. On both markets, the minimum volume is 0.1 MW for delivery in the German TSO zone [17] and [18].

In households as well as in the industry exist loads which can be shifted to those hours where generation and loads fit better in terms of reducing peak loads. A load shifting can stabilize the operation of a power system [16]. Load shifting is referred to DSM. Loads in industry differ from those in residential areas with households. A study of the German Energy Agency (dena) has analyzed and quantified the potentials of load shifting [15] which is considered in the simulation.

Table 2.2-2 - provides an overview of parameters used in the MATLAB simulation with its individual initial values for the first iteration. All possible solutions are analyzed in nested loops with variation of increments for each parameter. The analyses are repeated until the final values are reached and determine the simulation. In a second simulation the optimum values are set as fix parameters and presents the base of the following simulation results. n Tabelle 1 dargestellt..

Table 2.2-2 - Optimization Parameters

Parameter	Unit	Initial Value	Increm ent	Final Value
Installed capacity (solar and wind energy)	[MW]	100	100	500
Share of solar energy	[%]	10	10	30
Number of Electric Vehicles		1000	2000	7000
Maximum load	[MW]	10	20	90
Share of manageable load	[%]	10	10	30

In the case of imbalances due to higher power generation excess power is reduced in the following order: load shifting, EV smart charging, and loading of stationary storage units. In case of a power deficit the mechanism is the following: load-shifting, discharging of fixed storage units, EV V2G-mode and bio diesel generator.

Market participation is modeled in a simplified way. Excess power or deficit at the end of each time step is entirely sold or bought either in the Day-ahead or the Intraday market. The simulation outputs for each time step are the residual imbalances and the financial loss or benefit. In the end, the optimization algorithm chooses all parameter configurations which result in a complete balance for all time steps. Among these configurations, the algorithm then chooses the configuration which yields a maximum financial benefit. In the last step the optimization algorithm chooses all parameter configurations which result in a complete balance for all time steps. Among these configurations, the algorithm then chooses the configuration which yields a maximum financial benefit. Figure 2.2 summarizes the basic structure of the balancing algorithm.

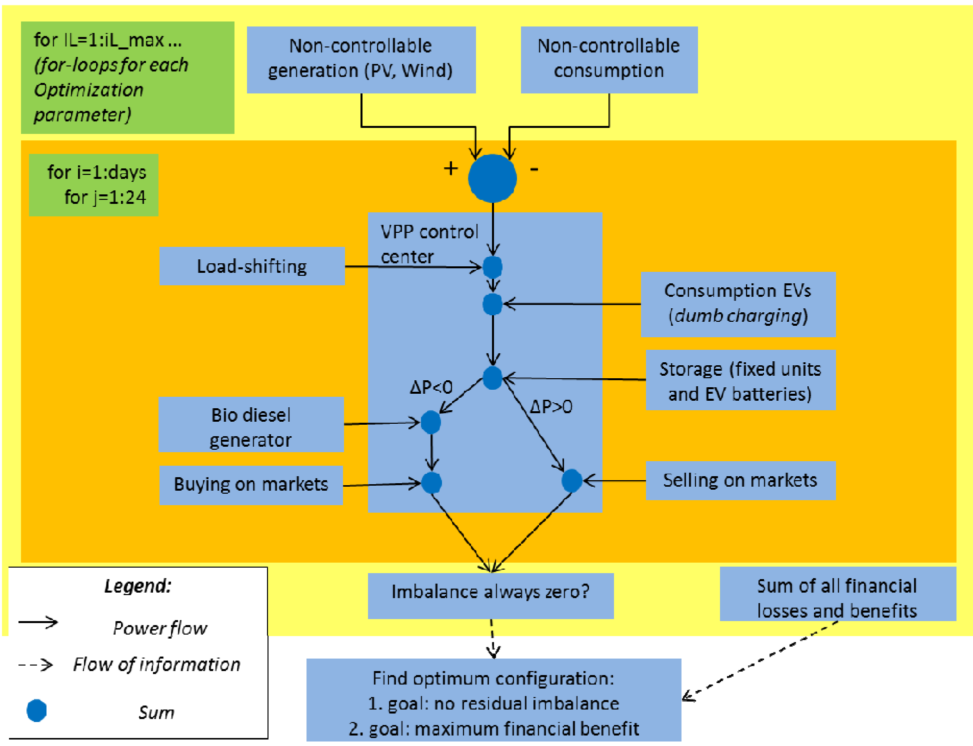

Figure 2.2 - Basic structure of balancing algorithm

The modeling of loads, solar and wind generation is based on historical data of the 50Hertz transmission power system from November 2008 until October 2009 [19]. For the so called “Scenario 2009” generation cost are 7 Ct/kWh for wind energy [20] and 17 Ct/kWh for solar energy [21]. The bio diesel generator with a maximum rated power of 50 MW is fuelled with colza oil. Its generation costs are 23.5 Ct/kWh in scenario 2009 what express the average colza oil prices from November 2008 to October 2009 [22].

