MIRABEL

Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution

Specific Targeted Research Project: 248195

D6.2 Specification and Design of trial cases

Work package 6 – Trial Test Integration & Validation

Leading partner: INEA

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1 Summary

The trial cases used for the testing of the Mirabel product follows the strategic impact defined in the Description of Work. It is expected that within the mass of the electricity consumers the Mirabel solution will enable increase the integrated share of RES in EES by 5% and reduce the peak demand for at least 5%, with a targeted approximate 8-9% for the total grid.
The delivery describes and resolves the issues necessary to execute the testing and provide the laboratory evaluation of the Mirabel solution. That includes description of the scenarios for the trial cases, definition of the testing environment and the definition of the successfulness criteria.
The description of the testing environment describes the boundary roles and their functionalities, which are not part of the solution but are necessary for the test execution. In that manner the delivery defines the models for the controlled production, the external markets and the consumption flexibilities.
The scenarios for the trial cases follow the tension of exposing the benefits of the Mirabel solution for the typical actors of the electricity energy system: the transmission system operator (TSO), the local distributor of the energy (LDE) and the household community. The scenarios reflect the findings from the previous deliveries of the project about the roles and processes, like the TSO uses the consumption flexibilities through the balance market and the LDE or household community needs to take a role of the balance responsibility party for using the solution and interacting on the electricity market. The scenarios are adapted to the full simulation environment for the LDE and TSO trial cases, and for the micro-grid test lab for the household community trial case.
The delivery defines the indicators for the evaluation of the testing results, which follows the strategic impact from the DoW. The indicators like peak demand criteria and imbalance indicator are used for the comparison of the testing result with the reference data and provides the measure of the Mirabel solution impact on the electricity energy system. Therefore they are called “successfulness criteria”.
The main input of this delivery are a Description of Work [DoW], D1.3 [D1.3], D1.2 [D1.2] and measurements from Meregio project [D6.1]. This delivery is a direct input for the deliveries D6.3, D6.4, D6.5 and D6.6.

2 Introduction

The following chapters resolve the issues necessary to execute the testing and provide the evaluation of the Mirabel solution. That includes the algorithms for using the measurements, models for the components and functionalities not included in the solutions, description of the test environment roles, definitions of the efficiency criteria, description of the trial cases, test plan, requirement definition for the simulation environment and test micro-grid implementation, and short quantity analyses of the input data.
The boundary elements which the Mirabel solution needs to communicate with need to be modeled in the way to reflect the behavior of the elements in the real environment. The delivery describes the roles and their functionalities in the testing environment, the models of the controlled production, external markets and flexibility of the consumers.
The algorithms describe the scalability of the consumers (household and industry) and calculation of the reference data, which are used for the comparison with the testing result. The algorithms for the creation of the reference data reconstruct the situation

without the effect of the Mirabel solution. The pricing concept and the RES ratio definition are used in the following chapter for the successfulness criteria definition.
In order to provide the quantitative evaluation of the Mirabel solution the successfulness criteria formulates the goals from DoW, like peak reduction criteria, quantification of the imbalances and the cost efficiency.
The trial cases follow the concept from the DoW where the applicability of the Mirabel solution to the specific actors in the electricity energy system is proposed like to the transmission system operator, local distributor of energy and household community. Each trial case is consisted of the several scenarios with different environment/boundary elements, which are a subject of the interest. The test plan for the scenarios execution consists of the systematic variation of the investigated parameters like share of the RES, share of the consumption flexibilities and others.
The chapters 8 and 9 provide the requirements for the implementation of the testing environment (Delivery D6.3) in the form of the design elements for the resource control routines and message exchange.
At the end of the delivery a short quantity analyses of the input data for the household and industry is given to provide general background for the testing.

Integration and testing of the Mirabel product consists of two parts: 1) Testing with the simulation and 2) Testing in the real – micro-grid - environment on the CRES test lab.

In both cases the same product installation is used.
The simulation is provided on the location of the “Aalborg Universitet” in Denmark, which is also the leader of the task 6.3 – Development of simulated testing environment.

The testing in the real environment is in Test lab on CRES, which is designed as a small micro-grid test lab possessing the RES and connected to the external public distribution grid.

3 Testing objectives

The testing environment designed is used to show that the Mirabel approach with flex offers is capable to handle the peak consumption problem and the problem of the efficiency at the RES integration. The testing strategy is directed to represent the effects of the Mirabel’s algorithms of scheduling, aggregation and forecasting on lowering the peak consumption and covering the RES imbalances. The goal of the testing is not only to show that the Mirabel approach integrates the RES production with higher efficiency but also that it supports the reduction in the controlled energy sources installation capacity.
Since the result of the Mirabel project is the realization of the “flex-offer” idea, where the algorithms of scheduling, aggregation and forecasting makes it working, also the testing strategy is adapted to that result and therefore it does not contain the elements for testing the “real product”. The elements like stress test, failure tests, system break down, un-predictively of the input data, etc. are described and executed in a very limited way. Their qualitative analyses are rather the subject of the Mirabel project successor which shell be a pilot project implementing the Mirabel result.
The testing strategy and objectives are adapted to the environments available. In the simulation environment the testing strategy is to provide the “real” circumstances and position of the Mirabel in the structure of the electricity market system. That includes the design of the balance group with corresponding amount of the prosumers and formation of the relevant roles and domains. The expected outcome of the testing would be the

quantification of the potential benefits for using the Mirabel approach for the parties involved.
The testing on the small scale micro-grid test lab the testing strategy is more directed to the analyses of Mirabel behavior on the particular elements and loads. The result is feasibility of the Mirabel on the small scale system and applicability of the particular smart grid elements for the inclusion in the demand response system.

4 Models and algorithms for testing

4.1 Limitations of the testing environment

The electricity grid (transport and distribution) is not taken into the account. The grid capacity limitations are not simulated. It is assumed that the grid is capable to transfer the required energy.

The minimal time scale is set to the most general time scale in electricity grid – quarter of hour. This interval is used for input measurements, output result and calculation of the efficiency result like peak consumption. The input data are interpolated or extrapolated correspondingly. The exception is the input market data where usually 1 hour time scale is used.

The external trading is limited to one hour energy product.

It is assumed that controlled production exactly sticks to the contracts and does not produce any imbalances. The same is valid for the execution of the external contracts. The imbalances are generated only at consumption and production of the RES.

4.2 Controlled production model

The portfolio of the controlled production in the real environment differs much from balance group to balance group. There are water, nuclear, coal power plants, gas turbines and many other which are different in their technical characteristic and pricing and is therefore difficult to provide some representing sample. Therefore it is decided not to use a production portfolio from existing real balance group but rather to model some generic production portfolio designed to balance the consumption in the optimal way.
The controlled production model consists of the power plants of the two types

- Base load power plant
- Peaking power plant

Base load plant, is an energy plant devoted to the production of base load supply. Base load plants are the production facilities used to meet some or all of a given region's continuous energy demand, and produce energy at a constant rate, usually at a low cost relative to other production facilities available to the system. Examples of base load plants using nonrenewable fuels include nuclear and coal-fired plants. Among the renewable energy sources, hydroelectric, geothermal, biogas, biomass, solar thermal with storage and ocean thermal energy conversion can provide base load power. Base load plants typically run at all times through the year except in the case of repairs or scheduled maintenance.

Each base load power plant on a grid is allotted a specific amount of the base load power demand to handle. The base load power is determined by the load duration curve of the

system. For a typical power system, the rule of thumb is that the base load power is usually 35-40% of the maximum load during the year.
Peaks or spikes in customer power demand are handled by smaller and more responsive types of power plants called peaking power plants, typically powered with gas turbines.
Whilst historically large power grids have had base load power plant to exclusively meet the base load, there is no specific technical requirement for this to be so. The base load can equally well be met by the appropriate quantity of intermittent power sources and peaking power plant.

Power plants are designated base load based on their low cost generation, efficiency and safety at rated output power levels. Base load power plants do not change production to match power consumption demands since it is more economical to operate them at constant production levels. Use of higher cost combined-cycle plants - peaking power units is thus minimized, and these plants can be cycled up and down to match more rapid fluctuations in consumption. Base load generators, such as nuclear and coal, often have very high fixed costs, high plant load factor and very low marginal costs. On the other hand, peak load generators, such as natural gas, have low fixed costs, low plant load factor and high marginal costs. Typically base load plants are large and provide a majority of the power used by a grid. Thus, they are more effective when used continuously to cover the power base load required by the grid ([Wiki1], [Wiki2]).

4.2.1 Capacity of the controlled production

The installed capacity of the controlled production is calculated from the load duration curve [Ste].

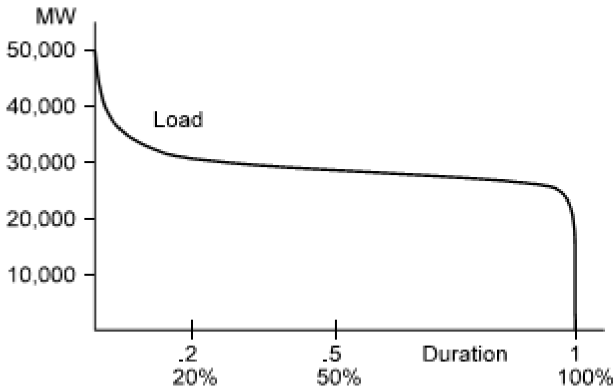

Figure 1: Load duration curve

The total capacity of the controlled production installed at the optimal balance group capable to operate in the isolated mode (without external trading) must be capable to cover the maximal consumption peaks which is determined from the duration of the load duration curve approaching to the zero value.
The portion of the base load power unit capacity (and peaking power unit) is determined economically from the general fact that base power unit is economically efficient up to 40% of the duration. The corresponding capacity is calculated from the load duration curve intersecting the reference duration.

4.2.2 Controlled Production cost

The annual production cost $c_{production}$ is calculated from the cost of the generator unit [Ste]. It is affected by the three factors: 1) fixed price, 2) variable price and 3) load duration, which determines the generation capacity factor.
The variable price (p_v) is the generator unit fuel cost for every kWh of electricity energy produced.
The fixed price (p_f) is the overnight cost of the capacity installed, which needs to be calculated to the annual cost on the base of the generation device amortization with the discount rate involved.

$$p_f = \frac{-r p_o}{1 - e^{-rT}},$$

where p_o is overnight cost per capacity unit installed, r is the discount rate (% per year) and T life of the plant. The p_f is one year price of the installed capacity unit.
Fixed price added to the variable price results into the “annual revenue requirement” (*ARR*) – with the assumption that the generation plant is 100% used. If it is used less the load duration - generation capacity factor (*cf*) needs to be taken into the account

$$ARR = p_f + cf * p_v$$

The *ARR* tells the required annual income from the installed capacity unit expressed in “EUR/MWy” which may be transformed to the “EUR/kWh” by multiplying with the corresponding factor. The generation capacity factor *cf* means “*cf=0*”– generator is not used at all and “*cf= 1*”- generator is used all the time.
To fulfill the revenue requirement the price of the energy generated is calculated as

$$p = ARR/ cf = p_f / cf + p_v$$

Equation 1: Price of the scheduled production

what means, that the price is minimal if the generator is producing energy all the time “*cf= 1*”.

The necessary input parameters (discount rate, overnight cost, life time of the plant and variable price) are sourced as an average from the real electricity energy system [Kap]. Since a significant variation of the parameter values the values used in the testing environment results in the averaged controlled production price equal to the average price on the external market.

4.3 External market model

The BRP in the real environment provides the external trading to balance the supply and demand in its balance group in the optimal way. There are several types of the external trading regarding the time parameters

- Long term trading
- Day ahead
- Intraday markets (hour ahead market), real time market, …
- Balance market

Long term trading is usually provided on the bilateral level, the day ahead is normally organized market while the intraday markets differs from one market balance area from another and may be organized or based in the private agreements between BRPs and producers.

On the long term contracts (bilateral contracts) the base electrical product and trapezoid (peak) product are mostly sold.

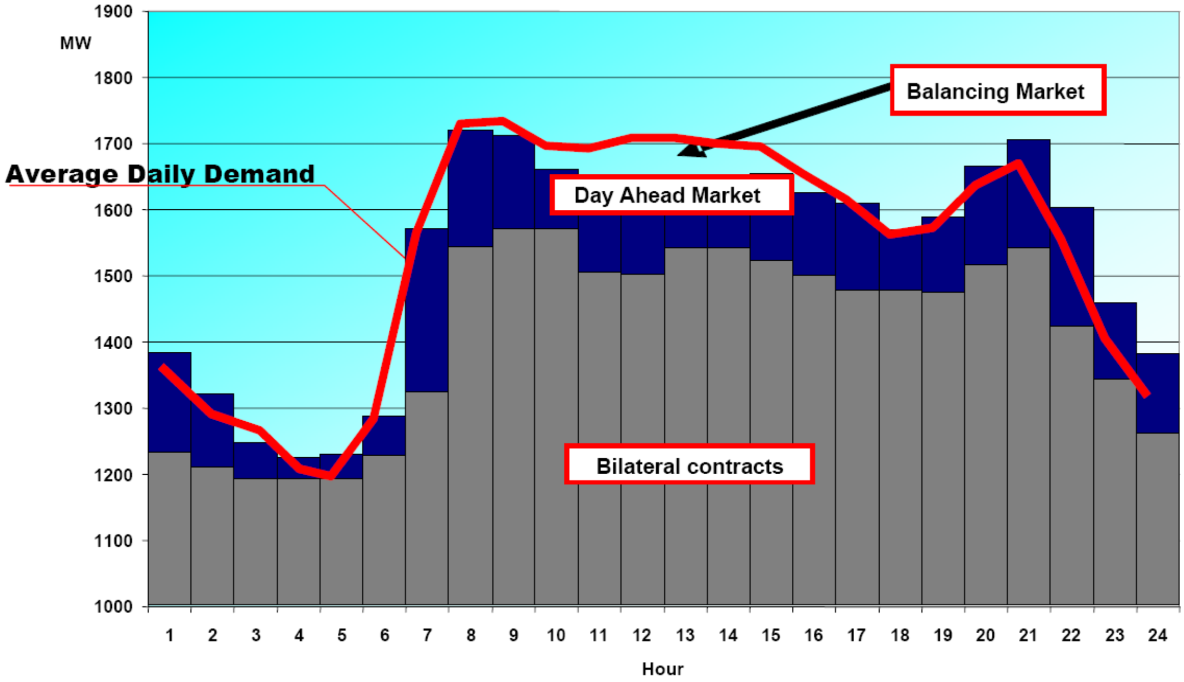

Figure 2: An example of covering the demand by the contract types

On the short term market – day ahead market mostly hour products are sold. On the consumption day the intra-day markets is used for the final balancing. The short term product (i.e. 15 min packet of energy) up to 1h product is a subject of trading. The balance market is used by the TSO to make an intervention at imbalances. The last mechanism is the most expensive.
The finale schedule of the energy flow is total of the all contracts provided.

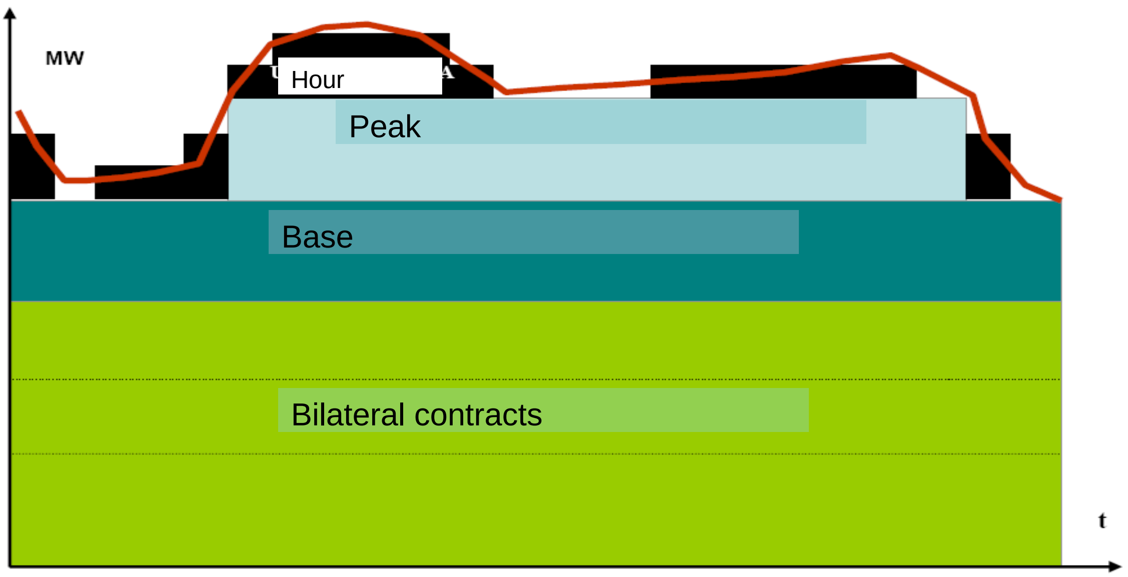

Figure 3: An example of the schedule consisted of the several product types

The scope of the Mirabel testing with external trading is to show the effect of the Mirabel product on the BRP balance when interacting with the external market. It is desired to capture the main characteristics of the external trading like price oscillations, price peaks and energy volume availability. On the other hand the specifics like BRP trading strategy, formation of the trading price and the products, etc. depends much on the BRP structure of the demand and supply portfolio, experiences and equipment for trading. These features vary from BRP to BRP and their implementations are out of the scope of the Mirabel project. Therefore the external market model in the Mirabel testing environment is simplified to embrace the main characteristics only.
The real markets on EEX [EPEX] are used as a base for the external market model in the testing environment. There are two types of markets

- Day ahead market based on auctioning trading
- Intraday market based on continuous trading.

In the model their main characteristics are

- Closing time
- Trading intervals
- Price of the hour products
- Amount of the energy sold

For example at the day ahead market the tested BRP may provide external contracts up to 12 am for the next day. Contracts are provided for 1 hour products. The traded amount of the energy is not limited (it is set according to the BRP needs). The prices at the day ahead market are set by the auction and once set it is not changed therefore it is reasonable input for the testing environment.
At the intraday market the tested BRP may provide external contracts after 12 am till 75 min before delivery for the next day. Contracts are provided for 1 hour products. The traded amount of the energy is limited to the one half of the maximal trading amount (it is the data about traded amount available therefore its half is assumed to be an average). The price is changing all the time till the delivery. Since only the last price is available in the history the one is used as an input in the testing environment.

The trading with the external market in the Mirabel testing environment is implemented as a “price taking”, what means that BRPs contract with external market does not affect the price. This is reasonable assumption for the day-ahead market since the size of the balance group tested is small compared to the market area of the EPEX market. The intraday market operates with significant smaller quantities therefore the price taking model must take into the account the quantity limit available. The price taking model simplifies the implementation since no special logic needs to be implemented for the external market processes in the testing environment. Only the EEX historical data of the prices and contracts are used and assumed that they would be set by the tested BRP and accepted by market operator if the BRP would participate in trading for that time. That means that the tested BRP trading strategy follows the market data very accurately.

4.4 Definition of the reference data

The testing result from the simulation with the Mirabel product – called reporting result - needs to be compared to the reference result to estimate the effect of the Mirabel algorithms.
The reference result needs to contain the data, which are also the output of the testing with the Mirabel product. These data are

- Consumption data of the consumers
- Production data of the controlled production. This is the main input for the calculation of the imbalances, which are used at the calculation of various parameters for the efficiency estimation

Following the peak demand parameter (see chapter 5.1) the reference data are the measured consumption, what is already the result, when no Mirabel functionality is involved. When the demand side of the balance group is defined (their consumption profile), then also the reference peak demand is defined.

The generation of the reference data of the controlled production is not straight forward as at consumption data, because there is no external data for the controlled production. It is assumed that in the real environment without Mirabel product the controlled production is scheduled according some (more or less) accurate prognoses of the consumption and RES production for the next scheduling period. Therefore the reference data is generated with the artificial uncertainty of the forecast. The forecast uncertainty is a numerical parameter, which defines the accuracy of the forest result for the RES production and open contract consumption. The schedule of the controlled production is provided from the real RES production and consumption data, which are modified to provide the desired artificial forecast uncertainty. Several test shell be provided with different value of the forecast uncertainty and the calculated imbalances shall serve as the reference data.

More concretely, the reference imbalance (baseline) is defined as follows. Let $y_t^{P,trad}$ denote the controlled production at time t, let $y_t^{P,RES}$ denote the RES production at time t, and let y_t^{C} denote the consumption at time t. Furthermore, let $\hat{y}_t^{P,RES}$ denote the forecasted RES production at time t and let $\hat{y}_t^{C}$ denote the forecasted consumption. There is no forecast for the controlled production because it is planned anyway. Then, the reference imbalance at time *t* is computed by

$$\Delta y_t = \begin{cases} y_t^{P,RES} - y_t^C, & \hat{y}_t^{P,RES} \geq \hat{y}_t^C \\ y_t^{P,trad} + y_t^{P,RES} - y_t^C, & otherwise, \end{cases}$$

where $y_t^{P,trad}$ is computed by $y_t^{P,trad} = \hat{y}_t^C - \hat{y}_t^{P,RES}$. If we predict RES production to be higher than consumption then we do not plan controlled energy production such that the imbalance is defined by the difference of these actual values. Otherwise, we plan controlled production such that the imbalance is defined as the forecast errors regarding production and consumption.

Therefore, the reference imbalance also includes the error between forecast values and actual values, where this error mainly depends on the forecast horizon. Due to the fact that, in MIRABEL, we address intra-day forecasting and re-scheduling (while the baseline does not), we explicitly include this type of uncertainty (error) into account when computing the reference imbalance. Essentially, we follow two alternative approaches for computing these errors:
Forecast Error Comparison: Here, we use our own forecast models in a day-ahead approach and include the actual values and these forecasted values into the imbalance computation.
Synthetic Error Comparison: In order to allow more general experiments, where we can vary the included errors, additionally, we use synthetically generated forecast values (real values plus random or systematic errors) and include the actual values and these synthetic forecasts into the imbalance computation.
The synthetic generated forecast is calculated generically

$$\hat{y}_t^C = y_t^C + \varepsilon_t^r + \varepsilon_t^s,$$

Equation 2: synthetic generated forecast

Where ε_t^r is a random error with zero mean, e.g., Gaussian white noise and ε_t^S is a bias, i.e., a constant value. Both errors are modeled multiplicative (finite relative variance to the actual value).
The normalized value of the forecast accuracy is introduced on the forecast data generated [D4.3].

$$\mathbf{SMAPE} = \frac{\mathbf{1}}{n} \sum_{\mathbf{1}}^{n} \frac{|y_t - \hat{y}_t|}{y_t + \hat{y}_t},$$

which values are within interval [0... no error; 1 ... max error]. The finite relative variance of the parameters ε_t^r and ε_t^S is set to the values generating several forecasting sets with the different value of SMAPE.
The reference data used for the calculation of the Mirabel efficiency and successfulness are calculated via external data of the imbalances covered by the TSO interventions.
The total reference imbalance (baseline) is computed by

$$\Delta y = \sum_{t=1}^{n} \Delta y_t.$$

It is assumed that the simulated balance group has some averaged imbalances of the TSO area. Therefore the total reference imbalance is extrapolated to the size of the TSO area (regarding the consumed energy) and compared to the external data of the imbalances. The reference set most close to the external data shall be used as a reference.

4.5 Pricing

The system being developed is bound to the economic realities via prices and therefore the priced provided to and operated by the system have to be close to the real prices. In this section we describe what electricity related prices are important for the project and testing and how this price data is generated. We also describe how these prices are connected and how they are integrated into one business model.

4.5.1 General financial flow

The BRPs financial balance consists of incomes and outcomes, which balance should be nonnegative.
The BRPs financial incomes comes from consumer payments, which pay actual consumed energy. Its outcomes are production costs of the producers and imbalance penalties. External market contracts give additional incomes or outcomes.
The portion of the controlled producers is dedicated to the TSO so beside the payments for the production from the BRP it also receives some payments from imbalance settlement responsible for the participation at grid balancing.
The financial balance of the BRP is calculated to estimate

- Correctness of the open contract price. If the BRP has a surplus of the financial balance then the price may be reduced and vice versa
- Correctness of the discounts in the flex contracts. If the BRP has a surplus of the financial balance then the discount may be enlarged.

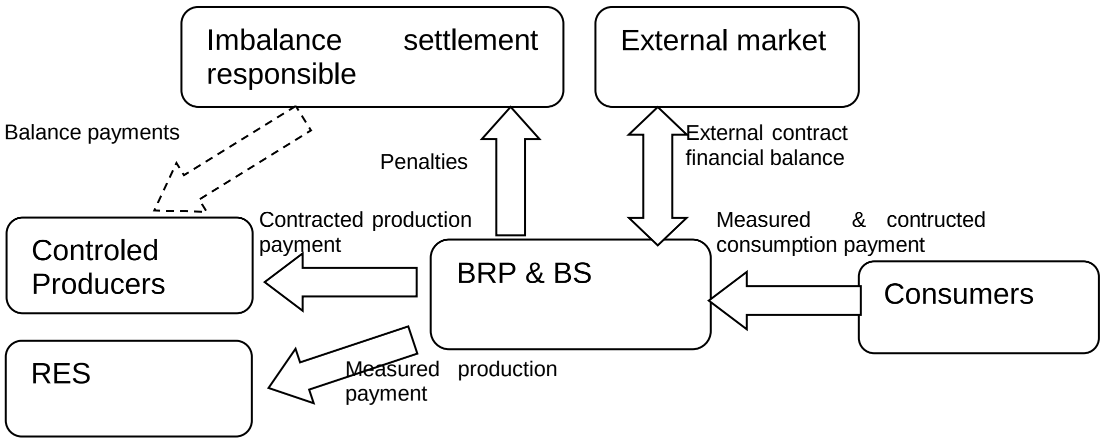

Figure 4: Financial flow in the testing environment

4.5.2 Open contract consumption price

The open contract consumption price is the source of the financial income for the BRP to cover its expenses. The open contract price is used for both types of consumers – household and industry – and is the most used consumption contract in the EES.
In the real environment the open contract price differs according to the tariff scheme and consumer type.
This price is normally above the optimal production cost because the consumer has no responsibility for balancing supply and demand – this responsibility is taken by the electricity company (role of the balance responsible party).
The tariff scheme may be one tariff- when the price is the same all the time, or a multi tariff – where open contract price is time-depends, that is, there are several prices for different time periods within one day. In this case, open contract price is specified for an interval for which it is valid. For example, there could day prices valid between 6:00 and 22:00, and night prices valid for the interval between 22:00 and 6:00.
In the real environment there are differences in prices between the household and industry consumer. The contracts between the BRP and industry consumer are confidential and contains the supply price, which may differ from one industry partner/branch to another and is different from the household consumer.
In the Mirabel testing environment the single tariff scheme and the same open contract price is used for industry and household.

The open contract consumption price is calculated on the bases of the total – one year – costs.

$$p_{open\ contract} = (c_{production} + c_{imbalance})/E_{consumed}$$

The production cost is calculated separately for the controlled production and for the RES. The RES production costs are described in the chapter 4.5.3.
The controlled production cost is calculated from the reference data contracted amounts (see chapter 4.4) and from the load duration curve Figure 1.
The BRP tries to cover the consumption with its controlled production. The referenced consumption forecast is calculated from the Equation 2. The result is put into the form of the load duration curve, where the "*x*" axes is equivalent to the generation capacity factor. The total production for the interval specified is calculated as an integral of the "vertical axes" - power

$$c_{production} = \int_{P=0}^{P=annual\ peak} dP * cf(P) * p(cf),$$

the energy consumed (or produced) is calculated as

$$E_{consumed} = \int_{P=0}^{P=annualpeak} cf(P)dP,$$

where *cf(P)* is the capacity factor received from load duration curve and *p(cf)* is the controlled production price calculated from Equation 1.

The introduction of the RES into the production portfolio affects load duration curve and changes the $c_{production}$ (production of RES needs to be subtracted from the load duration curve amounts before the $c_{production}$ is calculated).

The imbalance penalties are calculated form the imbalance energy flows which are calculated in the reference data. The RES production amount and amount of the energy consumed may be calculated in two ways

- Calculation from the input measurements.
- Calculation from the prognoses in the reference data

The open contract price calculated from the last option tends to limit to the first one when "ε_t^S "is zero (see Equation 2).
In the Mirabel test environment the first option is used which gives the BRP financial balance equal to zero for the reference data.

4.5.3 Open contract production price

The price of renewable energy *(RES)* is more expensive than conventional (controlled) sources and they cannot compete with them on the open market. Therefore, these sources of electricity in the real environment have a special status in the form of the two options:

- Electricity companies have an obligation to buy the overall production from RES. The entailed higher costs are covered by the consumers who pay a higher price for the electricity energy used. For example, the prescribed price for RES could be 0.45 EUR/kWh while the current retail price is 0.20 EUR/kWh and market price is 0.05 EUR/kWh. The electricity retailer then increases the price for all its customers from 0.20 to 0.25 EUR/kWh in order to cover its higher costs for RES.
- RES producers get a subvention so that their price becomes competitive with respect to conventional electricity generation facilities. RES producers could get a subvention 0.25 EUR/kWh so that they can decrease their price from 0.45 to 0.20 EUR/kWh.

