MSc Program
Renewable Energy in Central and Eastern Europe

Scenarios for Greenfield smart distribution grid expansion

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **Thomas Wegscheider**, hereby declare

1. that I am the sole author of the present Master Thesis, " Scenarios for Greenfield smart distribution grid expansion ", 102 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

This master thesis is discussing three scenarios of Greenfield smart distribution grid expansion. The focus is on finding a cost optimized solution covering the legal and future requirements of a distribution service operator. The analysis shows that the focus for the communication section is concentrating on a fibre optic infrastructure, which offers a future proof open transmission technology. By analysing the commercial and the technical facts the solution is concentrating on the scenario, which includes a state of the art 3 tap transformer with active control, one type of electricity cables (4x150) and a Ethernet on fibre based communication infrastructure, which is the cost optimized solution by implementing the electricity grid and the communication infrastructure at the same time.

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List of abbreviations and symbols

a	anno
A	Ampere
AM	Air mass
AMI	Advanced Metering Infrastructure
CF	Cash Flow
DSO	Distribution System Operator

η	efficiency
EAN	Extended Area Network
EHV	Extreme High Voltage
FAN	Field Area Network
GWh	Giga Watt Hours
GPRS	General Packet Radio Service
GSM	Global System for Mobile
H	height
HV	High Voltage
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IET	Institute for Energy and Transport
IT	Information technology
JRC	Joint Research Centre
kW	Kilowatt
LAN	Local Area Network
LTE	Long Term Evolution
LV	Low Voltage
m	Mass
Mb/s	Mega Bit per second
MPLS	Multiprotocol Label Switching
MV	Medium Voltage
MW	Mega Watt
MWh	Mega Watt hours
NAN	Neighbourhood Area Network
P	Power
PLC	Powerline Communication
R	Resistance
SCADA	Supervisory Control and Data Acquisition
TSO	Transmission System Operator
WIMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
UMTS	Universal Mobile Telecommunications System
xDSL	Digital Subscriber Line

1 Introduction

The developments in the last decade in the energy business shows, that the distribution grid operator gets more and more technical problems with the situation that decentralized generation units in different sizes starts, according EU-Law [Electricity Directive 2009/72/EC], to deliver energy to the grid.

To disarm the technical situation and to carry the EU regulations, the developments started to get more intelligent into the network. These smart distribution grids are combinations of electricity and communication transmission infrastructure. On top Information Technology (IT) Services are supporting and controlling the bidirectional electricity flow between producer, consumer and storage, which helps to optimize the distribution grid and reduce the losses (European Technology Platform SmartGrids, 2012).

This master thesis is concentrating on the possible grid expansion methods with focus on the Greenfield approach. As base different implementation scenarios are used and help in the end to find out a technical and cost-efficient solution, which covers the legal and future requirements.

1.1 What are the core objective / the core question?

The core objective of the master thesis is how grid expansion in Greenfield areas can be realized in the future to cover the core requirements of an intelligent grid. These core requirements are:

1.) Capacity for Decentralized generated electricity
2.) Intelligent and real-time control of the distribution grid
3.) Base platform for future electricity services (e.g.: e-Mobility)

1.2 Methodology

To find out how to fulfil these requirements, the approach is to compare technical and economically three scenarios, which cover the core objectives.

The three main scenarios are:

1.) Classical grid expansion: first installed electrical infrastructure with different cable characteristics and a later separate installed communication infrastructure for smart grid applications.
2.) New defined base grid infrastructure, including the physical preparations for future smart technologies in the distribution network
3.) New defined base grid infrastructure, same as point 2 but including electricity controlling and Information and Communication Technology (ICT)-Infrastructure for a full smart distribution network.

The figures for the calculation are based on developments of the DG-DemoNet studies and additional research activities.

For the economical consideration the view from the investment side is used, by using the method of the Dynamic Investment Validation and impacts in the balance sheets of the distribution grid operator, especially on the profit&loss and the liquidity impacts.

As Base for the decision process the three implementation scenarios are outlining, which technological approach is feasible on the business perspective for the distribution grid operator, to guaranty an investment protection by the Greenfield expansion of the smart grid infrastructure.

1.3 Expected results

By analyzing the three scenarios, the expected outcome is, that related to the input of Decentralized Generation Sources produced energy in the distribution grid, the scenario 3 is the cost efficient implementation strategy. This opens from the beginning that the operator can provide services and optimization strategies just in time parallel to a high Decentralized Generation Sources energy production penetration.

If grid operator made a decision, not to invest from the beginning in a full solution, as it is in scenario 3, they should minimum invest in scenario 2, were an additional adaption are possible with a reduced effort and costs.

For both implementation scenarios it is absolute needed to use highly standardized products, to guaranty a high grade on investment protection for the operator

The major result of the master thesis is a concrete technical and economical result for future roll-out strategies.

1.4 Structure of the document

The document is build in that way that it starts with a survey of the most popular decentralized energy generation sources in chapter 2. The focus is set to the technologies photovoltaic, wind power, biomass and small hydro power. All the technologies were described with the focus how energy will be generated and what is the direct impact on the grid, where the generation sources are connected.

Chapter 3 has as main topic the grid itself. The structure is that it starts with the electro technical theory of the grid, following with information over the transformation from grid to smart grid. Finally the communication technologies are described in the last sub chapter.

Chapter 4 is focusing on the descriptions of the scenarios. Here is the basic frame conditions to the scenarios and the later in the calculation used load profiles described.

In chapter 5 all the scenarios are discussed, starting with a detailed description of each scenario followed by the technical analysis of the voltage behaviour without decentralised generation units. Then each scenario is analysed from the commercial point of view, where the discounted cost, the annuity costs, a sensitivity analysis, profit and loss impacts and the liquidity impacts are discussed.

Finally chapter 6 is concentrating on the data of chapter 5 and is comparing the details for the delivery of a decision base, described in Chapter 7

2 Decentralized Energy Generation Sources and the influence on the grid

The main changes in the electricity delivering structure are based on the deregulation of the electricity market according to the EU Law Electricity Directive 2003/54/EC and following 2009/72/EC, which describe a non-discriminatory transmission and distribution and the following established promotion systems, with the aim of reaching the EU Target 20/20/20 in mind, it opens up the market to small energy producers focus on renewable energy sources. In addition, some of the technologies allow the consumer to take up the role of a producer, for example via the installation PV.

The EU Target 20/20/20 is a set of binding legislation, which forces the member states of the EU to reach the climate and energy targets by 2020. This includes the three key objectives (European Commision, 2012):

- 20% reduction of greenhouse gas emissions, based in the level from 1990
- Increase the share of produced energy based on renewable resources to 20%
- 20 % improvement of the energy efficiency

All these necessary changes to the electricity market force the existing energy producers to incorporate technologies based on renewable sources and the new private based producers' impact in parallel with the established grid infrastructure in the transmission and in the distribution layer. The following subchapters concentrate on the top four renewable source based energy producing technologies and their impact on the grid. These four technologies are:

- Photovoltaic
- Windpower
- Small Hydro Power (SHP)
- Solid based Biomass

2.1 Photovoltaic

The development of Photovoltaic technology started in the 1950's and was driven by the space program in the US as energy source for satellites. In the last few years the technology has dropped to a price level, which makes it accessible for the private consumer segment to in invest in the technology. Based on the promotion systems and the price reduction of the PV cells (see Figure 1: PV installed capacity in Austria), the installed capacity in e.g. Austria rose from 32.4MW in 2008 to 362.2MW in 2012 (see Figure 1: PV installed capacity in Austria). The promotion system in Austria is split into two areas of PV installations. A group for higher 5kWpeek producers, which is supported with a feed in tariff and a lower group 5kWpeek, with a state grand and no feed in (Ökostromverordnung 2012 - ÖSVO 2012, Jahrgang 2012)

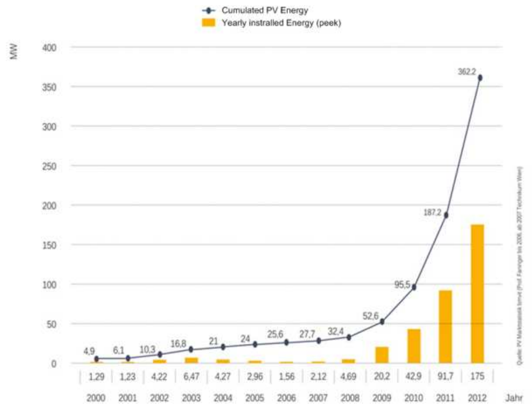

Figure 1: PV installed capacity in Austria (bmvit, 2013)

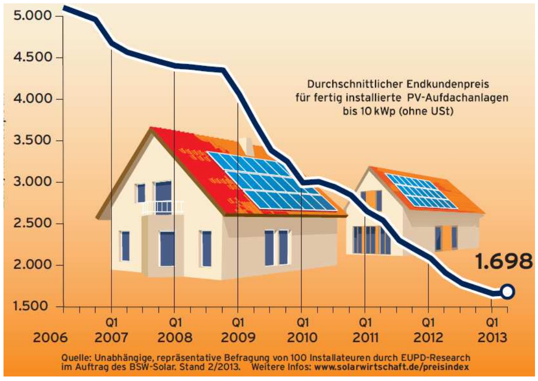

Figure 2: Price trend for 1kWp (BSW-Solar, 2013)

The majority of the PV capacity is mainly - based on the consumer group - installed in the distribution grid (Network Layer 7).

To understand the upcoming challenges for the Distribution System Operator (DSO), it is needed to see the interaction of this technology on the grid. For this the chapter gives a rough overview about PV technologies and the connectivity’s to the points were Smart grid infrastructure helps to stabilize the network and force the growth of this technology in the grid.

The sun is the greatest energy source in the field of renewable energies and the base for electricity production on photovoltaic technology (Quaschning, 2011).
To calculate the energy on a point outside the atmosphere, the specific radiation $M_{e,S}$ has to be set in relation to the distance between sun and earth.

$$E_e = M_{e,S} * \frac{A_S}{A_{SE}} = M_{e,S} * \frac{{r_S}^2}{{r_{SE}}^2}$$

Figure 3 : Calculation E_0 (Quaschning, 2011)

Due to the fact that the distance between earth and sun is not constant, the energy E is between 1321W/m² and 1412W/m². The arithmetic average is called solar constant E_0. $E_0 = 1360.8 \pm 0{,}5 \frac{W}{m^2}$ (Quaschning, 2011)

The energy, measured on the earth surface, the terrestrial solar energy, has caused by interferences in the atmosphere a lower energy level than outside the atmosphere. Passing the atmosphere the solar energy is interfering with different interference effects, like Rayleigh and Mie scattering, of the air, water and dust molecules. Molecules of O_3, H_2O and CO_2 absorbing dedicated wavelength of the solar radiation. By clear sky it is possible to measure a solar radiation of 1.000kW/m². (Zahoransky, 2010)

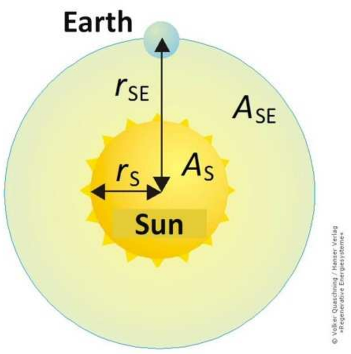

Figure 4: Calculation E_0 (Quaschning, 2011)

By increasing the way of the solar radiation through the atmosphere, the intensity of the solar radiation gets decreased. The value for the relation of the length of path is called Air Mass (AM):

$$AM = \frac{1}{\cos \theta_z}$$

$$\theta_z \ldots zenith\ angle$$

AM is used as standard for the quality of radiation. In Europe the AM 1.5 is used for test purposes. With an AM of 1.5 the zenith angle has a value of 48°, this means that the radiation has an 1.5 times longer way then by an configuration with AM=1 (Zahoransky, 2010)

For all the calculation of the cases the values of the radiation are derived with the tool of the Joint Research Centre of the Institute for Energy and Transport (IET) (European Commission - Joint Research Center, 2012).

To convert solar radiation, solar cells are mostly composed of silicon wafers, which are also required in the semiconductor industry. Silicon is the second most common material and can be found in silica and silica sand. The industrial process of the solar cells requires high-purity silicon. The construction of a solar cell is layer based, were one is a p-layer (base) and one is n-layer (emitter). On the boundary layer between the two layers an electrical field power affects (Zahoransky, 2010)

If sunlight irradiation hits the silicon solar cell, in p-n silicon electrons start to separate from their atoms. Electrons, which have a positive charge, and electron holes, which have a negative charge, start to move to the boundary layer. In the case of separating of the charges, an electrical flow is establishing, which can be worn out with metal contacts. If a consumer is connected on the system, electrons are moving from the emitter to the basis and are recombining with the holes. Now the process of separating the charges can start from the beginning.

This process is not consuming parts of the base material and can be repeated every time. (Zahoransky, 2010)

The today produced solar cells are mainly based on two production methods:

- Crystalline cells
- Thin film cells

By the crystalline cells the mono crystalline and poly crystalline sells established on the market. By the production both start with a block, which is cut in µm thick wafers.

Compared to crystalline cells, thin film cells have no crystalline base material, so called amorphous silicon (a-Si) is used. This material can be produced in extreme thin layers. This production method, however cannot reach the efficiency of crystalline products in the moment.

The electricity production of a PV System not only dependent on the technological parameter likes efficiency; it is also dependent on the environmental conditions. This includes the day and night periods, geographical weather conditions and seasonable conditions.

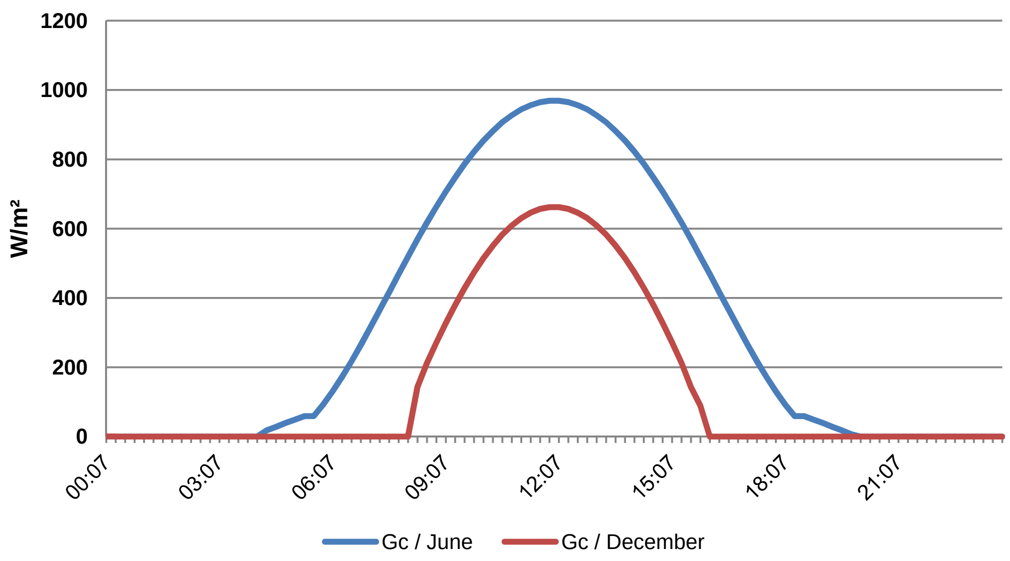

Figure 5: max. and min. solar radiation on a daily base (European Commission - Joint Research Center, 2012)

In Figure 5: max. and min. solar radiation on a daily base the solar radiation on the longest day and shortest day for Austria is shown. By going back to the grid requirements, the network has to take over according to the seasonal situation the produced energy in the time from starting ~06:00 respectively ~09:00 and ~20:00 respectively ~16:00. Additional to this the grid has to react to changes by the feed in caused by weather changes.

This was in the first view only a system, where only energy will be produced and not consumed. If the producer is an energy consumer too, the grid operator has to guaranty a security of energy supply. The Graphic Figure 6: Weekly View of a Household with a 5kWp PV System shows as an example a weekly view of the energy flow of a household with a 5kW$_p$ PV system. The negative values are the not consumed energy, which are feed in into the grid.

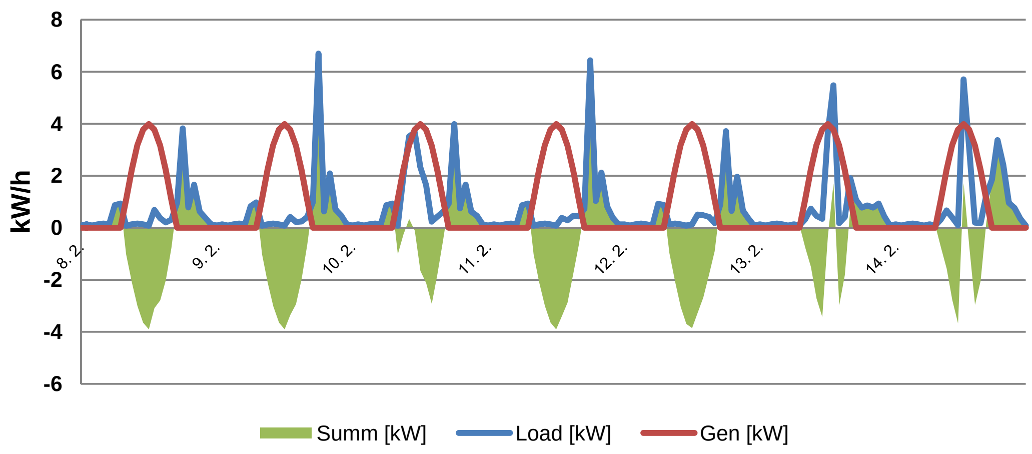

Figure 6: Weekly View of a Household with a 5kW$_p$ PV System (own calculation)

By consideration the market situation, that photovoltaic gets more and more part of the consumer mass market and dependencies based on the technological situation, that photovoltaic is direct dependent on the weather situation and the global radiation, it is a requirement that the DSO gets real time data of the last mile network. This can only be realised with a high capacity communication infrastructure of a smart grid network.