Loads are considered as a portion of historical load data for the 50Hertz transmission system in 2009. The electricity price paid by VPP consumers varies between a lower and upper price limit. Within this price interval the variation of the Intraday market price is considered exemplary as followed:

```
p_consumption_min   =10; % min electricity price for consumers (ct/kWh)
p_consumption _max =12; % max electricity price for consumers (ct/kWh)

max_Intra  =max(max(intradayprices));
min_Intra   =min(min(intradayprices));
p_ consumption=zeros(24,days);

for  1 = 1:days
            for j = 1:24
            p_consumption(j,i)=(((intradaypreise(j,i)-min_Intra)/...
            (max_Intra-min_Intra))*(p_consumption_max-p_consumption_min))+...
            p_consumption_min;
            end
end
```

The simulation only considers the part of the electricity price that actually represents a benefit for the VPP owner, which means that all expenses (e.g. taxes, grid fee) have already been deducted. In Scenario 2009 the price range is 10 to 12 Ct/kWh for “normal” energy consumption and 9 to 11 Ct/kWh for shifted energy.

The fixed storage units have a maximum energy capacity of 100 MWh and a maximum charge and discharge rate of 10 MW. Energy losses during storage are neglected. The assumed storage costs are 17 Ct/kWh [13]. The EV batteries have a maximum useable capacity of 28 kWh. When connected to the grid, the EVs absolutely have to be charged up to a minimum SOC of 80% (DC-mode). During SC-mode, they can be further charged between the minimum SOC and an SOC of 100%. In V2G-mode, the EVs can be discharged down to the minimum SOC. Those restriction are assumed in order to take care of the user behavior and significant rise in mobility losses, when the SOC is below 80%. The modeled EV-Pool is based on data for an operational profile including 1,000 commuters with different driving distances. The prices for EV consumption (DC- and SC-mode) vary within defined price ranges, following the variations of the intraday market price. For EV dumb charging, the prices vary from 10 to 12 Ct/kWh in Scenario 2009. For EV smart charging, the price ranges are 9-11 Ct/kWh. In V2G-mode, money has to be paid to the EV owners. Therefor price ranges are 10-12 Ct/kWh in Scenario 2009. The modeling of Day-ahead and Intraday market is based on price data of the European Power Exchange Spot (EPEX Spot) from November 2008 until October 2009.

In Scenario 2009 the optimum configuration consists of an installed capacity of 200 MW whereof 10% are solar energy and 90% wind energy, 3,000 EVs and a maximum load of 30 MW with a 10% share of shift able load. Table 2.2-3 - provides an overview of the assumed aggregated resources considered in the simulation. For these optimum configurations, the maximum power provided by the bio diesel generator is 27.2 MW in Scenario 2009, which means that the maximum rated power of 50 MW is not necessary.

Table 2.2-3 - Assumed Aggregated Resources Managed by the VPP Control Center

WEC installed capacity		180 MW
PV installed capacity		20 MW
BDG installed capacity		50 MW
EVs	Power capacity	11 MW
	Energy capacity	84 MWh
Storage Units	Power capacity	10 MW
	Energy capacity	100 MWh
Maximum Load		30 MW

In order to evaluate the suggested balancing algorithm, the power injection controlled by the VPP Control Center, including power generation by PVs, WECs and BDG, as well as discharging of storage units and EV batteries and buying energy on markets, can be compared to the overall load, including loads, charging of storage units and EV batteries as well as selling energy to the markets.

Figure 2.3 shows both power injection and extraction for an exemplary day in August 2009. The discharged power from the storage units means discharging of storage units like stationary batteries and EVs (V2G) means discharging of EV batteries during V2G-mode. Those capacities can be used to fill the valleys in the power generation profile. The residual peak power can be managed by load-shifting of manageable loads or charging of stationary storage units and EV batteries.

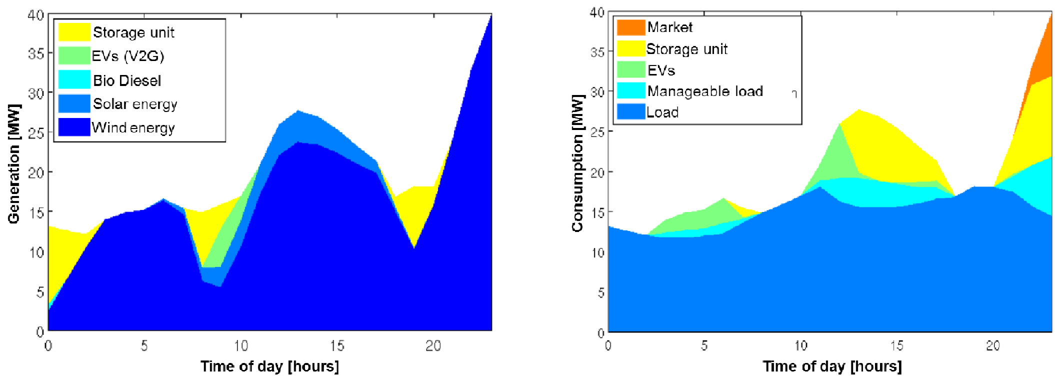

Figure 2.3 - Power injection into the VPP and power extraction from the VPP for August 15 in Scenario 2009