The first option is used when the RES use an open contract relation and the balance supplier must buy all its production.
The second option is used when RES production needs to compete with the controllable sources on the open market.
In the Mirabel project, we are going to use the first option where RES producers get a fixed price to cover the production cost.

The open contract production price is used for RES like wind and solar power plant. The test bed model is designed to use all the energy produced.
The open contract production price is calculated according to the production cost, which is consisted mostly from overnight cost. The variable energy cost of energy production is neglected – the fuel does not cost anything.

$$p_{open\ contract} = c_{production}/E_{produced}$$

The energy produced is year average production which beside the installed capacity depends on the weather conditions like wind speed and solar activity.
The one year production costs consist of the overnight cost only

$$c_{production} = \frac{-rc_{overnight}}{1-e^{-rT}}$$

The variable costs are neglected. The energy produced is calculated from the capacity installed and capacity factor "*cf*".

$$E_{produced} = P_{installed} * cf_{year\ average}$$

The capacity factor is a function of the RES type (solar or wind energy) and the local weather conditions like expected sunny/windy hours per year.

4.5.4 External Market price

The prices of the energy on the external market are the input data to the testing environment. The input is sourced from the EEX published data [EPEX]. There are the following data to be imported

- The day-ahead market price – the final price set as a result of the auction.
- The intraday market price. There are two sets a) low – purchase price and b) high – buying price.

4.5.5 Consumer Flex offer price

The possibility to freely schedule consumption is the reason why the BRP is ready to pay for the flex-offer mechanism. Since the consumption is on open contract in the real environment the payment is made in the form of better price of electricity when using flex-offers in comparison with open contract price. Thus it is assumed that open contract price is the worst possible price for the consumers and by using flex-offers they can get somewhat better prices.

In the Mirabel test environment all the flex offer hold the same price. It is very hard to estimate the efficiency of the Mirabel product in advance and a consequent cost saving, which may be shared among flex-offer issuers. Therefore the flex-offer discounted price cannot be determined correctly in advance.

In the Mirabel testing environment approach the flex-offers issued by consumers do not specify the price. The BRP automatically treats them as flex-offers with open contract price. The price bonus is provided by BRP automatically with its price setting procedure. In this case, BRP evaluates all flex-offers from the point of view of their flexibility value (see [D5.3]) and then set the price according to this evaluation. In the simplest form, flex-offers with large flexibility will get a better price bonus and flex-offers with no flexibility will be assigned the current open contract price.
The post-test calculation, which shall calculate the BRP cost balance, shall check the accuracy the price setting algorithm – whether there is still space for additional discounts or the discounts should be reduced.

4.5.6 Scheduled production price

The price of the scheduled production is set to the amount which covers the fixed and variable production costs (see chapter 4.2). There are several production units, which price is set according to their expected capacity factor. The expected capacity factor occupies the values from the range [0...1].

The scheduling shall always schedule the controlled production starting with the cheapest one. Therefore the last scheduled production price is actually a price of the next "*kWh*" produced. With the load duration curve (Figure 1), which defines the dependency of capacity factor from the consumption level it is defined as (Equation 1)

$$p(P) = p_f / cf(P) + p_v,$$

Equation 3: Scheduled price

where "*P*" is the consumption power. The price of the next "*kWh*" sold (Equation 3) is the actual price within the BRP for the specified interval. It depends on the moment consumption level – higher is consumption higher is also the price of the next *"kWh"* sold.

There are two options setting the price of the production during the test execution

- The price remains constant during the test execution. The post execution calculation shall show whether the producer gain the profit or loss
- The price is adapted during the simulation. The financial balance of the producer is close to zero

The price adaptation during the simulation is calculated from the capacity factor in the past and expected capacity factor for the specific interval in the future

$$p_{production} = \frac{p_f}{cf_{\text{expected}}(1 - f_t) + cf_{realized} f_t} + p_v,$$

where f_t is a portion of the time regarding the testing interval (one year), which has already passed.

4.5.7 Imbalance price

The imbalance price is calculated on the bases of the scheduled production price in the previous chapter. The calculation differs whether the imbalance is positive (exceed of the production) or negative (lack of the production).

The price is dependent from the level of the demand. Higher the demand is, more expensive are the imbalances.

The procedure is used also at the external trading. The BRP adapts its production to the situation on the external market. If the external price is low, the BRP buys the energy and reduces its own the production level – the imbalance price is reduced adequately.
In the case of the external trading and existence of the balance market the imbalance price is defined by the balance market data.
The imbalance price is also an input of the scheduling algorithm and it needs to be forecasted for a certain interval ahead. It is calculated:

- As a price of "*next kWh*" produced from according to the level of the production in that moment.
- As a forecast of the imbalance price on the imbalance market if the market is modeled on the external market.

4.5.8 Acceptance condition

Flex-offers issued by a prosumer can be either accepted or rejected by the BRP. Informally, a flex-offer should be accepted if there is high probability that it will be "useful" in future after it is executed. Since the usefulness depends on future situation, this procedure is inherently uncertain, that is, we cannot guarantee that an accepted flex-offer will be really useful or a rejected flex-offer will be really useless. For example, other flex-offers can be accepted which change the valuation of this flex-offer. Or prices can change (market price, imbalance price etc.). Therefore, the quality of the acceptance procedure depends on the quality of available forecasts.

Another important factor to be considered when accepting flex-offers is that their value (usefulness) for BRP in most cases cannot be estimated individually but rather it depends on other flex-offers. Therefore, an ideal acceptance procedure has to perform very complex global optimization for each individual flex-offer in order to make a decision about its acceptance. In other words, for each new flex-offer (or a set of flex-offers waiting for their acceptance) BRP has to execute a complex scheduling along with the existing (already accepted and scheduled) flex-offers. This procedure will also take into account new scheduling parameters like imbalance prices which may change at this time. Such an approach is obviously infeasible for performance reasons (note that scheduling requires aggregation). Therefore, we use an approximate acceptance procedure which is based on evaluating individual flex-offers in the current BRP context.

The context in which flex-offers are evaluated has the following major constituents:

- Current electricity balance (accepted flex-offers, electricity bought on the market, RES obligations, open contract forecasts etc.)
- Current prices (imbalance prices, market prices, open contract price etc.)

To evaluate the value (usefulness) of flex-offers the following criteria are taken into account:

- Quantitative criteria need to be evaluated in terms of costs and other quantitative parameters
  - Cost reduction due to decrease of the current imbalance and hence less payment for imbalance.
  - Cost reduction due to better flex-offer price in comparison to alternative sources like market price.
- Qualitative criteria
  - Peak reduction.
  - Peak load
  - Flex-offer potential. It describes how this flex-offer might be useful under changing conditions (independent of its usefulness in the current context).
  - Flex-offer flexibility interval where it can be scheduled. The longer this interval, the better this flex-offer is.
  - Flex-offer schedule before time –the amount of time the BRP has for scheduling. Flex-offer that can be scheduled later has higher value for BRP.

Quantitative and qualitative criteria are evaluated by finding the best position of this flex-offer under the current conditions. The best position means setting the starting time in such a way that the corresponding criterion is maximized. Flex-offer potential is evaluated using its own parameters possibly taking into account a limited context within its interval of flexibility. More detailed description of the acceptance procedure can be found in D5.3 [D5.3] and D5.4 [D5.4].

4.6 RES ratio

The RES ratio is a parameter which gives a measure of the amount of the RES in the simulation environment. There are two values for the definition of the RES ratio

- Installed capacity. The peak production power is used as a parameter. This parameter is defined by equipment producer
- Produced energy. The amount of the energy produced in the interval under the examination is used as a parameter. This parameter is actually a measured result.

The installed capacity ratio measures how much of the installed production power on the grid belongs to the RES

$$RES\_CapRatio = \frac{ResCapacity}{Controled\ ProductionCapacity} \quad \boldsymbol{RES\ ratio} = \frac{\sum_{period} \boldsymbol{RES\ energy}}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 4: Calculation of the RES capacity ratio

With the additional RES installed in the environment the capacity of the controlled production remains the same. This is necessary because the controlled production still needs to satisfy the consumption in the case of the bad production whether conditions.

The parameter used for the estimation of the RES integration efficiency is based on the energy.

$$RES\_EnRatio = \frac{\sum_{period} ResEnergy}{\sum_{period} TotalEnergy} \quad \boldsymbol{RES\ ratio} = \frac{\sum_{period} \boldsymbol{RES\ energy}}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 5: Calculation of the RES energy ratio

The "*ResEnergy*" is the energy produced by RES while the "*TotalEnergy*" is the energy consumed.
The "RES_EnRatio" parameter is not equivalent to the "RES_CapRatio" since the energy from RES since the RES production may be too large to be absorbed by the consumption and therefore needs to turn off. In the testing environment this situation is detected when the imbalances exceeds the TSO balancing capacity.

The RES ratio is compared between the reference data and reporting data.
At the execution of the test scenarios one defines the "RES_CapRatio", which is the source of the calculation of the "RES_EnRatio". The "RES_EnRatio" is the parameter which is used as an independent variable for efficiency coefficient calculation dependency.

The indicators are calculated separately for the solar and wind energy and a combination of both types.

4.7 Scalability of the input data

The goal of the scalability is to generate the proper input data reflecting the representative balance group with sensible consumption and production portfolio.

The scalability is provided on

- Household consumption. The measurements from the Meregio project contain around 1000 household consumers. Typical middle size balance group has around 100.000 household consumers
- Industry consumption. The typical ratio between industry and household consumption is around 2:1 at the energy consumed, Therefore the industry consumption input data needs to be escalated correspondingly.
- RES production. The size of the RES production is a subject of testing. Its portion is a variable parameter relative to the controlled production.

4.7.1 Fulfilling the missing data

The measured input data has irregular values and measurement time gaps due to the bad connection or the measurement equipment failure what needs to be resolved and fulfilled before the scalability.

The corrections, which need to be close to the real value, are calculated by forecasting.

It is assumed that the measurement values contain periodical behavior and the missing measurements actually behaves similar as in the past or in the future The forecast is provided by the extrapolation of the existing measurement with the Fourier transformation.

The calculation is based on the 24h hour period – most typical repeat period. A several days of valid measurements before (or after) the day with the missing data gap is used as an input of the forecasting. Then the Fourier transformation result is used to generate the time history function.

$$P_i(t) = a_{i0} + \sum_{n=1}^{\infty} (a_{in} \cos n\omega_0 t + b_{in} \sin n\omega_0 t),$$

Equation 6: Input data time history with the Fourier Transformation

This function is used to calculate the missing data at the time “*t*”.

If the measurements gap lasts more than the 24 hour period then the function result is already ready to fulfill.

If the gap occupies only a portion of the 24 hour period then the forecast result values need to be added by the constant to get a smooth function during intraday.

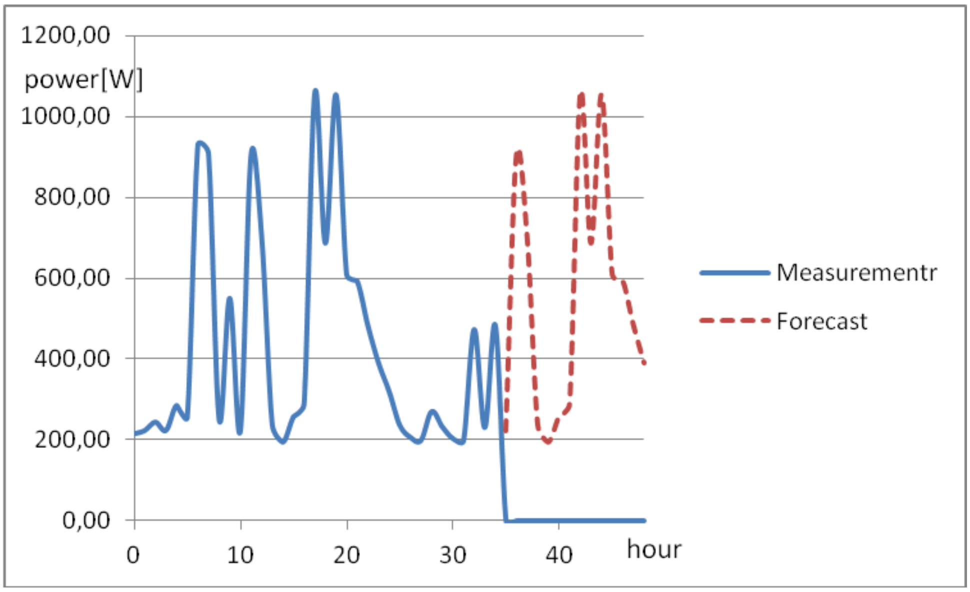

Figure 5: Fulfilling the missing data

To provide the better forecast one may take day type into the consideration. The most typical day types are workday and weekend. This is not valid for the RES production.
The procedure for the fulfilling the missing data is the following:

- Find the day with the missing data in the dataset
- Get the satisfying amount (10 days) of valid measurements before the missing gap (with the same day type as a missing gap)
- Calculate the Fourier coefficient of the selected measurements
- Calculate the forecast for the 24 hour period with the missing gap
- Adapt the forecasting result to the actual consumption. In the case the missing data gap lasts only a part of the day the existing data are used to adapt calculation in the way that the last measurement data prior the gap must match the calculated forecast.
- If the missing data gap is at the beginning of the time history then the reverse process is used – the measurement data after the gap are used for the calculation.

4.7.2 Scalability of the household consumption data

The scalability of the household consumption data multiplies the existing measured data of the household consumption from the Meregio project to the size and amount of the middle size of the balance group.
The1000 measured household data from Meregio data is multiplied by 100 to get the desired consumption portfolio.
The scalability result must keep the main characteristic of the household consumption like

- Typical consumption profile (differing according to the day type)
- Average power
- Distribution of the average power classes
- Peak occurrence distribution
- Peak size distribution
- Seasonal deviations,
- etc.

The scalability procedure assumes that household consumers have some similar periodical behavior, therefore the Fourier transformation is used as a basic.
The existing measurements are used as in input into the Fourier transformation which is used to calculate the set of the Fourier coefficients for each consumer.

$$a_{i,n} = \int P_i(t)\sin(\omega_n t)dt$$

Equation 7: Fourier transformation of the measurement

where “$P_i(t)$” is consumption measurement of the household “i”. Putting the coefficient “a_n“ from all the consumers into the distribution diagram one gets its main characteristics like average value and distribution with.

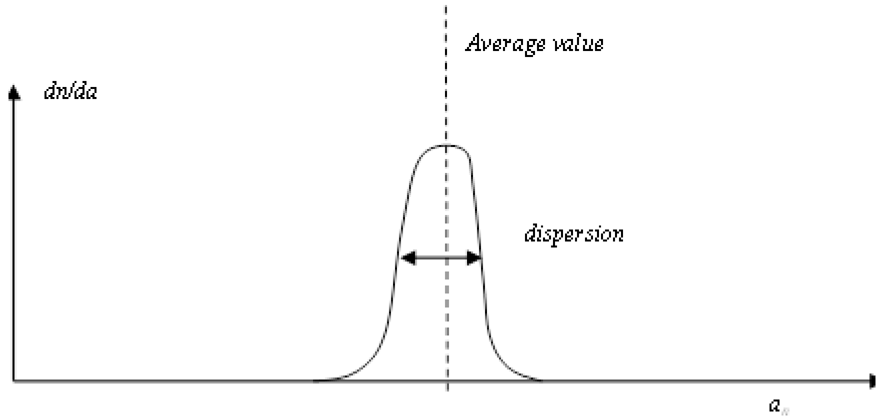

Figure 6: Distribution of the Fourier Coefficient values

The scalability procedure provides the new signals by random generator, which generates the new values of “a_{jn},” with the normal distribution around average value and with dispersion width.

The procedure of the scalability consists of the following steps

- Fulfilling the missing data
- Calculation of the Fourier coefficients.
- Calculation of the average value, and dispersion parameter for the each coefficient
- Generation of the of the new Fourier coefficients for the new consumer by random generator
- Reverse Fourier transformation for the generation of the new consumer consumption time history

4.7.3 Scalability of the Industry consumers

Similarly as a household consumer also the industry consumer contain some periodical behavior but on the other hand the pattern of the input data is far too small to provide the scalability based on the statistically oriented Fourier transformation.
Beside that the industry consumer needs to be subdivided into the particular industry branches before one can seek the characteristic consumption. Since the industry consumption portfolio differs much from balance group to balance group also the industry consumption in general may differ significantly.

Therefore the main goal of the industry consumers is to sustain the proper consumption portion according to the total consumption.
The scalability procedure of the industry consumption data generates the new consumption data by randomizing the existing signal.

$$P_j(t) = P_i(t) + k \cdot random() \cdot P_i(t)$$

Equation 8: Fourier transformation of the measurement

Where the result of the "*random ()*" is random value between *[-1...1]* and "*k"* is a multiplier set to for example 10% generating the 10% modification.

4.7.4 Scalability of the RES production

There will be used only two sets of the input data for the RES production – one for wind mill generation and one for photovoltaic.
Since the RES production capacity is a subject of investigation and therefore it is a parameter varying from zero to a certain extend. The RES data are therefore escalated by corresponding interpolation or extrapolation of the existing measurements to achieve the desired parameter value.

4.8 Consumption flexibility model

The consumption flexibilities in the testing environment are created according to the input consumption measurement data the creation of the flexibilities follows the following facts

- The flexibilities are based on the appliance model. The flexibility belongs to one device at one consumer
- For the households: The total consumer consumption with flexibilities within the 24 hour period remains equal to the input data. That means that on average consumer consumption remains the same regardless of whether the flexibilities are applied or not.
- For the industry consumers: the flexibilities are applied to the appliances detected. According to the branch the particular industry input data belongs the appliances are detected and flexibilities are generated

4.8.1 Flexibilities for the households

The input data from the Meregio project does not fully support fully appliance based approach since it provide the total consumption only and does not give the information about the flexible load types and powers of the particular consumer and operation intervals. Therefore the generic flexible appliance model with the following characteristic is used in the testing environment:

- One flexible appliance per consumer
- The amount of the flexible energy is fixed for each consumer. Its value depends on the consumer average daily consumption. Additionally it may depend also on the day type – the flexibility during the weekend is different than during the workday
- The consumption power profile is assumed to be constant. The consumption duration is a variation parameter
- The time flexibility is a variation parameter

The procedure of the FO generation consists of the following steps:

1. Calculation of the energy amount in the flex offer

2. Detection of the consumption origin of the Flex offer. The flex load (dish washer) actually participates in the total consumption measurement if the Meregio data.
3. Calculation of the flexibility parameters (Start before, Start after, assignment, acceptance and FO issue time).

Ad 1) the energy amount may be calculated from
a) Multi-tariff Meregio data - This is a conservative method which shall gave the lower bound of the flex energy amount. Due to the automated Mirabel approach the actual flexibility is expected to be larger.
b) Appliance based model - This should be best estimate method when defining the particular set appliance per consumer as reasonable as possible.
In both approaches the flexible energy is calculated on the daily bases

Ad 2) once the flex energy amount for the particular consumer for the particular day is estimated, its consumption origin in the Meregio measurements must be detected to get the open contract (uncontrolled) consumption time history. The consumption origin may be placed at any moment of the daily consumption where the measurement exceeds the power of the flexible load consumption profile. The origin may be chosen randomly. The weighted function is the size of the measured consumption power (what avoids to locate the flex load origin at the night when only some background consumption exist).

The calculation of the open contract consumption is provided by determining the consumption time of the consumer flexible appliance from its consumption measurement. The consumption profile of the flexible appliance must “fit” into the measurement profile. For example the appliance of the power 500W and its consumption duration of 2h may be located at three time positions during the consumer consumption: 9:00, 17:00 and 20:00. The random generator chooses one location as flexible appliance consumption origin. Choose is weighted by the amount of the measured energy. For example the origin at 20:00 has a higher probability to be chosen than the rest.

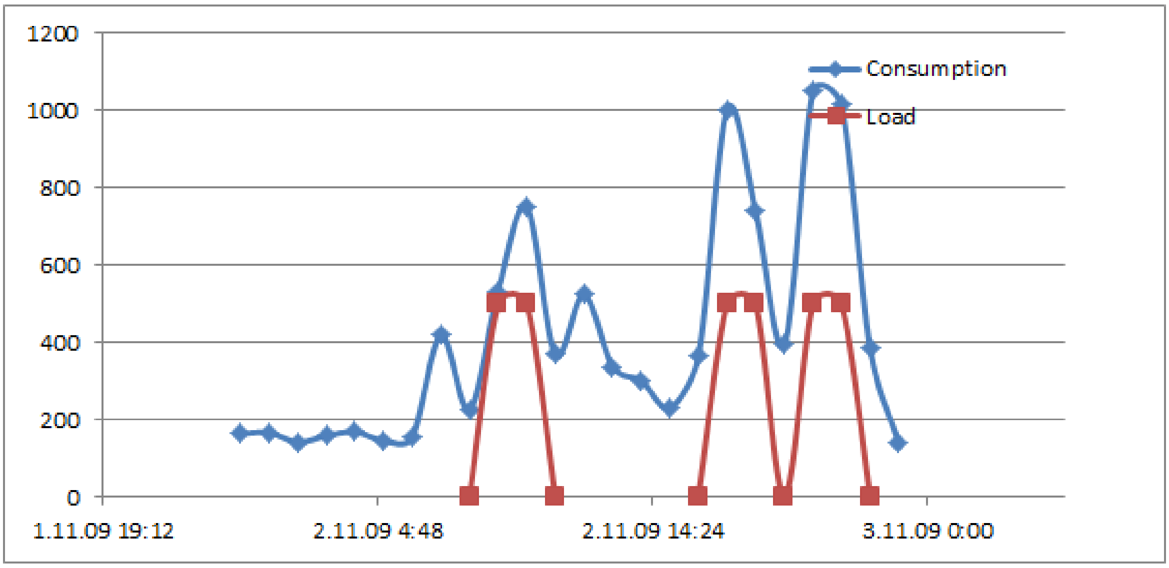

Figure 7: Possible location of the flexible appliance consumption according to the consumer consumption

Ad 3) the flex energy parameter are varied with the random generator.

4.8.2 Flexibilities for the industry consumers

The appliances in the industry differ from the ones foreseen as the flexibility holders in the households. Mostly they are involved into the production process and their adaptation capacity needs to be a result of the precise feasibility study.
Some of the most representative appliances are

1) Production units: gas turbines, diesel generators
2) Coolers and heaters
3) Background consumption systems like ventilation, lighting, etc.

Ad1) the production units are usually directly involved into the production process, but usually not with the full capacity. Normally there is always a band for enlarging and reducing a power.
Ad2) a coolers and heaters normally operate in the optimal mode – at optimal temperature. But usually the appliances have a high and a low limit of the temperature where they are still in operation and the production process is not affected (see Figure 1).

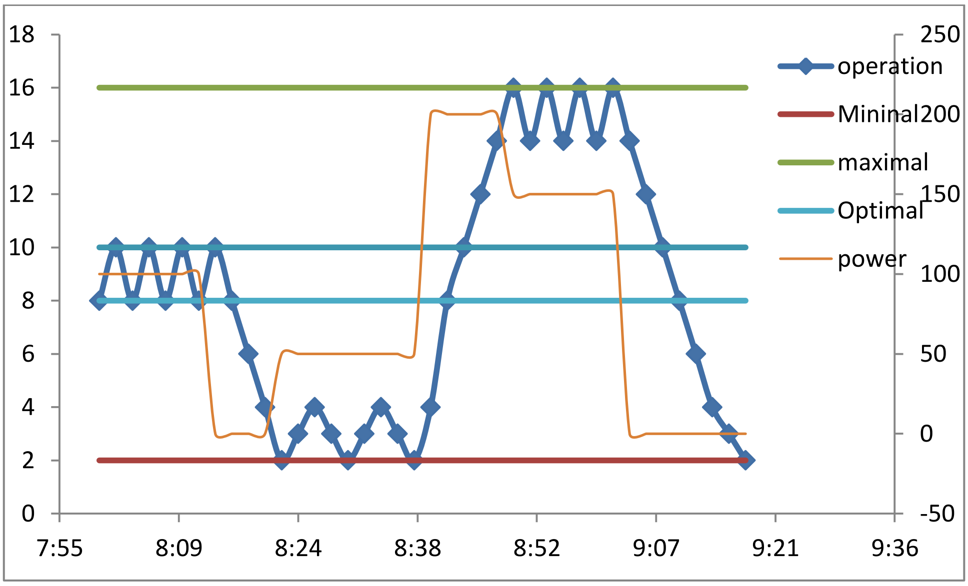

Figure 8: Normal maximal and minimal operation of the appliance

The total energy consumed by the appliances remains the same, but the power profile and corresponding energy consumed within the time interval may vary within the limits.
The flexibility of such appliance may be set in the following ways

- The minimal power needed for operation is the energy on the open contract, the energy necessary to reach the optimal operation is put into the flexibility with the fixed total amount but the flexible consumption profile
- All the energy needed is in the flex offer with the total energy constraint but flexible energy within the flexibility intervals
- The optimal operation consumption energy is on open contract. The changes are either production or consumption flexibilities with the variable amount of the energy.

In contrast to the household appliances where the short term consumption duration with long time flexibility is foreseen, in the industry the long term consumption with energy flexibility is foreseen. To sustain the flexibility one need to

- Cut the appliance flexibility into the several short time period flexibilities
- Send subsequent flexibilities during the operation of already scheduled flexibilities.

Ad3) the background system like lights and ventilation systems may reduce the consumption for the limited amount of the time. The behaviour is treated as production flexibility. The setting of the flexibility should be within the technical limits and enable the scheduling to use it for the peak reduction. The flex offer setting needs to hold a fixed power and variable duration. The price needs to be higher than the base production unit price but lower than the highest peaking production unit one.

4.9 Stress test, Failure conditions, unpredictability

Since the Mirabel project shall not provide the real product based on some HW configuration but rather the solution approach and algorithms, it is not feasible to provide the stress test and failure test which may be provided on the following subjects

- The assigned flexibility is not used by prosumer according to the scheduling algorithm
- The breakdown of the production unit
- The breakdown of the BRP center
- No connection to the TSO
- No connection to the external market

The goal of the Mirabel project is to recognize and represent the benefits of its algorithms and its unique approach therefore it is out of the project scope to analyze the failure conditions.

The alternative, the analyses and solution proposal is necessary for the situation of the service center break down or assignment message loss.

During the development the stress test s for the particular component (aggregation forecasting and scheduling) are provided, which give the result of the main component limitations.

4.9.1 Forecasting stress test

As mentioned in Section 3.6, we refer for details on the experimental evaluation to the deliverables D4.1, D4.2 and D4.3. In general, our stress tests mainly comprise the investigation of varying data sizes (input rates of new measurements, size of training data, and data granularity in terms of temporal precision), varying forecast horizon, and in future work, also varying number of system nodes.

4.9.2 Aggregation stress test

The goal of the aggregation component stress test is to investigate if the aggregation component is capable of *correctly transforming* N realistic (micro) flex-offers into M aggregated flex-offers in a fixed duration of time. Here, the term “correctly transforming” means that any assignment to any aggregated flex-offer can always be disaggregated into respective assignments to underlying (micro) flex-offers. The number N is chosen to be 600.000. It corresponds to a maximum expected number of flex-offers handled by a BRP node that services 100.000 users (see Section 3.7) issuing 6 flex-offers per day in average. The number M must be in range between M_L and M_H. The M_H is chosen to be 10.000, which is a maximum numbers of flex-offers the scheduling component can handle in a reasonable time (see D5.3). M_L is chosen to be 1000 (the scheduling component completes in few seconds). We think that lower than 1000 M_L values might substantially reduce the scheduling potential. Note, M_L and M_H values will be chosen more reasonably during foreseen aggregation and scheduling components integration test.

Another stress test investigates what is a maximum number (N value) of input flex-offers the flex-offer component can handle in fixed time duration and fixed [M_L ... M_H] interval.

One of the discussed flex-offer generators will be used to derive realistic flex-offers for all tests. As a part of the stress test result, recommendations for the aggregation parameters are provided.

4.9.3 Scheduling stress test

While the scheduling module returns feasible schedules for all given aggregated flex-offers in the given amount of time, there exist boundary situations where this is not the case. For example, the amount of time available for scheduling can be so small (a few milliseconds), that scheduling cannot construct a single feasible solution. Also, if the given aggregated flex-offers have not been properly preprocessed (removing the flex-offers whose assignment before time is in conflict with its time flexibilities and the current time, see deliverable D5.3 for more details), it might not be possible to schedule them in time. Moreover, some errors in the given flex-offers (such as inconsistencies in the energy flexibilities and the required amount of total energy) can become apparent only at scheduling. Finally, while the scheduling module sees to finishing in the given amount of time, unexpected events can delay its completion.
Therefore, the stress test for the scheduling module consists of different (borderline) scenarios aimed at catching the mentioned problems.