2.2 Windpower

In the last ten years the installed power plants based on Windpower have the highest share on energy production in the renewable energy section (see Figure 7: Development approved REN PowerPlants according administrative decision Database)

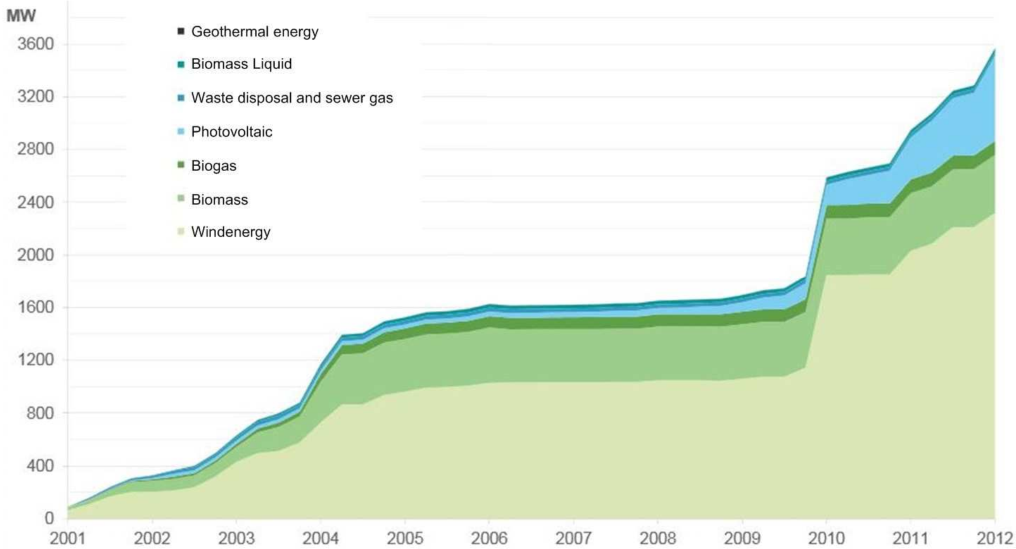

Figure 7: Development approved REN PowerPlants according administrative decision Database (Energie-Control Austria, 2013)

The continuous growth was controlled over the method of the promotion system with the feed in tariffs (Ökostromverordnung 2012 - ÖSVO 2012, Jahrgang 2012). But in the last three years there was a doubling of the installed capacity. To this the geographical and wind conditions supports the situation that most of the installed capacity is concentrated in the eastern part of Austria (see Figure 8: Austrian Windpower Map)

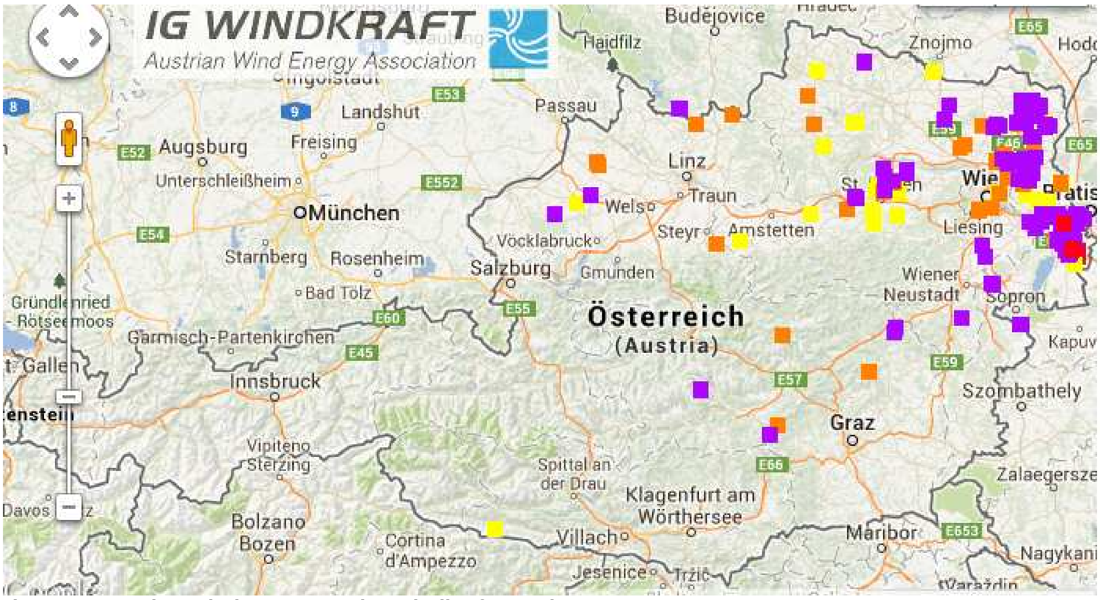

Figure 8: Austrian Windpower Map (IG Windkraft, 2013)

To the growth and the geographical situation of Windpower, it is needed to understand the relation between wind energy and produced energy to get a full picture on the influence of this technology on the grid infrastructure.

For the energy production it is important to combine the geothermic conditions with the technical possibilities. For this, by the site selection it is required a Wind analysis. This analysis base on wind speed measurements or statistic parameter out of tables or wind maps. The Output of this analysis are wind speed distribution diagrams of a site. The critical point of this method is that most of the time average values of time periods are used. It is important that's the measurement samples represent a very short time period. In the following graphic (see Figure 9: Wind frequency distribution of an Site in Germany) it is shown that on this side the highest rate of ~1.500 hours the wind has a speed of 3-4m/s shared over one year .

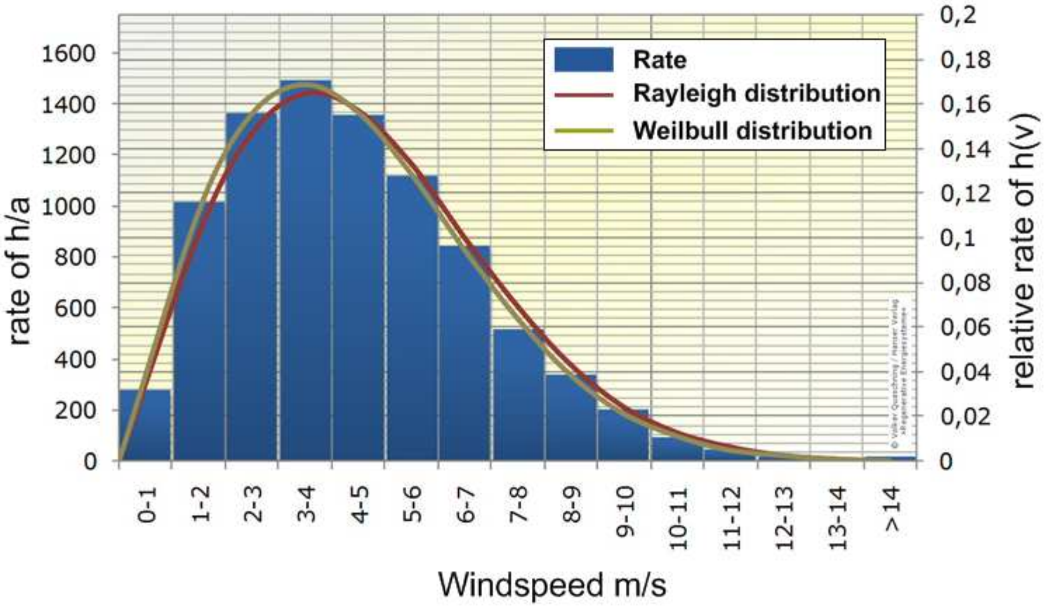

Figure 9: Wind frequency distribution of an Site in Germany (Quaschning, 2011)

To get out the energy of the wind it is important to understand the physical relation between wind speed, harvesting area and the weather influence factors like air pressure or temperature.

The kinetic energy *E* carried by the wind speed *v* can be calculated according the following equation (Quaschning, 2011):

$$E = \frac{1}{2} \cdot m \cdot v^2$$

The in the wind included Power *P* is calculated by differencing the Energy over the time. By constant wind speed *v* the equation is (Quaschning, 2011):

$$P = \dot{E} = \frac{1}{2} \cdot \dot{m} \cdot v^2$$

Out of mass *m*, which is the product of the density ρ and the Volume *V*, the air-mass flow calculates as following (Quaschning, 2011):

$$\dot{m} = \rho \cdot \dot{V} = \rho \cdot A \cdot \dot{s} = \rho \cdot A \cdot v$$

The power *P* of the wind results out of the combination of the equations before:

$$P = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

The density ρ of the air is additional dependent on the air pressure *p* and the temperature. These values can be read out of measurement tables.

By using wind power, power has to be extracted out of the wind. This is done by a wind power plant by reducing the wind speed v_1 to v_2 by passing the turbine and using the power deviation as shown *in Figure 10: Streaming process of a free standing wind turbine.*

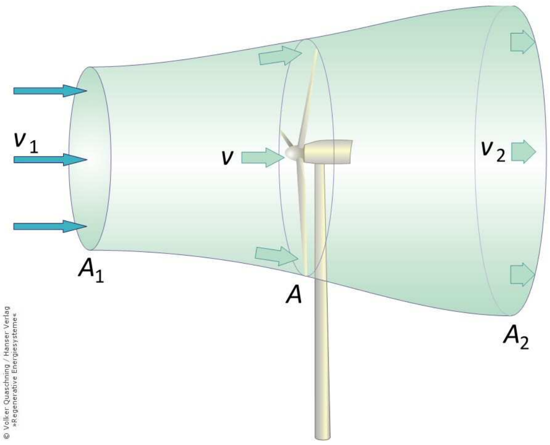

Figure 10: Streaming process of a free standing wind turbine (Quaschning, 2011)

The important point is that the air-mass flow has before and after the turbine the same volume and this results that the wind streams with the wind speed v_2 over a larger area A_2 (see Figure 10: Streaming process of a free standing wind turbine)

The wind power deviation is transformed over a generator to electrical energy. In Figure 11: Gearless synchrongenerator with an intermediate direct current link it is shown as an example, how the generation to the connectivity to the grid look like today in state of the art wind power plants.

In this case the wind energy is transformed over the synchrongenerator into alternate current voltage, transferred from alternate current to direct current and then retransferred into a grid connected alternate current. In this configuration, the generator can run in a different frequency as the grid. By changing the frequency on the generator it is possible to influence the generator rotation. This offer a wide spread of rotations and can be optimised optimally to the prevailing wind speeds on a site. (Quaschning, 2011)

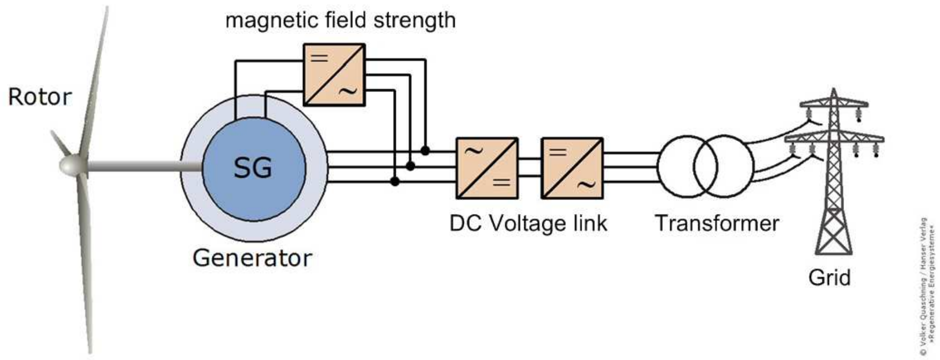

Figure 11: Gearless synchrongenerator with an intermediate direct current link (Quaschning, 2011)

The today established wind power plants are mostly in a size between 2 and 7.5MW and are connected to the grid in the network layer 5 (Medium Voltage) and large scale wind parks direct connected to the network layer 3 (High Voltage).

To get a better view to the theoretical dependencies, the following three 24 hour's snapshots from the SCADA System of a wind turbine in Bruch/Leitha, shows the real energy production and the volatility, which has to be controlled by the grid.

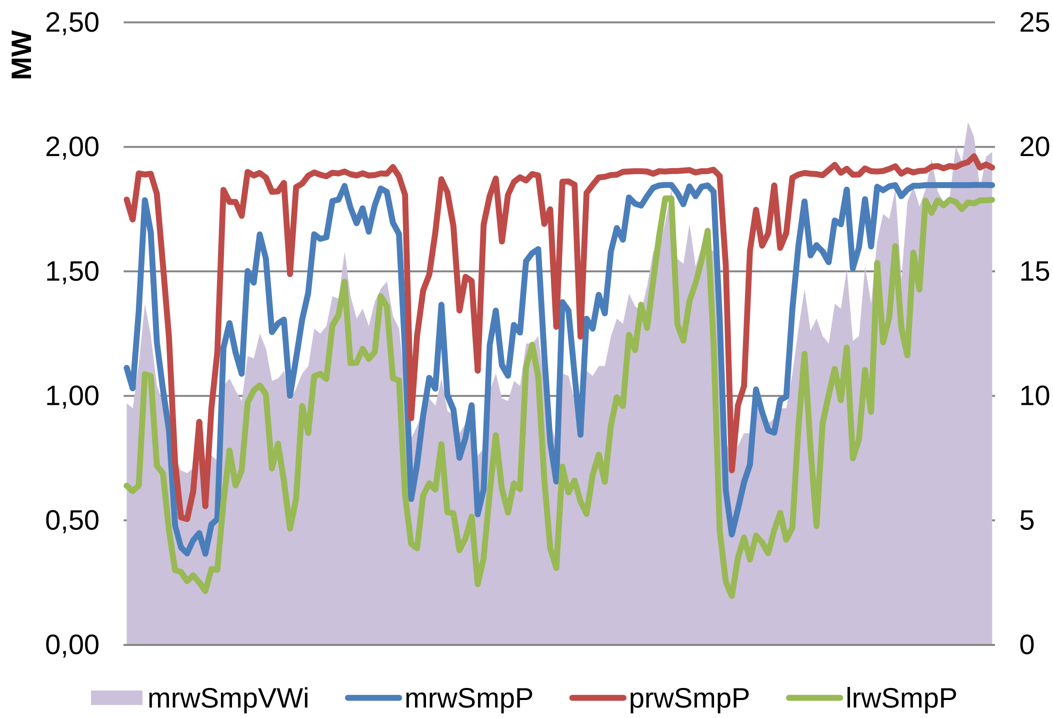

Figure 12: 24 Hour Energy Profile of a Windpower Plant (Date: 26/1/2007) (Energiepark Bruck/Leitha, 2007)

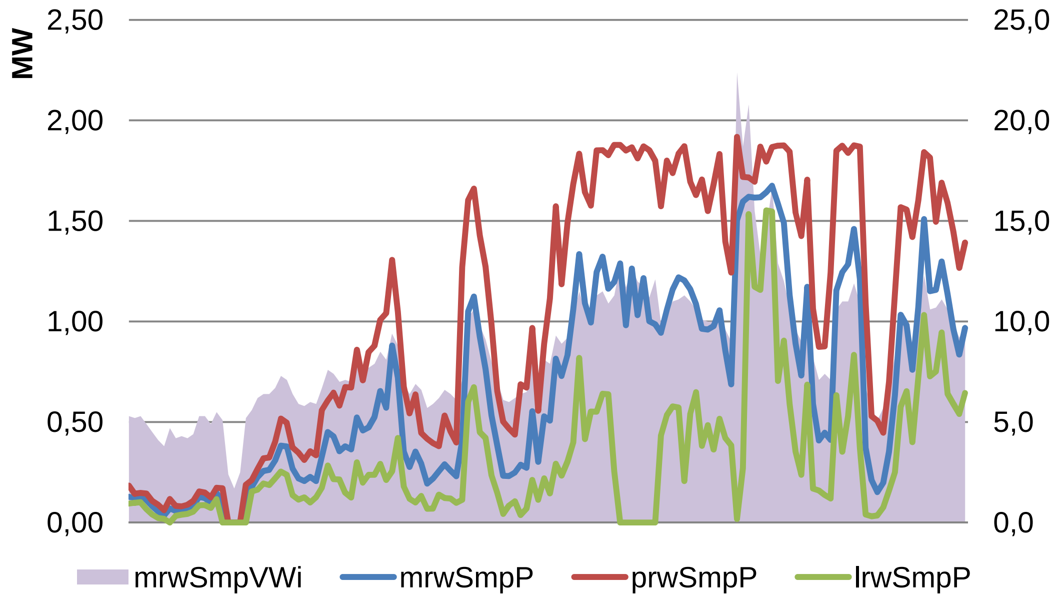

Figure 13: 24 Hour Energy Profile of a Windpower Plant (Date: 21/06/2007) (Energiepark Bruck/Leitha, 2007)

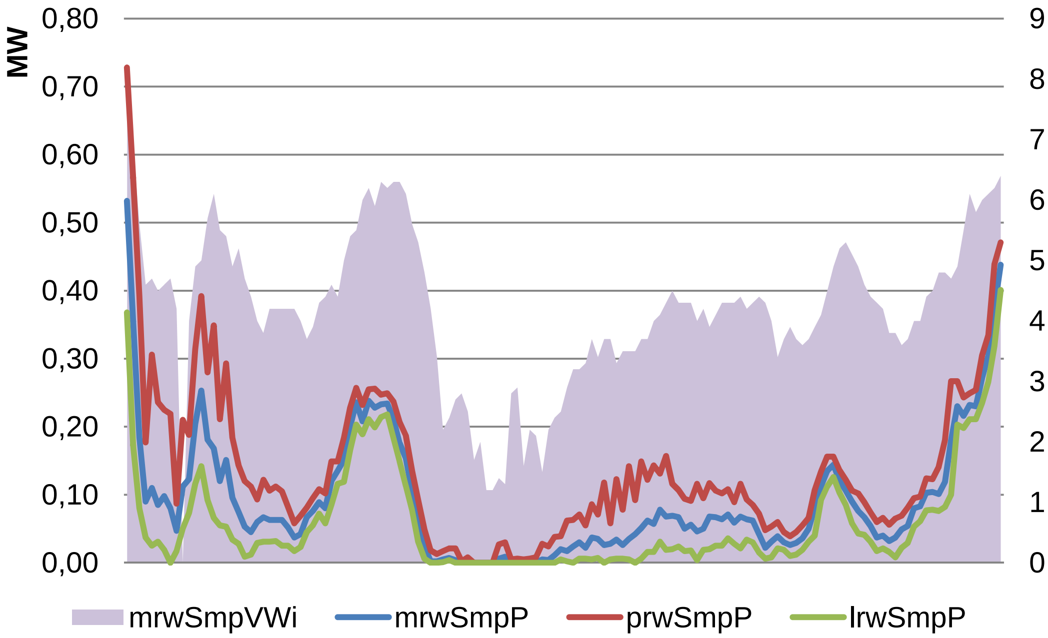

Figure 14: 24 Hour Energy Profile of a Windpower Plant (Date: 16/10/2007) (Energiepark Bruck/Leitha, 2007)

Every picture is a 24 hours snapshot with a 10 minutes sampling rate and shows the following values per sampling for the energy production on the primary axis:

- Blue line – mrwSmpP: average power
- Red line – prwSmpP: maximum power
- Green line – lrwSmpP: minimum power

The secondary axis outlines the values for the average wind speed (mrwSmpVWi) and is shown in the diagram as a violet area. (Karl, 2012)

By combining all this information, that wind power is a focused and needed decentralised energy producing technology and the physical dependencies like wind speed and air pressure, which are not under human or technical control, it is needed to connect installations based on this technology in a intelligent grid infrastructure, to open the Transmission System Operator (TSO) and DSOs the possibility to react on the volatile energy production and guaranty a required supply security for the consumers.

2.3 Biomass

Biomass the third described technology was based on the situation of high forest ration in Austria, one of the forced technologies in the renewable energy sector. This technology provides two output energy types for customers in a regional are. These are on one side electricity and on the other site heat energy. The fact of available feedstock and the provided output energy forms opens the way for establishing CHP Plants (Combined Heat and Power) in industrial areas, where technical heat is needed and in municipal utilities for the supply of their customers with electrical energy and with heat for the district heating system.

The total energy utilization of an installation should exceed 80% and is now regulated by the authority with higher 60% energy efficiency to get subsidies (Ökostromverordnung 2012 - ÖSVO 2012, Jahrgang 2012). The today possible efficiency for electricity production is between 10 and 40% dependent on the used power generation technology. The remaining energy is thermal energy (Hofbauer, 2009).