The annual analysis shows energy trading with the market especially in hours of high wind injection where the storage systems are not able to fully balance the energy supply and demand. With a lower installed capacity of WECs or a higher capacity of storage systems like EVs this effect can be reduced. DSM and peak shaving contributes with 10% up to 15% to balance VPP generation with the adopted load in a time period of one year.

Finally, the economic performance of the VPP in scenario 2009 is evaluated in order to draw conclusions about future developments. Therefore all expenses for the simulation period are added up and divided by the sum of all revenues. The expenses are composed by the electricity generating costs for solar energy, wind energy and the diesel generator, the storage costs, the prices to be paid to EV owners during V2G-mode and the expenses for buying electricity on the markets. Revenues are generated by selling electricity to consumers and EV owners and by selling energy on the markets. If the expense/revenue ratio is below 1, this means that the VPP generates a financial benefit. A ratio above 1 constitutes an overall financial loss. For the optimum configuration in Scenario 2009, the ratio is 1.1. The VPP economic performance in Scenario 2009 shows overall average generating costs of about 140 €/MWh. This means that operating the suggested VPP might actually become more profitable in the future which is due to the expected decrease of wind energy generation cost, solar energy generation cost and storage cost, as well as increasing electricity prices in the future. Since energy traded in the Day-ahead and Intraday market is still cheaper than energy provided by RES this VPP concept becomes more economical reasonable in the future.

The simulation has shown that by using electricity storage, load-shifting and intelligent integration of EVs, imbalances of intermittent generation from RES and loads can be reduced.

3 IDENTIFICATION OF SYSTEM BENEFITS OF EV ELECTRICITY MARKET PARTICIPATION UNDER VPP CONCEPT

VPPs provide bids and offers of its managed generation and/or demand in electricity markets, mainly in energy and reserve markets. Therefore, VPP resources are controllable under market mechanisms. VPP is the interface between the SO and small generation and/or demand. VPP acts as demand aggregator for EV energy consumption or as DER aggregator. VPPs can fulfil several functions:

- SC means that EVs are charged when it is convenient for the electric system for satisfying the EV mobility requirements derived of the vehicle usage. Smart grids are able to send information of system conditions to consumers, for example in form of prices. Intelligent electric devices can then react and maintain, reduce or increase their consumption taking into account their technical characteristics and the consumer's necessities. In that way, electricity consumers receive and pay the real impact their electricity usage is causing in the operation of the system. SC is a central component of a VPP and the integration of EVs in this context can be easily done.
- Participate with RES generation and EV demand in providing operation reserve. Different reserve types are distinguished depending on the response time, the time of provision and automatic entrance. Secondary reserves enter automatically if variations of either the consumption or generation side of the demand-generation equilibrium are occurring. In Europe, secondary reserves are active from 15 seconds after such a variation up to 15 minutes. Then, the tertiary reserves enter. When secondary reserves are active and tertiary reserves start to be used to supply the generation imbalance, tertiary reserve frees the secondary reserve. They need to be online within 15 minutes and need to be able to offer the contracted reserve during two hours. While secondary reserves must be online, tertiary reserves can be as well offline, provided that the start-up is accordingly rapid.
- Decrease of RES generation and demand such as EV demand in the market. These DER might able to partially self-correct unbalances internal to the VPP using load shifting in case of demand excess or EV charging in case of generation excess in the VPP.
- Therefore, uncertainty decreases because the SO requires less operation reserve (these requirements are linked to the amount of demand and RES generation in the market),

The ROM Model has been developed at the Instituto de Investigación Tecnológica (IIT), ICAI, Universidad Pontificia Comillas. The ROM models objective is to determine technical and economic impact of the EVs and RES into the medium-term system operation, including reliability assessment.