4.9.4 Unpredictability of the human behavior

The Mirabel system is tested also from the side of the unpredictability component – human behavior. It is tested in the way, whether the consumer shall stick to the flex-offer contract or they consume in their own way.
The ration of the real consumer not obeying the consumption from the flex-offers assigned is not known. Therefore it is modeled with the randomly chosen consumers consuming in the same way as input measurements regardless the flex-contracts. With the parameterized probability the random generator shell determine the fraction of the consumers which uses the load contrary with the contract and the time parameters of the load usage.
The unpredictability is tested separately. The other tests estimating the peak reduction and the rest of the successfulness criteria are executed with no unpredictability of the human behavior.
In order to examine the influence of the human behavior on the Mirabel efficiency several tests with different fraction of disobedient consumers need to be modeled and an influence on the successfulness criteria shall be measured.
This component of the unpredictability is introduced on the consumer node. After the flex-offer assignment the random generator with the parameterized probability decides whether the consumer consumes according to the contract or its consumption proceeds according to the input measurement.

4.10 Test environment roles

The Figure 9 shows the roles and their relations in the testing environment. This chapter describes the general picture of the environment. The particular testing scenario, which is focused on the examination of the one part of the environment or one feature, may not use all the roles and relations. The test case specifics are given in the chapter 6.

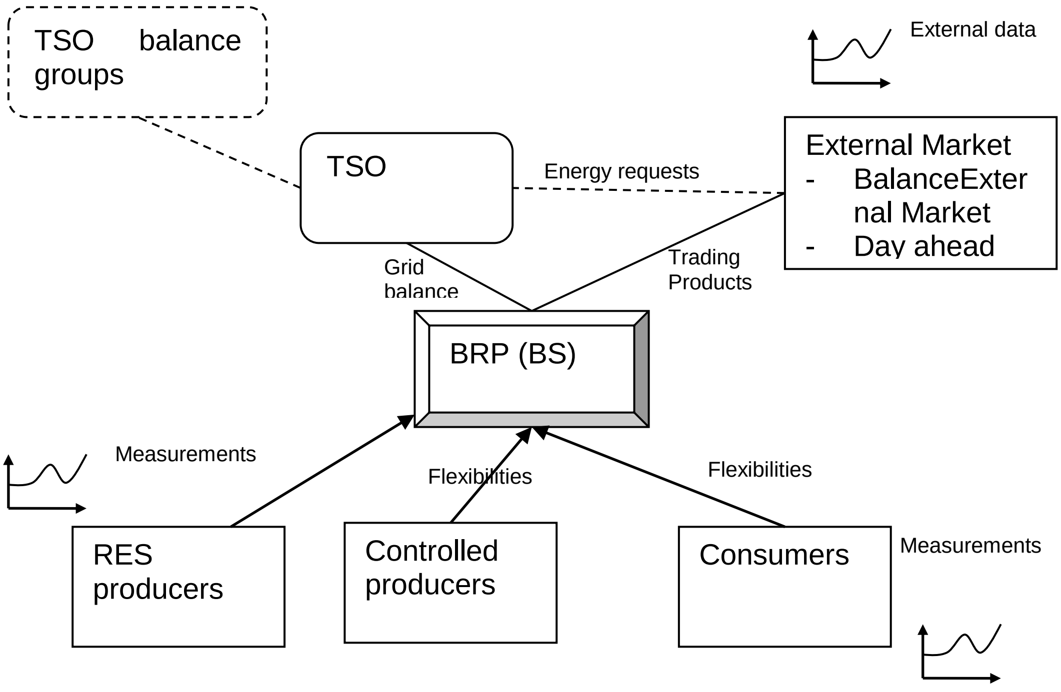

Figure 9: Test environment roles

Balance responsible party and balance supplier

The balance responsible party with one balance supplier is the entity using the Mirabel product containing the forecasting, aggregation and scheduling component with corresponding control component.

In addition to the Mirabel activities – manipulation with the flexibilities to cover the imbalances – this entity provides the following activities

- Communication with the external market
- Prognoses the imbalance price
- Handle the weather forecasts

All the data needed for its operation are provided by other entities. They also provide the triggers necessary

System operator with TSO balance groups

In the simulation environment the system operator is used to

- Balance the grid. It is assumed that the TSO covers all the deviations between the production and consumption. The deviations are only a calculation of the difference between the actual production and consumption
- Providing the request for the balance market. The TSO is responsible for the transport grid involving many balance groups including the simulated balance group. His energy requests on the balance market are sourced from the imbalances of all

the BGs and are used to balance all the TSO area. The simulated balance group provides the bids on the balance market and executes the eventual TSO requests.

Consumers
Consumers consists of the numerous of the households and industry consumers, which are presented from real measurements and multiplied by scalability. According to the measurement and the flex-offer model they generate the flex-offers.

Controlled production
The controlled production is unit implements the mode described in the chapter 4.2. It consists of the two types of the production units

- Base load production unit and
- Peaking production unit.

The controlled production consists of several units of each type. Each unit has a different capacity ration and correspondingly different price. The controlled production does not have the any input data. It offers its production capacity and is scheduled by the BRP scheduling result.

RES production
RES production consists of the variable capacity of the wind mills photovoltaic panels, which are presented from real measurements and multiplied/reduced by scalability.

Market operator
In the simulation environment there are the following market types simulated

- Day ahead market
- Intraday market
- Balance market

Due to transformation of the market offers into the common form – energy amount and price – the one generic market entity may replace all the types. The market type is defined by the set of the input data sourced from the real environment

To improve the scenario test result relevance the external market data time frame should be synchronized in time and location with the production and consumption data.

5 Successfulness criteria

The successfulness criteria are used to estimate the effect provided by the Mirabel product on the consumption of the electricity energy. They are in the form of the key performance indicators (KPI), which are evaluating several aspects of the Mirabel solution influence on the electricity production, consumption and the balance between them. The expected benefits have some cost reduction consequence which is needed to be shared among all the roles involved.

The criteria provided fulfill the strategic impact in the [DoW] and are based on the “Definition of methodologies” document from the dedicated project [3e-Houses].

5.1 Peak Criteria

The peak consumption is one of the most important parameters at the design of the electricity grid, the definition of the production portfolio and capacity and of course on the

total cost. The criteria directly affects the system operator (TSO and DSO), which is responsible for the safety and the reliability of the network, because the grid capacity is the constraint for the peak height.
It is expected that Mirabel result shall reduce the peak consumption since the scheduling takes into account also the production price, which is higher at peak consumption than at lower one. Therefore it is a cost benefit for the BRP to schedule the flexible consumption in the time period of lower consumption.
The peak consumption is relevant successfulness criteria only in the situation with no RES. The Mirabel scheduling algorithm for the consumption follows the production and if there is RES in the production portfolio, which is quite irregular, also the consumption trying to follow the production shall bi irregular.

Estimating the peak reduction the two criteria may be used
- Maximal demand
- Load factor

5.1.1 Maximal demand reduction

The maximal demand reduction estimates the possible reduction of the production capacity installed on the grid.
The maximal demand reduction needs two parameters to be calculated
Peak consumption from reference data
Peak consumption with Mirabel scheduling result – reporting data

The reference data are the consumption measurements, when no demand interventions were executed, while the reporting data are the consumption as scheduled from the Mirabel product.
The demand reduction is calculated as

$$Reduction = \frac{P_{peakrep}}{P_{peakref}},$$

Equation 9: Calculation of the demand reduction

Where $P_{peakrep}$ is the peak power in the reported time interval and the $P_{peakref}$ is the peak power in the referenced time interval. The referenced time interval is time frame with no interventions while the reporting time interval is time frame with interventions.
In the case of the Mirabel trial case simulation the reference and reporting time interval are the same. In the reference time period the measured data are used while in the reporting period the application result data are used.

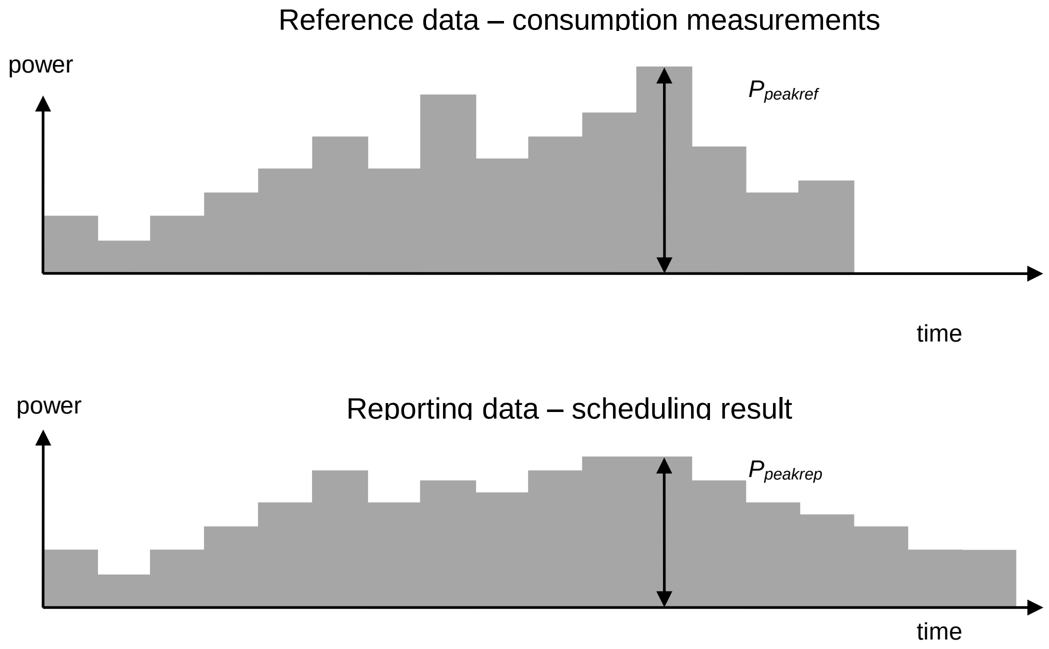

Figure 10: The data for the demand reduction criteria

The peak consumptions and reduction are calculated over the prescribed period

- Over the time interval the measured data extend
- Over a year
- Over a month
- Over a week
- Over a day

A month period is not very suitable for the calculation since its interval is not of constant duration and the consumption is related to the human behavior which is typical to the daily, weekly and yearly period.
When calculating the peak consumption on the day, week or month period base, it is needed to provide the averaging over the year or over the interval of the measured data.

At the calculation of the peak criteria it is necessary to define the day types to separate the work day from weekend and holiday and make also separate calculation.

The peak reduction criterion depends on the averaging interval of the power calculation. It is agreed that the averaging period is set to most general time interval – 15 min.

5.1.2 Load factor

The load factor (LF) calculates the irregularity of the consumption. It is defined [3e-Houses] as

$$LF = \frac{P_{min}}{P_{max}},$$

Equation 10: Calculation of the load factor

The load factor is calculated for the same periods as for “Maximal demand reduction” (Chapter 5.1.1). It is calculated separately for the “reference data” and for “reporting data”. The successfulness is estimated by comparing the values of “reference data” and “reporting data”.

5.2 Balance group imbalances indicator

One of the main obstacles at integration of RES like wind and photovoltaic power is their unpredictability resulting into the imbalances. The imbalances need to be covered by the TSO with immediate interventions of increasing or reducing the production power. Since the TSO has a limited capacity for the grid stabilization in the real environment it is very important for the electricity grid stability to keep the imbalances as low as possible.
The imbalances are measured on the level of the balance group. The imbalances of the balance group are calculated as the energy needed to be inserted by TSO to balance the production with the consumption.
There are several types of the TSO intervention differed according to the characteristic time interval – primary, secondary and tertiary. In the Mirabel testing environment the first two has too short characteristic time interval (several minutes) therefore only the tertiary interventions are relevant to be followed.
The source of imbalance is inability of the control demand and (RES) supply. The nature of demand and the part of the supply is it can only be predicted and not controlled.
The size of imbalance depends on the size of the total consumption and RES production in the balance group and the type of the production/consumption (controlled, RES; household, industry).
At the definition of the “imbalance indicator” it is sensible to provide the normalization according to the total energy flow of the balance group since there may be a surplus or lack of energy the absolute value must be used at the TSO intervention.

$$\boldsymbol{imbalance\ indicator} = \frac{\left(\sum_{(period|\square)} \boldsymbol{TSO\ energy}\middle|\square\right)}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 11: Calculation of the TSO energy indicator

Where “Total energy” is the maximum either of energy consumed or produced by the BG in the specified period.
The imbalance indicator is calculated for the same periods as peak reduction (subchapter 5.1).

In the simulation environment the “TsoEnergy” is calculated as a difference between actual production and actual consumption. Unlike the real environment where the production and consumption must be equal all the time, in the simulation there is a difference, because there is no active TSO entity simulated. The simulation environment is simplified by implicit assumption, that TSO automatically covers all the imbalances.

$$\boldsymbol{imbalance\ indicator} = \frac{\left(\sum_{(period|\square)} \boldsymbol{TSO\ energy}\middle|\square\right)}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 12: Calculation of the TSO energy indicator

The “MarketEnergyBalance” is amount of the energy transferred from/to external market.

The imbalance indicator is dedicated to the balance group and the balance responsible party is the stakeholder mostly concerned about this item.
Beside the imbalance indicator also the following parameters necessary for the TSO are calculated:

- necessary capacity for production enlargement = Max(TsoEnergy$_{time}$),
- necessary capacity for production reduction = Min (TsoEnergy$_{time}$) – TsoEnergy may be negative.

5.3 Billing of the penalties

One of the scheduling criteria is also the minimization of the imbalance penalties. The reduction of the imbalance at the moment, when they are expensive may also be sourced from enlargement of the imbalances from the time they are cheap. The imbalance as absolute quantity remains the same, but the total penalty cost for the BRP is lower. Therefore the following indicator is introduced

$$PenaltyIndicator = \frac{\sum_{period} TsoEnergy * \mathrm{Im}balance\,\mathrm{Pr}ice}{\sum_{period} TotalEnergy}$$

$$\boldsymbol{imbalance\ indicator} = \frac{\left(\sum_{(period|\square)} \boldsymbol{TSO\ energy}\left|\square\right.\right)}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 13: Calculation of the penalty indicator

The most transparent imbalance price is represented by the imbalance market. In the trial case, where there is no external market in the environment the imbalance price is correlated with the highest contract price of the production in the specified moment.

5.4 Optimal controlled production portfolio

The controlled production portfolio is calculated according to the expected consumption and expected production of the RES. The share of the peaking production unit related to the total controlled production capacity depends on the actual consumption - peak height and duration, etc.
The controlled production is modeled according to the consumption measurements. The test with the Mirabel product is executed with the same controlled production portfolio as the reference data. But since the Mirabel changes the consumption, the controlled production portfolio is not optimal anymore.
Regarding the controlled production the following is calculated after the test execution

- optimal ratio of the peaking production unit and base units – it is calculated from the resulted load duration function
- estimation of the additional savings at the total cost if the optimal controlled production would be used.

The additional savings are calculated from existing result of the controlled production, where the price is related to the optimal production portfolio.

5.5 Consumer benefit

The consumer offering the flexibility benefits by lower price and lower cost of the energy consumed. The indicator estimating the consumer benefit averages the reduced prices and compares it to the open contract price.

$$PriceReductionIndicator = OpenContractPrice - \frac{\sum_{period} FlexContractPrice * FlexContractEnergy + BrpCostBalance}{\sum_{period} FlexContractEnergy}$$

$$\boldsymbol{imbalance\ indicator} = \frac{\left(\sum_{(period|\square)} \boldsymbol{TSO\ energy} \middle| \square\right)}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 14: Calculation of the price reduction indicator

and its relative variant

$$Specific\ PriceReductionIndicator = \frac{PriceReductionIndicator}{OpenContractPrice}$$

$$\boldsymbol{imbalance\ indicator} = \frac{\left(\sum_{(period|\square)} \boldsymbol{TSO\ energy} \middle| \square\right)}{\sum_{period} \boldsymbol{Total\ energy}},$$

Equation 15: Calculation of the penalty indicator

Since the “FlexContractPrice” calculated by the price setting algorithm is based on some prognoses of the scheduling result, the indicator needs to be recalculated according to the BRP cost balance, which is a difference between financial incomes and outcomes of the BRP.

5.6 RES usage efficiency and CO2 emissions

Usage efficiency of the RES depends on the controlled production portfolio. The Mirabel product should allow larger amount of RES capacity in the specified controlled production portfolio than environment without it. Actually if the same ratio of RES needs to be installed without demand response, the controlled production portfolio needs to be changed to support balancing the grid (the base power plants needs to be transformed into peaking power plants). Concurrently also the balancing capacity of the TSO needs to be adapted.

Therefore the RES usage efficiency is given as a function of the controlled production portfolio from the RES capacity installed or a function of the TSO intervention capacity from the RES capacity installed.

The Mirabel product is well relevant to the popular environment indicator – reduction of the CO2 emissions. But In the Mirabel approach of testing in the simulation environment there it is very difficult to show direct influence on the reduction of the amount of CO2 because the CO2 is produced by the controlled production. In the Mirabel controlled production model it is not relevant the type of the producer – it may be gas turbine, coal plant or nuclear plant. In the real environment it differs much from balance group to balance group and from country to country. From this point of view it is completely non relevant to define the reference CO2 emissions.

The CO2 emission reduction depends on the ratio of the RES energy produced and consumed what is correlated to the RES capacity installed. Therefore no corresponding indicator is defined for the CO2 emissions.

5.7 Internal parameters for testing the Mirabel components

5.7.1 Forecasting

Regarding the experimental evaluation of WP4 (Forecasting), there are several relevant parameters and measures. We refer for details to the deliverables D4.1, D4.2 and D4.3. Furthermore, in the following, we give a brief summary of these criteria.

The most important measurements are the runtime (execution time) and accuracy. First, runtime mainly refers to the time required for creating and updating forecast models, while the use of these forecast models is fairly in-expensive. Second, accuracy refers to the error between forecasted and actual values, where we support different errors metrics (e.g., MSE, MAE, SMAPE, etc.). Due to the global optimization (with time budget), both accuracy and runtime need to be analysed in combination.

Beside the measurements many influencing parameters exist. This includes the used forecast models, parameter estimators, error metrics, forecast horizons (e.g., very-short, short, mid, long), as well as model evaluation and adaptation techniques. In addition, the performance in terms of accuracy and runtime is evaluated with regard to different datasets, ranging from production to consumption data and from household- to country-level data as well as flex offers. These datasets are combined with different external information such as weather and context knowledge (maximum capacity, calendar information, etc.).

5.7.2 Aggregation

The quality of the aggregation (exclusively) can be evaluated by quantifying 1) how much of flexibility is lost during aggregation; 2) how much of peak energy potential is lost during aggregation; 2) what is a complexity of aggregation, and 3) what compression ratio is achieved during aggregation. In the general case, we define these quantities as follows:

- *Complexity* – is a maximum number of operations needed to aggregate N flex-offers;
- *Compression ratio* - is a number in the range [0..1] indicating an average ratio between a number of flex-offers after and before aggregation;
- *Flexibility loss* – is a number that quantifies an amount of flexibilities lost during aggregation. It is a difference between total flexibilities expressed by sets of flex-offers before and after aggregation.
- *Peak energy potential loss* – is a number that quantifies a difference between extreme energy amounts that can be fixed (scheduled) at some time interval before and after aggregation.

Using the simplified flex-offer representation, which was assumed for the Mirabel testing scenarios, the *flexibility* and the *peak energy potential losses* are defined as follows:

- *Flexibility loss. Given* a set of initial flex-offers A and a set of aggregated flex-offers B, the flexibility loss is a difference between total flexibilities expressed in A and total flexibilities expressed in B. Total flexibilities expressed by a flex-offer set (e.g., A or B) is a sum of flexibilities, expressed by each individual flex-offer. Here, a flexibility expressed by a single flex-offer is a product of its time flexibility (startBefore – startAfter) and a sum of its all energy flexibilities (maxEnergy - minEnergy). Thus, the flexibility loss *fLoss* can be expressed using the following equation:

$$fLoss = \sum_{a\in A} fFlex(a) - \sum_{b\in B} fFlex(b)$$

where the function *fFlex* is defined as follows:

$$fFlex(f) = (f.startBefore - f.startAfter) \cdot \sum_{e\in f.enInts} (e.maxEnergy - e.minEnergy)$$

Here the attribute *enInts* corresponds to an energy constraint profile of a flex-offer.

- *Peak energy potential loss*. Given the same flex-offer sets A and B, the maximum/minimum peak energy potential loss is a difference between the maximum/minimum peak energy potential computed for A and B. Here, the maximum/minimum peak energy potential is a number equal to a maximum/minimum energy amount at some arbitrary time interval yielded by some schedule of A after trying all possible schedules of A. The given equation expresses the minimum peak energy potential loss for sets A and B:

$$pLossMin = \underset{\forall t \in fInt(A)}{MAX}\left(\sum_{\forall b\in B} minAmount(b,t) - \sum_{\forall a\in A} minAmount(a,t)\right)$$

where

$$fInt(F) = \left[\underset{\forall f \in F}{MIN}(f.startAfter), \underset{\forall f \in F}{MAX}(f.endBefore)\right],$$

$$minAmount(f,t) = \underset{\forall i \in [t-(f.startBefore - f.startAfter),t]}{MIN}(f.enInts[i].minEnergy)$$

Similarly, the maximum peak energy potential loss for the sets A and B is expressed with the following equation:

$$pLossMax = \underset{\forall t \in fInt(A)}{MAX}\left(\sum_{\forall a\in A} maxAmount(a,t) - \sum_{\forall b\in B} maxAmount(b,t)\right)$$

where

$$maxAmount(f,t) = \underset{\forall i \in [t-(f.startBefore - f.startAfter),t]}{MAX}(f.enInts[i].maxEnergy)$$

Two numbers, namely *pLossMin* and *pLossMax*, will be used in Mirabel to quantify peak energy potential losses due to the aggregation.

By applying flex-offer aggregation using various sets A, an average flexibility loss and average peak energy potential loss can be computed for the Mirabel's aggregation algorithm. The values of complexity, compression ratio, average flexibility loss, average peak energy potential loss are metrics of the aggregation successfulness.

5.7.3 Scheduling

In principle the scheduling module returns feasible schedules for all given aggregated flex-offers in the given amount of time. A feasible schedule is a schedule where the flex-offer start time and energy amount have been set according to the given flexibilities. However, the quality of the resulting schedules depends mostly on the complexity of the scheduling problem and the available time for finding a solution.

In order to test the performance of the scheduling module, different settings of the following parameters need to be explored:
- various scheduling intervals,
- various imbalance profiles,
- various imbalance price profiles,
- various configurations of sets of aggregated flex-offers with respect to energy amount and flexibility, time duration and flexibility, price, overall constraint, assignment before time and assignment before interval, and the number of flex-offers in each set,
- Various flex-offer processing time and maximum execution time.

Since the optimal solution is not known, the quality of the obtained solution can only be assessed in comparison to some initial solutions or by looking at the convergence of the scheduling algorithm in time. See deliverables D5.3 and D5.4 for a more detailed analysis of the performance of the scheduling algorithms.

6 Trial cases

The trial cases are used to test and evaluate the efficiency of the Mirabel product. The trial cases are focused to the roles of EES which are the most actively involved in the Mirabel processes
- TSO trial case - Evaluation of the Mirabel for the transmission system operator
- LDE trial case - Evaluation of the Mirabel for the LDE acting as a BRP
- Household community trial case Evaluation of the Mirabel for the household community

6.1 TSO trial case

The TSO provides the system service of the frequency regulation. The usage of the system service may be separated into two tasks
- balancing the grid due to the irregular consumption/production
- interventions due to the major production unit failures

The second is out of the scope of the Mirabel testing and only the first is examined
The goal of this trial case is to recognize and estimate the benefits, which can the Mirabel system provide for the TSO.
In this scenario the regulation via balance market is simulated. The TSO plays active role and uses the energy from the simulated balance market for its needs for balancing the grid. The energy on the balance market is provided by the balance group with flexibilities.
The trial case shall be provided in the simulated environment with the “real-world” data provided by the EnBW. The test case shall be supervised by EnBW.

6.1.1 Environment

The environment consists of one balance group, which holds the controlled production only and consumers offering the flexibilities. The TSO generates the requests for balancing the transport grid.
The balance market subcase environment consists of
- Balance responsible party
- Transmission system operator
- Consumers
- Controlled production

- Balance market

There is no RES in the simulated BG because the aim of the test is to analyze the potential of the consumer flex-offers for the TSO and the RES is generating imbalances resulting in the reduction of this potential.

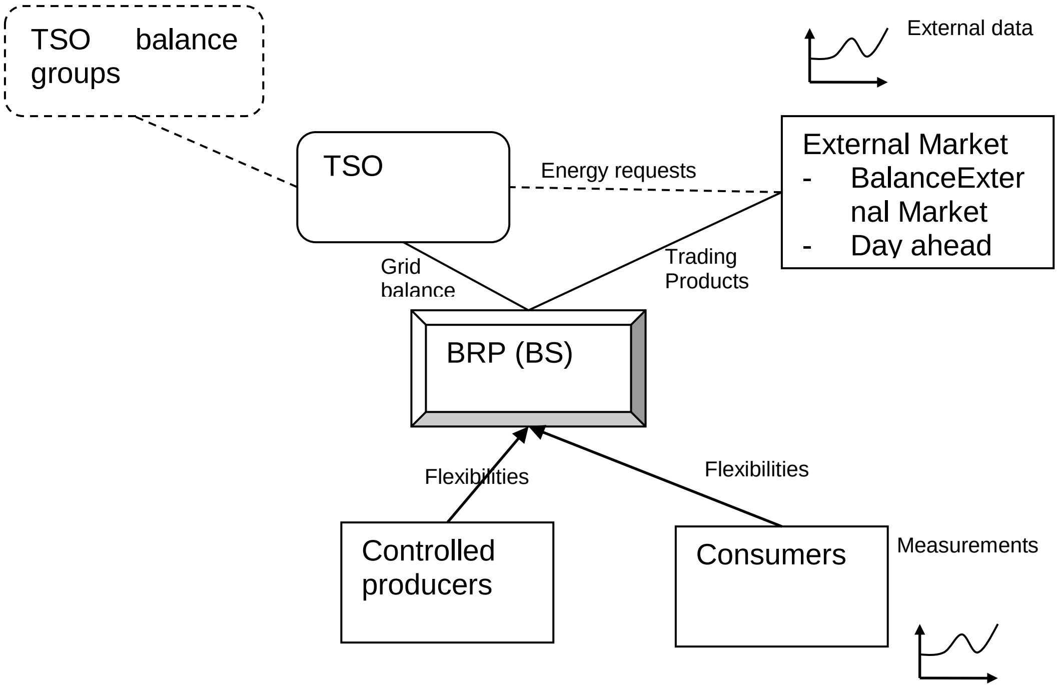

Figure 11: Environment of the TSO trial case

6.1.2 Test Scenario

In this scenario the simulated BRP, besides covering the imbalances with the flexibilities, also offers the flexibilities in the form of the balance market products. The TSO uses these products according to its needs for balancing the grid.
The testing environment shell provide

- the consumption with the consumption flexibilities
- production with the production flexibilities
- the balance market contracts in the form of the TSO requests

The consumption and consumption flexibilities are provided according the input measurement data and flexibility model. The amount of the flexibilities is a varying parameter – several tests shell be executed with the different value of the flexibility amount. The production flexibilities are provided according to the model of the controlled production. The TSO requests are generated according to the input data. They are in the form of the time history data consisted of the records with the energy amounts and prices.
The BRPs scheduling algorithm shall schedule the consumption and production to minimize costs what results in the reduction of the peak consumption. The introduction of the TSO requests from the balance market changes the BRPs scheduling priorities,

which now serve the external requests before reducing its own consumption peak. The necessary condition for the test efficiency is that the TSO requests are that they are better from the economical point of view than potential imbalance costs of the BRP caused by the rescheduling of the consumption.

6.1.3 Input data

The input data for this scenario are
- Consumption data of the consumers
- TSO intervention data

The consumption data of the consumers is the time history set of records containing
- Time stamp
- Averaged power consumed

The TSO intervention data is the time history set of records containing
- Time stamp
- Price (of the request or of the balance market contract)
- Amount of the energy for intervention

The pre-test execution calculation shall use these data to generate the following data necessary for the test execution
- Schedule of the consumption flexibilities
- Schedule of the open contract consumption (without energy offered by the flexibilities)

Independently the imbalance prices are calculated as set of time history records containing the “timestamp, price” data. This necessary input for the scheduling is calculated as described in 4.5.7.

6.1.4 Testing goals and examined indicators

The goal of this scenario is to estimate the usability of the Mirabel flexibilities to balance the grid from the standpoint of the TSO (emulation of the balance market). In different words, how much the Mirabel product is capable to participate on the balance market?
The indicators, which shall be followed here, are
- Amount of the balance energy used by TSO. This is calculated as an amount of the flex offer energy assigned to the TSO request. The result is compared to the total TSO request on the balance market in the specified period (one year). The relative indicator “average flex energy” used by TSO per energy unit consumed is calculated
- Ratio between imbalances caused and imbalances covered. This indicator is a comparison of the average flex energy used by TSO for balancing per average imbalance energy produced by consumer.
- Cost benefit BRP is the cost difference at BRP between the situation serving to the balance market and situation with no Mirabel product. The bonus gained by the balance market is delivered among the flexibility issuers and the bonus per offered flex energy unit is calculated.

The scenarios need to be executed for the most representative day of the TSO activities. The execution of the simulation for the whole (one year) testing period is not necessary. The examined indicators are recalculated to the desired period by the corresponding extrapolation.