The market situation in Austria shows that by watching the installed capacity biomass has a market share of 11% (Energie-Control Austria, 2013), but by the overall renewable energy based produced electricity an market share of 30% (Energie-Control Austria, 2013).

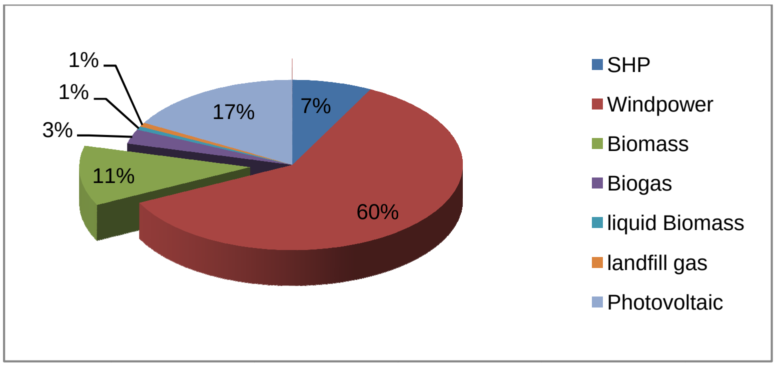

Figure 15: Market comparison installed capacity of renewable Sources in Austria 2013 (Energie-Control Austria, 2013)

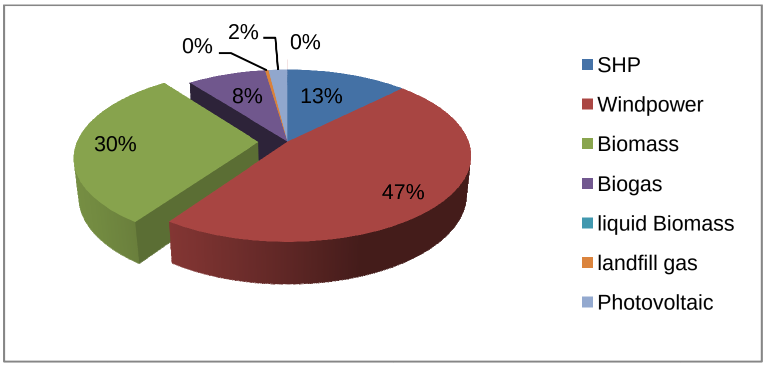

Figure 16: Market comparison produced energy of renewable Sources in Austria 2013 (Energie-Control Austria, 2013)

In this short review the concentration is set to the combustion systems, which represent the 30% market share. The other technologies like biogas or liquid biomass, which represent a market share less than 10% are out of focus (see Figure 16: Market comparison produced energy of renewable Sources in Austria 2013)

The typical installed processes from combustion based systems are (Hofbauer, 2009):

- Steam turbines used as expansion engine with water as process medium. In the process the water is evaporated under pressure and superheated
- Steam engines used in the Ranking cycle with or without superheating. The on the market available steam engines are in a range between 50kW$_{el}$ and 2MW$_{el}$ (Hofbauer, 2009)
- Steam turbines used in an organic Rankine cycle (ORC) with evaporation of an organic medium in a tertiary cycle separated from the heat production (the combustion heat is transferred to a thermal oil in the boiler which is fed to an external evaporator for the organic medium with a lower boiling temperature than water)

A core element of the CHP Plant is the combustion system and Table 1: Comparison of different biomass combustion systems shows the different types and the thermal energy range and the used feedstock.

Table 1: Comparison of different biomass combustion systems (Hofbauer, 2009)

Type	Energy Range	Feedstock type
Grate Combustor		
Underfeed Stocker	10 kW to 2,5 MW	Chips with ash content less than 1% and pellets
	50 kW to 60 MW	all type of Woodfuel, Ashcontent up to 50%
	6 kW to 60 kW	Pellets
Fluidized bed combustor		
Bubbling (stationary) fluidized bed combuster	5 MW to 50 MW	every type of Woodfuel with ash softening > 1.000℃, particel cross-section dimension under 100mm
Circulating fluidized bed combustor	30 MW to 100 MW	every type of Woodfuel with ash softening > 1.000℃, particel cross-section dimension under 60mm
Pulverized Biomass Combustor		
Dust combustion	0,5 MW to 10 MW	particel cross-section dimension 1 to 4mm

Dust combustion as co-firing for Power Plants with fossil Fuel	Summary 0,1 to 10 GW with max. ca.10% Biomass content	Wood: particel cross-section dimension < 2 to 4mm; Straw: particel cross-section dimension under 6mm; Miscanthus: particel cross-section dimension under 4mm

After the thermal conversion two types of CHP Plants are mostly installed. Small CHP Plants use an ORC process with fixed electricity to heat ratio and large scale CHP Plants with a steam process on a Rankin circle with a dynamic electricity to heat ratio.

To see the difference between the two processes both are following described in a general way.

The Organic Ranking Cycle (ORC) process is based on the classic Clausius-Rankin Cycle, same as the conventional steam process, but with the different that the heat transport media is not steam (water), it is an organic liquid with a lower boiling- and condensing temperature. This offers the possibility to operate in a lower temperature and pressure level. The flue gas from the combustion process is heating up the organic working media in a boiler, which is connected with the closed process cycle.

With assistance of this thermo oil, the thermal energy, which came out of the combustion process, is transferred on a defined temperature level over an evaporator to the working media of the ORC process.

This vaporized and overheated organic material is then unstressed over a turbine, which is mechanically connected to a generator. The unstressed steam of the organic working material will be condensed over a condenser, where useful heat can be gained for the delivery of technical heat. After the condenser the organic working material is pumped back to the evaporator and the ORC process is then closed again.

For the case that no heat can be distributes to heat consumer, the implementation requires a air-cooler parallel to the heat distribution system, to guaranty an operation with only electricity production. In Figure 17: Working Principal of an ORC Installation the graphic shows a typical ORC installation

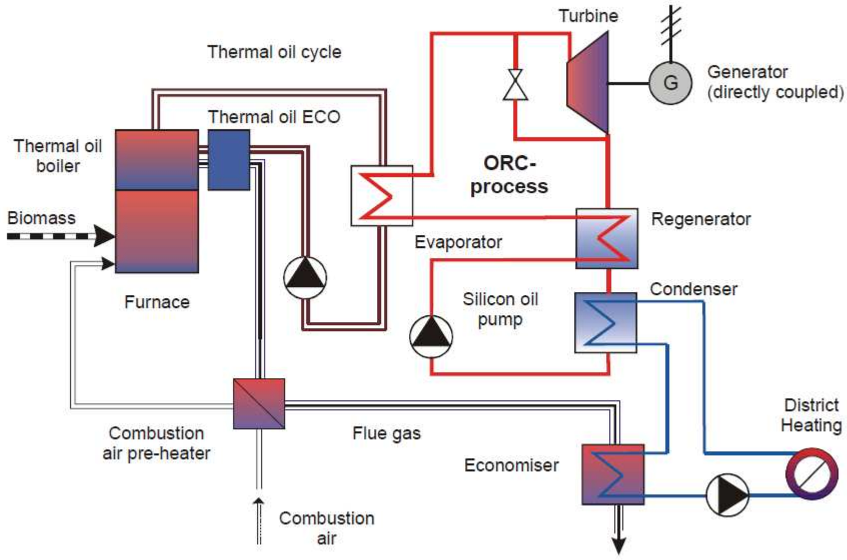

Figure 17: Working Principal of an ORC Installation (Stadtwärme Lienz in Cooperation with BIOS Bioenergiesysteme, 2003)

The description of this process bases on the book “Energie aus Biomasse” from Mr. Hofbauer et.al. (Hofbauer, 2009)

For steam process on a rankine circle with a dynamic electricity to heat ratio, the working media is water. This liquid working media is converted for the work flow into steam. This steam is then unstressed over the steam turbine, which is mechanically connected to a generator, afterwards condensed and as last step flow back to the heat producer.

The technical realization of this process looks like that water is under high pressure nearly isobar heated up, transferred to steam and overheated. This steam is then transferred to the steam turbine, were it is under execution of energy preferably adiabatic unstressed, this means that the enthalpy of the heat media steam will be transferred into mechanical work. Afterwards the steam runs over a condensation unit and is transferred back to liquid by disposal of heat energy. The here produced thermal energy can be used for the providing of heat services

The condensed water is, after storing in a feedwaterstorage, repressured to the pressure of the boiler pressure with a feed water pump and send back to the steam producing process.

The efficiency of the steam process is related to the temperature level of the stream production and of the condensing. (Hofbauer, 2009)

The following diagram shows an example of a calculation of a large scale CHP powerplant with the target to produce as much electrical energy as possible by compliance the regulatory requirements.

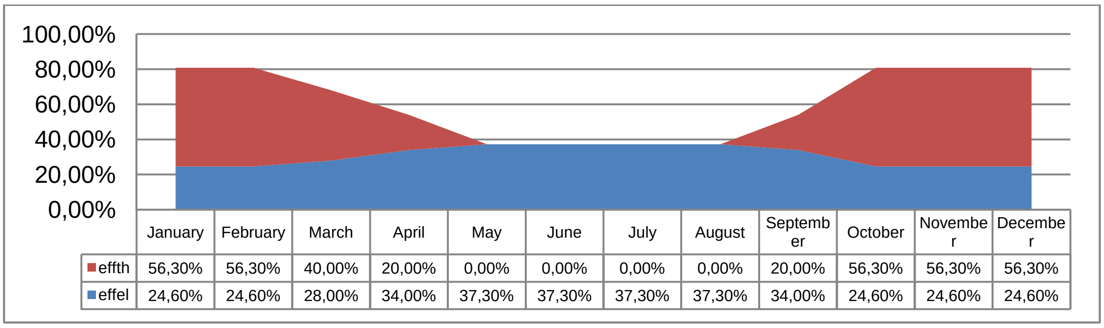

Figure 18: Efficiency Diagram of a large scale CHP Plants with a dynamic electricity to heat ratio (own calculation)

By analysing the technical situation, the production of electricity is completely under technical control, without influence from natural circumstances. For the grid, this type of energy facility can be used for the providing of base load.

The typical CHP plants are based on their electricity output connected on the grid level 7 (very small CHP), level 5 (small CHP) and level 3 (large scale CHP)

If these installations are connected to an intelligent grid, installations from private operators in industrial areas and municipally facilities can be used for additional services for the TSO and DSO. This service can help them to stabilise the grid by influences of volatile energy producer or peek loads in a grid segment on demand response base.

2.4 Small Hydropower

Hydropower is in Austria the energy producing technology with the highest market share of 57.6% (Energie-Control Austria, 2013) . Important for the decentralized renewable energy producing technologies are Small Hydro Power (SHP) plants, which are declared by the EU with a maximum energy output of less than 10MW (Pelikan, 2008).

The market situation about this renewable energy technology shows, that by watching the installed capacity SHP have a market share of 7% (Energie-Control Austria, 2013), but by the overall renewable energy based produced electricity a market share of 13% (Energie-Control Austria, 2013).

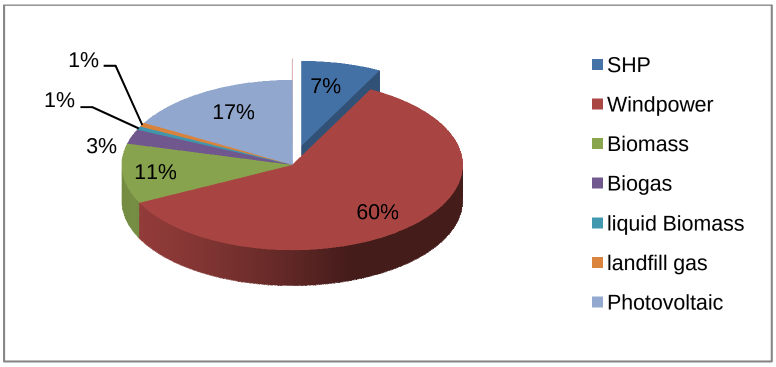

Figure 19: Market comparison installed capacity of renewable Sources in Austria 2013 (Energie-Control Austria, 2013)

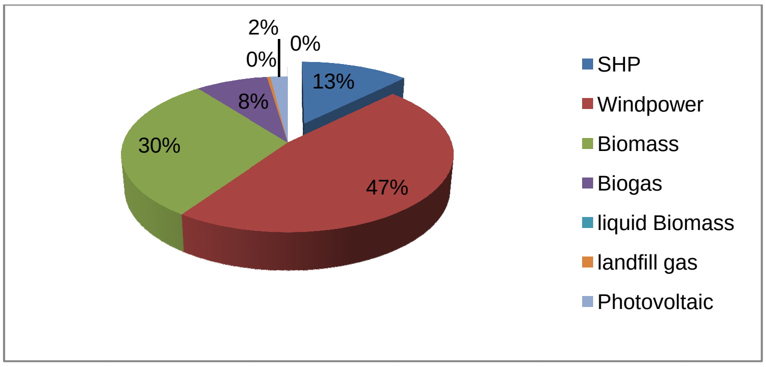

Figure 20: Market comparison produced energy of renewable Sources in Austria 2013 (Energie-Control Austria, 2013)

By analysing this technology it is visible that the only dependency, which influences the grid infrastructure, is the deviation of the water flow. This characteristic is included into the design of a SHP, and so high water flows of high water have no impact on the produced energy output. Only water flows under the design level reduce the energy output.

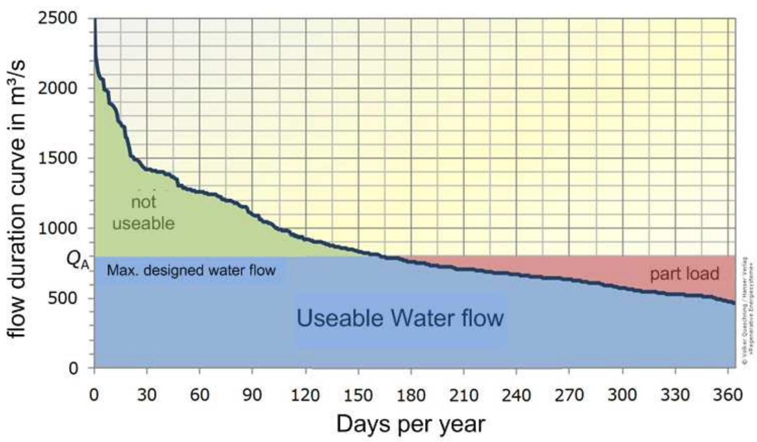

Figure 21: Evaluating the max. water flow (Quaschning, 2011)

In Figure 21: Evaluating the max. water flow the evaluating of the maximum design flow is visible. As base are used the average flow duration curve of the planed area. By the design the maximum water flow Q_A will be defined. This is the value, were the power plant can produce the maximum output. The water flow above runs unused over the weir construction. For the area lower Q_A, the plant produce only a part load (Quaschning, 2011).

From the design three major designs are used:

- Low or high head Power Plant
- Storage power plant
- Pump Storage

By a low head power plant the water flow is dammed by a fixed or gated weir to create a small reservoir and a high difference between before and after the power plant. The water flows from the higher water level over the turbine, which is powering a generator, to the lower water level. The connected transformer transforms the electricity to the grid level (Figure 22: Schema of a low head power plant).

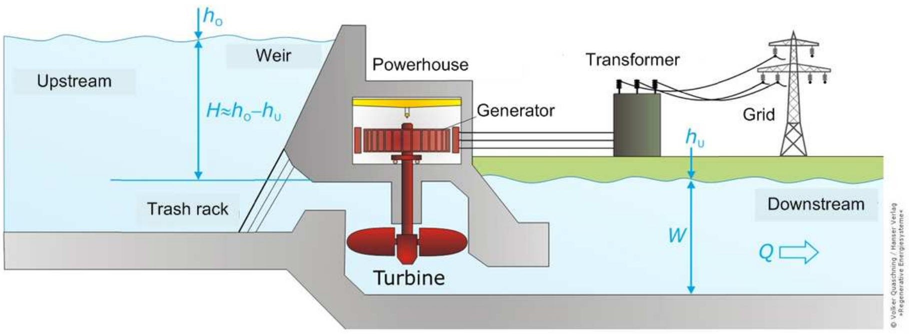

Figure 22: Schema of a low head power plant (Quaschning, 2011)

The maximum power is P_W is calculated out of the density of the water ρ_W (~1.000kg/m³), the available height, the gravity g (=9,81m/s²) and the flow Q (m³/s) (Quaschning, 2011).

$$P_W = \rho_W \cdot g \cdot Q \cdot H$$

The available height is the difference between the water level before and after the power plant, this shows that the power P_W is in the first approximation proportional to the flow Q. Q has an additional limit, it cannot be higher as the value Q_A. In most of the hydrographical documentations, the trend of the available height H is not documented, but the value gauge height W can be found. Out of this, the information over the maximum constructed height H_A and the gauge height W_A by the maximum flow Q_A, the height H can be calculated as following (Quaschning, 2011):

$$H = (H_A + W_A) - W$$

With the efficiency of the turbine η_T, the efficiency of the generator η_G and the lossfactor f_z the electrical power can be calculated (Quaschning, 2011):

$$P_{el} = (1 - f_z) \cdot \eta_G \cdot \eta_T \cdot \rho_W \cdot g \cdot Q \cdot H$$

f_z combines all the losses like transformer loss, gear box loss or outages and is in a range between 3% to 10% (Quaschning, 2011).

High head constructions are mostly found in alpine area, where parts of the water of a river are collected in an intake and transferred over a penstock to the power house. With this method a high height difference is covered in the construction. The calculations follows the same rules as described before.

The storage power plant has as difference to the low head power plant, a large dam structure with heights like in the alpine up to more than 100m and electricity producing potentials higher then 10MW and is not in the focus of the SHP Categories.

Pump Storage has a special role in the category of the hydro power plants. This category is not designed for the use of natural water flows, is designed to store over capacity of energy. The general function is similar to the high head plants, it works between two reservoirs, were overcapacity is available; the water is pumped up to higher one. If capacity is needed the water flows over a penstock through the power house to the lower reservoir. Modern pump storages have an efficiency of around 80% (Quaschning, 2011).

For the grid infrastructure hydro power plants, which are connected by real small installations on Network Layer 7 and larger facilities up to 10MW on Network Layer 3, are seen for a high period of time as base load systems. All changes in the flow rate are not coming up in a short time and are possible to calculate. The technical infrastructure of the turbines, with the possibility to control the flow rate in the turbines, can be used for stabilisation activities in grid segments.

Last but not least the pump storage can use for the prompt delivery of energy by loosing capacity of renewable sources based on weather changes. Only by connecting this facility types in a intelligent grid infrastructure

2.5 Overview of decentralized Energy production

To show the difference between the four previous described energy generating technologies, the following table gives a short overview between productions and feed in into the grid and outlines the following information. Vulnerability of the generating technology, the dependencies, who needs the information of the changes and on which network layer are the producers typically connected.

Table 2: Dependencies electricity producing technology on the grid

Technology	vulnerability level	dependent on	Information needed by	Network Layer
Photovoltaic	high	Weather and global radiation	DSO	7
Windpower	high	Weather and wind situation	TSO or DSO	3 and 5
Biomass	low	Feedstock	TSO or DSO	3, 5 and 7
Small Hydro Power	low / medium	Flow rate	TSO or DSO	5 and 7

Combining all the information, intelligent grid infrastructure has the task to find a way to stabilize the energy flow in the network. This can only realised with a full duplex communication between the TSO or DSO and the electricity producing units or the required electro technical network elements.