The ROM tool follows a combined modelling approach whereby a daily optimization model is followed by a sequential hourly simulation, with a resolution of one hour. This replicates the sequence of the markets and the decisions, reproducing the hierarchy and the chronology of the decision levels and allows representing that uncertainty is revealed over time. Although some markets might be handled with time fractions lower than an hour, the ROM approximates these markets in hourly time fractions. The daily optimization of the ROM model presents the day-ahead market, while the real time simulation indicates some intraday markets. As the time

unit of the model is one hour these operation reserves are considered in a simplified manner. The model takes into account spinning reserve which combines the secondary reserve with parts of the tertiary reserve. Spinning reserve requires the generation to be already online.
A chronological approach is used to sequentially evaluate the system operation for every day of a year. Decisions above this scope as the weekly scheduling of pumped storage hydro plants are done internally in the model by heuristic criteria. The management of hydro resources and seasonal pumped storage that exceeds the year time frame must be computed by another higher–level model and be taken as an input into the ROM. Monte Carlo simulation of several yearly scenarios is used to deal with the stochasticity of the demand and the intermittent generation.
The model has been described in detail in [24]. All variables used in this section are explained in the following tables. The notation and data used for the calculations are shown in Table 3-1, Table 3-2 and Table 3-3.

Table 3-1-Sets

Name	Meaning
p	Periods (hours)
g	Generators
t	Thermal units ($\{t\} \subset \{g\}$)
h	Hydro plants (reservoirs) ($\{h\} \subset \{g\}$)

Table 3-2-Parameters

Name	Meaning	Unit
UR_p, DR_p	Upward and downward reserve in period p	MW
URC, DRC	Upward and downward reserve deficiency cost	€/MWh
$NSEC$	Non-supplied energy cost	€/MWh
FC^t	Fixed cost of thermal unit t	€/h
VC^g	Variable cost of thermal unit g including fuel cost and O&M	€/MWh
SC^t	Start-up cost of thermal unit t	€
MC_p	Marginal cost in each period p calculated in a pre-run	€

Table 3-3-Variables

Name	Meaning	Unit
$opcost$	Total system operation cost	€
nse_p	Non-supplied energy in period p	MW
$urdef_p, drdef_p$	Upward and downward reserve deficiency in period p	MW
st_p^t, sh_p^t	Start-up and shut-down of thermal unit t in period p	[0,1]
c_p^t	Commitment of thermal unit t in period p	[0,1]
gp_p^g	Output of generator g in period p	MW

gur_p^g, gdr_p^g	Upward and downward power reserve of generator $g \notin b$ in period p	MW
pur_p^h, pdr_p^h	Upward and downward power reserve of pumped storage hydro plant $h \in b$ in period p	MW
dru_p, drp_p	Upward and downward power reserve of demands in period p	MW

3.1 Impact of VPP services in system operation

Two different mechanisms are explored to evaluate the VPP impact in the system operation. One is the introduction of a demand response option which enables the demand to provide operation reserves via automatic load response. Here demand that is part of a VPP is dispatched in a centralised (SO point of view) approach. The other is the aggregation of small generation or consumption components in a VPP and, as a consequence, reducing the uncertainty from a system point of view. Uncertainty reduction is evaluated which causes a decrease in reserve requirements.

Including large quantities of intermittent generation, variable and relatively uncertain in their electricity generation, may lead to cost increases. This is mainly caused by wind's uncertainty and to a lower extent by its variability. While uncertainties due to demand variations or to conventional generation equipment failures stay rather constant, variations due to increased wind power injection will augment with an increasing installed generation capacity. For eventualities like variations in demand or wind forecasting error or the outage of generation equipment, reserves must be provided.

Nowadays, reserves are mainly provided by conventional power plants. In the future WECs will also need to provide them. Smart grid technologies offer the opportunity to demands to react to system conditions or even to provide system reserves.

In the next section we present how to consider the centralised approach of the VPP providing up and down operation reserves.

3.1.1 VPP providing up and down operation reserves

The ROM model [23] has been modified to introduce the possibility of demand providing operation reserves. The total upward and downward reserves for each period p now introduce the variables of up and down reserves by the demand, dru_p and drd_p respectively:

$$\begin{aligned} &\sum_{g \notin b} gur_p^g + \sum_{h \in b} pur_p^h + dru_p + urdef_p \geq UR_p \\ &\sum_{g \notin b} gdr_p^g + \sum_{h \in b} pdr_p^h + drd_p + drdef_p \geq DR_p \end{aligned} \quad \forall p \qquad \textbf{(1)}$$

Up and down reserves by the demand are not limited in their offer, but these values are bounded by the total upward and downward reserves required in each hour

$$\begin{aligned} dru_p &\le UR_p \\ drd_p &\le DR_p \end{aligned} \quad \forall p \quad \textbf{(2)}$$

For estimating the cost of offering reserves by the demand a pre-run of the ROM model without flexible demand is analysed. The marginal cost in each hour MC_p is taken as a reference price and the cost of offering reserves is introduced as a new term of the objective function.

$$opcost = \sum_p \left[\begin{array}{l} \sum_t \left(FC^t c_p^t + SC_t st_p^t + VC^g gp_p^g \right) + \\ NSEC\, nse_p + URC\, urdef_p + DRC\, drdef_p \end{array} \right] + \sum_p MC_p \left[dru_p + drd_p \right] \quad (3)$$