6.2 LDE trial case

In this trial case the LDE is registered as a balance responsible party in EES. It covers the electricity energy consumption with its own production capacities and with activities on the external market. On the external market it may also sell the energy exceed With the Mirabel solution the LDE uses the following mechanisms for covering the imbalances

- Buying/selling the energy on the external market -long term process
- (Dis)Activating the controlled production
- Controlling the flexible consumption: - short term process

The remaining unbalanced energy is served by TSO and treated as undesired imbalances.

The goal of this trial case is to recognize and estimate the benefits which can the Mirabel system provide for the BRP reducing the consumption peak, imbalances and enlarge the RES ration in the BRP production portfolio without increasing the imbalances.

The trial case consists of the scenarios

- isolated mode without external trading and
- external trading,
- unpredictability test

The scenario in the isolated mode isolates the BG from external influences. The BG has well balanced the production and consumption and this scenario shell show the pure influence of the Mirabel solution on the consumption parameters and RES integration.
The scenario with external trading exposes the Mirabel solution to the real environment and shows the effect of the “infinitive large” system (the consumption of the MBA area is 100x larger than the simulated BG) on the simulated BG.

The environment for the scenario “isolated mode” is also used to execute the unpredictability of the human behavior.

The trial case shall be provided in the simulated environment with the “real-world” data provided by the EnBW. The test case shall be supervised by EnBW.

6.2.1 Environment

The environment is very similar to the one at TSO trial case except the renewable energy producers are introduced.
There is one balance group under the testing control, which contains the defined portfolio of households and industry consumers. The balance group is well balanced – its consumption is covered by its production capacities consisted of controlled production and RES.
The imbalances on the grid are covered implicitly by the TSO.

The trial case environment consists of

- Balance responsible party
- Market operator for day ahead and intraday market – at the external trading scenario only
- Transmission system operator
- Consumers
- Controlled production
- RES
- Only at external trading scenario: External markets (day ahead and intraday markets)

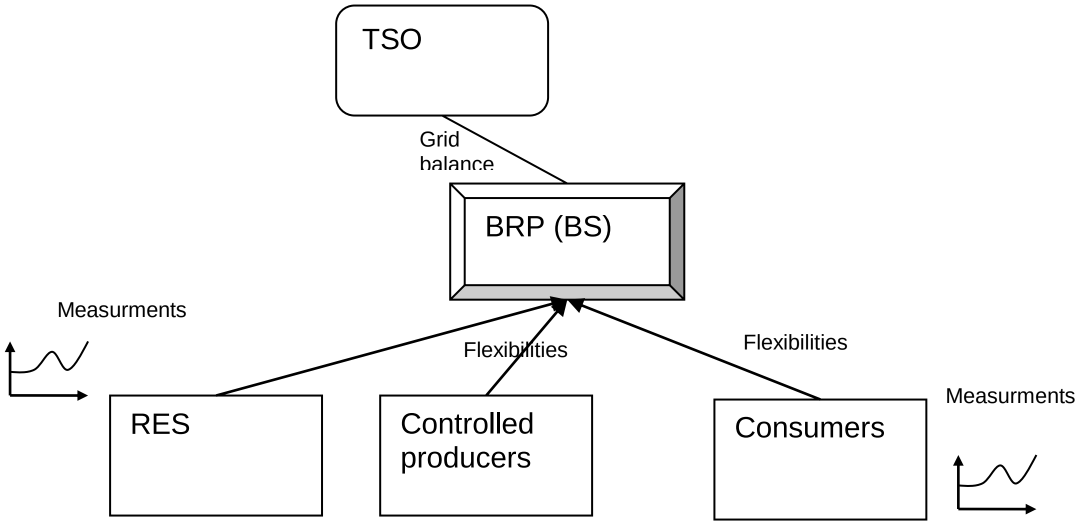

Figure 12: LDE trial case – isolated mode scenario

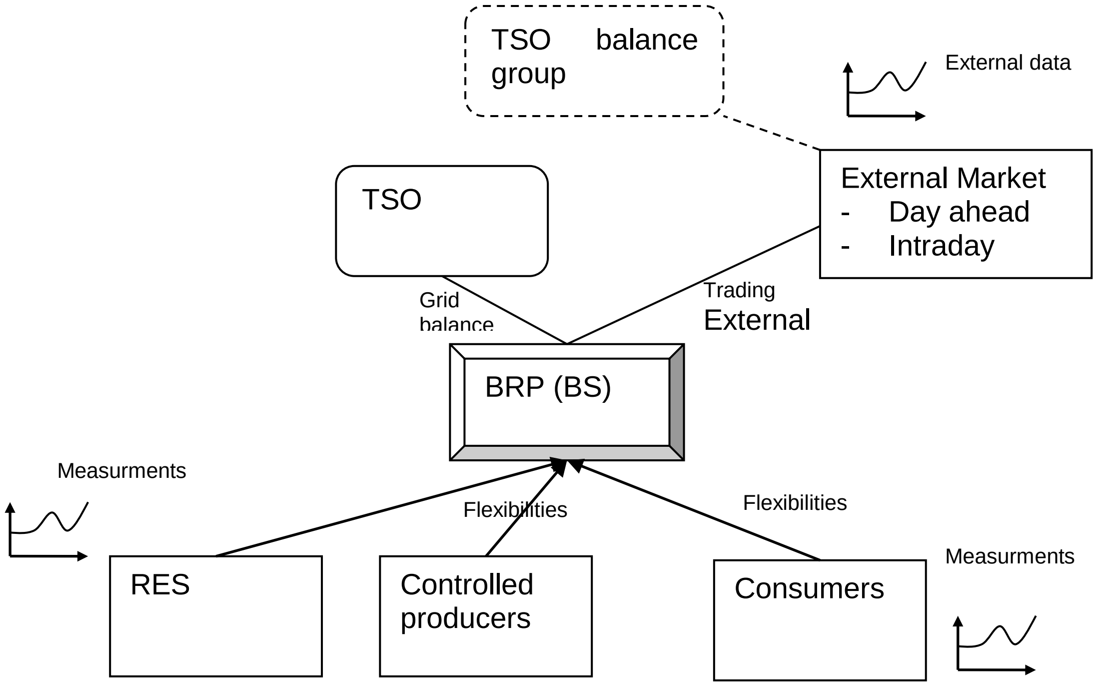

Figure 13: LDE trial case – external trading scenario

6.2.2 Test Scenario

In the scenario the BRP uses the consumption flexibilities to reduce the peak consumption and RES production imbalances.

In the case of the presence of the external market the BRP also uses it to sell the excess of (RES) energy or buy its deficit. It can also react on the market situation to buy the excess of the external energy, when it is cheap or sell its own energy when there is the deficit and the price is high.
The testing environment shell provide

- the consumption with the consumption flexibilities
- production with the production flexibilities
- the RES production measurements
- in the case of the external market environment also the external contracts with prices and amounts.

The consumption and consumption flexibilities are provided according the input measurement data and flexibility model. The amount of the flexibilities is a varying parameter – several tests shell be executed with the different value of the flexibility amount. The production flexibilities are provided according to the model of the controlled production. The RES production is generated according to the input data. The amount of the RES capacity installed is a varying parameter – several tests shell be executed with the different value of the RES capacity.
In the case of the external market environment, the external market bids are generated according to the input data. They are in the form of the time history data consisted of the records with the energy amounts and prices.
The Scheduling algorithm provides scheduling according to the

- Production flexibilities sent by controlled producers
- forecasts of the RES
- Open contract consumption data forecasts
- Flexibilities sent by consumers
- External market data

The BRPs scheduling algorithm shall schedule the flexible consumption and production to minimize costs what results in the reduction of the peak consumption and reducing the imbalances generated by the RES unpredictability.
At every configuration (share of RES and amount of the flexibilities) the TSO interventions are compared between the situations when Miracle product is installed and when Miracle product is not installed.
The output result is consumption which is an input for the calculation of the imbalances and other indicators.

Unpredictability test scenario
The unpredictability test scenario is executed in the same way and on the same environment as the isolated mode scenario. The difference is that the prosumer component in testing environment shall decide with a certain extend of probability not to use the assigned schedule of consumption but rather the default schedule which is equal to the input measurement.
The scenario is executed for several probabilities of the human unpredictability for the several levels of the RES but for the same value of the flexibility amount.

6.2.3 Input data

The input data for this scenario are

- Consumption data of the consumers
- Production data of the RES
- In the case of the environment with the external Market also intraday and day ahead market data

The consumption data of the consumers and the production of the RES is the time history set of records containing

- Time stamp
- Average power consumed/produced

The external market data is a set of rime history records with

- Time stamp
- Price
- Amount of the energy in the case of intraday market

The pre-test execution calculation shall use these data to generate the following data necessary for the test execution

- Schedule of the consumption flexibilities
- Schedule of the open contract consumption (without energy offered by the flexibilities)
- Schedule of the external markets bids

Independently the imbalance prices are calculated as set of time history records containing the "timestamp, price" data. This necessary input for the scheduling is calculated as described in 4.5.7.

6.2.4 Testing goals and examined indicators

The goal of the "isolated mode" and "external market" scenarios is to estimate the usability of the Mirabel flexibilities to reduce the consumption peaks and improve the grid stability at introduction of the RES into the production portfolio.
The indicators, which shall be followed here, are

- The power peak – the observation is concentrated in the reduction of the consumption peak power
- Amount of the energy intervened by the TSO. This is the main indicator showing the efficiency of the RES integration. Keeping this indicator value within reasonable and real values is showing the ratio of the successfully installed and consumed energy from RES.
- Ratio between energy produced by RES and the intervened energy. This indicator shows an indirect connection the imbalances between the forecast in-accuracy and imbalances. The Mirabel solution shall significantly affect the value of the indicator.
- Cost benefit of the BRP is the cost difference between the situations The BRP is solving the imbalances with and without flexibilities. In the second case the imbalances are larger and BRP needs to raise an open contract price. The bonus gained by the reducing the imbalances with the Mirabel solution delivered among the flexibility issuers and the bonus per offered flex energy unit is calculated.
- Evaluation of the demand/supply plan adjustment time – one calculates the minimal time interval when the Mirabel solution is capable to react on sudden imbalances and adapt the schedule.
- In the environment with the external market also the amount of the energy sold on the external market is followed.

At the human unpredictability scenario the dependency of the observed indicators from the probability of the flexibility assignment execution is observed.

The scenarios need to be executed for the most representative days of the year and the most representative weeks of the year with the maximal scheduling accuracy. The execution on the 1 year interval needs to be execution with the lowest acceptable accuracy. The examined indicators are recalculated to the desired period by the corresponding extrapolation.

6.3 Community consumers trial case

The community consumers' trial case shall be provided in the micro-grid and the laboratory building on the location of CRES and supervised by CRES. The test lab micro-grid has a consumption capacity up to four households, photovoltaic production and controlled production and in addition may be connected to the external public grid.
The goal of this trial case is to test the behavior of the Mirabel on the limit number of consumers operating in the isolated mode.
As distinguished from the trial cases in the simulation environment, this trial case deals with the real grid elements – real RES, real consumption loads, production units and real measurements. This trial case can provide real measurements of the imbalances, which can be collected on much smaller time scale as at simulation environment. The Mirabel solution integrated in the real test environment of the micro-grid test lab shall test its ability to cooperate and communicate with the real micro-grid devises through a middleware which can be installed in any real household, industrial consumer or prosumer without the need of developing an additional communication system. Beside the exposure of the potential problems at the eventual integration of the Mirabel solution in the real environment this trial case also enables the testing the effect of the special loads (like electric vehicle, hydrogen fuel cell, heat pump, etc.) included in the Mirabel on the balance of the grid.
The trial case consists of the three testing scenarios

- Household community balance test
- LDE operation in the isolated mode
- Small scale end-to-end test

The first two tests are using the experimental micro-grid of CRES for studying the effects on RES share in a Balance group integrating controlled and RES production and the third using real loads including human behaviour (heat pump and PVs). Further scope of all these scenarios is to examine thoroughly the applicability of the Mirabel result on small groups of consumers and RES production units, small scale end-to-end test, introduction of several storage elements into the grid, etc.

6.3.1 Household community balance test

In this case the microgrid facility will be used for the emulation of a small household community consuming the energy from "real" RES – photovoltaic modules. The test case is the repetition of the LDE test case (subchapter 6.2) on the small scale. The four household consumers equiped with the RES uses the Mirabel solution to operate independatly from the external grid as much as possible.

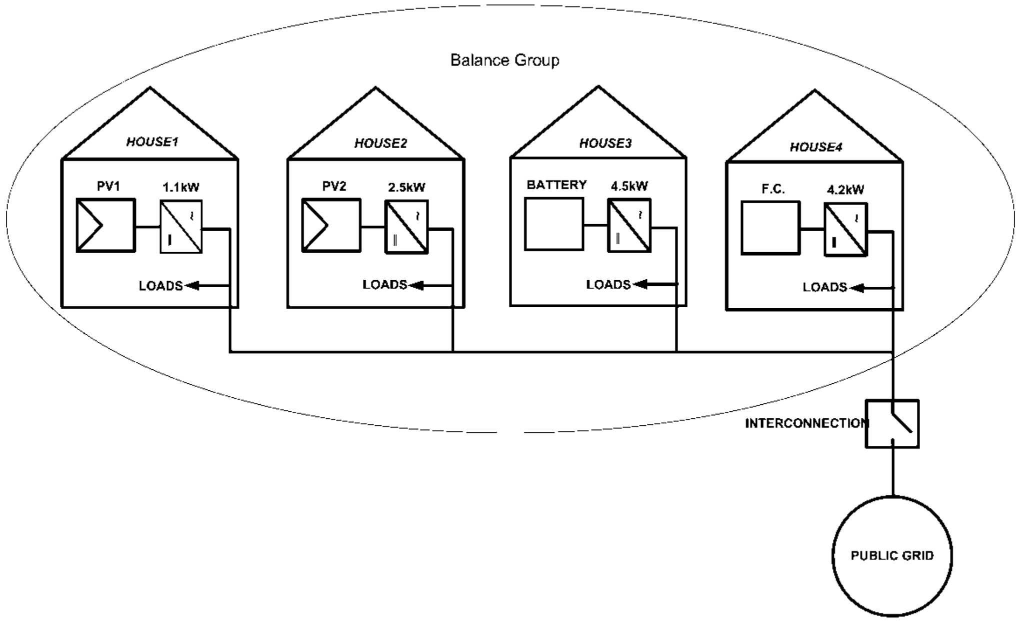

Figure 14: Household community trial case prosumers

6.3.1.1 Environment

The Figure 15 illustrates the basic concept of this trial case implementation. Specifically, there is one balance group under the testing control, which contains a limited number of households (4) which in fact are prosumers and hence can cover not only their energy needs individually but also to contribute flexibilities to the whole balance group.

From the production capacity point of view the balance group is self-sufficient – its consumption is covered by its production capacities consisted of RES, controllable production (emulated by the connection to the external grid), No external trading is provided (simulated).

All the imbalances on the grid are covered implicitly by the system operator, the operation of whom is emulated be the connection to the external grid.

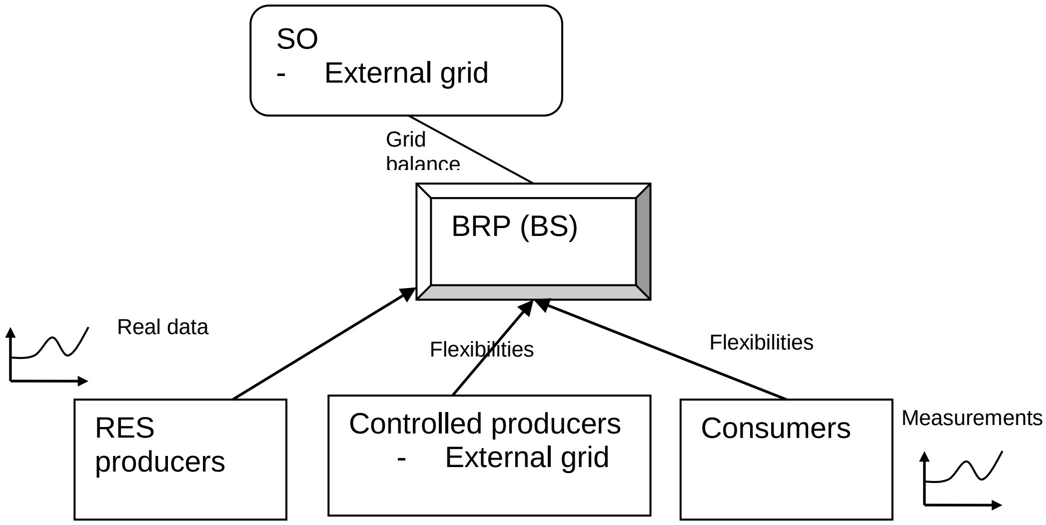

Figure 15: Household community trial case environment roles

To summarize, the external grid is used to support the

- the emulation of the controlable sources and
- balancing the consumption and production within the microgrid.

6.3.1.2 Scenario

In the scenario the BRP uses the offer flexibilities to compensate the peak consumption and RES production. Main objective is the reduction of power exchange between the community and the public grid investigated in an intraday schedule frame.

The testing environment shell provide

- the consumption with the consumption flexibilities
- the controlled production with the production flexibilities
- the RES production
- balancing the grid

The consumption and consumption flexibilities are provided according the input measurement data and flexibility model. The amount of the flexibilities is a varying parameter – several tests shell be executed with the different value of the flexibility amount. The consumption is realized with the electric resistors which are controlled according to the measured input data from the Meregio project.

The production flexibilities are provided according to the model of the controlled production. The controlled production is realized with the external grid.

The RES production is generated from the real facilities. The RES production is forecasted according to the measurement history of those facilities. There are two realizations of the RES production

- basic, where only the actually installed photovoltaic modules are active (1.1kW and 2.2kW of the power installed

- enhanced, where additionally the battery storage is used for the emulation of the PV panels. The battery needs to be full before the test execution and its output is controlled via real PV production signal to sustain the real production profile. The enhanced RES emulation doubled the total capacity.

The Scheduling algorithm provides scheduling according to the

- Production flexibilities sent by controlled producers
- forecasts of the RES
- Open contract consumption data forecasts
- Flexibilities sent by consumers

The BRPs scheduling algorithm shall schedule the flexible consumption and production to minimize costs what results in the reduction of the peak consumption and reducing the imbalances generated by the RES unpredictability.
At every configuration (share of RES and amount of the flexibilities) the TSO interventions are compared between the situations when Miracle product is installed and when Miracle product is not installed.
The output result is consumption which is an input for the calculation of the imbalances and other indicators.

The scheduling algorithm schedules the production and consumption according to the data available for the next operation interval. The scheduling of each time interval would have been completed a certain time before its execution (Figure 16). The following time scenarios are examined

- 24 hour test execution.
- 12 hour test execution.
- Selected time interval test execution.

The 24 hour test examines the whole most representative period - 24 hours. The few tests executed for this period needs to analyze the overall behavior of the installation and influence of the daily activities on the nightly consumption.
Since the photovoltaic is the only RES installed, the main activities shall be provided during the daylight, therefore the mostly the 12 hour test execution shall be used for the testing.
The behavior of the particular elements shall be tested for the typical intervals over the daylight. Specifically, the tests planned are one in morning, one at noon and evening and one at night. Each tests presents special interest for the following reasons:

- Early morning hours (e.g. 07:00-09:00) is related to small RES (PV) production and relatively small consumption.
- Midday hours (12:00-16:00) present peaks in both production and consumption.
- Finally, night hours (21:00-23:00) present usually high consumption with zero PV production

The test plan regarding the time is illustrated in the Figure 16b.
Tests will be repeated for the same time schedule for different week days in order repeatability to be achieved.

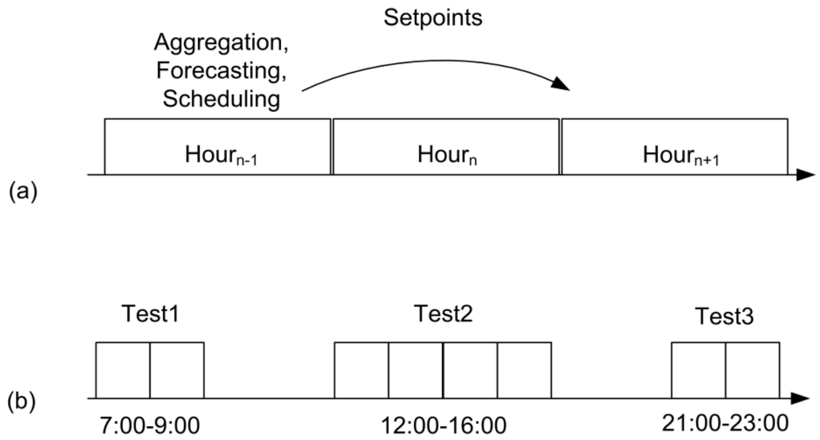

Figure 16: Test implementation: a) scheduling and b) selected time of tests

6.3.1.3 Input data

The input data for this scenario are

- Consumption data of the consumers

The production of the RES is received from the real devices.

The consumption data of the consumers is the time history set of records containing

- Time stamp
- Average power consumed/produced

The pre-test execution calculation shall use these data to generate the following data necessary for the test execution

- Schedule of the consumption flexibilities
- Schedule of the open contract consumption (without energy offered by the flexibilities)
- Schedule of the external markets bids

Independently the imbalance prices are calculated as set of time history records containing the “timestamp, price” data. This necessary input for the scheduling is calculated as described in 4.5.7.

For the generation of the reference scenarios-data (see subchapter 4.4) no additional testing is needed. The data are calculated from real measurements of RES and consumption input data as described in the subchapter 4.4. The reference data for the controlled production is calculated from the prognosis of the consumption and RES production as presented on the Figure 17.

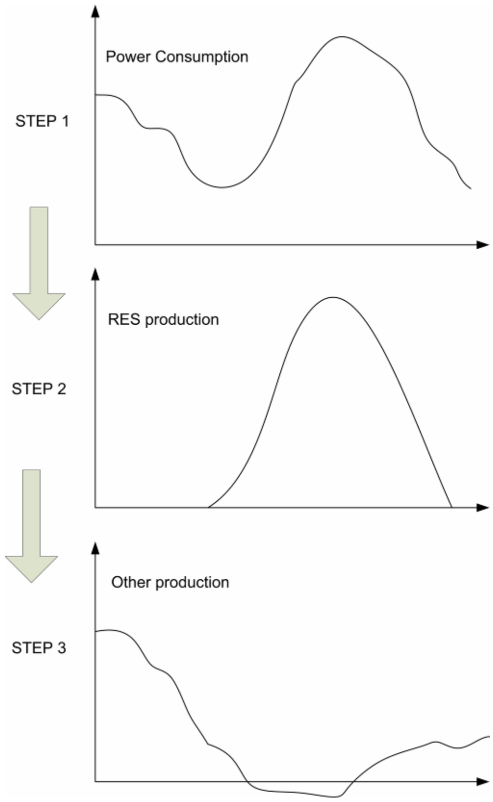

Figure 17: Example of reference scenario

6.3.1.4 Testing goals

The goal of the household community balance test is to estimate the usability of the Mirabel flexibilities to reduce the consumption peaks and improve the grid stability at introduction of the RES into the production portfolio on the small scale of the consumption.

The indicators, which shall be followed here, are

- The power peak – the observation is concentrated in the reduction of the consumption peak power
- Amount of the energy intervened by the TSO. This is the main indicator showing the efficiency of the RES integration. Keeping this indicator value within reasonable and real values is showing the ratio of the successfully installed and consumed energy from RES.
- Ratio between energy produced by RES and the intervened energy. This indicator shows an indirect connection the imbalances between the forecast (in) accuracy and imbalances. The Mirabel solution shall significantly affect the value of the indicator.
- Evaluation of the demand/supply plan adjustment time – one calculates the minimal time interval when the Mirabel solution is capable to react on sudden imbalances and adapt the schedule.

The scenarios need to be executed for a set of succeeding days and at the typical intraday tie intervals.

6.3.2 LDE operation in the isolated mode

The second “community consumes trial case” scenario extends the first one with

- Disconnection form the external grid
- Introducing of the diesel generator as a controlled production unit and SO balancing unit.
- Introducing the storage units (batteries and hydrogen fuel cell) into the prosumer portfolio.

The goal of the scenario is to examine the effect of Mirabel on the operation in the isolated mode and efficiency of the introduction of the storage units into the system. The Figure 18 illustrates the basic concept of the selected trial case.

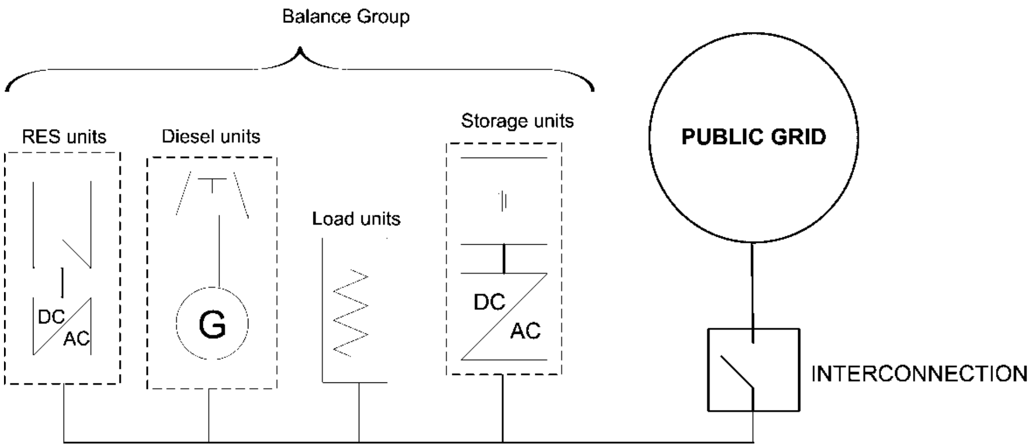

Figure 18: Isolated LDE trial case prosumers

6.3.2.1 Environment

The difference to the environment of the “household community balance test scenario” (subchapter 6.3.1), the isolated LDE scenario is executed with the disconnection of the CRES micro-grid from the external public grid. The functionalities of the public grid – controlled production and grid balance – are replaced by the diesel generator.
Additionally the storage units like batteries and HFC are introduced in the system. The storage units are included

- to emulate the behavior of the real appliances like electric vehicles,
- to support grid stability by absorbing the deviations and energy surpluses.

The roles and entities of the selected trial case are depicted in the Figure 19.

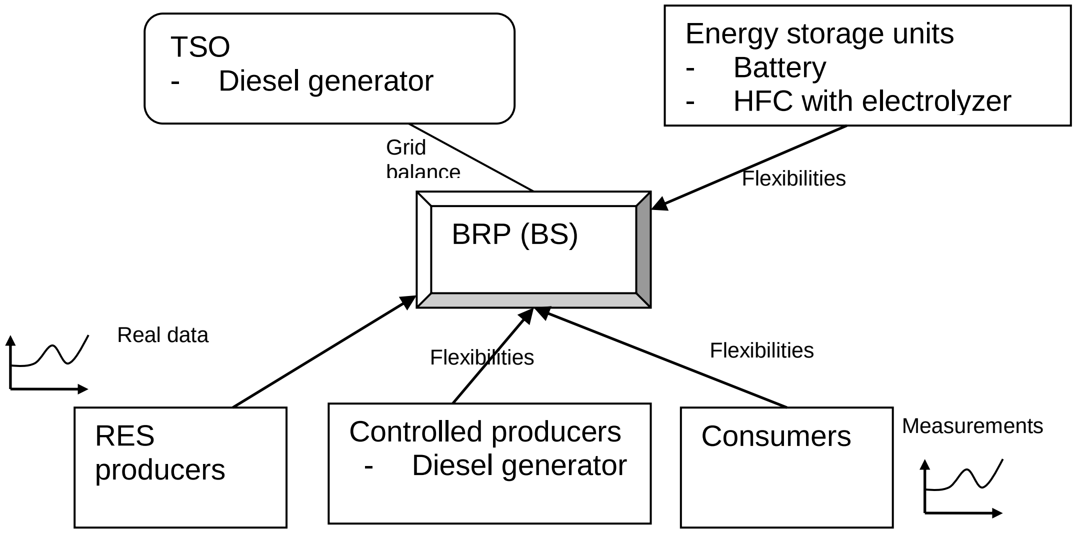

Figure 19: Environment roles for the isolated LDE trial case scenario

6.3.2.2 Scenario

The scenario is similar to the household trial case described in the subchapter 6.3.1.2. Since, the RES and load profiles are similar to the household community case, the same testing procedure regarding test time planning and time – intervals for testing is followed as described in 6.3.1.2. Moreover, the procedure for producing reference data for this case is also followed as described to the household community test.
In addition to the household community scenario, the isolated LDE scenario considers also the behavior of the storage units like

- Emulation of the electric vehicles introduces
    - The additional consumption in the EES due to the charging
    - Supporting the grid stability by active control of the charge/discharge speed
- Activating additional capacities of batteries HFC and electrolyzer for
    - Consumption when original consumption is low or at exceed of the RES production
    - Production at the peak consumption or the lack of the RES production.