3 Evolution from the electricity grid to a smart electricity grid

The core objective of the following chapter is concentrated on the structure and function of the grid and outlines the fundamental changes in the structure based on technical and regulatory dependency. The chapter is build in a way, that it starts with the historical structure of a top down distribution hierarchy, followed by the transformation steps from grid to smart grid. The last subchapter concentrates on the requirements of a communication infrastructure in the distribution grid.

3.1 Fundamentals to the grid

In the beginning of the electrification of the industry at the end of 19th century, the production of electricity was build near the industrial facilities. This shows that the owner of the industrial facility was most of the cases the owner of the power plant. This structure was a complete isolated structure, called isolated network, with no dependencies (Panos, 2009).

To get more security into the electricity supply and the parallel expansion of the electricity consumer, it was needed to interconnect more power plants to a meshed structure. This structure change requires in the same moment regulations for the operation of this structure, which are for example the definition of the net frequent or the voltage of the transmission ways. This opens the possibility to create redundancies for the existing consumer and an evolving expansion of the consumer base and the electricity producing facilities.

In an interconnected network outages of power plants or load increases can be balanced by other energy facilities through the increase of their output power or through the allocation of peak load or reserve power plants. Additional to the security aspects a good mix of producing technologies can be used for the providing an optimized pricing structure for the end consumer. (Panos, 2009).

The energy transport itself is dependent on Ohm’s law and the Kirchhoff's circuit laws, that means that the voltage decrease along the power line. A part of the feed in electrical energy is transformed in thermal energy and gets lost to the surroundings. The lost is proportional to the length of the wire and the quadrate of the electricity. By increasing the voltage by equal power and equal wire resistor the electricity decrease and the loss will decrease by the quadrate of the electricity. This physical dependence is the reason for the high voltages in the long distance transmission by low loss rate (Panos, 2009). The today established interconnection grid is built up in a layer structure with different voltage levels according to the usage requirements and connected over transformers.

In detail the grid is split into four hierarchical voltage layers, which represent transmission and distribution of electrical energy. The four grid layers are (Schwab, 2012):

- Extra High Voltage grid EHV – 220kV and 380kV
- High Voltage grid HV – 110kV
- Medium Voltage grid MV – 10kV, 20kV and 30kV
- Low Voltage grid LV – 235V, 400V and 690V

According to Information of Austrian Power Grid (Austrian Power Grid, 2013) the nomenclature of the grid layer in Austria are following: (see Figure 23)

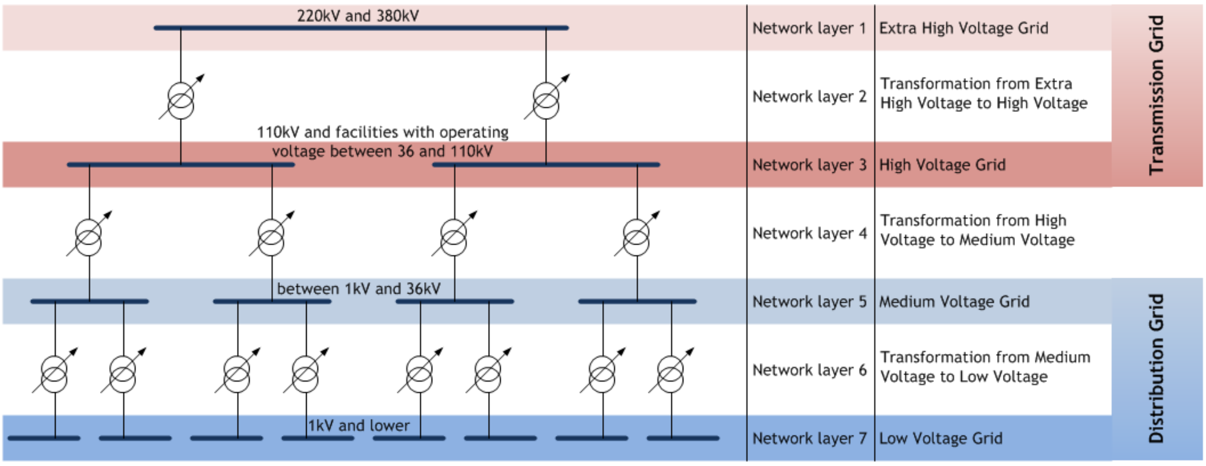

Figure 23: Austrian grid layer nomenclature

The Extra High Voltage and the High Voltage grids are grouped into the transmission grids controlled by TSOs and the Medium Voltage and Low Voltage grids into distribution grids controlled by DSOs.

The following two tables show the grid infrastructure in Austria and outline the relation between Transmission grids and Distribution grids.

Table 3: Length of the Austrian Power grid (Energie-Control Austria, 2013)

Austrian grid status 31. December 2012 (Datastatus: August 2013)					
Length of Powerline					
Network Layer	Overhead Line		Cablebased		**Summary**
	km	Percentage	km	Percentage	**km**
380 kV	1.363	0,6%	55	0,0%	**1.417**
220 kV	1.854	0,8%	3	0,0%	**1.857**
110 kV	6.010	2,5%	516	0,2%	**6.526**
from 1kV to 110 kV	28.242	11,9%	37.741	15,9%	**65.983**
1 kV and lower	36.526	15,4%	125.083	52,7%	**161.609**
Summary	**73.995**	**31,2%**	**163.397**	**68,8%**	**237.392**

Table 4: System length of the Austrian Power grid (Energie-Control Austria, 2013)

System length (1)					
Network Layer	Overhead Line		Cablebased		**Summary**
	km	Percentage	km	Percentage	**km**
380 kV	2.783	1,1%	55	0,0%	**2.838**
220 kV	3.662	1,4%	5	0,0%	**3.667**
110 kV	10.501	4,1%	660	0,3%	**11.161**
from 1kV to 110 kV	28.755	11,4%	39.319	15,5%	**68.074**
1 kV and lower	37.088	14,7%	130.325	51,5%	**167.412**
Summary	**82.788**	**32,7%**	**170.363**	**67,3%**	**253.151**

In the time period between the 1960 and the 1980, driven by the economic growth in Europe, this grid structure was forced by constructing large electricity generation units to fulfil the strategy of “Economy of Scale”. Under this term it was meant to establish large generation and grid infrastructure by minimal cost. In this case the supply security had not the highest priority. Now the structure is optimized for an energy supply from top down, from large energy producing units in the Extra High Voltage or High Voltage grid to the distribution grids.

Following the document is concentrating on the technical conditions of the distribution grids and is not taking into consideration information about the Transmission grids.

3.1.1 Fundamental basics to electricity

Before going into the technical aspects of the distribution grid, the subchapter is providing a short overview over the fundamental basics of electro technical systems to understand, why production of decentralized energy generation requires changes in the technical concept of a distribution grid.

The base item in all electrical calculations are the voltage U [V], the electricity I [A] and the resistance R [Ω], which are in a direct relation according Ohm’s law:

$$\mathrm{U} = \mathrm{R} \cdot \mathrm{I} \text{ [V]}$$

For the definition of the electrical power P applies the following formula:

$$\mathrm{P} = \mathrm{U} \cdot \mathrm{I} = \mathrm{R} \cdot \mathrm{I}^2 \text{ [W]}$$

The resistance R has two connection possibilities:

- Serial connection
- Parallel connection

In the serial connection the electricity I flow through all resistors and the Voltage U is in relation to the Resistance R.

The equivalent Resistance Re is calculated: $\mathrm{R_e} = \mathrm{R_1} + \mathrm{R_2} + \cdots + \mathrm{R_n} = \sum \mathrm{R_i}$ [Ω]

In the parallel connection all Resistance R have the same Voltage V and a Electricity I is in relation to the Resistance R.

The equivalent Resistance Re is calculated: $\frac{1}{\mathrm{R_e}} = \frac{1}{\mathrm{R_1}} + \frac{1}{\mathrm{R_2}} + \cdots + \frac{1}{\mathrm{R_n}} = \frac{1}{\sum \frac{1}{\mathrm{R_i}}}$ [Ω]

The second important law is the Kirchhoff's circuit laws, which defines in the point rule that the sum of the electricity in a point is 0: ΣIi=0 and in the mesh rule that the Voltages in a mesh is 0: ΣUi=0

All the before descript formulas are the basic based on direct electricity. For the use in an alternate current environment the additional information is needed. Alternate current is a current, where the polarity, the current strength and voltages changing in a periodic way. The most used form is the sinusoidal oscillation. The production of base on an inductive way, were an electrical conductor is moved through a magnetic field.

For the simplification of calculations effective values were established. These effective values have the same effects as direct current values. Between the effective and the peek values is the following relation (Panos, 2009):

$$\mathrm{U_{eff}} = \mathrm{U} = \frac{\mathrm{U_s}}{\sqrt{2}} \qquad \mathrm{I_{eff}} = \mathrm{I} = \frac{\mathrm{I_s}}{\sqrt{2}}$$

Beside the ohmic resistance are now in alternate current environment capacitive and inductive resistance available. Are in the circuit only ohmic resistances, then is the electricity and the voltage in sync. If only inductive resistances are in the circuit, the electricity is ahead 90° phase shifted and by c apacitive resistances the voltage is ahead 90° phase shifted (Panos, 2009).

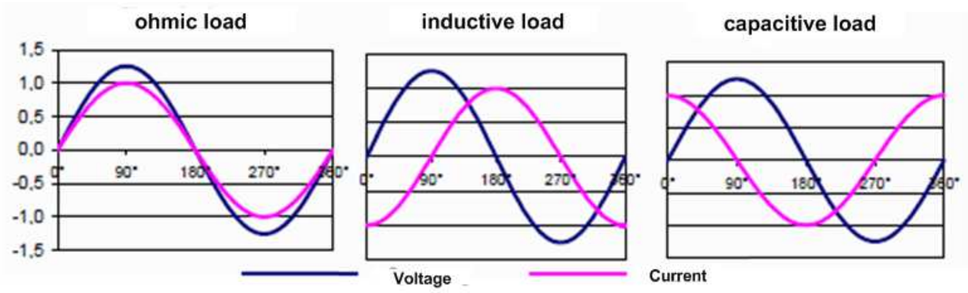

Figure 24: Voltage and Electricity by AC (Panos, 2009)

In the alternate current calculation the definition of the power is now expanded with the following definition (Panos, 2009):

- P = active Power by ohmic resistance
- Q = reactive Power by capacitive and inductive resistance
- S = apparent Power is the geometric sum of P and Q

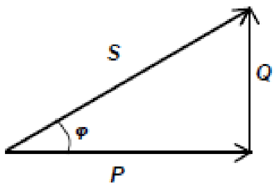

Figure 25: Power diagram (Panos, 2009)

The quotient of the active and the apparent power is the power factor: $\cos\varphi = \frac{P}{S}$

Additional the calculation of the different power categories in detail:

- Apparent Power: $S = U \cdot I = \sqrt{P^2 + Q^2}$ [VA]
- Active Power: $P = S \cdot cos\varphi = U \cdot I \cdot cos\varphi$ [W]
- Reactive Power: $Q = S \cdot sin\varphi = U \cdot I \cdot sin\varphi$ [Var]

The relation between reactive to active power based on the power factor and is calculated:

$$\frac{Q}{P} = \sqrt{\frac{1}{cos^2\varphi} - 1}$$

In praxis reactive powers can be found in the electrical power supply, if inductive loads like electrical engines or generators are connected or capacitive loads produced through long grid segments. If the reactive power is too high, compensations have to be implemented (Panos, 2009).

By 3 phases alternate current, which is implemented in central Europe, three inductive coils with an 120° offset are mounted on an axis and rotating in a homogeny magnetic field. These produce three alternate currents with a phase shift of 120°. In this Version the sum of all phases is at every time 0. This offers the possibility to transport the electricity over a three wire system, instead of 6 wires by separated alternate currents (Panos, 2009).

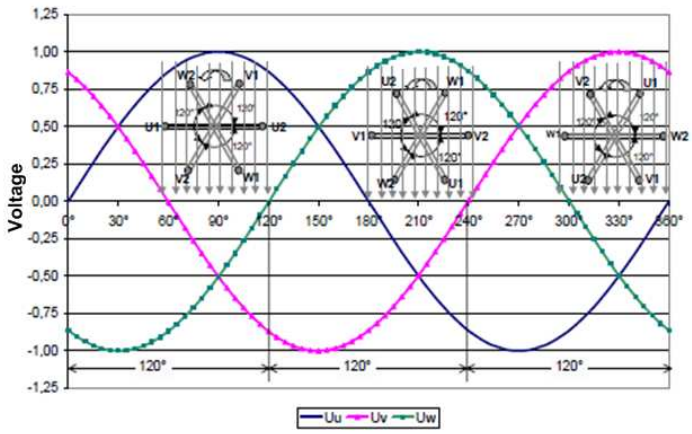

Figure 26: Voltage characteristic by 3 phases alternate current (Panos, 2009)

The last formula, which is used by the calculations in the master thesis are the power calculations for a transformer. A transformer is a non active engine, which works same as a generator with the inductive principle. It is split into a primary and a secondary side, which are over a iron core connected. The transformation rate is defined over the relation between the coils of the primary and the secondary side (Panos, 2009).

The calculation of the nominal capacity S_N in a 3 phase alternate current environment is: $S_N = \sqrt{3} \cdot U_{IN} \cdot I_{IN} = \sqrt{3} \cdot U_{OUT} \cdot I_{OUT}$ [VA]

3.1.2 Fundamentals to the distribution grid

The distribution grid, operated by the DSOs, represents in the energy supply grid infrastructure the largest group. In Austria it is 93.7% of the whole grid infrastructure (Energie-Control Austria, 2013). The medium voltage grid (Layer 5) and the low voltage grid (Layer 7), which is the real last mile to the customers, are general combined under the term distribution grid.

The current distribution architecture is oriented on a passive operation of the grid. This means that the network is planned to work without controls from outside, only safety protections are included. In the planning phase the planners work with worst case scenarios which cover the following requirements (Brunner, 2010):

- Minimum generation with maximum loads – lowest voltage values are expected
- Maximum generation with minimum loads – highest voltage values are expected
- Maximum generation with maximum loads
- Minimum generation with minimum loads

By the operation, producers and consumers are only in exceptional cases involved (Brunner, 2010). For all four cases the nodes in the distribution grid have to be in the defined limits of the standard specification EN50160.

The European standard specification EN50160 describes the voltage characteristic of electricity supply in the distribution network in consideration of:

- Network frequency
- Voltage
- Waveform / harmonic
- Symmetric of the line voltage

The values according the specifications are (DIN Deutsches Institut für Normung e. V., 2011):

Network frequency:

- Network with interconnection
    - 50Hz ± 1% (49.5Hz up to 50.5Hz) 99.5% of a one year observation period
    - 50Hz + 4% / -6% (47Hz up to 52Hz) 100% of the time
- Network without synchronic interconnection
    - 50Hz ± 2% (49Hz up to 51Hz) 95% of a one week observation period
    - 50Hz ± 15% (42.5Hz up to 57.5Hz) 100% of the time

Voltage:

- For normal operation the supply voltage are allowed to be in a spread of ± 10% of the nominal voltage

In current distribution networks the last possible running configuration adaption is the on-load-tap-change transformer (e.g. 110kV/30kV) in the substation. The voltage control is performed by keeping the voltage at the 30kV busbar constant. Taking into account the busbar voltage as well as the worst case scenarios one can be sure that the voltage is within the limits in the entire network. This frame conditions offer the network operator in the past the possibility not to monitor the entire distribution network.

One important planning parameter is the characteristic of the cable infrastructure. According to the Ohm's law the cable a resistance has to taken in consideration. The cable loss power in this case is the resistance in relation to the length of the cable and the quadrate of the electricity. By only ohmic loads the voltage drops from the transform to the last consumer. This voltage level differs on a daily trend, with the load of the consumers on the network segment. If now decentralized generations are in the network segment, not only voltage decreases based on ohmic loads are on the network segment, increases are available too. (see Figure 27: Voltage band management)

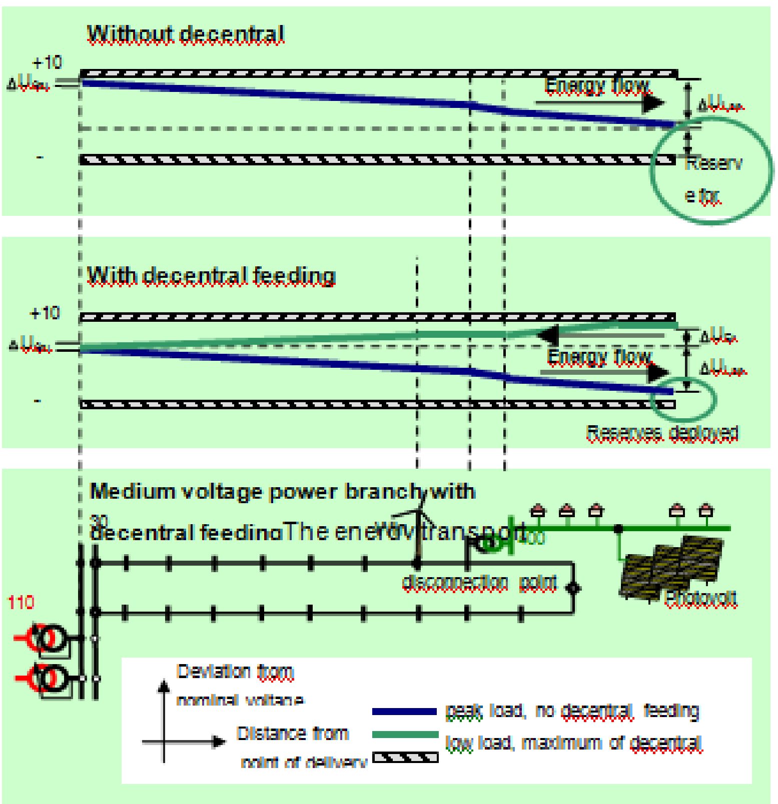

Figure 27: Voltage band management (Brunner, 2008)

In summary in every network segment, the transmission capacity is limited by the voltage band limits and the maximum permitted electricity, defined by the material of the cable infrastructure. In real there are voltage reserves all the time available in the distribution network (see Figure 28), the challenge is to adapt the infrastructure in a way that this reserves are available for the network operation. The only way to reach this target is to change from a passive to an active network operation.

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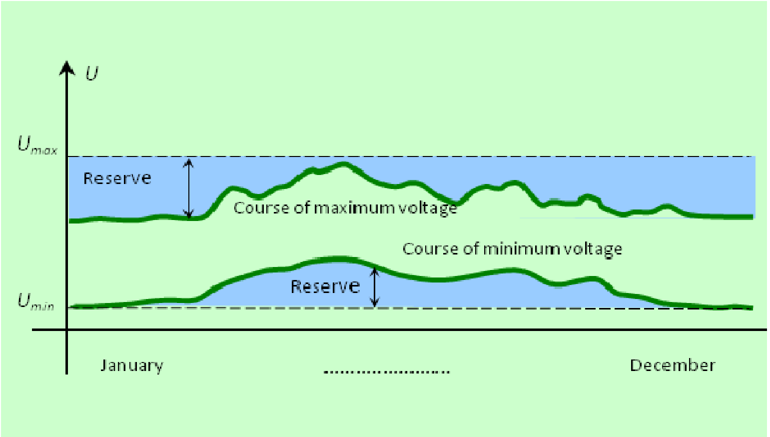


Figure 28: Extended reserves in the network (Brunner, 2008)

For an active network operation the grid infrastructure have to expanded by an ICT infrastructure and controllable network elements, which means the distribution network has to get SMART.