3.1.2 VPP contributing to reduce operation reserves

Another way of handling demand is the decentralised one. A VPP combines many small components of the electric system and acts as an aggregator. These components are typically one or a combination of different DERs types: distributed generation (including micro wind turbines, photovoltaic cells and micro cogeneration), demands (thermostatically controlled demands or EV batteries) and electrochemical storages (EV batteries). In a VPP demand and generation of electricity are compensated partly by the components of that VPP. So, a VPP will enter in the market and look for selling or buying only the excess or deficit of electricity. In that way a part of the variations of electricity generation and consumption of DERs are levelled out and the uncertainty related to the forecasting errors of these generators or loads is reduced in the electric system as a whole.

Operation reserves are determined as a way to hedge the system against short-term uncertainties. These can be originated by demand or by generation uncertainty. In the demand side, changes in forecasted demand are mainly due to temperature effects. In the generation side, the variability can be associated to forced outages of the unit or to wind forecasting errors of the intermittent generation (mainly wind generation). The amount of operation reserves is determined to cover a high percentage of variation of these uncertain parameters (for example, a 95 % of the occurrences). A typical value of the reserve will be the sum of a small percentage of the demand (2 %, for example), the size of the largest unit (1000 MW, for example) and a percentage of the wind generation (10 %, for example).

In this case the reduction of uncertainties due to the VPP is analysed, namely the reduction of wind forecasting errors, and how this influences the level of necessary operation reserves.

3.1.3 Case study

The mainland Spain power system in 2020 has been used as the case study. It is an appropriate case given the high share of wind generation. Therefore, these VPP operation modes may have a high impact on the system operation. The electric grid has not been taken into account. 575.000 EVs in the system have been considered.

It has to be taken into account that in this part we use the point of view of the system, not of the VPP components or the VPP operator as in chapter 2. First demands in VPPs are able to provide system reserves then the uncertainty reduction is analyzed. Results are shown as well from the point of view of the SO, that means results indicate what is happening in the market when VPP are acting.

Using the ROM model the following results could be found. When demand of a VPP is able to provide operation reserves the following provision for weekdays and weekend for up and down reserves is obtained. The first figure represents the total reserve provided by demands in VPPs in MW and the second one the share of the reserve in % provided by the demand with respect to the total Spanish System reserve requirement. A system-wide use of VPPs is assumed.

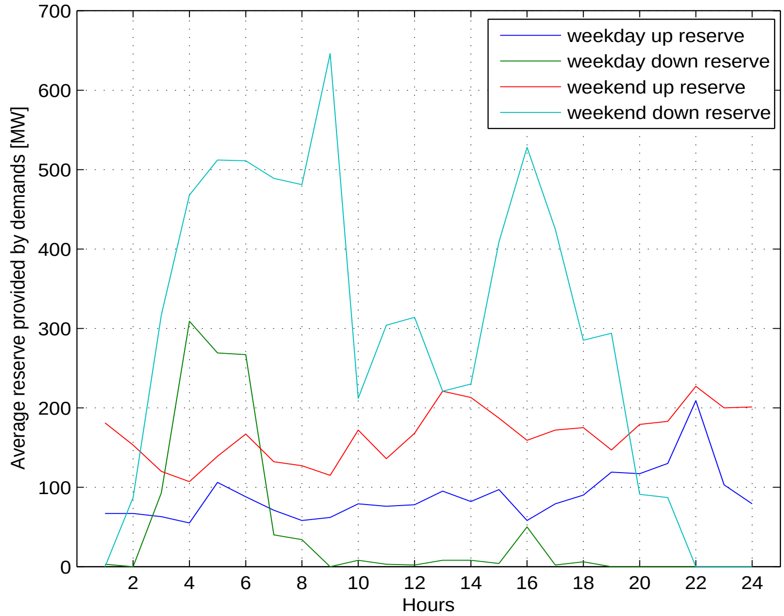

Figure 3.1 Up and down operation reserves provided by demand of VPP for mainland Spain 2020