The introduction of the storage unites enlarges the number of the test executions with several different combinations storage devices

- Batteries as an electric vehicle
- Batteries as a storage units
- HFC with the electrolyzer

6.3.2.1 Input data

The required data are the same to the ones in the household community scenario in 6.3.1.3.
The main difference in this trial case scenario is that the controlled production data are obtained from the diesel generator production measurements instead from the external grid electricity flows.

6.3.2.2 Testing goals

The testing goals and the evaluation procedure is the same as at household community scenario 6.3.1.4.
In addition the household community scenario results are used also as a reference for the estimation of the storage unit efficiency stabilizing the grid and using the RES energy.

6.3.3 Small scale "end-to-end" test

The real laboratories building offers the environment to execute the end-to-end test in a fully realistic environment the applicability of Mirabel.
The selected trial case is the one of independent end users which constitute the demand side of a BG which has a BRP using the Mirabel product. The end users (consumers) have a predominant load (in our case a heat pump providing heating during the winter and cooling during the summer) and declare this load through making flex - offers to their BRP. The system consists of a central heat-pump and a distribution system consisting of fan coils (Figure 20). Each of them is equipped with a manual thermostat for the corresponding temperature set point. The supply of the heat pump can be covered from RES source which can be part of the same BG or another BG. The trial case scenario is to examine the operation of the heat pump without Mirabel product and with it. The total heat pump load (20 kW_{peak}) can be considered as the aggregated demand side of the BG which consists of four different users' profiles making flex - offers with different flexibilities according to their profile needs.

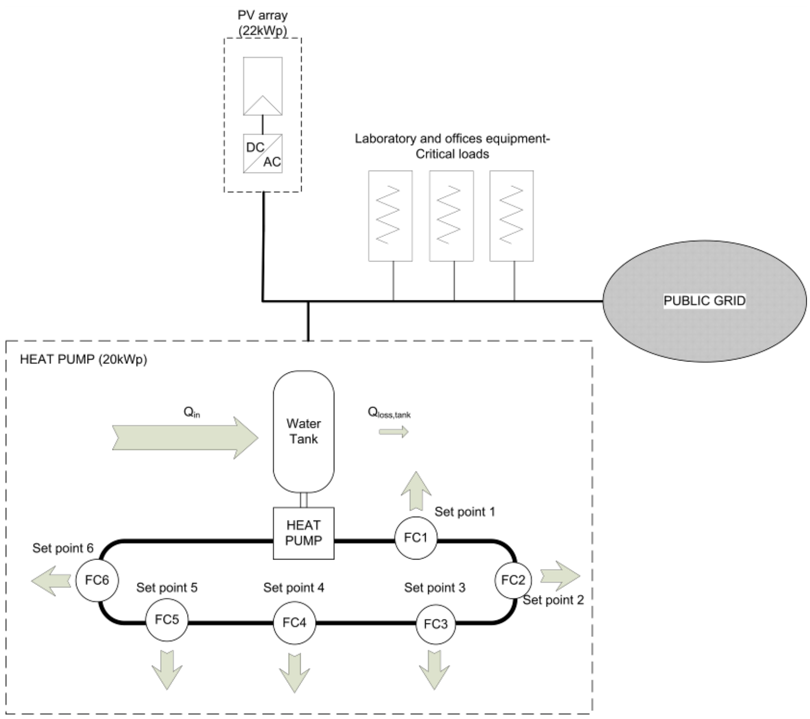

Figure 20: End-to-end test with the heat pump

The important constraint on this test case is the operation of the existing heat pump control system, which has a limiting setting of the operation power.

6.3.3.1 Environment

The selected environment consists of the one business building, with relatively predictable consumption background (lighting, operation engines, electronic devices etc.) and controllable heat pump used for covering the cooling/heating needs of the building. In addition, the building is equipped with a PV system of 22kWp peak installed capacity. The concept of the entities involved is shown in the Figure 20. Summarizing the main actors of the test environment are:

- One heat pump (20kWp)
- One PV system (22kWp)
- Several small electric consumers (office and laboratory equipment) as the background
- Controlled production emulated by external grid

In this “end-to-end” trial case the simulation environment does not need to provide external input data.
The controlled production data are calculated before the test execution from the expected consumption and historic consumption measurements.

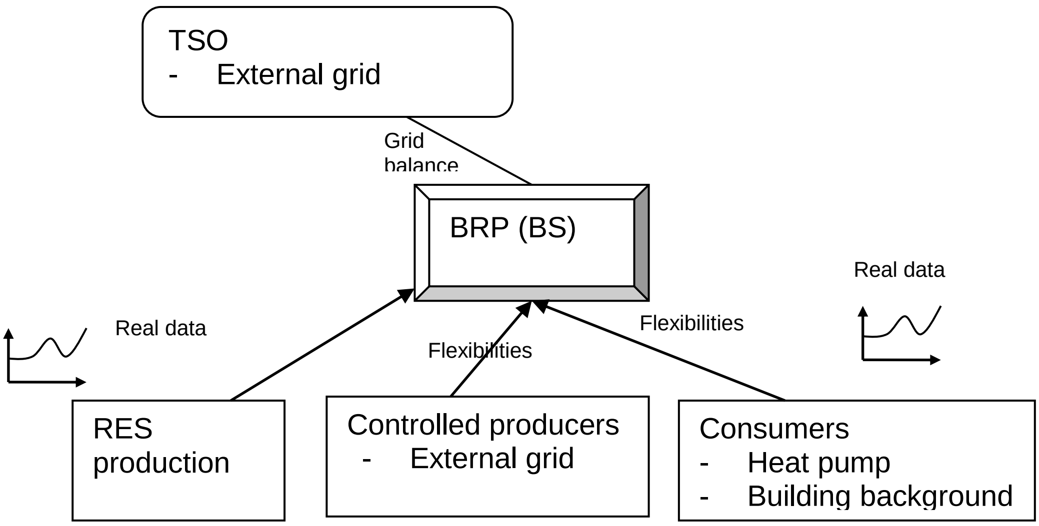

Figure 21: Environment roles for the isolated LDE trial case scenario

6.3.3.2 Scenario

In the scenario the BRP uses the heat pump flexibility to compensate the peak consumption and RES production in the laboratories building. The consumption building acts as the energy reservoir. The parameterized room temperature range is used to adapt consumption. The RES production and building consumption are forecasted on the intra-day bases to schedule the heat pump consumption.
In the contrast to the household community trial case, the consumption profile is typical for the business building and more synchronized with the RES (PV) production. This is because the building is occupied during working hours (between 08:00 and 18:00). This most representative time intervals for testing are:

- Early morning hours (e.g. 08:00-10:00) is related to small RES (PV) production and relatively high consumption from the heat pump in order to balance thermally the building.
- Midday hours (12:00-16:00) present peaks in PV production and depending on the weather conditions in the consumption.

In contrast to the LDE trial case and the first two community consumers trial scenarios the reference data for this scenario cannot be obtained directly from the input data because the input is now "real environment". The reference data for the test result analyses are obtained either by
- Historical data of the lab building consumption with the similar boundaries (day of the year, amount of employees, whether conditions, …)
- Execution of the test without the Mirabel solution and with the similar boundaries.

6.3.3.3 Input data

In contrast to the previous trial cases, the historical input data are not needed in this scenario. The online measurement of active power/energy is monitored. In addition also the measurements of some environmental variables like indoor, outdoor temperature as well as solar irradiance are needed because these factors affect considerably the behavior of the heat pump.
It is worth mentioning that there is already experience with the experimental implementation in the same building with the same conditions in the frame of project EUDEEP. Summarizing, all the required data for the test are:
- Real RES production
- Real consumption of the heat pump
- Real consumption of other loads
- Generated power from PVs
- Environmental variables (temperatures, irradiance)

6.3.3.4 Testing goals

The main goal of this scenario is testing of the Mirabel solution in the real "end-to-end" environment and applicability on the business building consumption profile.
The examined parameter is the variation of the RES energy exported to the external grid, (with and without Mirabel solution), peak demand, the electricity price for peak demand and the costs derived.
This is the closest scenario for Mirabel for examining the behavior of consumers with a predominant load. Also the BG's supply side share of RES (PVs) covering the demand side heat pump load increase can be examined with the introduction of miracle and without it.

As mentioned above the parameters examined under this trial case are the following:
- Amount of the imbalances covered by the external grid
- RES energy exported to the external grid.
- Peak load demand variation,
- Electricity price for peak demand and the costs derived
- BG's supply side share of RES (PVs) covering the demand side heat pump load increase can be examined

As additional objectives the trial case shall evaluate:

- Energy capacity of the heat pump system
- Applicability of the MIRABEL in the single units

7 Test plan

The Mirabel test plan is used to plan the testing equipment capacity and schedule the test execution according to the time frame available. The test plan consists of the list of the test need to be executed with the following data

- Test configuration with the value of the variation parameters
- Foreseen test case execution duration

The tests do not have direct dependency on each other, but anyway it is highly recommended to keep the proposed order of the execution since the order is made with increasing testing environment complexity and experiences from the executed test may improve the efficiency of the test execution for the following ones.

The test plan is generated separately for

- The simulation environment for the TSO and LDE test case
- The CRES micro-grid for the community consumers trial case

Each plan consists from its own list of variation parameters and its own test duration.

7.1 Test plan of the simulation environment

The test approach at the simulation environment is testing from the shortest – 24- interval to the longest – 1 year – interval. For each duration interval the various combinations of variation parameter values are used. The shortest duration interval is tested the most precisely with the largest number of the tests and combinations of the variation parameters. The longest duration interval is tested with the minimal number of test with the most representative values of the variation parameters only.

The test plan is based on the assumption of the following assumptions

- The scenario execution duration with the optimal accuracy lasts 30% of the real time. That means that the scenario with 24 hour testing interval shall last approx. 8 hours
- The scenario duration with the minimal acceptable accuracy lasts 3% of the real time. That means that the scenario with 365 days testing interval shall last approx. 10 days. the following optimal execution duration
- No test execution concurrency is available.

The test execution speedup factors of 30% execution time for optimal accuracy and of 3% execution time for minimal acceptable accuracy are derived from the stress test result of the aggregation and scheduling (see 4.9.2 and 4.9.3). The integration task T6.4 and its delivery D6.4, when testing with all the components running together shall be provided will give the more accurate estimation of the speedup factors. The integration shall also give an answer how much test execution concurrency is possible to execute on the test environment and what are the performance limits of the Mirabel solution processing the huge amount of the flex offers. The test list may be adapted according to the integration result.

The tests list consists of the following testing scenarios

- TSO – TSO trial case scenario
- LDE1 – LDE trial case – isolated mode scenario

- LDE2 – LDE trial case – external trading scenario
- LDE3 – LDE trial case - unpredictability test scenario

Each scenario is tested against various combinations of parameters values.

7.1.1 Variation parameters

The variation parameters with the values are presented in the table below.

Parameter	Min val	Max val	Step
Wind	0	30%	3%-5%
PV	0	30%	3%-5%
Flexibility amount	Min (6 %)	Max (15 %)	Med(10%)
Flexibility time	Min (4 hour)	Max(12 hour)	Med(8hour)
Unpredictability	0	50%	10%-20%
Testing interval	24 h	365 days	-

Table 1: Variation parameters in the simulation environment

The variation of the RES is separated into the three types
- Wind
- Photovoltaic
- Combination of both

The parameter is varied with the values 0%, 3%, 6%, 10%, 15%, 20%, 25% and 30% where the percentage means the ratio of the RES peak power installed and controlled production capacity installed.
The combination of both RES types holds only the 5%+5%, 10%+10% and 15%+15%.

The energy of the consumption flexibility offered is varied from the most conservative value (6%) calculated from the Meregio project to the most optimistic one obtained from the Mirabel questionnaire 15%, where the value is the ration of the average daily consumer consumption.

The time of the consumption flexibility offered is varied from the conservative value (4 hours) to the optimistic one obtained from the Mirabel questionnaire (12 hours).

The unpredictability is used at one scenario only and tells the ration of the consumers not obeying the assignment data but rather consume the electricity by original input data.

The testing interval changes from 24 hours where the most systematic parameters values combinations are set over the 2 weeks interval to the 365 day duration interval, where only the most representative variation parameters are examined.

7.1.2 24 hour interval tests

In the set of the 24 hour tests for each scenario several the most representative days input data are chosen
- TSO tests – 5 most representative days according to the TSO activities on the balance market
- LDE tests – 3 most representative days according to the consumption input data

At the TSO tests only the amount of the flexibility is varied.
The LDE1 tests systematically check the influence of the ratio and type of the RES. All these tests are provided with the medium amount of the consumption flexibility. Separately the dependency on the consumption flexibility (energy and time) is tested at the most representative values of the RES share.
The LDE2 tests check the influence of the ratio and type of the RES.
The LDE3 tests vary only the unpredictability parameter value.

Test trial	**RES ratio**	**Flex amount**	**Flex time**	**Unprd. Proba.**	**No. of test executions**	**Testing interval [hour]**	**Test duration [hour]**	**External market**
TSO-1d.1	0W 0P	MIN	MED	0	5	24	7,92	yes
TSO-1d.2	0W 0P	MED	MED	0	5	24	7,92	yes
TSO-1d.3	0W 0P	MAX	MED	0	5	24	7,92	yes
LDE1-1d.1	0W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.2	3W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.3	6W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.4	10W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.5	15W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.6	20W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.7	25W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.8	30W 0P	MED	MED	0	3	24	7,92	no
LDE1-1d.9	0W 3P	MED	MED	0	3	24	7,92	no
LDE1-1d.10	0W 6P	MED	MED	0	3	24	7,92	no
LDE1-1d.11	0W 10P	MED	MED	0	3	24	7,92	no
LDE1-1d.12	0W 15P	MED	MED	0	3	24	7,92	no
LDE1-1d.13	0W 20P	MED	MED	0	3	24	7,92	no
LDE1-1d.14	0W 25P	MED	MED	0	3	24	7,92	no
LDE1-1d.15	0W 30P	MED	MED	0	3	24	7,92	no
LDE1-1d.16	5W 5P	MED	MED	0	3	24	7,92	no
LDE1-1d.17	10W 10P	MED	MED	0	3	24	7,92	no
LDE1-1d.18	15W 15P	MED	MED	0	3	24	7,92	no
LDE1-1d.19	10W 10P	MED	MIN	0	3	24	7,92	no
LDE1-1d.20	10W 10P	MED	MED	0	3	24	7,92	no
LDE1-1d.21	10W 10P	MED	MAX	0	3	24	7,92	no
LDE1-1d.22	20W 0P	MIN	MED	0	3	24	7,92	no
LDE1-1d.23	20W 0P	MAX	MED	0	3	24	7,92	no
LDE1-1d.24	0W 20P	MIN	MED	0	3	24	7,92	no
LDE1-1d.25	0W 20P	MAX	MED	0	3	24	7,92	no
LDE1-1d.26	5W 5P	MIN	MED	0	3	24	7,92	no
LDE1-1d.27	10W 10P	MIN	MED	0	3	24	7,92	no

LDE1-1d.28	15W 15P	MIN	MED	0	3	24	7,92	no
LDE1-1d.29	5W 05P	MAX	MED	0	3	24	7,92	no
LDE1-1d.30	10W 10P	MAX	MED	0	3	24	7,92	no
LDE1-1d.31	15W 15P	MAX	MED	0	3	24	7,92	no
LDE2-1d.1	0W 0P	MED	MED	0	3	24	7,92	yes
LDE2-1d.2	10W 0P	MED	MED	0	3	24	7,92	yes
LDE2-1d.3	20W 0P	MED	MED	0	3	24	7,92	yes
LDE2-1d.4	30W 0P	MED	MED	0	3	24	7,92	yes
LDE2-1d.5	0W 10P	MED	MED	0	3	24	7,92	yes
LDE2-1d.6	0W 20P	MED	MED	0	3	24	7,92	yes
LDE2-1d.7	0W 30P	MED	MED	0	3	24	7,92	yes
LDE2-1d.8	5W 05P	MED	MED	0	3	24	7,92	yes
LDE2-1d.9	10W 10P	MED	MED	0	3	24	7,92	yes
LDE2-1d.10	15W 15P	MED	MED	0	3	24	7,92	yes
LDE3-1d.1	15W 15P	MAX	MED	MIN	3	24	7,92	No
LDE3-1d.2	15W 15P	MAX	MED	MED	3	24	7,92	No
LDE3-1d.3	15W 15P	MAX	MED	MAX	3	24	7,92	No

Table 2: Test list for the 24 hours simulation tests

7.1.3 14 day test

In the set of the two-week tests for each scenario several the most representative two-week period input data are chosen

- TSO tests – 1 most representative two-week period according to the TSO activities on the balance market
- LDE tests – 2 most representative two-week periods according to the consumption input data

At the TSO test only the most representative parameters value are a subject of testing.
The LDE1 tests check the influence of the ratio and type of the RES with the most representative value of the RES ratio. All these tests are provided with the medium amount of the consumption flexibility. Separately the dependency on the consumption flexibility is tested at the most representative values of the RES share.
The LDE2 test is executed with the most representative variation parameter values only.
There is no LDE3 test foreseen for the two-week interval.

Test trial	**RES ratio**	**Flex ratio**	**Unprd. Proba.**	**No. of test executions**	**Testing interval**	**Test duration**	**External market**
TSO-14d.1	0W 0P	MED	0	1	336	110,88	yes
LDE1-14d.1	0W 0P	MED	0	2	336	110,88	no
LDE1-14d.2	20W 0P	MED	0	2	336	110,88	no
LDE1-14d.3	0W 20P	MED	0	2	336	110,88	no
LDE1-14d.4	5W 5P	MED	0	2	336	110,88	no

LDE1-14d.5	10W 10P	MED	0	2	336	110,88	no
LDE1-14d.6	15W 15P	MED	0	2	336	110,88	no
LDE1-14d.7	10W 10P	MIN	0	2	336	110,88	no
LDE1-14d.8	10W 10P	MAX	0	2	336	110,88	no
LDE2-14d.1	10W 10P	MED	0	2	336	110,88	yes

Table 3: Test list for the 2 weeks simulation tests

7.1.4 365 day test

In the set of the 365 day tests for each scenario the whole set of 365 day of the input data is used.

At the TSO scenario no test is foreseen.
The LDE1 tests check the influence of the ratio of the RES with the most representative value of the RES ratio. All these tests are provided with the medium amount of the consumption flexibility.
The LDE2 test is executed with the most representative variation parameter values only.
There is no LDE3 test foreseen for the two-week interval.

Test trial	RES ratio	Flex ratio	Unprd. Proba.	No. of test executions	Testing interval	Test duration	External market
LDE1-365d.1	5W 5P	MED	0	1	8544	256,32	no
LDE1-365d.2	10W 10P	MED	0	1	8544	256,32	no
LDE1-365d.3	15W 15P	MED	0	1	8544	256,32	no
LDE2-365d.1	10W 10P	MED	0	1	8544	256,32	yes

Table 4: Test list for the 1 year simulation test

7.1.5 Foreseen test duration

The total execution of all the tests from the list should not exceed the prescribed time frame of the 6 month.

Simulation interval	Duration [h]
1 day	1164,24
24Days	2106,72
365Days	1025,28
Total	4296,24
Total months	**5,967**

Table 5: Summary of the simulation tests

The eventual delays due to unexpected problems shall be managed by enlarging the speed up factor and concurrent test execution. The optimal values for the speed up factor and potentials of the concurrent test execution shall be analyzed during integration.

7.2 Test plan of the CRES micro-grid (community consumers trial case)

All the tests at the micro-grid test lab are executed in the real time. They are executed either for the 24 hour interval, 12 hour interval or the most representative intraday intervals (see 6.3.1.2). The execution of the 24 hour tests are split into two days due to the safety and logistic limitation – the test execution must be accompanied by the safety staff what is not the case during the night.

For each duration interval the various combinations of variation parameter values are used. The 24 hour testing interval is used at few test cases only to test and analyze the influence of the day activity on the nightly consumption.
Since the PVs are the only RES installed in the micro-grid only daylight activities are matter of interest. Therefore the 12 hour testing interval is mostly used for testing.
The intraday testing periods are used for testing of the behavior and efficiency of the particular elements.

The tests list consists of the following testing scenarios

- CRES1 – household community balance test
- CRES2 – LDE operation in the isolated mode
- CRES3 – small scale end-to-end test

Each scenario is tested against various combinations of variation parameters values.

7.2.1 Variation parameters

The variation parameters with the values are presented in the table below.

Parameter	Min value	Max value	Step
RES	basic	Max	
Flexibility	Min (6 %)	Max (15 %)	Med (10%)
Unpredictability	-	-	-
Testing interval	4 h	24 h	12 h

Table 6: Variation parameters on CRES test lab

The variation of the RES is separated consists of the “basic”, where the actually installed PV panels are used, and “maximal” where in addition the batteries online emulates the PV panel activity.

The flexibility of the consumption is varied in the same way as at the simulation environment (see 7.1.1).

The unpredictability is not tested in this environment.

The testing interval changes from 24 hours where the most systematic parameters values combinations are set over the 2 weeks interval to the 365 day duration interval, where only the most representative variation parameters are examined.

7.2.2 Test list

In the test list below for each scenario several subsequent execution days with corresponding input data are chosen

- 3 executions are chosen to test the most representative values (medium ratio of the flexibilities
- three executions are chosen to test the dependency of the result on the variation parameters – RES and flexibility ratio.

The LDE2 scenario is tested against various combinations of the storage units:

- Bt batteries with full capacity
- EV batteries as electric vehicle
- HFCE HFC with electrolyzer
- Bt&HFCE batteries with full capacity + HFC with electrolyzer

The LDE3 test case has fixed amount of RES and also no consumption flexibility variation is provided.

Test trial	**Priority****	**RES ratio**	**Flex ratio**	**Storage unit**	**No. of test executions**	**Testing interval [h]**	**Net test duration [h]**	**External market**
CRES1-1	1	basic	MIN	0	3	12	12	no
CRES1-2	1	max	MIN	0	3	12	12	no
CRES1-3	1	basic	MED	0	3	24	24	no
CRES1-4	1	max	MED	0	3	24	24	no
CRES1-5	1	basic	MAX	0	3	12	12	no
CRES1-6	1	max	MAX	0	3	12	12	no
CRES2-1	2	basic	MIN	0	3	12	12	no
CRES2-2	1	max	MIN	0	3	12	12	no
CRES2-3	2	basic	MED	0	3	12	12	no
CRES2-4	1	max	MED	0	3	12	12	no
CRES2-5	2	basic	MAX	0	3	12	12	no
CRES2-6	1	max	MAX	0	3	12	12	no
CRES2-S.1	1	basic	MED	Bt	3	4	4	no
CRES2-S.2	2	max*	MED	Bt	3	4	4	no
CRES2-S.3	1	basic	MIN	EV	3	12	12	no
CRES2-S.4	2	max*	MIN	EV	3	12	12	no
CRES2-S.5	1	basic	MED	EV	3	24	24	no
CRES2-S.6	2	max*	MED	EV	3	24	24	no
CRES2-S.7	1	basic	MAX	EV	3	12	12	no
CRES2-S.8	1	max*	MAX	EV	3	12	12	no

CRES2-S.9	2	basic	MED	HFCE	3	4	4	no
CRES2-S.10	1	max*	MED	HFCE	3	4	4	no
CRES2-S.11	2	basic	MED	Bt&HFCE	3	24	24	no
CRES2-S.12	1	max*	MED	Bt&HFCE	3	24	24	no
CRES3-1	1	fixed	fixed	0	6	12	12	no

Table 7: Test list for the CRES test lab

*This test has max RES ratio which means that in addition the batteries online emulates the PV panel activity. At the same time, the test has storage units as Batteries, meaning that batteries will be used as storage units with full capacity. In order to achieve this, the batteries capacity needs to be split into the two parts. One is used for the emulation of the PVs and the second for the storage with the full capacity. So the “maximal’ RES ratio will not be the same as the “maximal” RES ratio used in other tests.
** Priority “2” means that these test shall be postponed to the end and executed if some time and free capacity of the test lab is available.

7.2.3 Duration foreseen

The total net time for the execution of the tests with the priority 1 from the list is calculated at 744 hours or 31 days of each testing period. Since the 24h duration tests are implemented in two consecutive days and for the preparation of the testing environment status for each an additional day is needed, grossly the time needed for the execution of 1 day net time for each individual test is 2 to 3 days. So the gross total time needed for the trial cases implementation on the real testing environment is 78 days for each test plan round of testing. There have been allocated two rounds of testing for Mirabel in 2012, so for the execution of both rounds the gross total time needed is 156 days. This is allocated to 7.1 months, considering a month of 22 working days, which results to a 60% occupancy of the CRES testing environment for the Mirabel at 2012. However, in the case the testing rounds finishes with the test plan list completed and there is time available, the selected tests with the priority “2” will be executed.

TestType	duration [day]
CRES1	12
CRES2	16
CRES3	3
Total net time	31
Total time	77,5
Total months	**3,52**

Table 8: Summary of the tests on CRES test lab

8 Design of the testing environment

8.1 Simulated entities

The testing environment shall provide the functionalities which are not part of the Mirabel but are necessary for its operation. This includes the boundary entities which are not part of the Mirabel solution and the entities, which have some functionality not included in the solution.
The affected entities are the following

- Balance responsible party
- Consumers
- Controlled producers
- Organized market
- Metered data responsible
- Weather forecast responsible

There is no need to simulate the system operator since its functionalities

- Control of the grid limitations is not relevant since the grid is not modeled
- Active balancing the production and consumption is not modeled but rather implicitly the difference between production and consumption is assumed to be the TSO activity

There is no need to simulate the RES production. The production data are stored in advance in the database.

8.1.1 Balance responsible party

The task of the balance responsible party is to provide the imbalance price forecast for the requested period in the future on the request of the Mirabel process.
The imbalance prices are provided either

- Internal from the schedule of the controlled production. The input to the calculation is the highest price of the scheduled production for each latest scheduled interval.
- From external source like balance market (the data are stored in DB)

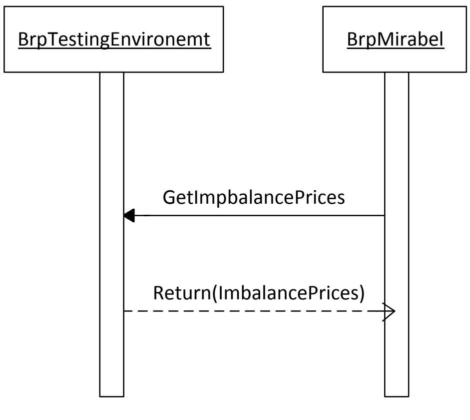

Figure 22: Communication between BRP entity and Mirabel component

8.1.2 Consumers

The tasks of the consumers are

- Sending the flex offer messages
- Accepting the acceptance and assignment messages
- Consuming the energy according to the input data and assignment data

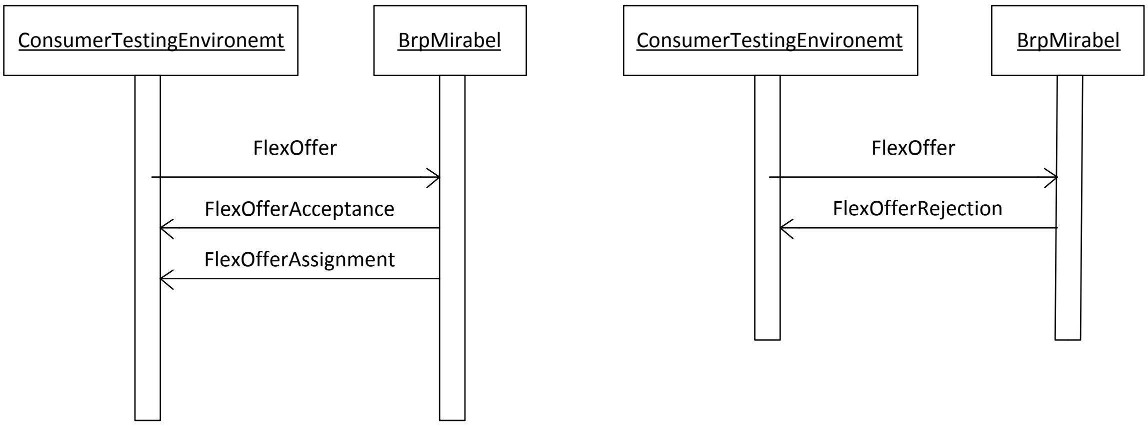

Figure 23: Communication between Consumer entity and Mirabel component

Every flex-offer message sent must be kept for the evidence for the control of the return. If the return does not arrive in time the same routine as the rejection is received is executed.