3.2 Changes from grid to smart grid

Before talking about Smart Grids it is required first to explain the definition "Smart Grid", which has to cover the following requirement:

The Smart Grid bases on an intelligent System, which offers an energy and cost-efficient balance between a number of consumer, producer and in the future storages. This balance can be reached through the management of the energy-production, the energy storage, energy consumption and the grid. (Lugmaier, 2009)

Out of this the member of the "Technologieplattform Smart Grids Austria" agreed to the following definition:

Smart Grids are electricity grids, that supports with a harmonized management, based on real-time and bidirectional communication between Components of the grid the

- Producer
- Storage

- Consumer

to guaranty an energy- and cost efficient system operation for the future requirements. (Lugmaier, 2009)

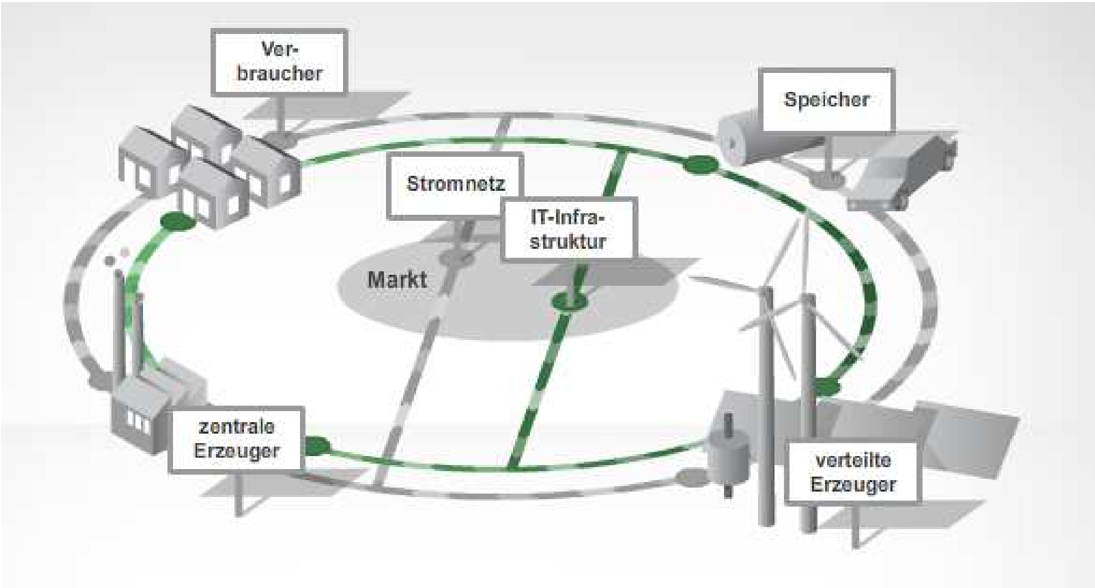


Figure 29: Smart Grid definition - Technologieplattform Smart Grids Austria (Lugmaier, 2009)

This definition shows that the existing grid infrastructure has to be expanded by ICT components, not only in the high layers of the grid in the transmission grids, were controls are established, it is required to extend the distribution grids up to the consumer.

Second the important question is why smart grids are needed, what are the main driver and what are the impacts on the existing infrastructure in especially to the distribution grids and there to the low voltage distribution grid?

One of the main drivers is the change in the European electricity market by starting the deregulation with the EU Law Electricity Directive 2003/54/EC and following 2009/72/EC. This regulation opens the market for small energy producer based on renewable energy. In some of the technologies, consumer came additional into the role of a produce, as it is in most of the installed PV installations.

With these regulations the network operators are now in the situation, that the network has to be operated in two ways operation instead as it was designed in a top down network. Especially in the distribution network, which is mainly passive operated, the situation get critical, out of the reason that the main amount of renewable energy producer based on their size are connected there and has according to the EU law non-discriminatory connected. These decentralized generation units' influence as in chapter 3.1.2 Fundamentals to the distribution described the distribution network. To get rid of these upcoming capacity problems it is needed to change from passive to active operation, which implies that the network has to adapt with additional ICT infrastructure and controllable network elements.

Additional to the EU Law Electricity Directive 2003/54/EC the Austrian Smart Metering Law (Intelligente Messgeräte-Einführungsverordnung – IME-VO) increase the infrastructure requirements of the network operator. The law forces the distribution network operator to change in a regulated time period the metering infrastructure from a passive system to an intelligent system (smart meters). The time period looks as following (138. Verordnung: Intelligente Messgeräte-Einführungsverordnung – IME-VO, 2012):

- end 2015 minimum 10% of the metering infrastructure
- end 2017 minimum 70% of the metering infrastructure
- according technical capabilities, with end 2019 95% of the metering infrastructure

Last but not least the third main driver is the commercial side by the operation of a network. The operator has to act in a commercial way, by fulfilling the regulatory aspects as it is required in a regulated market.

This three arguments regulatory framework, technical needs and the commercial aspects are the main drivers, which interacts and build the framework for the developments of smart grids.

Summarizing smart grids should help on one side the reuse of existing main infrastructure, e.g. cable infrastructure, increase the supply security, protect the investment of the operator, by fulfilling the regulatory framework. On the other side it is a technological platform for future developments and services. These services can be for example (Aichele, 2012):

- More detailed calculation and controlling of the loads for base-, normal- and peak load by increasing the amount of decentralized electricity generation.
- Controlling consumer loads, by offering load based price models, to adapt the consumer behaviour to shift loads.

Another view to the topic smart grid is the view from the consumer and market side shown in Table 5: Comparison of today's Grid vs. Smart Grid.

Table 5: Comparison of today's Grid vs. Smart Grid (Momoh, 2012)

Preferred Characteristics	Today ' s Grid	Smart Grid
Active Consumer Participation	Consumers are uninformed and do not participate	Informed, involved consumers — demand response and distributed energy resources
Accommodation of all generation and storage options	Dominated by central generation — many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug - and – play convenience focus on renewable
New products, services, and markets	Limited, poorly integrated wholesale markets; limited opportunities for consumers	Mature, well – integrated wholesale markets; growth of new electricity markets for consumers
Provision of power quality for the digital economy	Focus on outages — slow response to power quality issues	Power quality a priority with a variety of quality/price options — rapid resolution of issues
Optimization of assets and operates efficiently	Little integration of operational data with asset management— business process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Anticipating responses to system disturbances (self-healing)	Responds to prevent further damage; focus on protecting assets following a fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers
Resiliency against cyber attack and natural	Vulnerable to malicious acts of terror and natural	Resilient to cyber attack and natural disasters; rapid restoration

disasters	disasters; slow response	capabilities

The basic requirements from this side are the same, that's a high ICT integration and a higher control of the network elements is needed.

What does it mean from the technical point of view?

At transmission network level the controls of the network elements are established on Supervisory Control and Data Acquisition (SCADA) base. The communication is handled over the in the last years build fibre optic infrastructure in the ground wire of the over head line.

On the distribution network looks the situation as described before complete different. The network operation has to switch from passive to active, for this the electro technical infrastructure needs the following adoptions:

- Intelligent voltage control at substation (on load tap change transformer) between HV (the transmission grid) / MV and MV and LV (last mile)
- Active and reactive power control at decentralized power generation.

The implementation of the on load tap change transformer between the MV and the LV network is required, out of the reason that around 70% of the voltage band available is typically allocated to the voltage drop at maximum load. With the control of active and reactive power at decentralized power generation units, it is possible to optimize the power input to the network by critical limits in the voltage band.

The majority of the changes are related to the communication infrastructure. In Figure 30: End-to-end smart grid communications model , the complete end-to-end smart grid communication model according the Institute of Electrical and Electronics Engineers (IEEE) is shown. In this model the complete communication flow is shown, without differencing the legal structures, defined by the market regulations of the EU directives. But what is visible, are the broad set of supported networks and the relationship of various networks to the smart grid bulk generation, transmission, distribution and customer domains. In this model the public internet provides a communication capability that span over all four domains, and offers only an alternative (IEEE Standards Association, 2011). According the market regulation perspective, all domains represent legal entities and the communication has to be realized over clearinghouse functionalities.

Back to the communication model, in the core it starts with company internal Local Area Network (LAN) technologies, connected to Backbone/Core networks based on Metropolitan Networks (MAN) or Wide Area Networks (WAN). This Core represent the company with its premises and is needed for the inside processes of the core business. Current large WAN implementations are mainly built on fibre based Multiprotocol Label Switching (MPLS) infrastructure.

The second network area includes in this model the backhaul and the last mile to the customer. This is the area where in the future most of the investments have to be done, out of the reason that this communication is not realized in the current infrastructure. The Backhaul network has the function to connect the utility controls and operations, including the AMI enterprise with the WAN, distribution substation networks and the different types of last mile networks. Under the last mile networks IEEE understands three general subtypes:

- Neighbourhood Area Network (NAN) / Advanced Metering Infrastructure (AMI)
- Extended Area Network (EAN) / Advanced Metering Infrastructure (AMI)
- Field Area Network (FAN)

The NAN/AMI (Neighbourhood Area Network / Advanced Metering Infrastructure) has the function to connect smart meters and field devices to the operational centre.

The FAN (Field Area Network), including the substations and field devices, has the function to connect all critical utility assets and guaranty the communication of operation control data to the operational centre. (IEEE Standards Association, 2011).

All this last mile communications can be realized over a variation of transmission technologies, which are equal to the access network of telecommunication companies. By grouping these technologies, the main groups are:

- Wireline communication
- Wireless communication

The wireline technologies typically are Power Line Communication (PLC), Digital Subscriber Line (xDSL) and Ethernet over Fibre. Wireless technologies typically are Global System for Mobile Communications (GSM) / General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS), Long Term

Evolution (LTE), Worldwide Interoperability for Microwave Access (WIMAX), Wireless local Area Network (WLAN), ZIGBEE and Microwave link.

The third and last network area is the customer premises, representing the home or building management network. This network can offer a gateway to permit applications to get control of devices and provides auditing and logging functionality to record transactions and from this network (IEEE Standards Association, 2011). In the home area more and more wireless solutions came on the market and in the large scale building management system wireline (standard Ethernet networks) and wireless technologies (WLAN) are used.

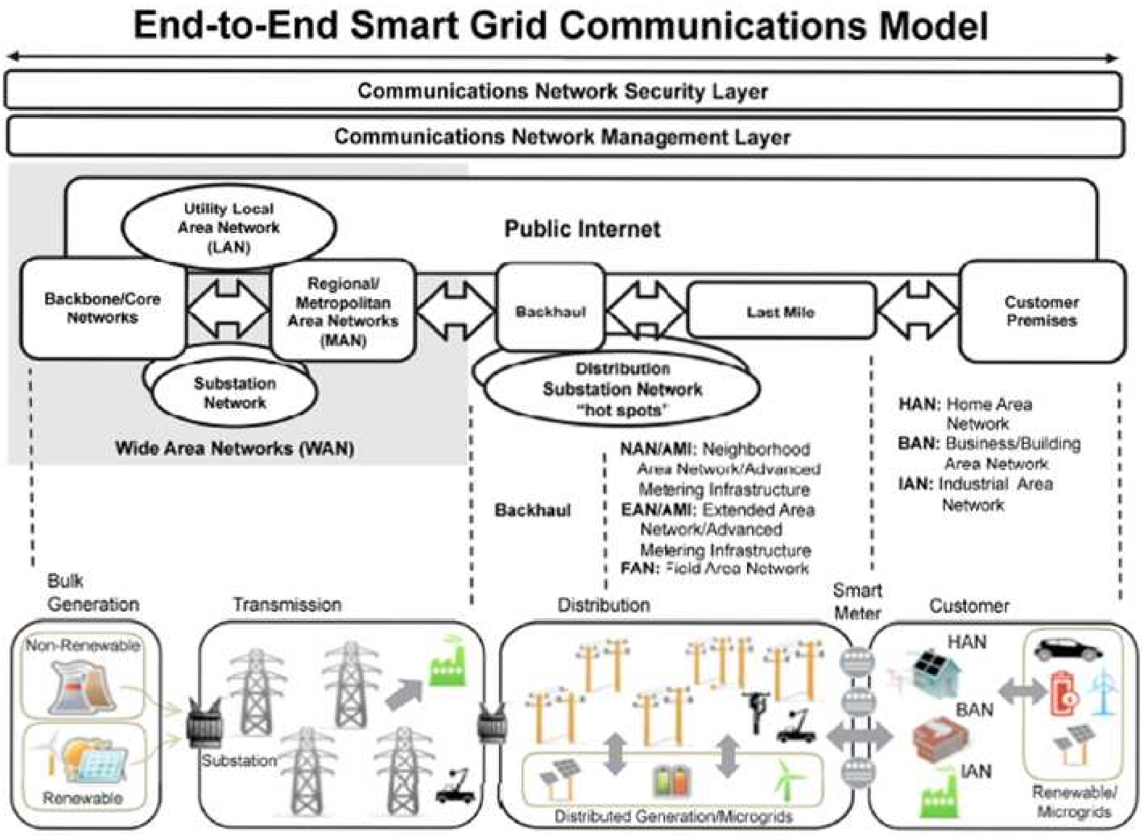


Figure 30: End-to-end smart grid communications model (IEEE Standards Association, 2011)

3.3 Requirements for ICT in a smart grid distribution network

One of the core topics is the implementation of a bidirectional broadband communication infrastructure, transporting measurement- and control data in real time to the control centre. The requirements to this future proof communication infrastructure is orienting on telecommunication standards (Servatius, 2012):

- Network definition according the OSI seven Layer model

- Usage of the TCP/IP Network protocol stack
- Usage of standard interfaces
- Implementing a Next Generation Network in the ICT Infrastructure of the energy supply: a IP Platform for all smart grid and smart metering applications
- Metering, applications and communications logical and functional separated (gateway according OMS(M441))
- IP based communication between house gateway and central IT structure.

This opens a variation of possibilities for the future operation (Servatius, 2012):

- More intelligent in the system, e.g. in the Software and less Hardware input
- Simplified update process for locale software
- Timestamp on the gateway with assistance of the Network Time Protocol (NTP)
- Real time access for the customer over central portals
- Real time data available for operational use, demand response or future products and services
- Logical sub networks over VPNs
- Scalability for other broadband services in the network operation (e.g. video control of sites)

By using open standards in the communications infrastructure, e.g. TCP/IP, it opens a wide range for the implementation of applications and suppliers. The all IP approach offers a scalable platform for the future of smart grid communication and with the high number on suppliers a cost efficient way for the implementation.

To reach this target it is important to take attention to the last mile solutions with a variation of technologies shown by the following subchapter and sorted into wireline and wireless communication technologies.

3.3.1 Wireline communication solutions

For the wireline communication three main technologies are available for the use of Smart grid infrastructure. The first is powerline communication, using the electricity supply infrastructure, then the classical telecommunication technologies based on copper wire and last the since the last years established fibre optic wire based technologies.

3.3.1.1 Narrow- and Broadband Powerline Communication

Narrowband Powerline Communication used the low and medium voltage grid for the data transmission. It works in the standardised “Cenelec-A-Band” with a frequency spread between 3 to 95 kHz and provides a data bandwidth between 2 and 10kb/s, which is lower as classical modem connections with 56kb/s. New developed systems can provide theoretical data bandwidth up to 128kb/s. The advantage is that it can use the existing electricity infrastructure, but the disadvantage is that the low bandwidth makes it unusable for the data transfer of smart grid data, that has to be delivered in some cases in real time for example reading of metering data on-demand (Servatius, 2012).

The Broadband Powerline Communication (BPL), based on the standard IEEE 1901, works different to the Narrowband Powerline Communication with a frequency spread between 1 and 30 MHz and provides a data bandwidth on the distribution low voltage network between 1 and 5Mb/s. This technology based on the available bandwidth can be seen as usable for real time applications on IP base (Servatius, 2012) . Realised are this network similar to radio networks. The Head-End, which is the bridge to the regional or backbone network, provides the capacity for a few kilometres of wireline and is equal to a Basestation of a radio network. The important point is that a power supply network is not designed for the transport of data. The communication signal is characterized by a strong attenuation, changing impedance and fading, as well by the interference of noise caused by devices like engines or generator connected to the network. To reach the planed coverage area it is sometimes required to install repeaters in the network (Haidine, 2009)

To make the transmission method more transparent the following section will explain it on base on a comparison with a Wireless network.

The design process of a Broadband Powerline Access Network has a strong similarity of a Wireless network (see Figure 31: Analogy between BPL cells and wireless cells)

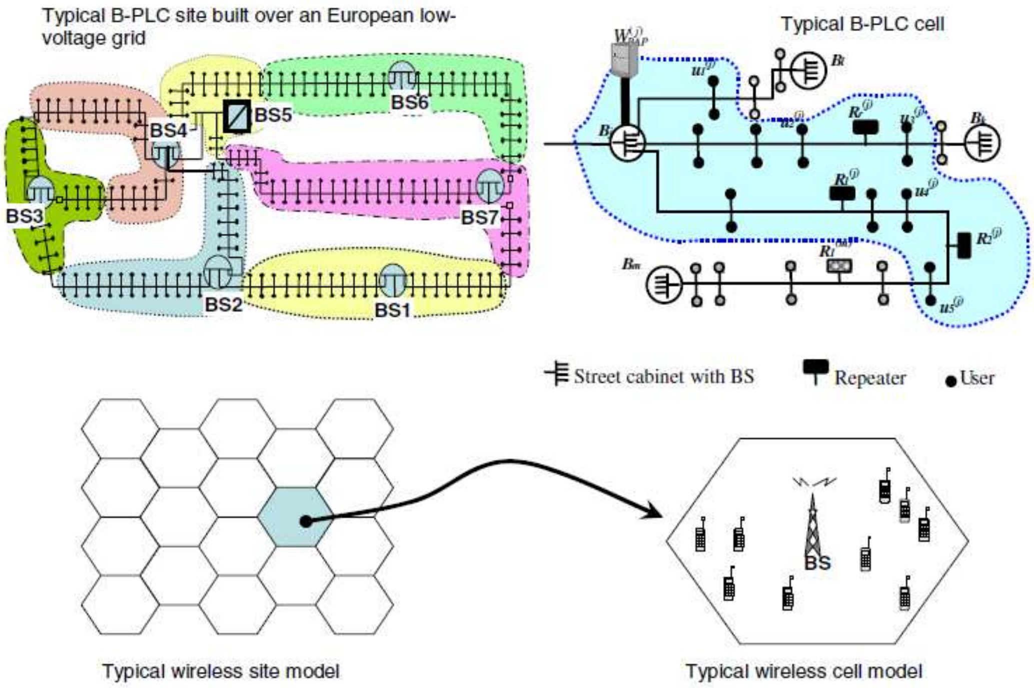


Figure 31: Analogy between BPL cells and wireless cells (Haidine, 2009)

Both have a strong complex cell and neighbourhood structures, with the different that BPL has two types of neighbourhoods. The first one is the in-line neighbourhood, which means that one or more segments building the wiring of the cell, located to near to a line segment of this cell. The second one is the in-space neighbourhood. (see Figure 32: Types of Interferences in a BPL site) (Haidine, 2009)

In the planning phase a neighbourhood matrix is used for the definition of neighbourhood of cells in the BPL network.