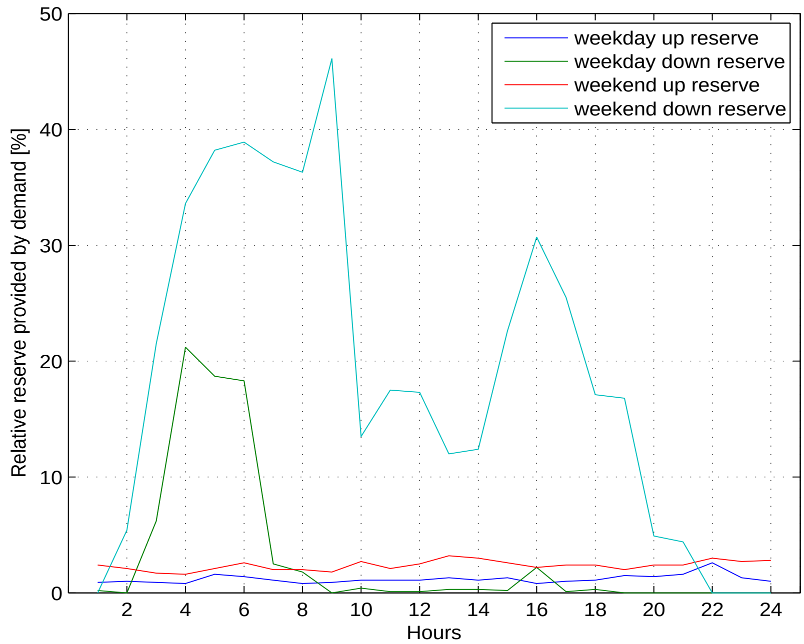

Figure 3.2 Up and down operation reserves provided by demand of VPP for mainland Spain 2020

Upwards reserve means that VPP demand offers to consume less or to increase VPP generation. Downward reserve by VPP demand indicates the offer to increase consumption or decrease generation. While downwards reserves are provided mainly during night hours and in the valley between the two day peaks, upwards

reserves are more balanced during the days. In general, on weekends a higher amount of reserves are offered by demand than on weekdays.
Looking at the relative numbers of these reserves provided by VPP demands a similar pattern for the behaviour of up- and downwards reserves is found. The level of upwards reserve offers is more balanced and lower in quantity than the downwards reserves offers. It can be observed as well that downwards reserves provided by demands amount to a higher share of the total reserve needs compared to the upwards ones. It goes up to 46 % of total reserve requirements on weekends and 21 % on weekdays, while upwards reserves oscillate between 0.8 % and 3.2 % being slightly higher on weekends.

For the second analysis of analyzing the ability of VPPs to reduce the uncertainty the following is assumed. VPPs are made up of demands and wind generation. These components are operated apart from the market operation via a VPP operator. In this way the demand and the RES generation which remains in the market is reduced. This reduction has consequences for the forecast errors, which are lower as well and for the reserve requirements, which depend on demand and wind generation. As in this part the point of view of the system is represented, the VPP operation is not considered in specific. Different scenarios have been created incrementing the amount of demand and generation in VPPs, i.e. decreasing demand and RES-Generation in the market. Historic time series obtained from public data available from REE web page (http://www.esios.ree.es/web-publica/) for demand and wind generation from 2008 have been scaled to 2020. The resulting data series for demand and wind forecasting errors for the base case (without VPP) are summarised in the next table.

Table 3-4-Absolute and relative values of expected value and 95 % quantile for demand and wind forecasting error without VPP

		MW	%
Demand error	Mean	-117	-0.2
	Quantile 95 %	1488	4.6
Wind error wrt output	Mean	548	4.5
	Quantile 95 %	3220	45.2
Wind error wrt installed capacity	Mean		1.4
	Quantile 95 %		8.8

The expected error value (that is the difference between the forecasted and real demand/wind) is slightly negative for demand and slightly positive for wind errors. That may be because forecasts tend to be rather conservative.
In order to determine the operation reserve needs, it has been estimated that they are able to handle 95 % of the wind forecasting errors (under a normal distribution that would be twice the standard deviations from the mean value). They are represented first with absolute and then with relative values. Wind forecasting error series were calculated once respective to wind output and once respective to installed wind generation capacity.

To introduce VPP contribution to decreasing uncertainty it has been assumed that a part of the demand and the corresponding part of wind energy would be cancelled out in the VPP. The VPP is optimized internally but in case of excess or deficit of energy the VPP may sell or buy energy in the market. That means this excess demand or wind generation is incorporated in the market again.

Four cases were analysed with 2.5 % to 10 % of demand participating in a VPP. If 2.5 % of demands leave the market, the same total amount of energy generated by wind is taken out of the market and managed in the VPP. As demand and wind generation do not necessarily correlate in their energy demand and offers, in each hour an excess or a deficit of energy of that VPP is resulting. This excess or deficit of energy enters in the market again since the VPP needs to balance its generation and consumption. However, as the VPP has to handle its energy balance through the market (or subsequent intra-daily markets), the uncertainty related to its generation and consumption is not considered in the real-time. Demand errors are reduced by the same percentage which was used to indicate percentage of demands out of the market (2.5 %-10 %). If demand in that VPP exceeds wind generation then demand errors are not reduced by x. $derr_0$ is the original demand error when no VPP contribution exists, de is the demand excess and d_{VPP} the demand in that VPP. If demand excess remains, this demand is added again to the demand in the market.

$$
\begin{aligned}
derr_x &= derr_0(1-x) \\
derr_x &= derr_0\left(1-x\frac{de}{d_{VPP}}\right)
\end{aligned}
\qquad \textbf{(4)}
$$

The same happens to wind errors, i.e. the difference of forecasted and real wind generation: if wind exceeds demand, wind error is reduced only by a fraction of y, the corresponding percentage of withdrawn wind energy.