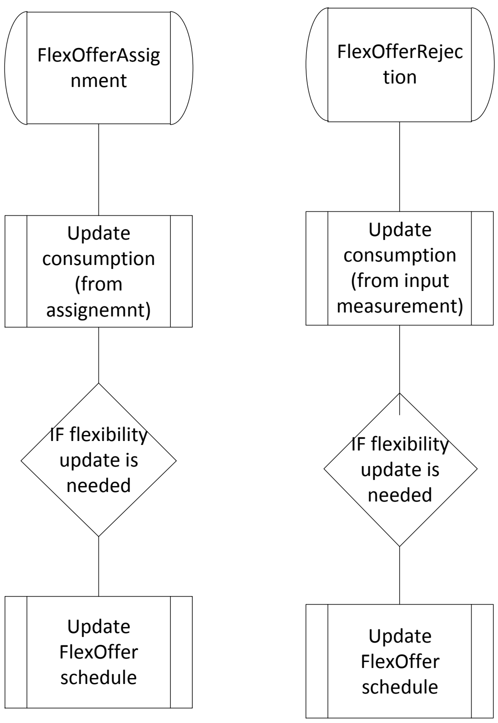

Figure 24: Actions of the consumer entity in the testing environment

At the reception of the assignment message the consumer consumption data are adapted according to the assignment message. The loads with time flexibility only and simple operation schedule (i.e. washing machine) has all its flexibility known in advance and the assignment of its operation does not affect its further flexibility activity. On the other hand the flexibility offer od the loads with energy flexibility (like batteries) and more complex/unpredictable time behavior depends on the operation in the past which was determined by the previous assignment. Therefore its further flexibility activity depends on the content of the assignment and the flex offer schedule for the future must be updated at the reception of the message.
At the reception of the rejection message or timeout the consumption is returned to the default values, which is the same as the input data for the period of the rejected flex offer.

8.1.3 Producer

The Mirabel flex-offer approach also covers the activities of the controlled producers, what is used in the testing environment. The producers offer their production capacity to the BRP, which schedules their activity according to the consumption needs. The producer role in the testing environment is making the following
The tasks of the producers are
- Sending the flex offer messages
- Accepting the acceptance and assignment messages
- Producing the energy according to the input data and assignment data

In contrast to the consumer the producer flex-offer message sent does not need to be kept for the evidence for the control of the return. Since there is no open contract at the controlled production, all the energy is produced according to the content of the assignment message.

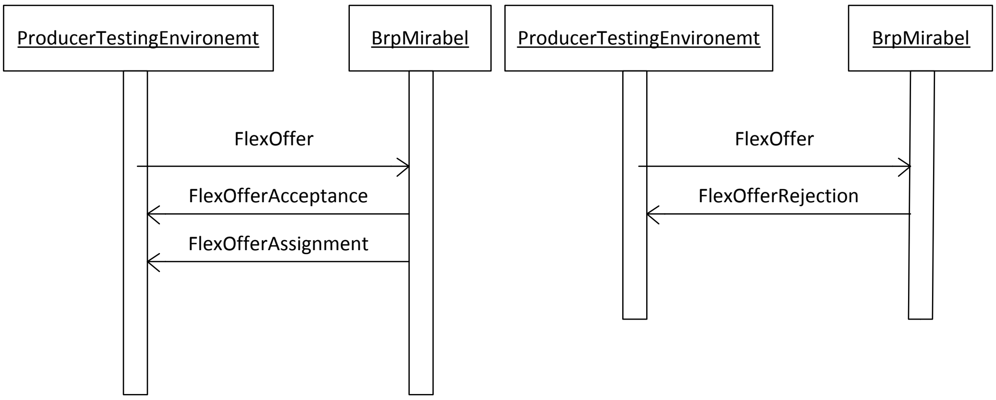

Figure 25: Communication between Producer entity and Mirabel component

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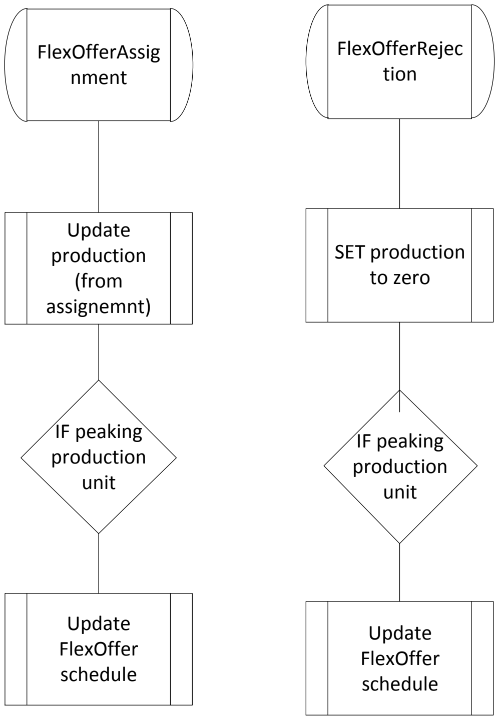

Figure 26: Actions of the producer entity in the testing environment

At the reception of the assignment message the producer production data are adapted according to the assignment message. In the case of the sender is the peaking production unit the flex offer schedule for the future is updated for further flex offer activity. In difference to the base production unit the peaking production unit may change its production on the short time scale but its flexibility depends on the actual schedule.
At the reception of the rejection message or timeout the production is zero.

8.1.4 Market operator

Communicating with the external market the BRP needs to convert a share of its open consumption, open production and the flexibilities into the trading product. At fixing the flexibilities needs to form the products in the way to gain the maximal profit. This goal requires modeling the BRP algorithms for the creation of the complex market products, implement its business policy from long term bilateral trading to short term organized external market, forecasting of the external market price, etc., on one side and modeling of the organized external market on the testing environment. All these are out of the scope of the project.
The implementation simplification is used instead, when the historical data from the external market is used as an input in the Mirabel scheduling process. The external market bid results are transformed in the form of the flex offer and send to the Mirabel BRP as an input. This is not according to the process in the real environment but reasonable and acceptable simplification replacing the complex BRP bid creation and formation of the market products. With the implementation of this simplification the external market is brought into the environment which enables to simulate of the influence of its main characteristics like price oscillations on the Mirabel solution.

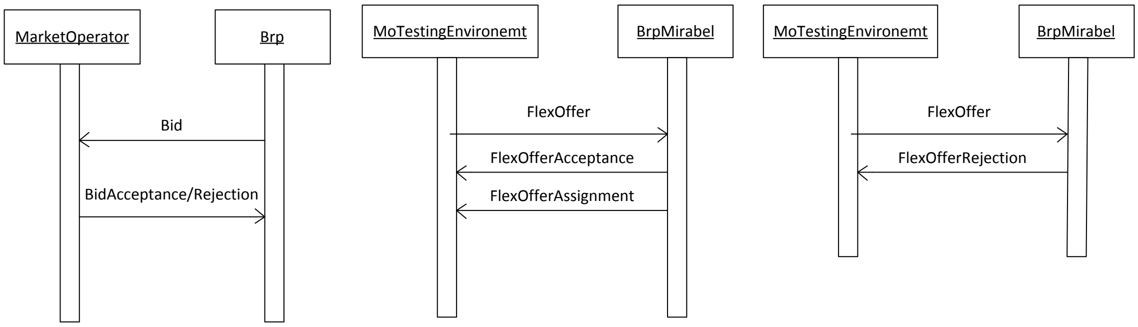

Figure 27: Communication between market operator and BRP according to the roles and process definition – left, and its simplification implemented in the Mirabel testing environment – middle and right.

The tasks of the market operator entity in the testing environment are

- Sending the flex offer messages
- Accepting the acceptance and assignment messages
- External energy flow according to the contract

The trading products and corresponding flex offers from the market testing environment entity are one hour product. The flex offer generation corresponds to the two market tapes – day-ahead market and intraday market. Each market bid results in the two flex offers – production flex offer for the buying energy bid and the consumption flex offer for the selling energy bid.

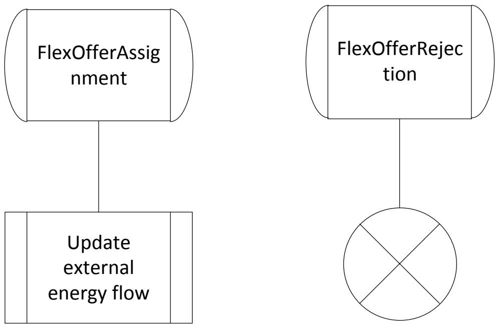

Figure 28: Actions of the producer entity in the testing environment

8.1.5 Metered data responsible and Weather data responsible role tasks

The metered data responsible role tasks in the testing environment are reduced to the triggering the forecast. The forecast entity needs the external information about the recorded data to update its forecasts.

The weather data responsible is not specified in the harmonized model [ETSO], but the Mirabel BRP entity needs the external component which informs the forecasting about the weather conditions.

Both entities are implemented as a simple periodic trigger to the forecasting component.

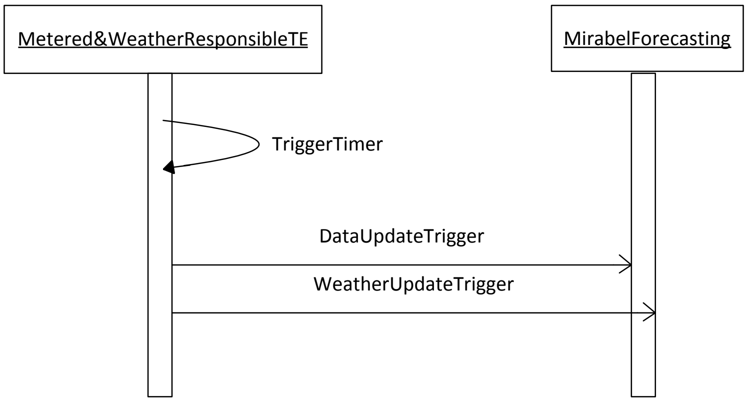

Figure 29: Communication between Metered data responsible and weather data responsible to the Mirabel forecasting component

8.2 Test environment SW architecture

The testing environment must cover all the necessary boundaries needed by the Mirabel solution for its operation. The architecture of the testing environment is defined by the communication – messages and routine calls from/to the Mirabel control and application components.

8.2.1 External communication

The external communication between the Mirabel components and testing environment consists of

- Flex offer messages (flex-offer, acceptance, assignment) exchanged between the communication components of the testing environment and Mirabel control component
- External routine calls
  - Imbalance prices called by the control component
  - Forecast triggers (meter data and weather forecast)
  - Test execution time

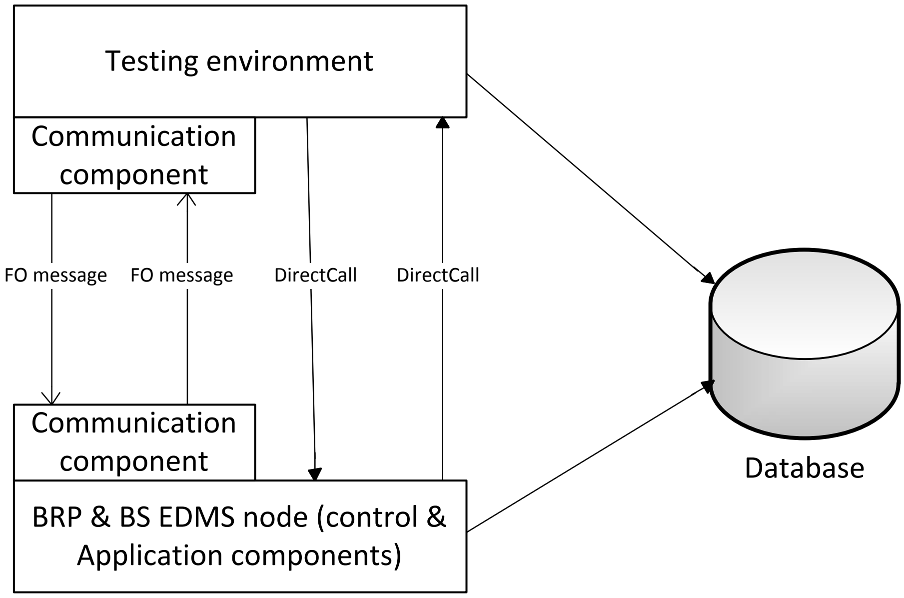

Figure 30: Communication between testing environment and Mirabel components

The testing environment and the Mirabel components use the same database. The internal database design distinguishes the parts belonging to the Mirabel and parts belonging to the testing environment.

8.2.2 Internal structure

The main component in the testing environment is the “TeControlComponent” which tasks are

- Holds the references to all the rest components of the testing environment
- Implements the interface for the communication with the Mirabel components
- Support the database access

The other entities within the testing environment are

- Flex offer scheduler. Its main task is to read the data about the flex offers from the database and schedule them according to the flex offer issue time. At the issue moment it sends the single flex offer data to the flex offer generator
- Flex offer generator is triggered by the scheduler, when it forms the flex offer message and sends it through the communication component
- Flex offer controlled is responsible for the processing of the messages received – acceptance/rejection and assignment message. It also holds the acceptance and assignment expiry control.
- “ITestingBrp” is the interface the testing environment must implement so it can execute the routines called by the Mirabel components
- “IMirabelBrp” is the referenced interface which the testing environment needs to store for the execution of the i.e. forecasting triggers
- IComunicationComponent – the reference to the communication component for sending and receiving the messages

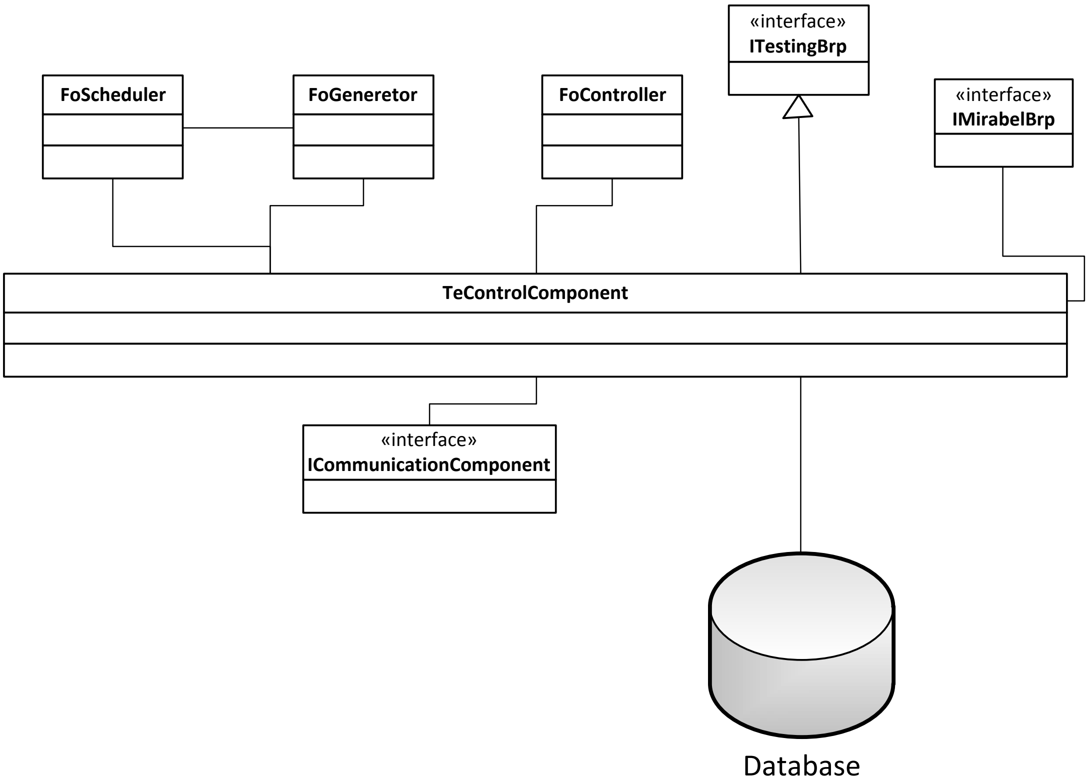

Figure 31: Testing environment SW structure

8.2.3 Initialization

The Mirabel testing environment with the Mirabel solution shall be implemented in the form of the service which starts the testing environment control component and the Mirabel control component. The necessary references (ItestingBrp and IMirabelBrp) need to be exchanged for the routine call during the operation.

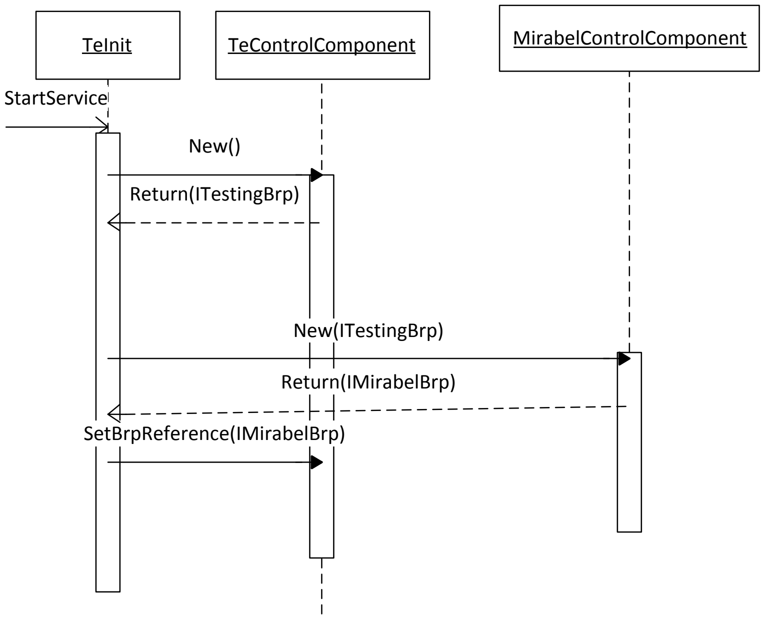

Figure 32: Initialization of the Testing environment with the Mirabel solution

Within the testing environment the components are initialized as presented on the Figure 33

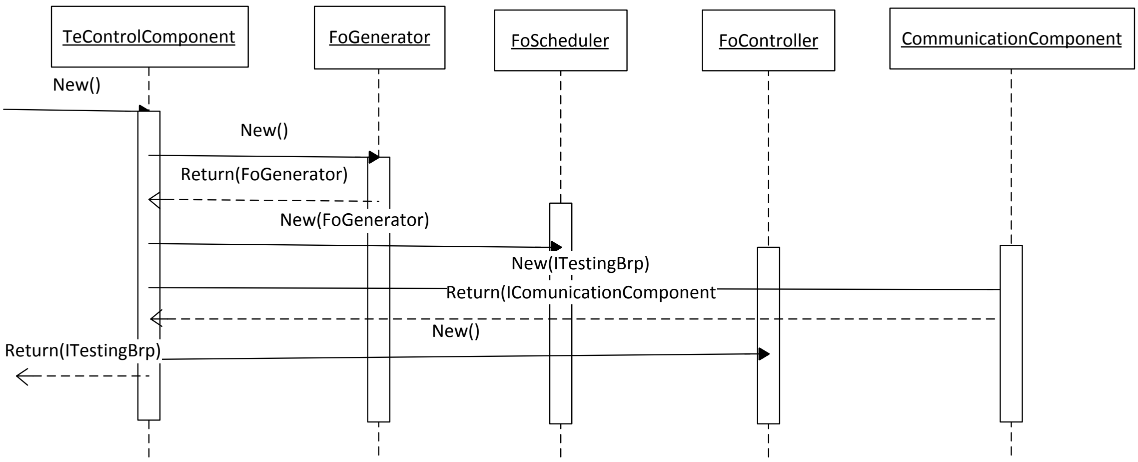

Figure 33: Initialization of the components within the testing environment

8.3 Run time routines

8.3.1 Flex offer scheduler

The main task of the flex offer scheduler is to send the flex offer data to the flex offer generator in the moment of the flex offer issue time. The parameters “fromTime” and “toTime” defines the time interval of the issued flex offers. The flex offers with the issue time within the interval shall be sent in the next iteration. The evidence of the flex offer messages sent is stored for the response control.

All the data about the flex offers are stored in the database. When the flex offer scheduler main routine is triggered it first sets the “fromTime” and “toTime” parameters for querying the flex offer data from DB. The “fromTime” is set to the “totime” of the previous iteration while the “toTime” is set for a certain period ahead from the “fromTime”. The period length is set to the optimal value of the scheduler and flex offer generator performance.
At the end the routine sets the schedule trigger to the time moment of the next iteration. The schedule trigger time is set to the “toTime” time moment.

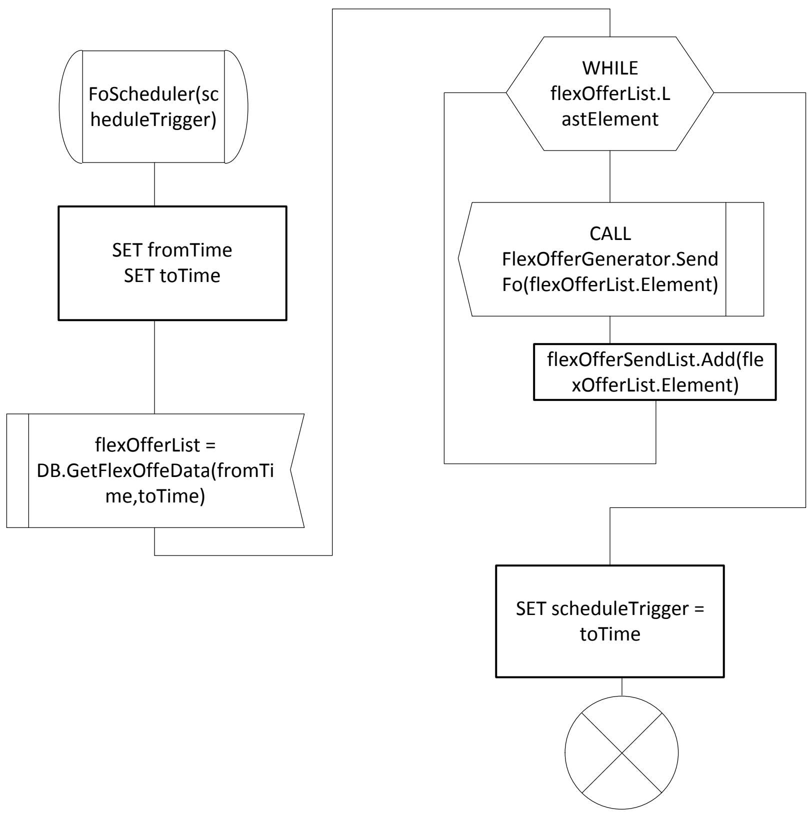

Figure 34: Flex offer scheduler main procedure

In the case the “scheduleTriggerTime” is smaller than test execution time (see 8.3.4) then the performance of the scheduler is too small and alarm should be reported.

8.3.2 Flex offer generator

The flex offer generator is called by the scheduler. Its task is to form the flex offer message and send it via communication component to the Mirabel BRP entity.

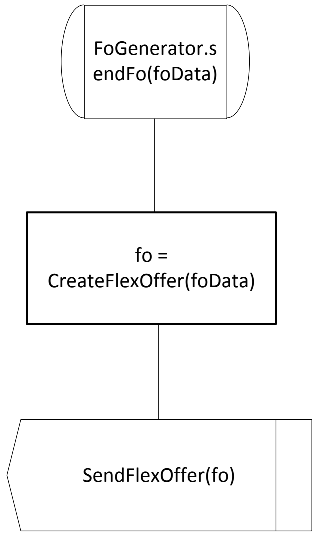

Figure 35: Flex offer generator procedure

8.3.3 Flex offer controller

The flex offer controller controls the responses on the flex offer messages. It is activated at the reception of the flex offer assignment, flex offer rejection and flex offer acceptance message. Further processing depends on the entity the message belongs to (either it is consumer, producer or market operator). The entity processing is described in the subchapters 8.1.2 - 8.1.4.

For each flex offer message also the time control is applied. If the response does not arrive in time the controller start the same processing as at the rejection.

After the processing of the rejection and assignment, the flex offer is removed from the evidence.

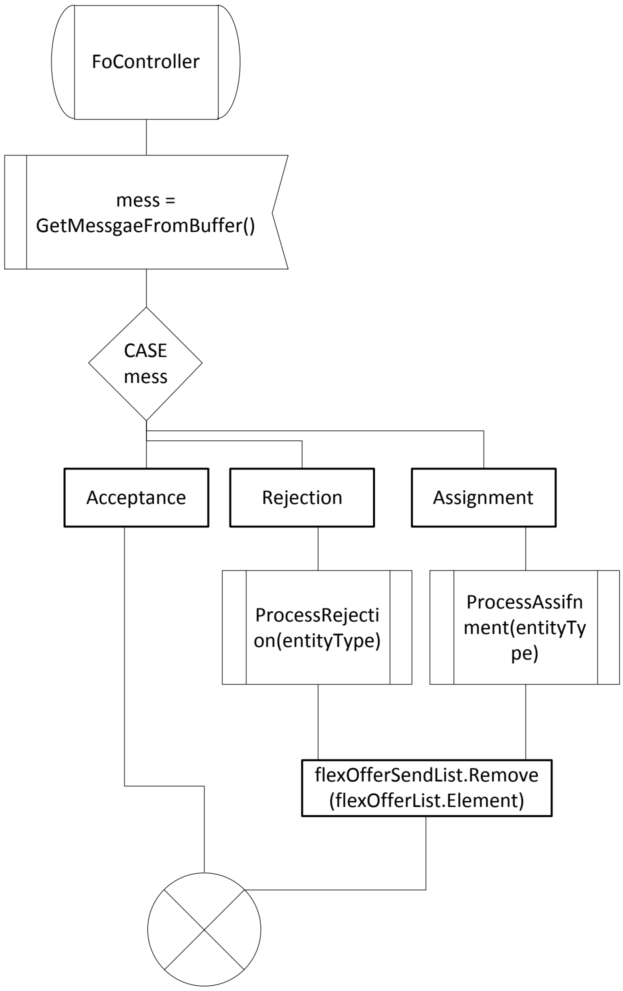

Figure 36: Flex offer controller main procedure

8.3.4 Test execution time

The test execution time function is used to control the execution moment. The test shall be executed for the specific period defined by the input data. At the beginning of the test execution the test execution time is set to the desired moment of the test start. Later the test execution time is enlarged according to the real time or it is speeded up by the “speed up factor” which value should be larger than 1.
The test execution time is calculated every time the function is called. Its input parameter is the test start time and speed up factor.

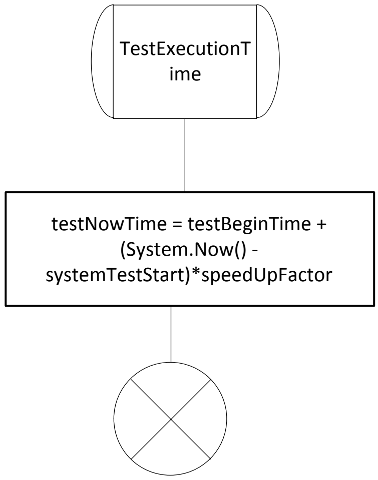

Figure 37: Test execution time function

8.3.5 Scenario Continuation

If the test execution is interrupted for some reason and it is desired to be continued from the interruption moment on then the running resources and parameters needs to be restored.
The running resources are

- The evidence of the flex offer sent
- The parameters of the test execution time routine.

On the other side the Mirabel control and application components also need to restore the resources at the interruption (like flex offer list, etc.)

8.4 Scenario Startup

The scenario start up procedure prepares for the steady state operation. At the beginning there is no pending flex offer in the system therefore the startup scenario procedure needs to send the corresponding flex offers from the database.
First the startup procedure blocks all the application activities in the Mirabel application. Then reads and sends all the flex offer specified in the database which has

- The issue time smaller than the test start time and
- The start before time is larger than the test start time.

All the flex offer sent in the scenario start up procedure needs to adapt the acceptance and the assignment time and set them to the test start time.

At the end the startup procedure unblock the Mirabel control and application component activities.

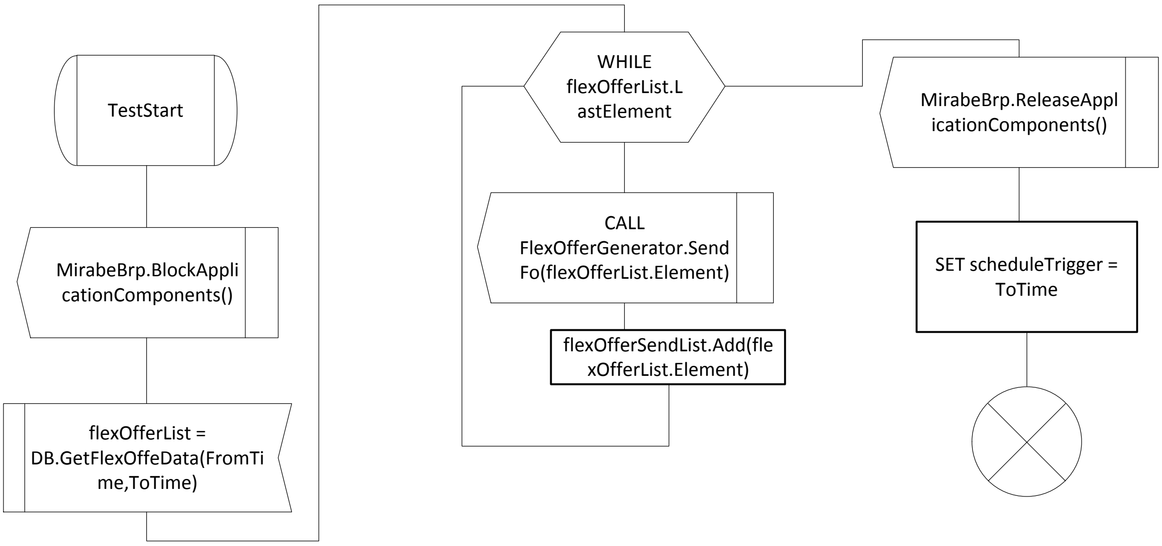

Figure 38: Initialization of the components within the testing environment

9 Testing environment on CRES

Additionally to the simulation environment the integration on the CRES test lab requires also the communication and control of the real consumption and production units. This chapter describes the design of

- the communication between the Mirabel testing environment and CRES test lab
- the control of the concrete prosumer loads and generators like batteries, heat pump, etc.