Out of the reason that a BPL cell can have an in-line and an in-space neighbourhood, there are two types of interferences. The on-space interference is equal to interferences of wireless technologies and base on electro-magnetic interferences. On the other hand the in-line interference is a conducted inference. (see Figure 32: Types of Interferences in a BPL site) (Haidine, 2009)

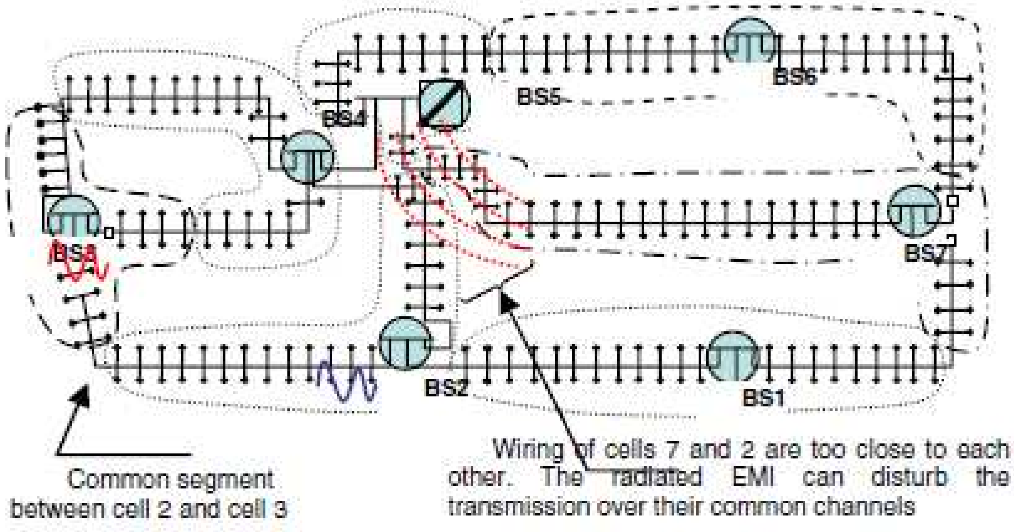


Figure 32: Types of Interferences in a BPL site (Haidine, 2009)

The Advantages of BPL are that no additional communication Infrastructure has to be built on the last mile. The supply operator can use its own infrastructure, which offers a fast roll-out of smart grid applications in the distribution network (Güngör, 2011).

The disadvantages are beginning with the security issues that BPL is working on broadcast base in the network. Next is that the powerline transmission medium is a harsh and noise environment and impacts the maximum data bandwidth, distance from node to head-end and number of devices (Güngör, 2011)

3.3.1.2 Copper based communication technologies

One of the most used copper based wireline technology is xDSL for accessing the internet in households'. xDSL stands for Digital Subscriber Line and is a high speed data transmission technology working using the existing telephone infrastructure (Vehbi C., 2011). This technology offers the possibility of bandwidth between one and 50 Mb/s. The future replacement VDSL 2 will theoretically offer for up- and downstream around 100Mb/s (Servatius, 2012).

The advantages of xDSL are the widespread of availability on the market as access technology for households. This offers the possibility to use this technology as transport media for prototyping and connectional tests in the field (Vehbi C., 2011)

The disadvantages' are that the operator of an xDSL network are often telecommunication companies, this means that the energy network operator is dependent on the quality and the security of the infrastructure of a third party. By using this way two possibilities are available, the first on with an own xDSL connection or second way the use of the connection and the network of the customer, in this case there are two dependencies. In the construction by the customer, additional installations have to be taken in consideration, out of the reason, that the xDSL and the electricity interconnection terminates on different places in a building (Schwab, 2012).

3.3.1.3 Fibre optic based Communication

Fibre optic high-speed data transmission is used in the core network of large companies and telecom operations since years. In the in-house and campus area, means networks with small dimension, multimode fibre of the type 50/125µm (Europe) or 62.5/125µm (US) were used. For long distance communication typical single mode fibres with the configuration 8/125µm or 9/125 µm are used.

Another reason for forcing this basic transmission infrastructure is the strategy in Europe to provide customer a high bandwidth possibility for information services like Internet, TV, video on demand....In Austria for example one initiative is called "Breitband Austria Zwanzigdreizehn". Based on these initiatives, projects with fibre optic infrastructure in the last mile under the term Fibre to the Home (FTTH) or Fibre to the Curb (FTTC) are realised in the last years from telecom operators

The interesting point on this transmission technology is that a wide range of transmission technologies can setup on it. The classical technologies in the wide area network are SDH or ATM and nowadays equipment on IP-Platform.

By using fibre optic in the last mile, connection modules for switches are available up to 10 GB/s. Now in the focus of combining information collection and controlling of an energy network, this technology offers a connectivity, which is galvanic isolated and this gives a physical protection of the network elements.

By designing network structures for the last mile of distribution network operator, the last mile is part of the access network, as it is in a Telco infrastructure and is a separated network structure, connected with routers to the core or regional backbone of the TSO/DSO. The requirements on this equipment are resistance against temperature and humidity. Equipment of this type is nowadays used in the industrial or military areas. Most of this equipment can be implemented with a basic redundancy.

Advantages: The advantages of fibre optic infrastructures are the widespread of available equipment out of industrial usage on the market with high data bandwidth. Another point is the galvanic isolation protection of the communication infrastructure.

Disadvantage is that this technology is mainly used in the present installations only for establishing backbone infrastructure of telecommunication companies or by large service operator for the communication to the core elements of the decentralised facilities. The last mile communication is realised with classic copper based technologies and changing to fibre optic means investing a high volume in this infrastructure.

3.3.2 Wireless communication solutions

Wireless communication solutions are since years an established technology used by telecommunication operator for the connection of the internal communication to sites (MW), where wireline based communication is to cost intensive or for the communication of mobile customer solutions (GSM/UMTS/LTE/WiMax). All this wireless communication technologies are defined in frequency bands and regulated by the local authorities. The local authority in Austria is the RTR. Only a small area of the frequencies is free and can be used by every one for their applications. These are the WLAN frequencies 2400 to 2483 MHz and 5150 to 5725 MHz (only in-house). The other frequencies can only be used after acquisition by an auction of the RTR. Figure 33: Overview of the frequency band shows the number of frequency bands regulated by the local authorities.

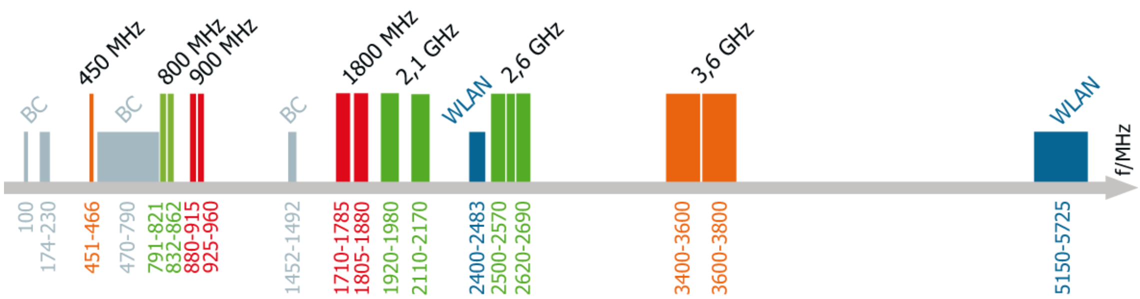


Figure 33: Overview of the frequency band (Rundfunk und Telekom Regulierungs GmbH, 2013)

3.3.2.1 GSM/GPRS

GSM which stands for Global System for Mobil Communication is a technology developed end of the 80s and rolled out in Europe in the beginning of the 90s (the American equivalent was CDMA). This technology bases on a time slot method, where 8 time slots are channel and works in the frequency band 900MHz and

1,800MHz. The focus by the development of GSM was in the beginning the mobile voice communication with a basic data bandwidth for data transfer. The provided Data bandwidth with Circuit Switched Data (CSD) was 14.4 kb/s and was expanded with further developments to maximum 115.2 kb/s with High Speed Circuit Switched Data (HSCSD). With end of the 90s the need for mobile data services with higher bandwidth comes up and the roll out of General Packet Radio Services starts in Europe. This technology bundles the 8 time slots to one and offers theoretical up to 220 kb/s by the Enhanced Data Rate for GSM Evolution (EDGE). In praxis the operator has to guaranty for the voice call all the time free capacity and so the real data trough put is still only the capacity from 3 to 4 time slots per channel. So the bandwidth is still only some kb/s (Servatius, 2012).

From the concept by using this technology all the network elements have to expand with GSM modules with or without SIM Cards. The problem in summary is that the complete data traffic has to be managed by a third party; in this case the network operator has a direct dependency to a mobile network operator. For building up an own infrastructure it is required to get a mobile licence. From the cost side the implementation has beside the implementation of the GSM modules a cost factor per connection per month. In relation to the available bandwidth the costs are too high (Servatius, 2012). For mobile operator the impact of implementing smart network elements is that the capacity of the core network elements has to be expanded in a way that millions of network elements can be connected. For example the HLRs (Home Location Register) have to handle around 2 million subscribers more in their network in Austria.

Advantage: GSM has in the rural and urban areas a good coverage and is an established radio technology.

Disadvantage: A licence for the operation of the network is needed. The cost for the implementation of this technology in relation to the effective bandwidth is too high. From the practical point of view the radio coverage has to cover cellar areas, out of the reason that a high number of metering infrastructure is there installed, this can open not allowed connection failures in the border area of radio cells. Changing the mobile operator based on price offers is connected with a high implementation and cost effort.

3.3.2.2 UMTS/LTE

Universal Mobile Telecommunications System is the mobile standard of the 3rd Generation and works on the base WCDMA (Wide Code Division Multiplexing Access) in the frequency band 1,900MHz and 2,100MHz. UMTS offers in the base version a minimum bandwidth of 384kb/s. The last developments raise the bandwidth with HSPA+ up to 42Mb/s. In the practical use this maximum bandwidth is shared with all users in a UMTS cell and is related to the distance to the cell. A main technical difference to the GSM network is, that the core network of UMTS is changing with R4 and R5 to a complete IP based infrastructure. The future replacement for UMTS is the Long term evolution (LTE) with planned bandwidths from 50Mb/s up 100Mb/s. The first Roll Outs of this technology starts now in Europe (Servatius, 2012).

This higher bandwidth offers the use of services based on the IP Protocol with better scalability and real-time capability of UMTS. For using this technology, the network operator is dependent to a 3rd party, the UMTS mobile operator, who is managing the complete data traffic in its backbone. From the cost side the implementation has beside the implementation of the UMTS modules by the network elements a cost factor per connection per month. For the mobile operators, there is the same situation as in GSM networks, that the core network and additional the transmission infrastructure has to be expanded. For example the HSS (Home Subscriber Server) have to handle around 2 million subscribers more in their network in Austria.

Advantage: UMTS has in the rural areas a good coverage and is an established radio technology.

Disadvantage: A licence for the operation of the network is needed. The cost for the implementation of this technology in relation to the effective bandwidth is too high. From the practical point of view the radio coverage has the same problem as GSM to cover cellar areas, out of the reason that a high number of metering infrastructure is there installed, this can open not allowed connection failures in the border area of radio cells. Changing the mobile operator based on price offers is connected with a high implementation and cost effort.

3.3.2.3 WIMAX

The main idea from WIMAX was to develop a radio based point to multipoint technology for the fast Roll-Out of Broadband services, equal to xDSL, in urban or not developed areas. WIMAX can provide bandwidth up to 50Mb/s to longer distances. The regimentations are that the antennas needs line of sight (LOS). In central Europe in the last years all the efforts to establish WIMAX operator fails. The frequencies 3.4GHz to 3.6GHz for the use are regulated and a licence is needed. In Austria Electricity companies like Salzburg AG, EVN and BEWAG owns regional licences of WIMAX (Aichele, 2012; Rundfunk und Telekom Regulierungs GmbH, 2013).

Advantage: A base station of WIMAX can cover a large area with data services up to 50Mb/s

Disadvantage: A licence for the operation of the network is needed. The cost for the implementation of this technology for the basic installation, incl. HW is high. From the practical point of view that the radio communication needs LOS, additional installation effort by the endpoints has to be done, to connect the ODU (Out Door Unit) with the network elements of the operator installed for example in the cellar.

3.3.2.4 Microwave link

Microwave links is a standard technology for point to point communication used in the telecommunication area since century for broadband communication. For the use in the smart grid area as last mile communication technology it is not usable out of the reason that every link has to be licensed by the local authority and yearly costs has to be paid. This commercial and technical restriction makes microwave not to a favourite technology for smart grid networks.

3.3.2.5 WLAN

WLAN, specified by the IEEE under the standard 802.11 is very popular radio based IP-Network technology. The limitation is the maximum output power regulated by the authorities with 100mW in Europe. This reduces the usage only for the in-house and not for the last mile use. The available frequency bands are the free area 2.4GHz and 5GHz.

3.3.2.6 ZigBee

ZigBee is a wireless technology working in the frequency band 2.4GHz with a relative low output power of maximum 1mW. The low complexity, data rate and costs made it perfect for home automation service and gateway technology to the smart metering infrastructure for real-time energy consumption services (Güngör, 2011).

Advantage: ZigBee is working on 16 channels, with each 5MHz bandwidth in the 2.4GHz band. The data bandwidth is 250kb/s with a OQPSK modulation. ZigBee has a high in-house potential with its range from 1 to 100m and a base infrastructure for the home automation. With ZigBee Gateway functionality it is a good option for metering and energy management out of its simplicity, mobility, robustness, low bandwidth requirements, low cost, the operation in an unlicensed frequency band and the easy network implementation. All this advantages are being standardized based on the IEEE 802.15.4 standard (Güngör, 2011)

Disadvantage: One of the main disadvantages is that ZigBee is working in the same frequency range as IEEE 802.11 based WLAN and Bluetooth. Other points are the limitations in the processing capabilities, small memory size and the being subject to interference with the before described radio technologies in the same frequency band. These concerns about robustness under noise conditions increase the possibility of corrupting the entire communications channel due to the interference of 802.11/b/g in the vicinity of ZigBee (Güngör, 2011)

3.3.3 Overview of the last mile technologies

To show the difference on one view between the previous described communication technologies, the following table gives a short summary.

Table 6: Last Mile Solutions in one view (own and (Güngör, 2011) information)

Technology	Radio band	Bandwidth	Range	Licensed	Limitation
B-PLC	-	1-5 Mb/s	1-3km	free	Harsh, noisy channel environment
xDSL	-	up to 50Mb/s	up to 10km	free	3rd party dependent and monthly fees
Ethernet over Fibre	-	up to 10Gb/s	Up to 100km	free	
GSM/GPRS	900MHz, 1,800MHz	14,4kb/s/220kb/s	1-10km	yes	3rd party dependent and low bandwidth
UMTS	1,900MHz 2,100MHz	384kb/s - 42Mb/s	1-10km	yes	3rd party dependent and monthly fees
LTE		up to 100Mb/s (theoretical)	1-10km	yes	3rd party dependent

					and monthly fees
WIMAX	2.5GHz, 3.5GHz, 5.8GHz	up to 75Mb/s	10-50km (LOS)	yes	Licence required and not widespread
Microwave link	15GHz, 21GHz, 26GHz, 38GHz, 56GHz	Up to 155Mb/s (STM1-MW)	up to 150km (LOS)	yes	Licence required and costly spectrum fees
WLAN	2.4GHz	802.11a: 54Mb/s 802.11b: 11Mb/s 802.11g: 54Mb/s 802.11h: 54Mb/s 802.11n: 600Mb/s	up to 100m	free	Short range
ZigBee	2.4GHz	250kb/s	up to 100m	free	Low data range, short range

Comparing all the wireline and wireless based last mile technologies, Ethernet over Fibre on a single mode fibre optic infrastructure offer the highest flexibility. Fibre optic is at the time based on the technical development limited to 10GB/s, additional no limitation from legal side, means no licences required. This type of infrastructure is on one side a future proof technology and on the other side by own infrastructure there is no dependency against 3rd parties. Out of these points the master thesis is following concentrating on a communication infrastructure based on fibre optic with Ethernet switches.

4 Scenario definition

This master thesis is focusing on the business impacts of establishing a smart grid infrastructure in the distribution network of a DSO for a Greenfield scenario. The comparing parameters are the impacts for the DSO on:

1. the projects costs
2. the balance sheet:
    I. Cash Flow
    II. Profit and Loss Calculation

For the calculation the scenarios are embedded in a virtual municipality in Lower Austria. The general condition for all three scenarios is that a municipality plans to expand the housing developing area with 60 properties. Every property has a dimension of 700m² (see Figure 34: Theoretical area development plan).

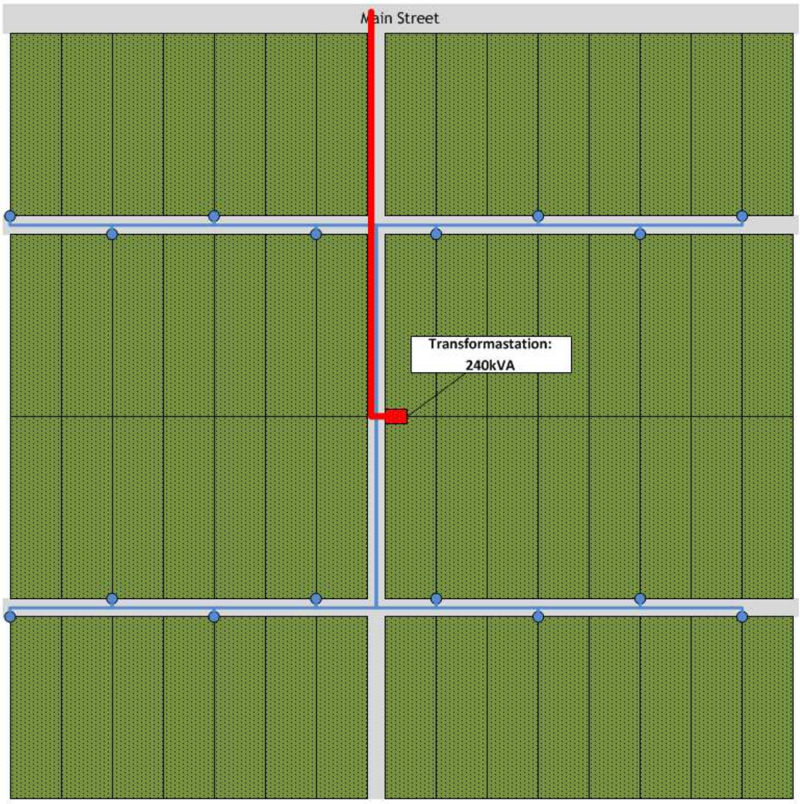


Figure 34: Theoretical area development plan (own data)

The first question for a DSO is, why is it needed to implement a smart grid infrastructure for a new housing development area?