Wind and demand errors, $derr$ and $werr$ respectively, are then summed up to obtain the total error $terr$ considering equation $terr = werr - derr$

To obtain the necessary reserve up- and downwards reserve are distinguished. Upwards reserve is necessary when more demand is consumed than forecasted (positive demand error), when less wind blows than forecasted (negative wind errors) or when a generator fails. Thus typical values for the calculation of reserves were used: 2% of demand plus the largest generation unit. Furthermore the 0.95 quantile of the wind series were used to determine the percentage of errors to prevent 95 % of all errors against wind variations. For the down reserve only a 2% of demand has been taken into account.

For the four VPP cases, 2.5 %, 5 %, 7.5 % and 10 % of demand leaving the market, the percentage used for determining reserve requirements for the wind variations is presented in Table 3-5. With a higher percentage of demand leaving the market to level energy consumption and wind energy out in a VPP, reserve requirements can be reduced. Wind error reduction is more important: up to 4.3 % of wind error can be reduced considering the installed wind capacity. For the calculation of reserves wind error with respect to current installed capacity has been used.

Table 3-5-Quantile 0.95 for wind errors

	2.5 %	5 %	7.5 %	10 %

Wind error wrt installed capacity	7.67	6.61	5.54	4.75

Now, these different reserve requirement cases were analysed with respect to the overall results.
Demand and wind which remains in the market and their characteristics are summarised in Table 3-6. With an increasing part of demand participating in VPPs (2.5 %, 5 %, 7.5 % and 10 %) annual energy and demand peaks are reduced for the corresponding cases. Annual wind and maximum output is reduced to cover the same amount of demand. Excess of demand in the VPP is added to the demand, excess of wind to wind series.

Table 3-6-Demand and wind characteristics in market for different cases

	Annual energy [TWh]	Peak demand [GW]	Annual wind output [TWh]	Installed wind capacity [GW]	Wind max output [GW]
VPP0	375	70	77	38	25
VPP2.5	365	69	67	33	22
VPP5	356	67	58	29	19
VPP7.5	347	65	49	24	16
VPP10	337	63	39	19	13

Reserve necessities are reduced from annually 42 TWh in a case without VPPs up to 31 TWh in the VPP 10 % case for upwards reserves and from 7.5 TWh to 6.7 TWh for downwards reserves. These are the sums of reserve necessities determined for the optimisation for the whole year. That corresponds to the mean of the hourly values represented in the figure below. In the highest VPP case reserve requirement reduction amounts to 27 % and 10 % for upwards and downwards reserves, respectively.

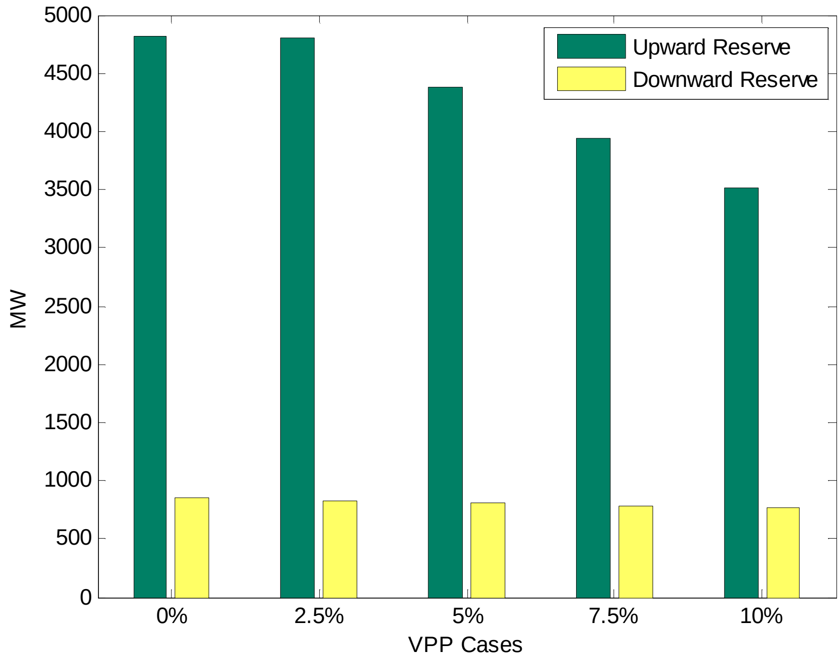

Figure 3.3- Mean reserves for different VPP cases

Differences in generation mainly due to less wind energy in the market are compensated by an increase in the generation of combined cycles and to smaller extent storage hydro units.