9.1 Diagram of processes

The diagram of processes consists of the four layers physical processes, CRES processes, INEA processes and Mirabel testing environment processes (Figure 39).

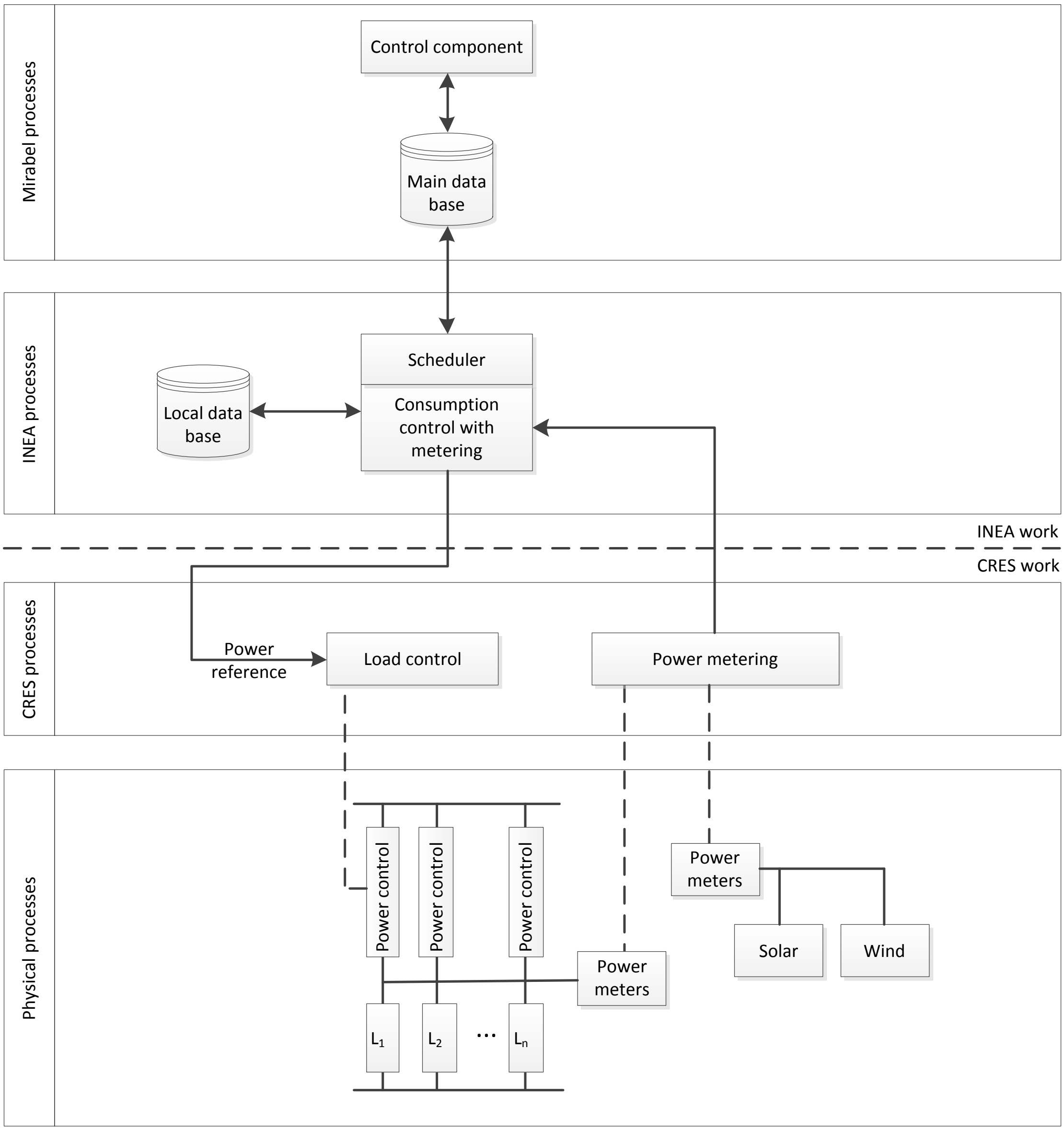

Figure 39: Diagram of processes

9.1.1 Physical processes

In the physical processes layer the loads and renewable energy sources (RES) are placed. We set loads powers and measure their energy consumptions. We also measure energy production of RES. Control for the loads settings is coming from control loads layer. And information about power metering is going to the CRES processes layer.

9.1.2 CRESS processes

CRES processes layer controls the loads energy consumption by setting loads power that are placed in physical processes layer so the energy consumption follows power reference signal. Power reference signal is provided by the INEA processes layer.

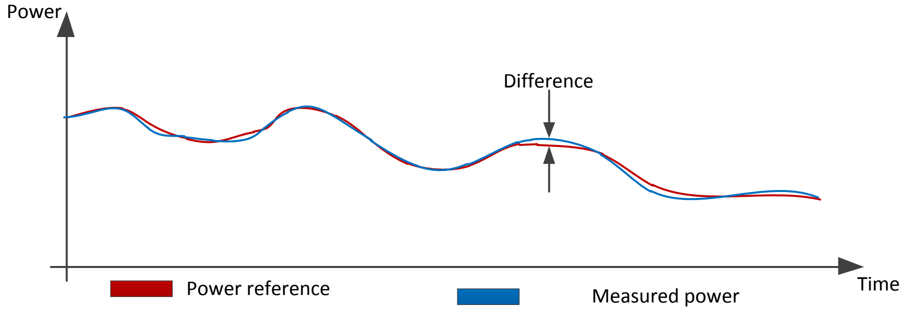

Figure 40: Control of loads consumption by power reference

Figure 40 represents an example of power reference signal and actual measured power of the loads. The control of the loads must ensure minimum difference. It also gathers all measurements data from physical processes layer and preprocess them for the INEA processes layer.

9.1.3 INEA processes

This layer calculates power reference for the loads control by the internal scheduling algorithm and gathers power measurements of loads and RES from the CRESS processes layer. It communicates with Mirabel processes layer via main data base to gather required information and save measurements.

9.1.4 MIRABEL processes

This is top layer where control component and main data base are located. It is connected only to the INEA processes layer.

9.2 Structure of testing environment

The diagram of testing environment can be divided into four layers Loads and RES, CRES control and communication devices, INEA application and Mirabel applications.

On the lowest level we have loads and RES. Load switching is done by CRES control device via connection C_1. Power measurement for the load consumption and production of RES are done by power meters that are connected to the CRES controlling device via connection C_2 and C_3. CRES OPC server that is installed on local computer is used to communicate with the CRES control device via C_4. INEA application is accessing data from CRES OPC server with OPC client via C_5. INEA application communicates with main data base and Mirabel application through connections C_6 and C_7.

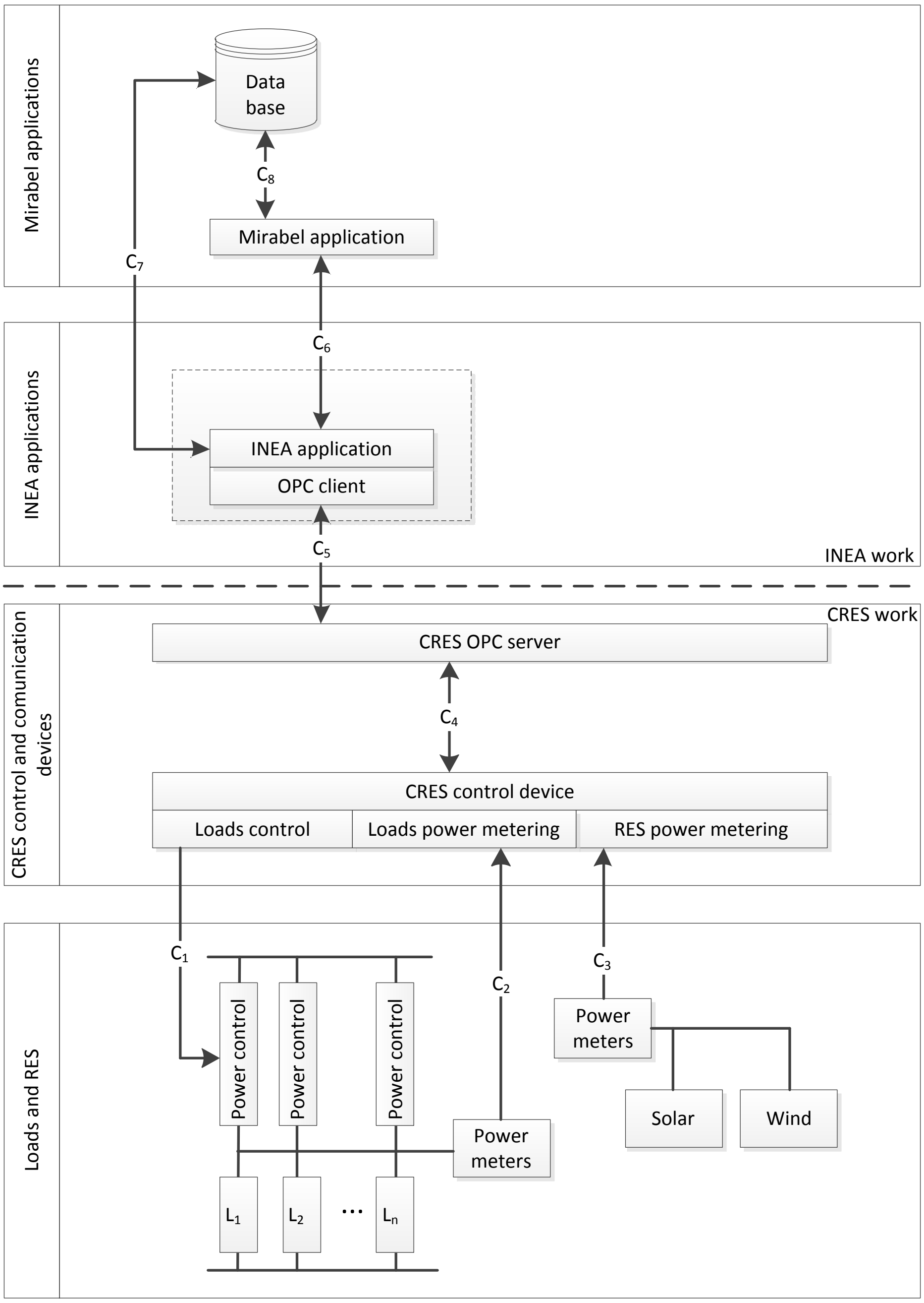

Figure 41: Structure of testing environment

The interaction between Mirabel and the experimental micro-grid will be done through the Supervisory Control and Data Acquisition system of CRES. Specifically, the means of communication is the OPC server running on the interface console. This OPC server contains a number of tags which are used as variables in the SCADA system. Through this, it is possible to supervise the actions of Mirabel without bypassing the supervisory control something critical for safety reasons. In addition to that it provides all necessary calculations which are not readily available to Mirabel like energies and other similar quantities. The SCADA, the OPC server and the application with OPC client will run on

the same machine while Mirabel will run on another computer. Both systems will communicate via the existing LAN.
Table describes connections that are used in diagram of structure

Label	Data transfer read	Data transfer write
C1	not applicable	Load switching
C2	Power measurements for loads consumption	not applicable
C3	Power measurement for RES productions	not applicable
C4	C2,C3 data	C1 data
C5	C2,C3 data	Power reference for load control process

Table 9: Description of connections between components of testing environment

9.3 Data that is transformed via connections

Table represents description of data that are transferred via connections. It describes data by connections on which they are transferred.

Connection	Data	Type*	Unit	Sampling time	From -> To
C4	Load energy measurement (1 to 4)	Float (cumulative)	kWh	1min	CRES control device -> CRES OPC server
	RES energy measurement	Float (cumulative)	kWh	1min	CRES control device -> CRES OPC server
	Power reference	Float	kW	minimum	CRES OPC server -> CRES control device
C5	Load energy measurement	float	kWh	15min	CRES OPC server -> OPC client
	RES energy measurement	float	kWh	15min	CRES OPC server -> OPC client
	Power reference	float	kW	15 min	OPC client -> CRES control device

* Cumulative means that value represents whole energy that has been consumed not just energy from the last interval

Table 10: Description of transferred data via connections

9.4 Connections between devices

Testing environment consist of four components INEA OPC client (IOC), LabView (LV), CRES control device (CCD) and CRES OPC server (COS). Connections between them are represented in Figure 42.

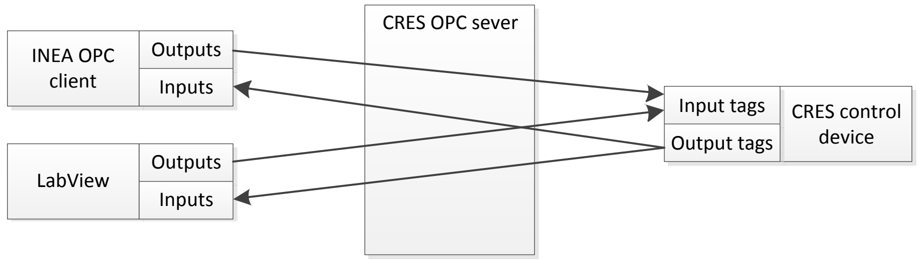

Figure 42: Connections between four basic elements

IOC communicates with CCD via COS. It uses data tags to write and read data. Data tags usually represent physical registers that are located in CCD.
The LV component communicates as OPC client via OPC server directly with CCD.
We have two possibilities of establishing connection between IOC and CCD. First option describes usage of additional free tags that are located on CCD and other describes usage of additional virtual tags that are located on COS.
We prefer second option if it is feasible.

9.5 Sending data from INEA OPC client to CRES control device

9.5.1 Usage of additional tags on CRES control device

CCD accepts information of demanded current load consumption (power reference) and adjusts actual load consumption according to that value. Power reference is provided by the IOC. Figure 43 represent data flow of power reference signal.

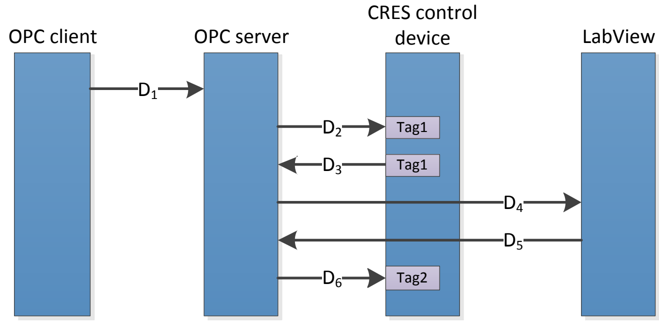

Figure 43: Flow of power reference signal

Power reference data is send to the COS from IOC (D1). COS writes data to Tag1 of CCD (D2). Then COS reads data on Tag1 (D3) and sends them to the LV component (D4). LV component process data and return processed data to the COS (D5). COS writes data to Tag2 on CCD. This data is then used as a power reference for control of the load energy consumption.

9.5.2 Usage of virtual tags on CRES OPC server

In this case we use virtual tags that are located on COS. Figure 44 represents flow of data.

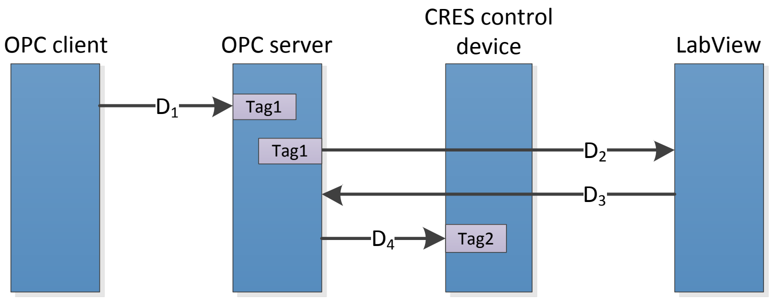

Figure 44: Flow of power reference signal

IOC writes data to the virtual Tag1 located on COS (D1). This data is read by LV component (D2) that process and write processed data to Tag2 that is located on CCD via COS (D3, D4).

9.6 Receiving data from CRES control device to INEA OPC client

9.6.1 Usage of additional tags on CRES control device

Measurements of electrical consumption of the loads are collected from CCD and send to the IOC. Figure 45 represents flow of transferred data.

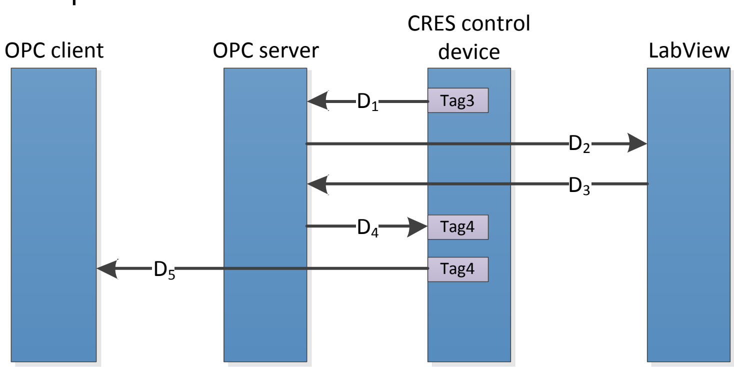

Figure 45: Receiving measurement data

Periodical time trigger triggers sending routine and sent data from Tag3 of the CCD to the COS (D1). COS sends data to the LV (D2) that processes them and returns to the COS (D4). COS writes received data to the Tag4 located on CCD. Data stored in Tag4 is than redden by the IOV (D5).

9.6.2 Usage of virtual tags on CRES OPC server

In this case we use COS virtual tags to write intermediate data.

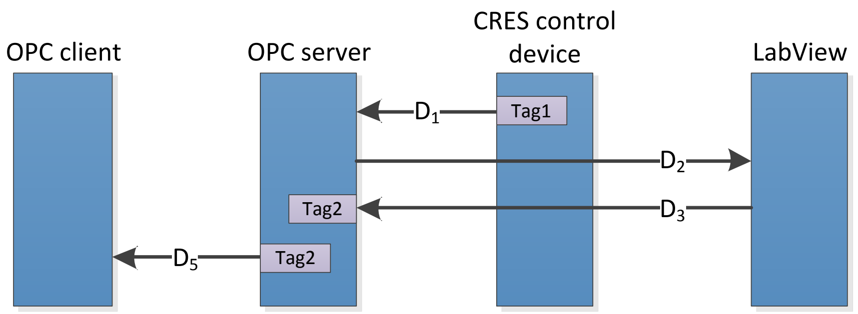

Figure 46: Receiving measurements data

Periodical time trigger triggers sending routine and sent data from Tag1 of the CCD to the COS (D1). This data is then sent to the LV that processes them (D2). LV writes processed data to Tag2 located on COS (D3). Data located on Tag2 is then read by the IOC (D5).

9.7 Generating the Flexibilities of complex loads

Complex loads are loads which energy consumption cannot be directly controlled. Their energy consumption is used to control some other process variable. In order to reduce or enlarge consumption that process variable has to be changed which will lead to a change in power consumption of the process. Typical representatives of this load types are heat pump systems, hydrogen fuel cell systems, battery storage devices and other storage systems. They all consume energy to control main process variable in heat pump systems this variable is temperature of storage tank in hydrogen fuel cell is the amount of stored hydrogen and in battery storage systems is the amount of energy that is stored.

9.7.1 Basic description of storage system

Figure 47 represents storage system basic description.

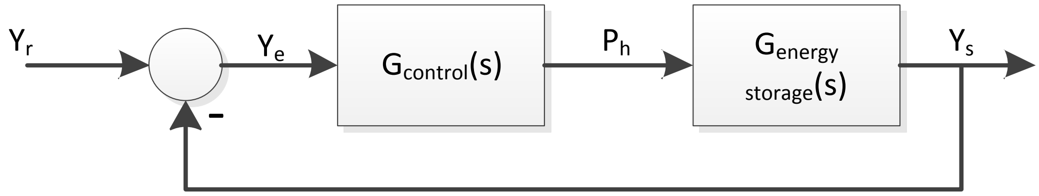

Figure 47: Complex loads system model

Storage system consist of two elements the control system ($G_{control}$) and system energy storage (G_{st}). Y_r is the input reference variable. Y_e is difference between main variable system Y_{st} (controlled variable) and reference variable. P_h is power of the actuator that control main variable value.

9.7.2 Energy storage system

Energy storage system is used for storing energy produced by the actuators. In heat pump systems it can be a water tank or a building that stores cold produced by heat pump. In hydrogen fuel cell systems is hydrogen storage tank which is filled by the electrolyzer and in battery storage devices is a electrolyte who stores electrical energy that is supplied by the battery control system. Figure 48 represents energy system.

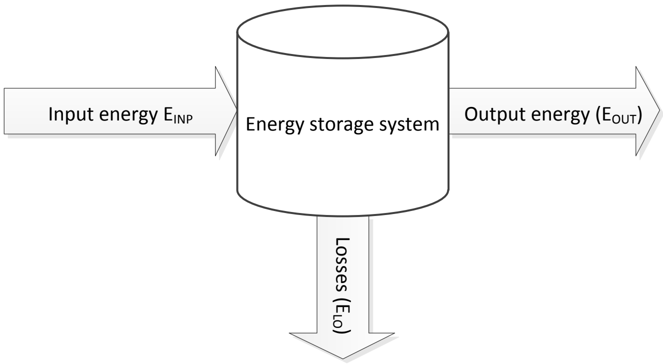

Figure 48: Energy storage system

Energy storage system is filed by the input energy provided by the actuator. It has its own energy losses and output energy that represents consumption of stored energy.
Equation (16) describes energy flows of energy storage tank.

$$E_{INP} = E_{LO} + E_{OUT} \quad (16)$$

9.7.3 Control system

Each energy storage system has its own control system that controls value of stored energy. In case of a heat pump system thermostat is controller and temperature of asset inside storage tank. Tank water temperature is regulated by switching power of the heater on and off. Equation (17) represents power of the heater depending of the water tank and reference temperature.

$$P_h(t) = \begin{cases} 1 \; if \; T_{st} < T_r - \Delta T \\ \\ 0 \; if \; T_{st} < T_r + \Delta T \end{cases} \quad (17)$$

The regulator uses hysteresis to control temperature in water tank (ΔT). Figure 49 represents operation of regulator system.

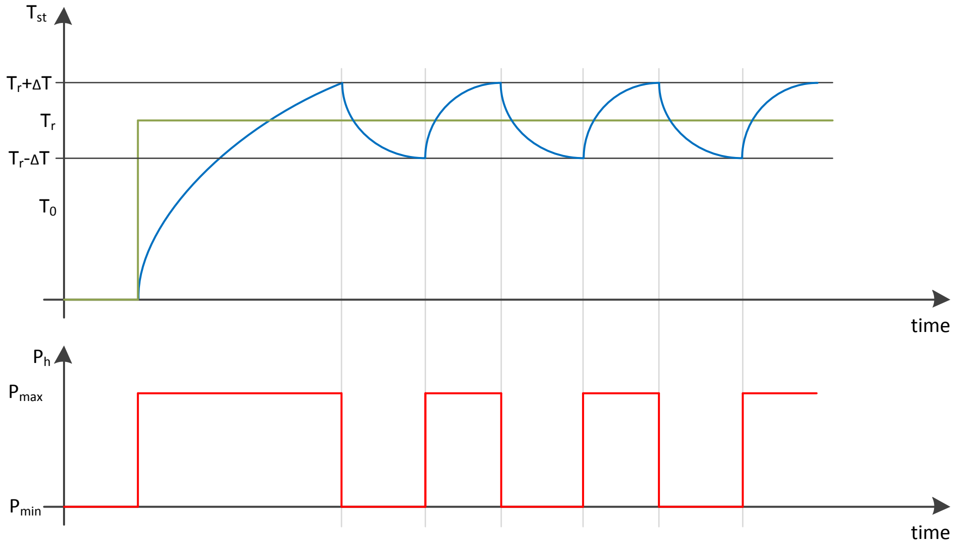

Figure 49: Control off the heater

Heater is turned on when water tank temperature is lower than reference temperature with subtracted hysteresis parameter (ΔT). And it is turned off when water temperature is greater than reference temperature with added hysteresis parameter.

9.7.4 Flexibility potential

System can be designed so that it has two flexibilities, flexibility by energy and by time.

9.7.5 Energy flexibility

9.7.5.1 Energy flexibility model od heat pump system

For the heat pump system we have two limits of temperature of water tank the upper temperature limit and the lower temperature limit. To sustain current temperature heat pump must work with some average power. Figure 50 represents tree different working areas of heat pump minimum maximum and the middle.

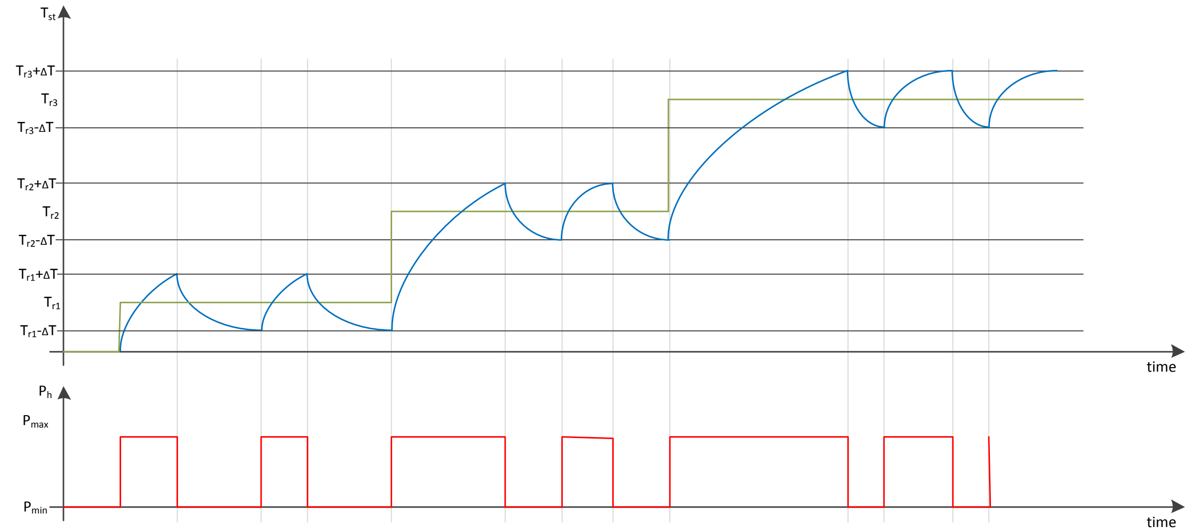

Figure 50: Temperature response to changed reference temperature

The power that heat pump is using for sustaining desired temperature is shown on the bottom graph of Figure 50.

9.7.5.2 Power consumption model of heat pump system

For sustaining reference temperature at constant output heat flow a certain amount of energy is needed that can be expressed in average power. Figure 51 represents average power dependence from temperature at output heat flow q_{OUT1}.

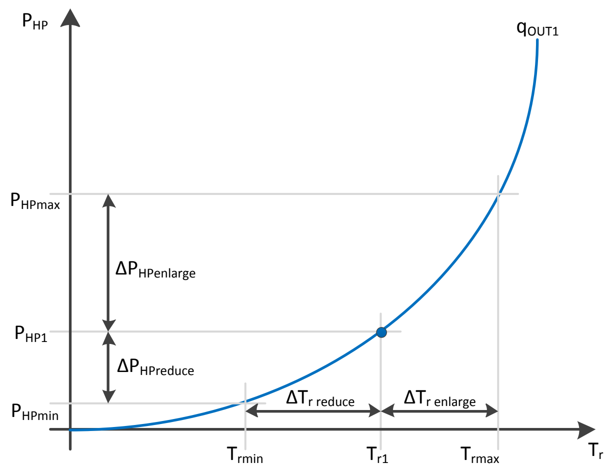

Figure 51: Average power of heat pump depending on the reference temperature

Current working temperature (T_{r1}) is somewhere in the middle of the allowed range. For sustaining that temperature average power P_{HP1} of heat pump is needed. If we change reference temperature we can enlarge or reduce average power consumption. This allows us to control power consumption of the heat pump and can offer reduction or enlargement of power consumption. Equations (18), (19) represent amount of energy that can be offered.

$$P_{offer\ enlarge}(q_{OUT1}) = \Delta P_{HP\ enlarge} = P_{HPmax} - P_{HP1} \quad (18)$$

$$P_{offer\ reduce}(q_{OUT1}) = \Delta P_{HP\ reduce} = P_{HP1} - P_{HPmin} \quad (19)$$

9.7.5.3 Power consumption characteristic of heat pump system

Power consumption characteristics can be measured as energy dependence from temperature and the output heat flow. Figure 52 represent characteristics measured at four different output heat flows.