There are two main arguments, the first is the regulatory requirements to allow decentralised energy generation and the second is the law to implement with end of

2018 90% intelligent metering equipment. The second point was described in chapter 3.2 Changes from grid to smart grid

The first point will be shown on the load of the distribution segment of the calculation scenarios. For this, additional parameters have to be defined to see how much energy is needed or produced on three represented days. The represented days are the 28/1, 21/06 and the 16/10, which have some specific characteristics. The 28/1 is one of shortest days without holidays, 21/06 the longest day in the year. The 16/10 has the characteristic that some of the load profiles have high peaks in the energy consumption.

The additional parameters are:

1. Load profile of the 60 properties
2. Percentage of the energy production in the distribution segment

4.1 Load profile:

To get a better understanding how the energy consumption of single households interacts with the distribution grid, it was needed to get more detailed information, then the Household H0 Profile. For the analysis Mr.Sterrer from Technikum Wien provides the load profiles from PVSol, which includes the profiles split into the following categories:

1. DINCI HH: Double Income no Kids
2. FNSKK HH: Family with non school aged kids, one parent is in maternity leave
3. FSKA HH: Family with school aged kids, both parents are working
4. P HH: retiree Household

These four profiles represent 4 consumer groups, which has to be spread over the 60 theoretical consumers. The base for the spread is the “Privathaushalte nach Haushaltsgröße, Bundesländern und Alter der Haushaltsreferenzperson - Jahresdurchschnitt 2011” Statistic of Statistik Austria, by excluding data from single Households and retired persons over 69. Out of this the profile distribution for the scenario looks like following:

Table 7: Load profile distribution

Type	Description	Quota	Am.
DINCI HH	Double Income no Kids	25%	15
FNSKK HH	Family with non school aged kids, one parent is in maternity leave	17%	10
FSKA HH	Family with school aged kids, both parents are working	34%	20
P HH	retiree Household	24%	15

To get the first overview the three graphs of the representative days shows the different consumer behaviour on a 24 hours base:

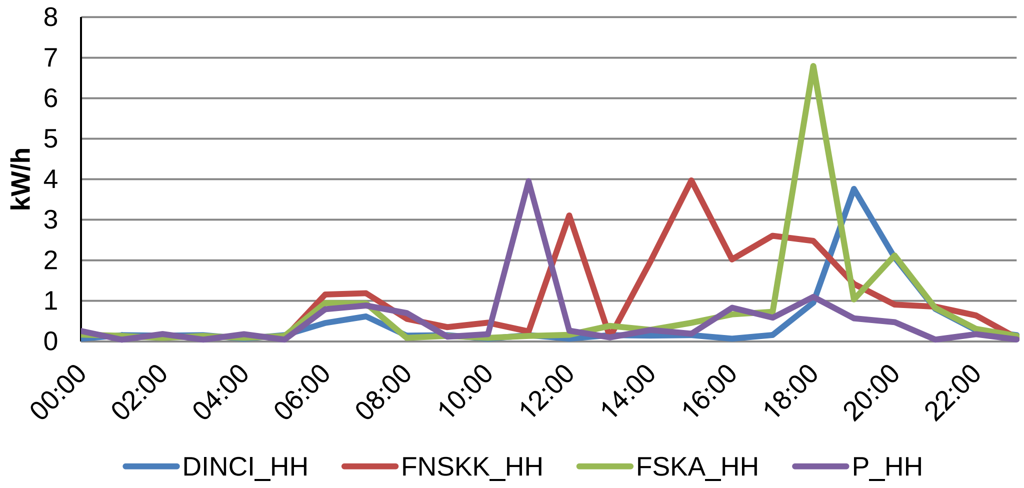


Figure 35: 24 hours load profile on the 28/1 (Sterrer, 2012)

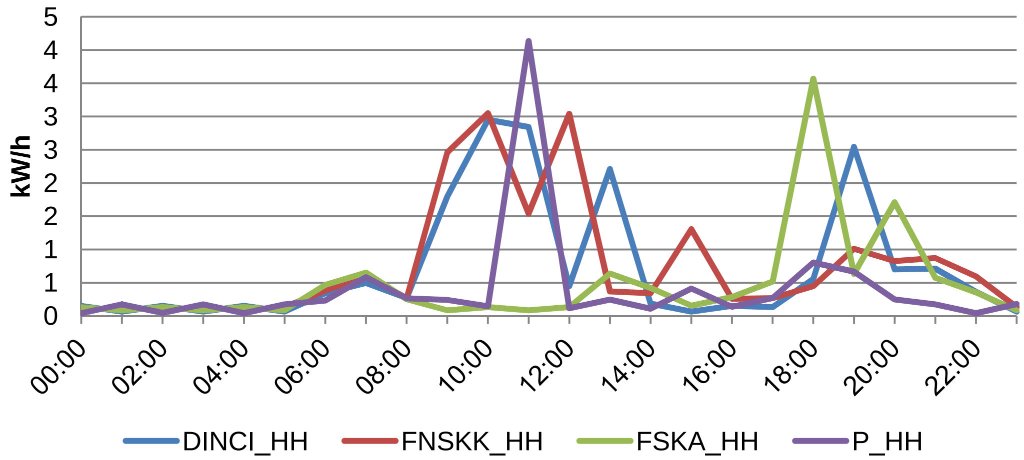


Figure 36: 24 hours load profile on the 21/6 (Sterrer, 2012)

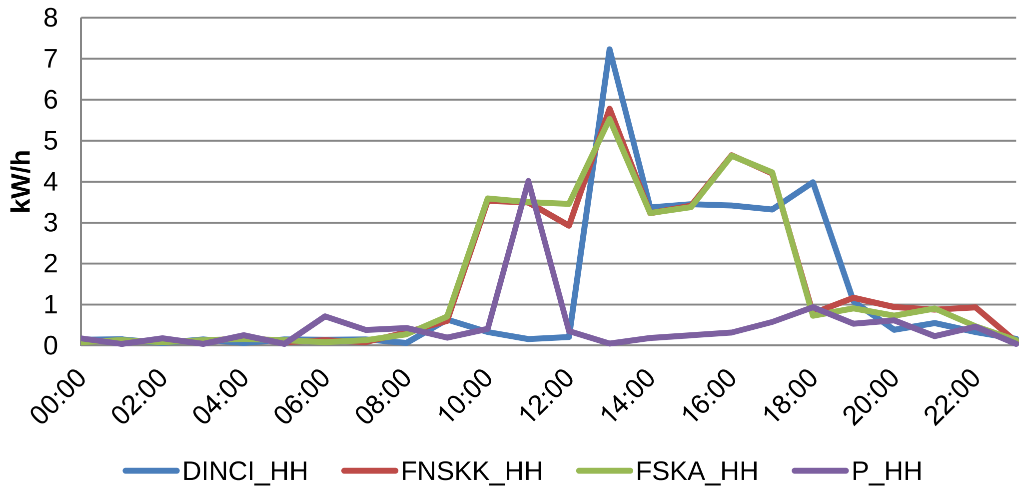


Figure 37: 24 hours load profile on the 16/10 (Sterrer, 2012)

4.2 Energy production

Additional to the customer behaviour the scenario comes with the assumption that 60% of the properties have a Photovoltaic installation. In this case all the installations are PV modules from TianWei, which are a poly crystalline system and produce maximum 240W per panel. For the calculation it is needed to find out the efficiency of the modules and for this the following formula is used:

$$\eta = \frac{P_{max} * \frac{1}{l_p * b_p}}{E}$$

η	Efficiency of the PV panel
P_{max}	Maximum energy production of the panel e.g.: 240W
l_p	length of the panel
b_p	width of the panel
E	Maximum radiation energy per m² defined in the Standard Test Condition (SRC) by Airmass AM=1.5 and the temperature T_c=25℃ : E=1000W/m² (Fechner, 2011)

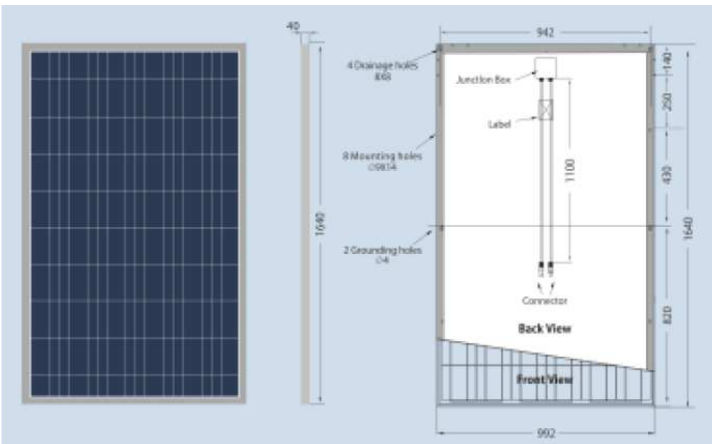
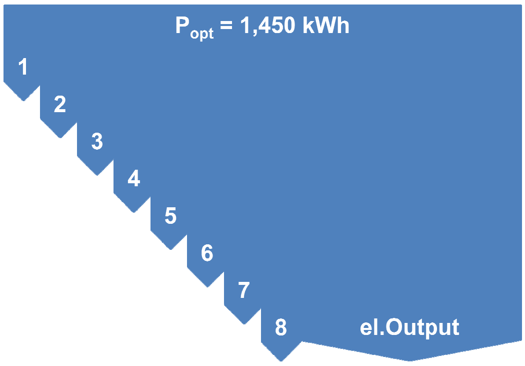


Figure 38: PV-module TianWei TW240P60-FA2 (TIANWEI, 2012)

The efficiency of this type of PV-panel is 14.75%.

To see the impact on the distribution grid it is important not only to see the PV module efficiency, it is important to calculate the full system efficiency from the module to the connection to the grid. The following figure is listing the losses on the whole system. The base of the energy P_{opt} with 1,450kWh/m²/year are realistic data for the site Bruck/Leitha and was calculated with the PVGIS-Tool (European Commission - Joint Research Center, 2012)

	Loss type
1	Reduction from nominal power
2	Dirt, Dust
3	Module temperature
4	Shading
5	Mismatch and DC losses
6	MPP tracking losses
7	Inverter losses
8	AC losses



	Loss
1	4.5%
2	2.0%
3	3.5%
4	2.0%
5	3.0%
6	1.5%
7	4.3%
8	2%

Case : PR=79.3%

Figure 39: System losses (Fechner, 2011) (Kostal, 2012)

4.3 Energetic profile of the distribution grid segment

By combining the information of the consumer consumption and the production of the decentralized energy the figures shows, that the regulatory changes have a significant impact on the distribution grid. As it was in the past, the DSO has “only” to adjust the consumption against the production – top down network. Now the grid requires a two way system.

The analysis of the representative days shows that the on the 28/1 in the time from around 09:00am to 02:00pm the generation is higher than the consumption even though this is the shortest day in the year. (Figure 40: 24 hours load profile of the grid segment on the 28/)

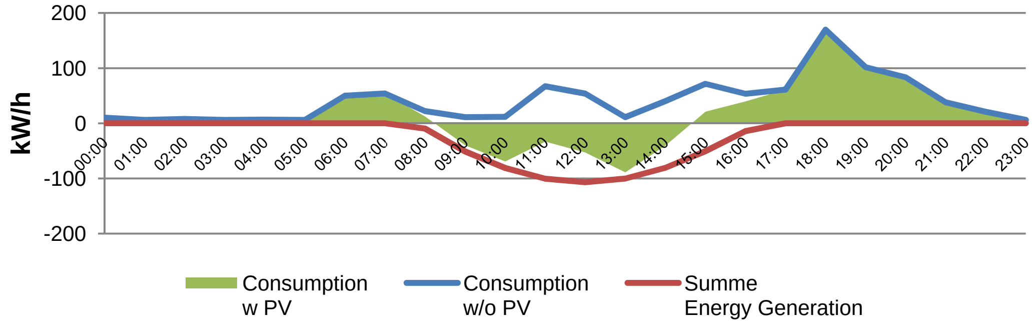


Figure 40: 24 hours load profile of the grid segment on the 28/1 (own calculation)

On the 21/06, this is the longest day in the year, most of the time between 07:00am and 05:30pm the generation is higher than the consumption. (Figure 41: 24 hours load profile of the grid segment on the 21/)

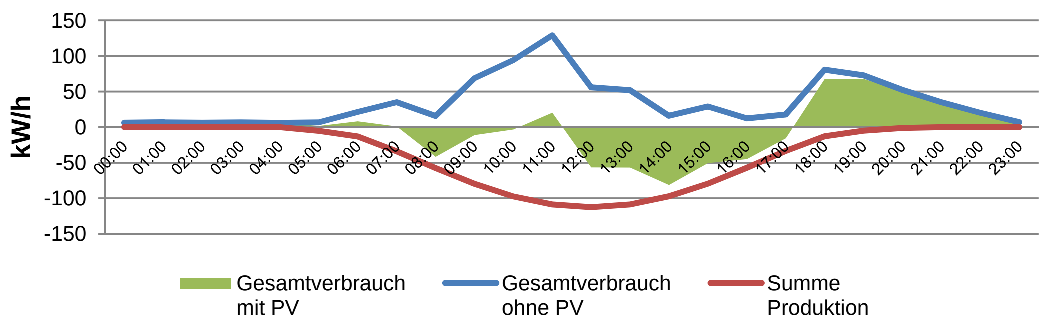


Figure 41: 24 hours load profile of the grid segment on the 21/6 (own calculation)

One of the interest facts by this examples is that the peak level is in both cases around the same level, but in the winter case it will be reached 2 times.

On the 16/10 it was clear from the beginning, is the consumption much higher than the production, only in a short period of time between 07:00am and 09:30 the generation is higher. (Figure 42: 24 hours load profile of the grid segment on the 16/)

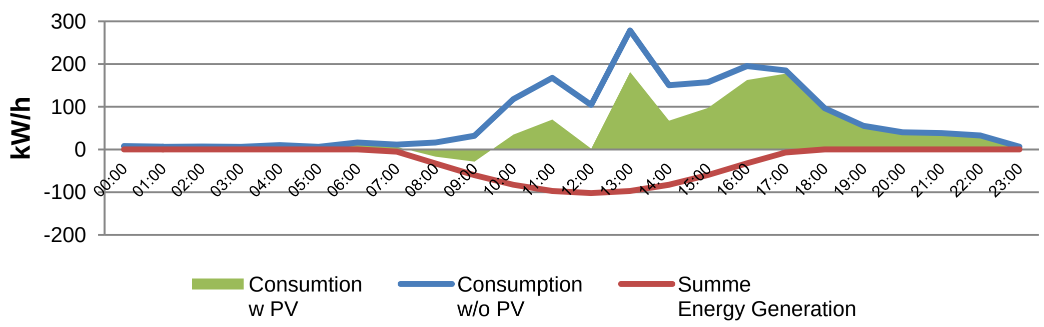


Figure 42: 24 hours load profile of the grid segment on the 16/10 (own calculation)

All three example shows, the DSO has to react in all cases to hold the balance in the network all the time. One Risk in this three examples is not visible, which is extreme critical for the DSO, it is the point that all generation units bases on the PV Technology in a concentrated area (4.84 hectare). This configuration is dependent on weather phenomena that mean, if clouds are over this area, the electricity production reduces or in the extreme case stops and in the same moment this distribution grid segment is not a producer it will be a consumer. This information is important for the stability of the network and has to be delivered in real time to the DSO. The sampling rate is for the DSO the reacting time!

These three representative days' shows, how important are the consumer behaviour and the involved infrastructure to guaranty a high availability of the distribution grid. To fulfil this technical requirements and future electricity services it is needed to build up a smart grid infrastructure that controls the grid elements.

4.4 Basic frame condition

All in the following chapter discussed scenarios start from the Greenfield and have in the end an electrical and a communication infrastructure. The electrical infrastructure includes the cables, transformer and interconnection point. The communication infrastructure is equipped with a fibre optic as transmission layer, rough type Ethernet switches and a smart meter infrastructure. For the cost calculation all the material costs and implementation costs are taken in consideration. One main infrastructure element, the costs for the construction of the low voltage grid transformer station is not taken in consideration out of the reason that these costs are equal for all three scenarios and have no impact on the result.

In the following section the main infrastructural topics for the scenarios will be described in more details. These topics are:

1.) Construction method
2.) Electricity grid
3.) Passive communication infrastructure
4.) Active communication infrastructure: Ethernet switches
5.) Smart meter
6.) Development plan

Construction method:

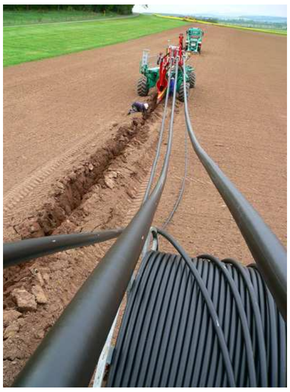


Figure 43: cable installation with a plug

In the Greenfield setup the scenarios starts with the situation that the infrastructure construction has to be done in a new established real estate area, where the installation can be done with an installation plug. This way of implementation is a very cost effective method and is in the range between €50 and €100.

In scenario 1 there is an additional second phase with construction work for the installation of the communication infrastructure needed. For this the calculations with a closed road structure of an urban area is required. Based on information from Salzburg Netz AG the costs are typically in the range between € 100 and € 200.

Electricity grid:

In the calculation, beside of the cabling infrastructure two types of transformers were taken into consideration. In scenario 1 is it a legacy 240kVA transformer, which is typical in non controlled low voltage distribution grids and in scenario 2 and 3 the new generation of 3 tap 240kVA transformers for an active controlled low voltage distribution grid.

Passive communication infrastructure:

The target is to connect every interconnection point with a fibre optic infrastructure. The different is the method of installation. Scenario 1 and 3 use a 2x4 mono mode fibre optic cable connecting all the interconnection points. The configuration of the active equipment uses only four fibres for the transmission with the target to realise a basic protection. The other four fibres are a reserve for future use. Scenario 2 works with the strategy to use fibre blow technology. This opens the way to install first only a duct structure with the installation of the electricity infrastructure. At the point that the fibre structure is needed, the required fibres will be blown in into the duct structure. In this scenario only the required four fibres are blown in. The rest of the available sub ducts can be used later for other services.

Finally all scenarios have the required four fibres for the transmission network and guaranty a future proof infrastructure, where the communication equipment is electrically isolated from the electrical infrastructure.

Active infrastructure: Ethernet switches:

Figure 44: RuggedSwitch i802

The requirement of active equipment is that it has to operate under outdoor condition, which means it has to be IP64 protected and working temperature between -20 and +50℃. This is needed out of the reason that the network elements are mounted in Outdoor cabinets with the electricity infrastructure. The optimise the costs it is planned to setup only standard products to reduce the installation costs and open the possibility to combine it with existing communication infrastructure. This equipment can be found in the industrial were it is used for the network infrastructure of large industrial facilities like refineries. For the scenarios the RuggedSwitch i802 is used, which is equipped with 6x100baseT Interfaces and 2 single mode interfaces with a maximum range of 20km. This equipment fulfils the requirement of temperature with an operation range between -40 and +85℃. With the support of the rapid Spanning Tree Protocol (RSTP) it is possible to establish with the four available fibres a fail over ring structure, which reacts in a timeless then 5ms. This type of protection helps only in the case of hardware failure of switches in the loop; it helps not in the case of a break in the cabling. With this equipment one additional requirement is fulfilled too, it is mountable on a DIN rail.