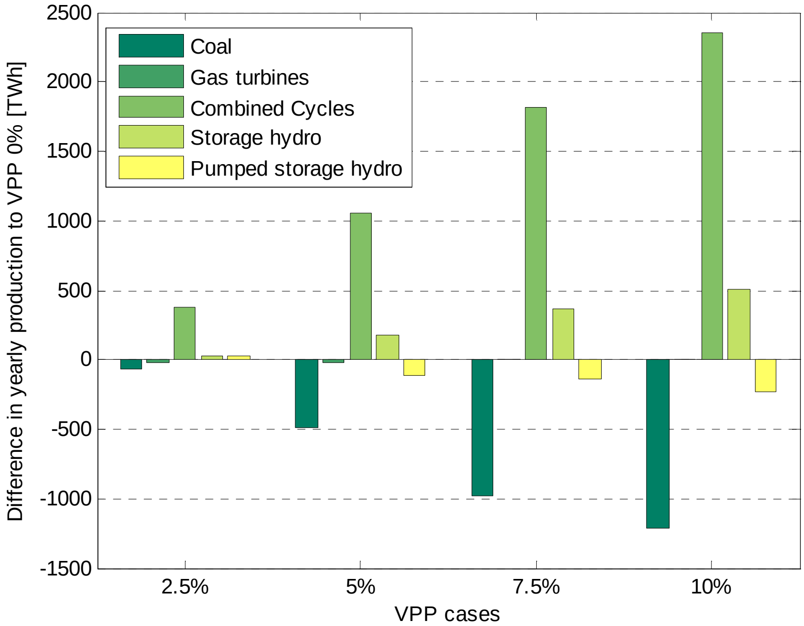

Figure 3.4-Difference in yearly production for different VPP cases

If the system operation cost for one year is compared a cost decrease with each 2.5 % of demand and the corresponding part of wind generation leaving the market and entering VPPs is observed. This is mainly due to the lower reserve requirements when more intermittent generation is leaving the market to be part of VPPs. It must be emphasised as well that a percentage reduction of demand in the market corresponds to a much higher withdrawal of wind energy to balance the total energy in the VPP. This may change, when wind and other renewable energies increase even more. The operation costs of the VPP are not considered in these computations and counterbalance the system benefits.

Table 3-7-System total operation cost comparison	Total cost [M€]	Cost increase [%]
VPP0	11,430	
VPP2.5	11,421	-0.08
VPP5	11,381	-0.42
VPP7.5	11,354	-0.66
VPP10	11,337	-0.81

Comparing the system total annual emissions in Table 3-8 it can be observed that CO_2 emissions are reduced the higher the share of demand and wind generation in

VPP is. This indicates a positive influence of the use of VPP respective to the CO2 emissions.

Table 3-8-System total emission comparison

	Total emission [$MtCO_2$]	Emission increase [%]
VPP0	61.908	
VPP2.5	61.993	0.08
VPP5	61.779	-0.17
VPP7.5	61.618	-0.45
VPP10	61.626	0.50

The following mean specific emissions have been used for the case study: 0.925 tCO2/MWh for coal units, 0.35 for CCGT and 0.53 for OCGT. Total emissions are calculated using the fuel consumption (which is a product of specific consumption and generation output) of each generation plant and the mentioned specific emissions. The sum for all the hours of a year is what is represented in the table above.
So, in this analysis VPPs are convenient for the demands participating in that VPP, as they are supplied by free generation. Reductions in uncertainty and thus in reserve levels in the market have a cost decreasing effect.

The difference of handling EVs inside the VPP or outside in the market has to be analysed in further studies taking into account as well the VPP operation cost.

Of the scenarios, which contained EVs in the internal operation of the VPP three have been selected and have been calculated without EVs to estimate the share of costs and emissions caused by EVs.

Table 3-9 Difference in system costs and emissions caused by EVs in VPP

	Total cost [M€]			Total emission [MtCO2]		
	575.000 EV in VPPs	0 EV in VPPs	Difference [%]	575.000 EV in VPPs	0 EV in VPPs	Difference [%]
VPP0	11,430	11,358	-0.63	61.895	61.444	-0.73
VPP5	11,420	11,311	-0.62	61.959	61.440	-0.58
VPP10	11,382	11,265	-0.64	61.801	61.248	-0.57

Table 3-9 shows these three scenarios and their difference respective to system costs and emissions. Without EVs costs as well as emissions are lower as EVs are an additional consumer. The values per EV can be found in Table 3-10. System costs and emissions are annual.

Table 3-10 Specific costs and emissions

Costs [€/EV]	Emissions [tCO2/EV]
119.16	0.65

More analysis has to be carried out respective to different demand profiles, different sizes of VPP components , the ability of demand in VPPs to be responsive (e.g. load shifting) and the inclusion of other DERs such as solar generation, whose generation correlates more than wind with consumption of electricity.

4 Conclusions

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