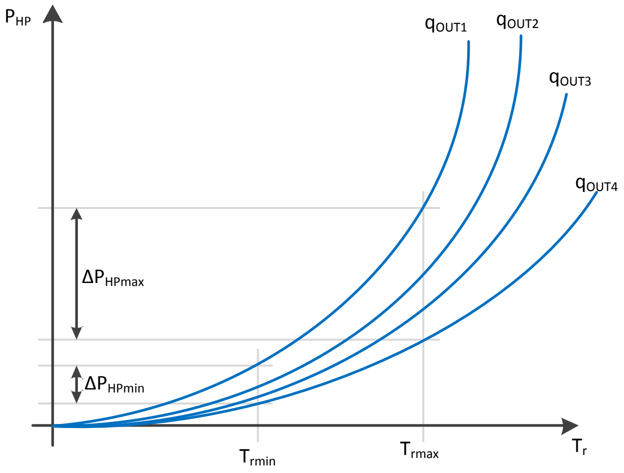

Figure 52: Power consumptions characteristic

Heat pump system must provide temperature of storage tank between minimum and maximum value not regarding to the energy consumption. Amount of energy that is necessary to sustain certain temperature is dependent from output heat flow. If outflow of heat is high than higher amount of energy must be used to sustain wright temperature. This is effects on an amount of energy that we can offer for enlargement or reduction.

9.7.5.4 Generating energy flex offers

For generating flex offer we must first calculate expected working, maximum and minimum energy consumption. Offers that we generate are than difference between expected working power consumption and expected maximum or minimum power consumption. Two offers are generated one for enlargement and other for reduction of power consumption (20), (21).

$$P_{offer\ enlarge}(t) = P_{\max expected}(t) - P_{work\ expected}(t) \quad (20)$$

$$P_{offer\ reduce}(t) = P_{work\ expected}(t) - P_{\min expected}(t) \quad (21)$$

After sending offers to control center the schedule for heat pump working power is delivered and new flex offers can be created. New flex offers are calculated as a difference between scheduled and expected minimum or maximum power consumptions (22), (23).

$$P_{offer\ enlarge}(t) = P_{\max expected}(t) - P_{scheduled}(t) \quad (22)$$

$$P_{offer\ reduce}(t) = P_{scheduled}(t) - P_{\min expected}(t) \quad (23)$$

This process is continues so the expected power consumption are also continually recalculating.
Generation of flex offers is shown on Figure 53.

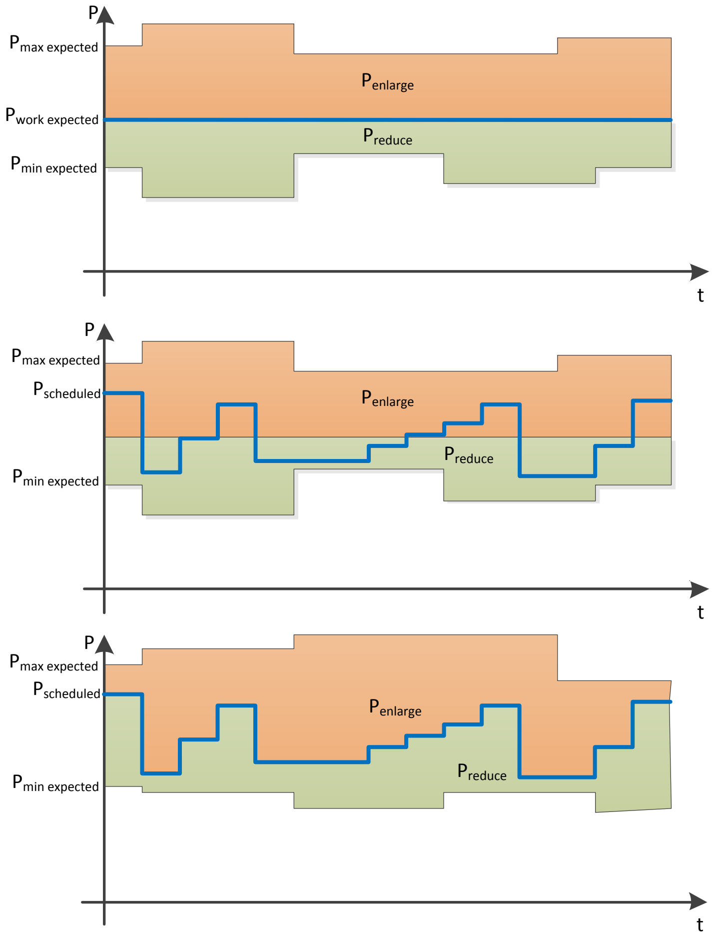

Figure 53: Flex offer generation

First graph represents expected power consumptions. These values are basic for first flex offer calculation. On the second graph the scheduled power consumption is drawn at which current power consumption of heat pump will be rune and the old expected power consumptions. On the third graph the newly calculated expected consumptions are drawn and scheduled power consumption. Now new offers for enlargement and reduction of consumption can be calculated from new conditions.

9.7.6 Time flexibility

9.7.6.1 Time flexibility model

Energy that this model can offer is difference between current energy consumption and maximum or minimum energy consumption. It does not have capabilities to continuously change energy consumption.

9.7.6.2 Power consumption model of heat pump system

Maximum and minimum energy consumption is dependent from output heat flow. In Figure 47 we see power consumption that is necessary to sustain maximum and minimum temperature at current heat outflow.

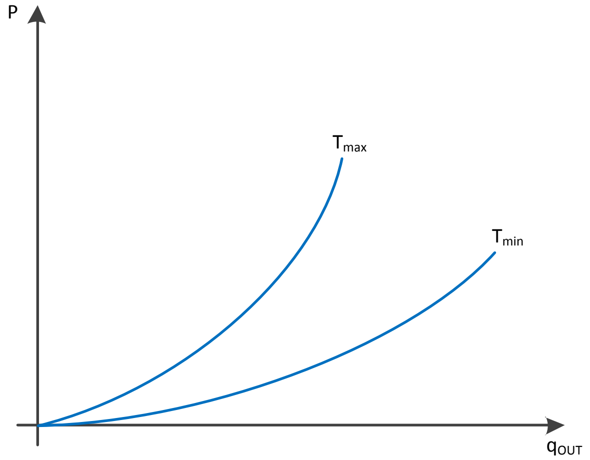

Figure 54: Used Power consumption to sustain max and min temperature at current heat outflow

9.7.6.3 Power consumption characteristic of heat pump system

Power consumption characteristic can be measured on heat pump system by fixing maximum or minimum temperature than change heat flow output and measure average power consumption. This test will provide two characteristic of energy consumption one for sustaining minimum temperature and another for sustaining maximum temperature of heat pump system.

9.7.6.4 Generating time flex offers

These flex offers are time flexible without energy flexibility. Example of flex offer is shown on Figure 55.

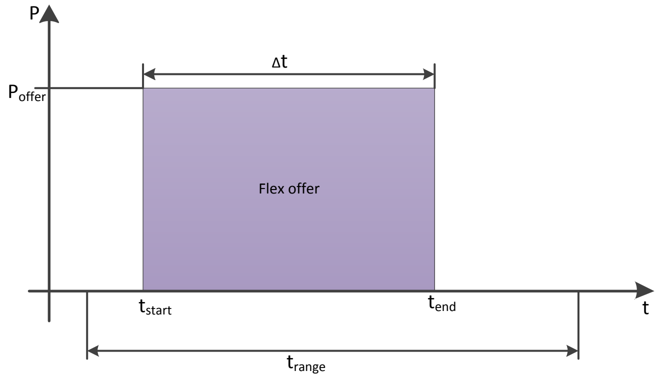

Figure 55: Flex offer limitations

Flex offer has fixed average power or energy consumption (P_{offer}) and flexible start end time with limitations. When flex offer is fixed start time and end time must be in range of range limitation (t_{range}) and length limitation (Δt) of flex offer limitation parameters. Equations (24) and (25) describes flex offers dependences from input parameters.

$$FO_{enlarge} = f\left(P_{\max expected}(t), t_{e\ start}\left(t_{e\ range}, \Delta t_e\right), t_{e\ end}\left(t_{e\ range}, \Delta t_e\right)\right)|_{t=[0,t_{e\ range}]} \quad (24)$$

$$FO_{reduce} = f\left(P_{\min expected}(t), t_{r\ start}\left(t_{r\ range}, \Delta t_r\right), t_{r\ end}\left(t_{r\ range}, \Delta t_r\right)\right)|_{t=[0,t_{r\ range}]} \quad (25)$$

Generating flex offers is described on Figure 56.

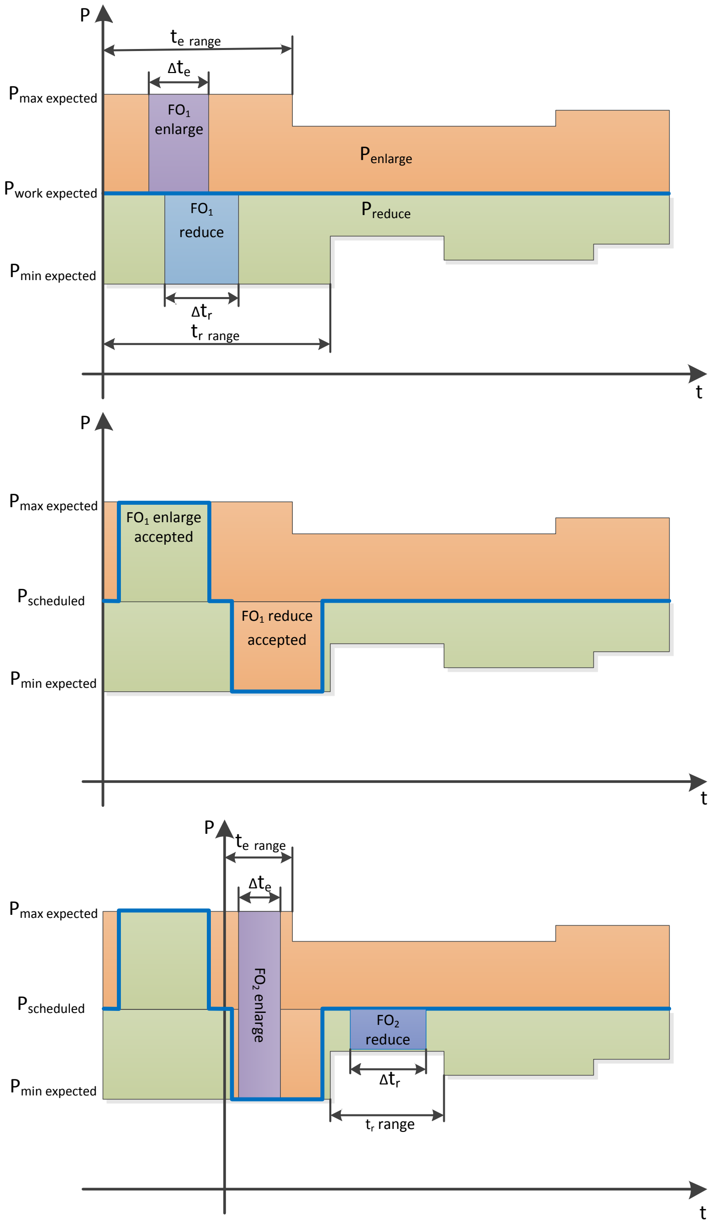

Figure 56: Generation of flex offers

On first graph we can see how first flex offers powers are calculated as a difference between expected work energy consumption and maximum or minimum power consumptions. The time limit range is defined as a range from beginning to the next change in expected maximum or minimum power consumption. This change happens when output heat flow changes. The maximum length of flex offers is equal to the range. Second graph represents accepted flex offers and scheduled working power consumption has changed. On third graph the certain amount of time has passed and we can see new flex offers are being generated same way as first one.

10 Input data quantity analyses

The goals of the quantitative analysis are an estimation of the potential of the flex-offer technology i.e. how many flex-offers can be expected and how many un-schedulable (non-plan able) renewable energy produced by wind and sun can be absorbed, an estimation of the costs, and an estimation of the message and data volume. It will be used for the simulation-based validation and the comparison with other approaches.

10.1 User behavior and environment parameters

The analysis is based on three studies of the user behaviour done within the Smart-A project[1], the MEREGIO project[2] and within the MIRABEL project. These studies analyse the behaviour of residential users.

Parameters related to the acceptance by users:

- *Percentage of consumers/producers which are willing to take part in a Flex-Offer-program.* In the user study of MIRABEL with 73 participants, 37% of the participants would take part in a MIRABEL system and 28% were undecided (Figure 2). So, for this estimation, we assume that approximately 50% of the consumers and producers would take part in the MIRABEL system.

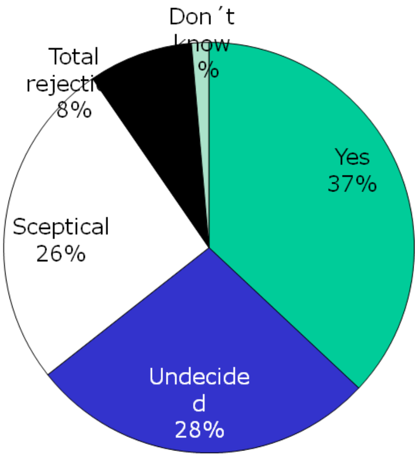

Figure 57: Results of user study

- *Flexible demand (absolute, average) in relation to overall demand.* In the MEREGIO pilot, from May 2010 to December 2010 on average 6.5 % of the

[1] http://www.smart-a.org
[2] http://www.meregio.de

consumption was flexible. According to BDEW[3], average consumption per household in Germany was 3.300 KWh in 2008. The flexible demand per household is therefore 214.5 kWh per year.

- *Expected flexibility in time (average flexibility in time).* In the report about acceptance of smart appliances of the Smart-A project, about 40% of the residential consumers have stated that they would postpone the start of their washing machine, dish washer, tumble dryer. For the air conditioner, 25 % of the people stated that a shift of up to 24 hours is acceptable; on the other hand 28% stated that they would only allow a shift up to 30 min. The authors believe that this value is not realistic since the people have no experiences with smart appliances. They believe that a realistic time shift is between one and four hours. In the estimation, we will use a 1, 2, 4, 6, 8, and 10 hour average time shift.
- *Expected savings (average expected saving).* EnBW roughly estimates that the saving per year has to be around 50€. In the MIRABEL user study we have seen that the expected savings increase with an increased flexibility in time.

Cost-related parameters

- *Price of imbalances (max, min, average per day, month, year).* The prices of used reserve power used by all four German Transmission System Operators are listed on the site of EnBW Transportnetze GmBH[4]. The prices are given with signs. The sign indicates if the power was used or produced. There is only one price per 15 min interval. Therefore we take the absolute values for the calculation. The average and maximal prices for February 2011 are 5.0 and 26.38 ct/kWh and for August 2010 4.78 and 45.78 ct/kWh. EnBW Transportnetze GmBH has also listed the used reserve power[5]. There is the amount of power listed which has been used and produced for each 15 min interval. We add these values to get the overall amount of used reserve power. The values are given for the primary and minute reserve. The values of the secondary reserve are mostly 0. Therefore we use the values of the primary reserve only. The maximum and average used primary reserve power in a 15 min interval in August 2010 is 1662 and 538.4 MW. In February 2011 it is 2016 and 657.8 MW.
- *Cost of appliances.* The cost of appliances is not considered because we expect that with the development of energy management systems for small consumers/producers an interface to appliances will be developed. So, in the future, nearly all offered appliances will be “smart-grid enabled”. In the Smart-A project, consumers have stated that they are willing to pay only slightly more (5 to 25€) for a smart appliance instead of a conventional one.
- *Cost of an additional device i.e. control boxes and for installation.* The cost of control boxes which run an energy management system can only be estimated. EnBW already uses control boxes but only for a few hundred customers. In the Smart-A project, residential consumers have stated that they would accept additional costs of 100€. The willingness to invest depends on possible savings. No data have been obtained for non-residential and industrial consumers with complex internal energy systems.

Parameters related to RES production

[3] http://www.bdew.de/internet.nsf/id/DE_Energiedaten
[4] http://www.enbw-transportnetze.de/strommarkt/bilanzkreismanagement/bilanzkreisabrechnung/
[5] http://www.enbw-transportnetze.de/strommarkt/regelenergie/abruf-regelenergie/?app=regelenergie&activeTab=table&auswahl=day&date=18.04.2011&view=1

- *Total amount of RES currently used and expected to be used by 2020.* In Germany in 2009, 7 % of the electrical energy was produced by wind and 1% by photovoltaic. The fraction of RES total was 16%[6].

10.2 Quantity analyses of the Meregio consumption data

The quantity analyses is based on the temporal set of the household consumption from Meregio project and consists of

- 87 consumers
- Measurements form November 2009 till august 2010.
- 1 hour measurement granularity
- The measured consumers were in the scheme with a single tariff

The testing shall be provided on the complete set of data consisted of the 1000 consumption measurements with 1 year time history. When the data will be available, the quantity analyses shall be updated.

10.2.1 Total consumption

The average Meregio consumer daily consumption is larger than an average household consumer, because due to the project directions the larger consumers were chosen. The average daily consumption is 14kWh.

Day Consumption	*1(<5kWh)*	*2(<10kWh)*	*3(<15kWh)*	*4(<20kWh)*	*5(>=20kWh)*
Number of consumers	4	14	31	28	9

Table 11: Average daily consumption classes

10.2.2 Day type analyses

The consumption depends on the day type. During the weekend the consumption is a higher than a work day.

Average total	Average workday	Average weekend
14kWh	13kWh	15kWh

Table 12: Average day consumption of the household

The Table 13, the

Day Consumption	1(<5kWh)	2(<10kWh)	3(<15kWh)	4(<20kWh)	5(>=20kWh)
Number of consumers	6	17	28	26	9

Table 14and the Figure 58 shows the distribution of the consumers according the consumption classes and the distribution change according to the day type.

[6] http://www.bdew.de/internet.nsf/id/7E91C15FC098DDFCC1257824002EC164

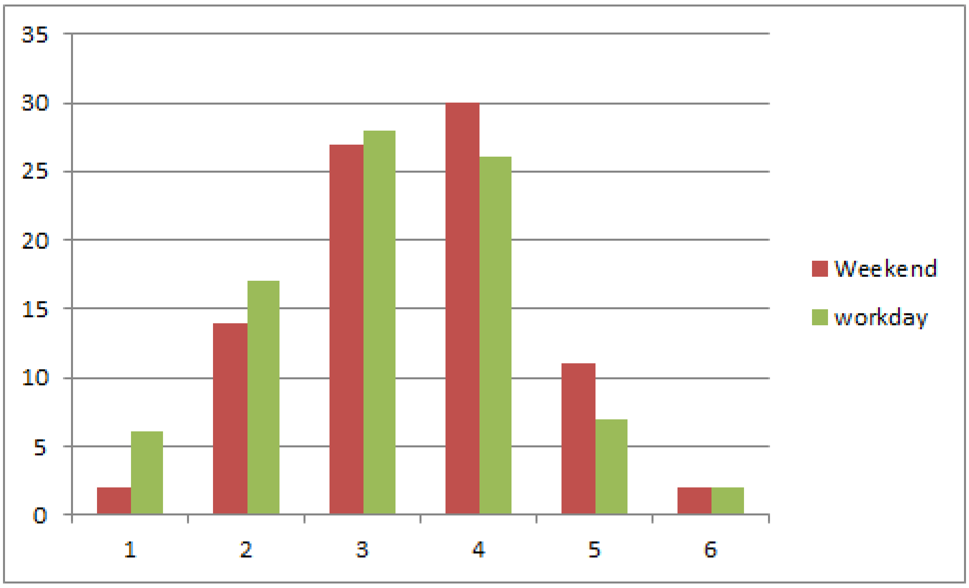

Figure 58: Average day consumption distribution

Day Consumption	*1(<5kWh)*	*2(<10kWh)*	*3(<15kWh)*	*4(<20kWh)*	*5(>=20kWh)*
Number of consumers	2	14	27	30	13

Table 13: Average daily consumption classes - weekend

Day Consumption	1(<5kWh)	2(<10kWh)	3(<15kWh)	4(<20kWh)	5(>=20kWh)
Number of consumers	6	17	28	26	9

Table 14: Average daily consumption classes - workday

From the day consumption profile (Figure 61) the difference between the difference form the weekend and workday is clearly visible. The work day has a local peak around 7AM and lower daily peak at noon.

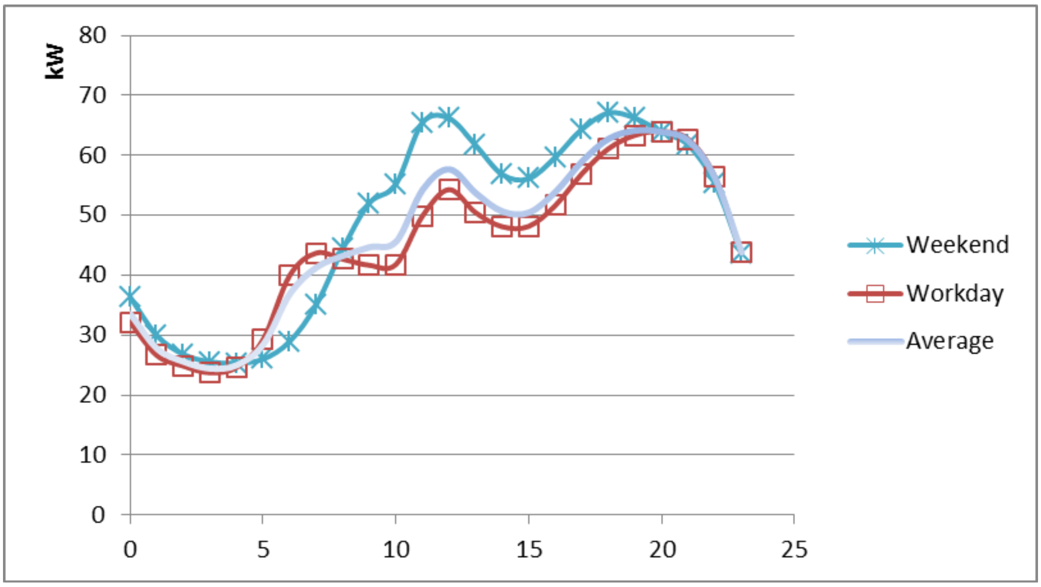

Figure 59: Average day consumption profile of the household

10.2.3 Season analyses

The household consumption depends also on the winter-summer season time. According to the Figure 60 the consumption, which shows averages of the one winter and one summer Tuesdays, during the winter the consumption is much higher than in the summer.

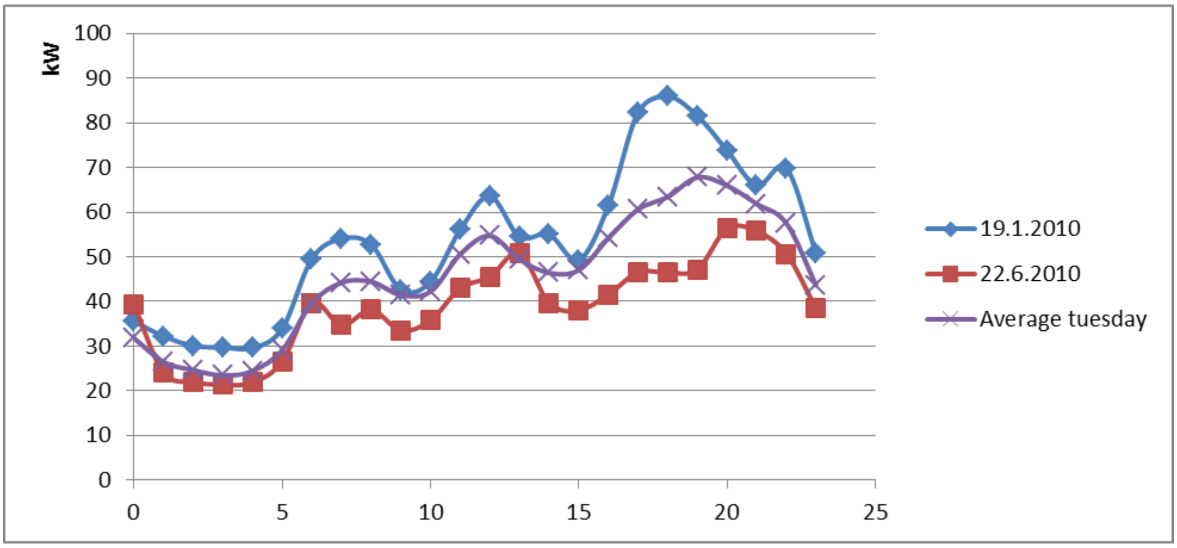

Figure 60: Seasonal dependence of the household consumption

10.2.4 Peak analyses

The total load from the Meregio input data is presented in the load duration diagram in the Figure 61, where the dependence of the consumption level from the time share is presented.

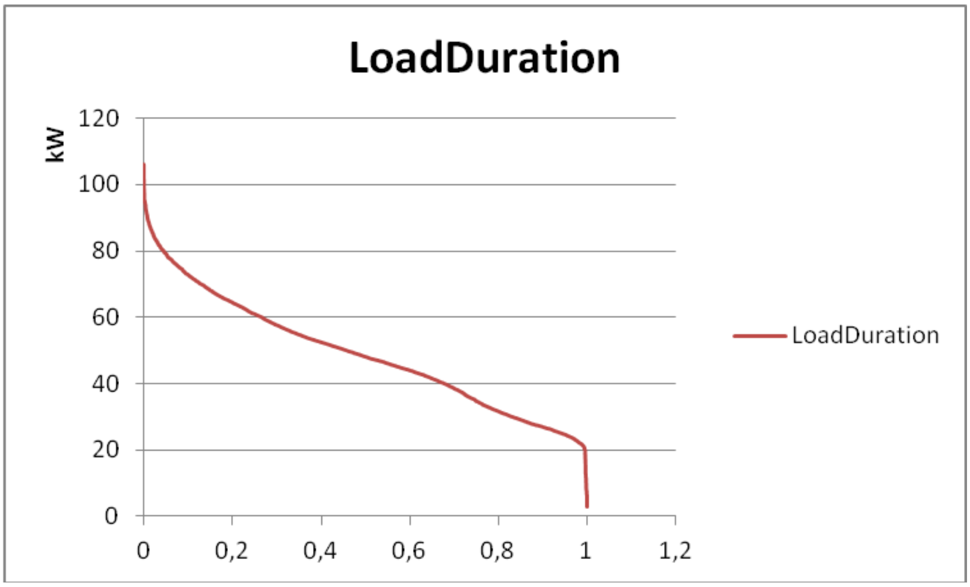

Figure 61: Load duration for the household consumers

Due to the small number of the consumers in the data set the peak is relatively very high. More than 20 % of the consumption capacity is used in up to 1% of the time.

10.3 Industry consumers

In the Mirabel testing the consumption data from the following industry branches are used: consumer from the following branches: paper industry, foundries, machinery, food, and motor.

Consumer Id	Branch	Average daily energy	Max Flexibility capacity reduction	Max Flexibility capacity enlargement
1	food	20 MWh	300 kW	200 kW
2	foundry	125 MWh	1000 kW	100 kW
3	Paper	110 MWh	2400 kWh	2400 kWh
4	Paper	240 MWH	4000 kWh	2200 kWh
5	Motor	42 MWh	200 kW	200 kWh
6	Motor	132 MWh	400 kW	400 kW

Table 15: Characteristics of the industry consumers

The average daily consumption and flexibility capacity is valid for the working day.
The flexibility capacity is maximal power change achieved by concurrent intervention on all the controllable loads.

The Industry consumers are capable either to reduce the consumption (delay some energy consuming process or increase internal energy sources) or enlarge the consumption by the rescheduling the process or reduce the internal production.

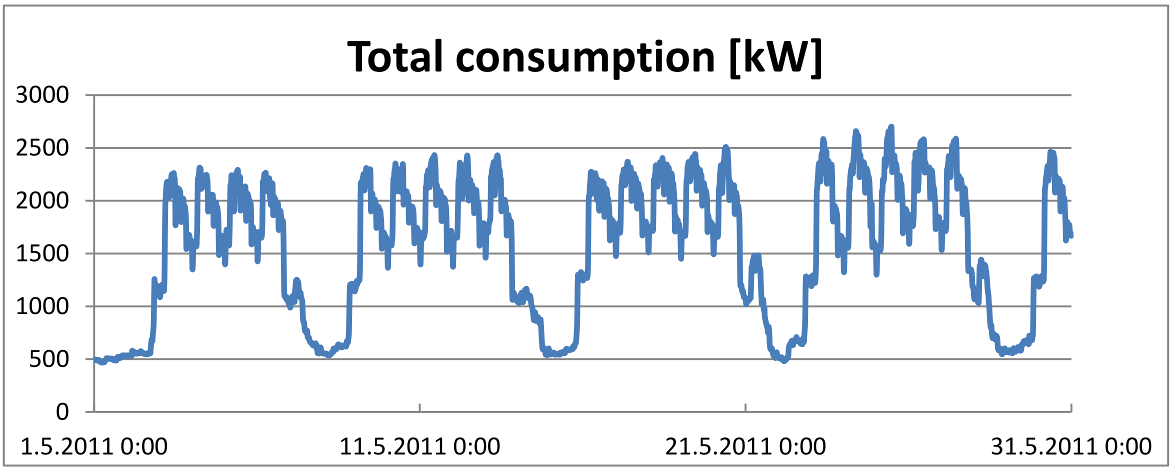

Figure 62: Consumption of the motor industry representative

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