Smart Meter:

In scenario 1 it starts with classic Ferraris meter, which is changed in the end of the scenario to a smart meter with Ethernet interface. Scenarios 2 use a smart meter, which can be added with an Ethernet interface and scenario 3 us e the same smart meter as scenario 2, but fully equipped with the Ethernet interface.

Finally all three scenario use the same smart meter with the same configuration.

Development plan:

In all scenarios the real estate development is planned for a time period of four years. The time period is between the year 2013 and 2016.

For all the calculation, the costs base on information's from Salzburg Netz AG for the majority of the electricity infrastructure, list price information for the electrical cables from SKW (Schwechater Kabelwerke, 2013) and the fibre optic infrastructure from Mattig-Schauer. The information of the active equipment came from research in the internet. Additional to the costs all calculation includes a future consumer price escalation with 3%.

5 Scenario analysis

In the following chapter three scenarios of a Greenfield approaches are discussed. The different between all, are the way how to realise the distribution grid configuration. The scenarios are:

1.) Classical grid expansion: first installed electrical infrastructure with different cable characteristics and a later separate installed communication infrastructure
2.) Enhanced grid expansion: build up with a 3 step transformer, one type electrical cable, empty ducts for the fibre optic infrastructure and later on installed fibre cables with Ethernet switches
3.) Full smart solution: build up 3 step transformer, one type electrical cable, fibre optic cable and Ethernet switches in one implementation step.

Finally all three scenarios have in the end the same communication infrastructure with Ethernet switches from the same type connected with fibre optic in a basic protection configuration and Smart Meters with Ethernet modules. Scenario 2 and 3 has additional the same electrical characteristic. Scenario 1 is limited by the functionality of the legacy transformer and the cable infrastructure

5.1 Scenario 1: Classical grid expansions

Scenario 1 represents a classical distribution grid expansion, where the communication infrastructure has to be build afterwards to get a smart grid configuration. The electricity configuration is similar to the realised configurations, which can be found in Austria.

5.1.1 Assumptions for Scenario 1

In the calculations of scenario 1 project costs the electrical and communication infrastructure are included. One main infrastructure element, the costs for the construction of low voltage grid transformer station is not taken in consideration out of the reason that these costs are equal for all three scenarios and have no impact on the result.

The scenario has three phases of the realisation which are:

1.) Realisation of the electricity infrastructure in the year 2013, 2014, 2015 and 2016

2.) Realisation of the communication infrastructure in the year 2017
3.) Up 2018 only maintenance of the infrastructure.

The costs for the first phase are the construction cost, cabling material and implementation of the interconnection point. The construction costs in the beginning are oriented on the situation that the scenario is on new established real estate area, where the cable construction can be done with a plug. The typical costs are in this phase between € 50 to € 100/m. For the calculation €75/m were used.

The cost calculation for the cabling infrastructure base on the selection of the cable types from the analysis of the project ISOLVES. In this project, 100 representative low voltage distribution networks in urban and rural areas were documented and analysed to find out the potentials for the implementation of an active distribution network. One outcome is the information about the cable types and the used amount. The Table 8 shows the information reduced to the cable characteristic and the statistic distribution:

Table 8: Statistic variation of electricity cables in the project ISOLVES

Cable type	length [m]	percentage
4x16	37298	18.31%
4x25	4158	2.04%
4x35	1387	0.68%
4x50	28109	13.80%
4x70	7825	3.84%
4x95	36998	18.16%
4x120	1520	0.75%
4x150	86032	42.23%
4x240	417	0.20%

This statistic distribution was reduced to the top four cable types and then in a similar distribution used for the cable types in scenario 1 (see Table 9):

Table 9: List of cable types in scenario 1 and the statistic variation

Cable type	length [m]	percentage
4x150	348	43%
4x95	156	19%
4x50	156	19%
4x16	156	19%
	815	100%

The required transformer is a legacy transformer 240kVA which costs around €8.000 and is calculated in the first phase of the implementation. The last calculation position is the interconnection point, which includes the costs for the rack, implementation costs and the metering infrastructure, which is in the beginning a Ferraris Meter.

In the second phase are again construction costs, but with the assumption that the area has a closed road structure of an urban area. The costs in this area are in range of € 100 to € 200 per meter. For the calculation the assumption is set to average of € 150 per meter.

Further the calculation in the second phase includes a four pair Single Mode fibre optic cable, the pigtails, splices, pipe couplings, the fibre optic switch and a replacement of the legacy Meter against a Smart Meter with Ethernet interface.

The third phase includes no changes in the infrastructure only work based on maintenance.

5.1.2 Electrical characteristic of Scenario 1

The low voltage distribution grid electrical configuration of scenario 1 is defined as before described with different cable types from the transformer to the interconnection points and between the interconnection points. It starts with 4x150 from the transformer to interconnection point 1 and reduces it up to the last one interconnection point 4 according Table 9.

This configuration shows on these short distances, one segment is maximum 196m, in a synchronised load situation without decentralised generation, based on the different load profiles on the reference days the following behaviour:

At the 28/1 the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.6% on a daily trend (see Figure 45: Scenario 1 / Total voltage deviation on a daily trend (28/1)).

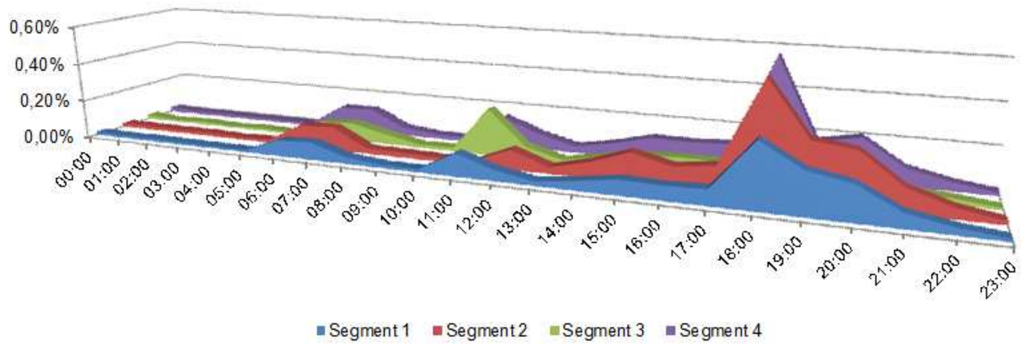


Figure 45: Scenario 1 / Total voltage deviation on a daily trend (28/1) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 06:00pm 64A (see Figure 46: Scenario 1 / Electricity deviation per segment on a daily trend (28/1)).

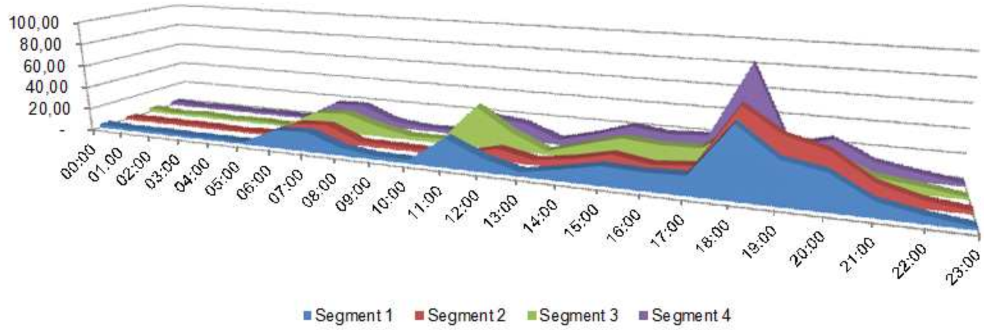


Figure 46: Scenario 1 / Electricity deviation per segment on a daily trend (28/1) (own calculation)

At the 21/6 the deviation of the maximum and minimum Voltage in a segment is in total between 0.01% and 0.32% on a daily trend (Figure 47: Scenario 1 / Total voltage deviation on a daily trend (21/6)). Based on the used load profiles there are two peek points at around 11:00am and 06:00pm.

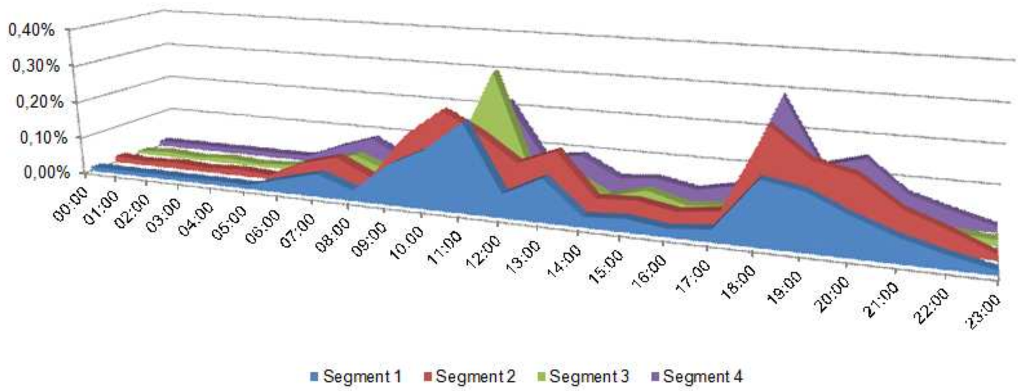


Figure 47: Scenario 1 / Total voltage deviation on a daily trend (21/6) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 11:00am 55A (see Figure 48: Scenario 1 / Electricity deviation per segment on a daily trend (21/6)).

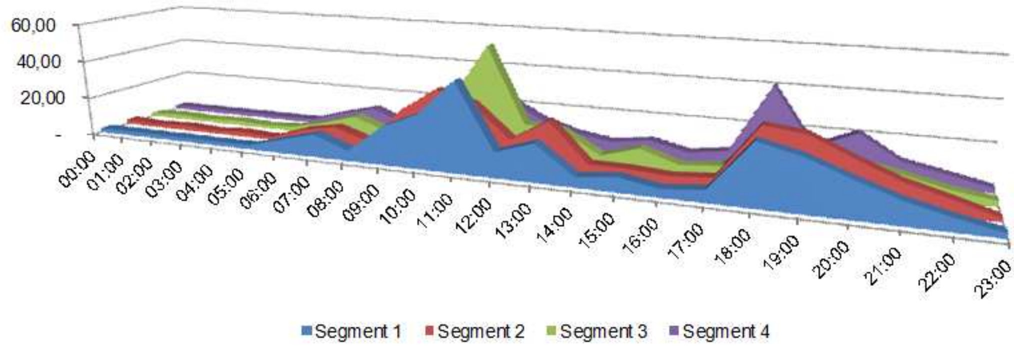


Figure 48: Scenario 1 / Electricity deviation per segment on a daily trend (21/6) (own calculation)

At the 16/10, where the used profiles shows the highest loads, the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.85% on a daily trend (see Figure 49: Scenario 1 / Total voltage deviation on a daily trend (16/10)).

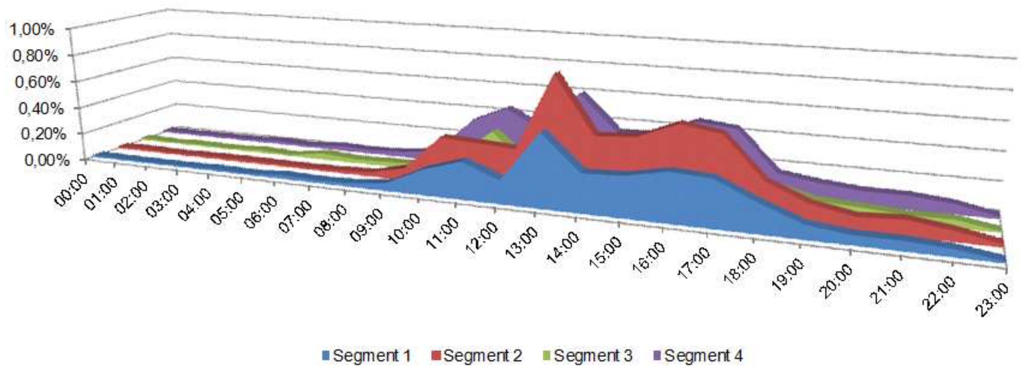


Figure 49: Scenario 1 / Total voltage deviation on a daily trend (16/10) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 01:00pm 118A (see Figure 50: Scenario 1 / Electricity deviation per segment on a daily trend (16/10)).

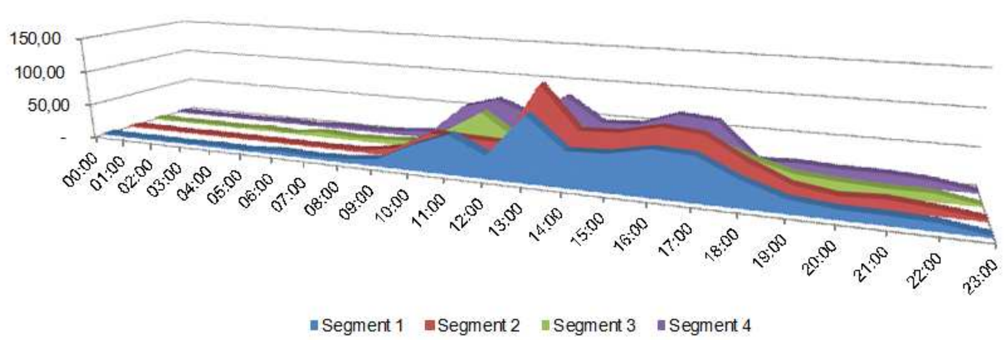


Figure 50: Scenario 1 / Electricity deviation per segment on a daily trend (16/10) (own calculation)

5.1.3 Commercial analysis of Scenario 1

In the commercial analysis only the costs of the scenario for a time period of 5 years is taken in consideration. The costs include in this time period the implementation costs and the maintenance costs in the defined operation time. This provides a serious base for the comparisons of the scenarios. To get a full overview, the cost impacts will be analysed from project cost side and balance sheet side.

The first analyse base on the discounted cash flow method and shows the planned costs of the implementation for the next 5 years. The used discount rate for all calculations was 4.5%.

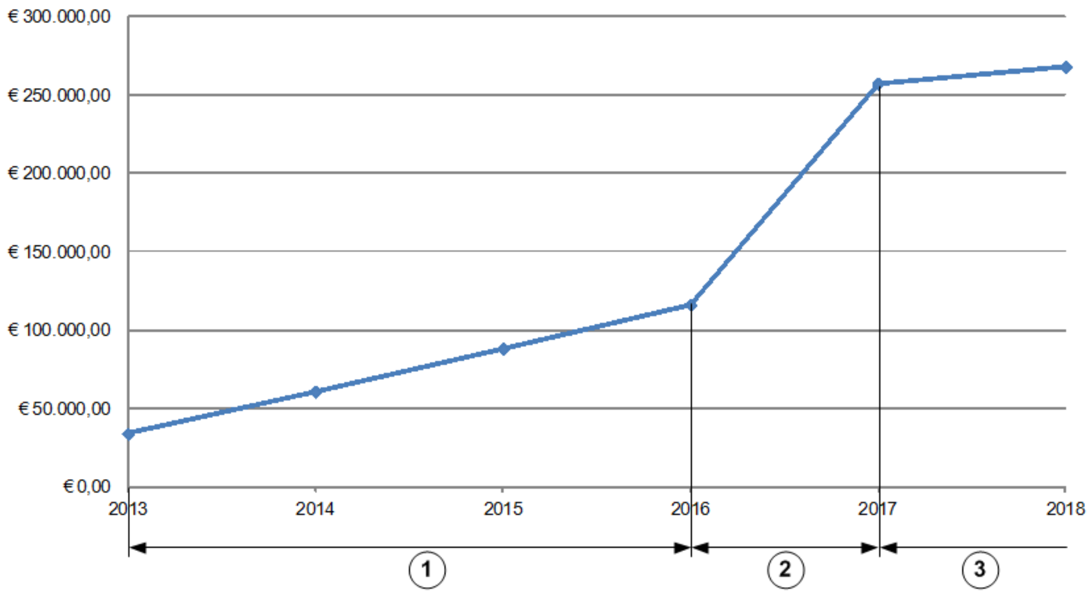


Figure 51: Scenario 1 / cumulated discounted cash flow (own calculation)

By analysing the cumulated discounted cash flow chart (see Figure 51: Scenario 1 / cumulated discounted cash flow) the three phases of the installation are visible again. The phases are with their dependencies:

Phase 1 includes only costs for the implementation of the electrical low voltage distribution grid, without any communication. The costs contains with the year 2014 a part of maintenance costs, where the percentage in total is increasing year per year (Figure 52: Scenario 1 / total cost distribution between implementation and maintenance).

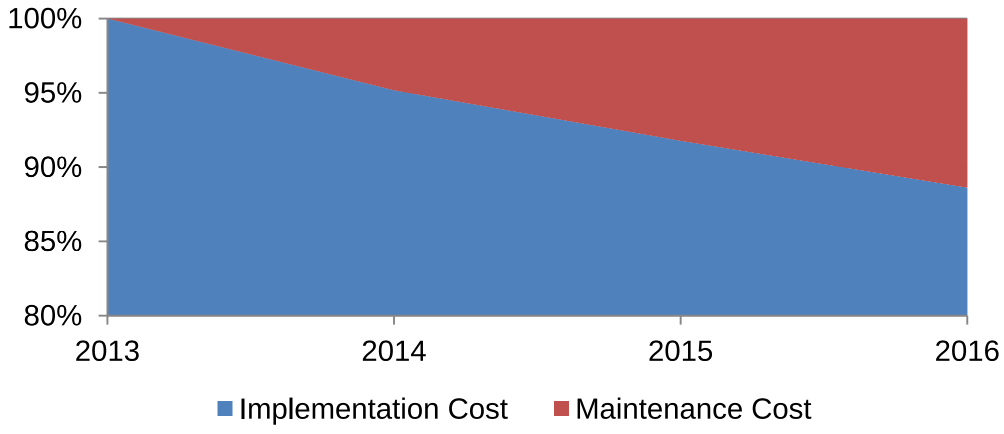


Figure 52: Scenario 1 / total cost distribution between implementation and maintenance (own calculation)

In phase 2 the low voltage distribution grid will be expanded with the required communication infrastructure. This extreme cost increase is based on the additional construction work, which is 72% of the total cost in the year 2017. The rest are electrical infrastructure maintenance 3%, changing of the existing metering infrastructure to smart meters 2% and the communication infrastructure costs for fibre optic cable, switches and implementation 22%.

With Phase 3 only inflation-adjusted maintenance costs are included.

By calculating all the discounted cash flows with a discount rate from 4.5% there is a cost annuity by a 5 year period of €61,049.86. The sensitivity analysis based on this calculated annuity shows that the changes on the operational costs has less influence , then changes in the investment costs or the consumer price index (see Figure 53: Scenario 1 / Sensitivity analysis **(own calculation)**).

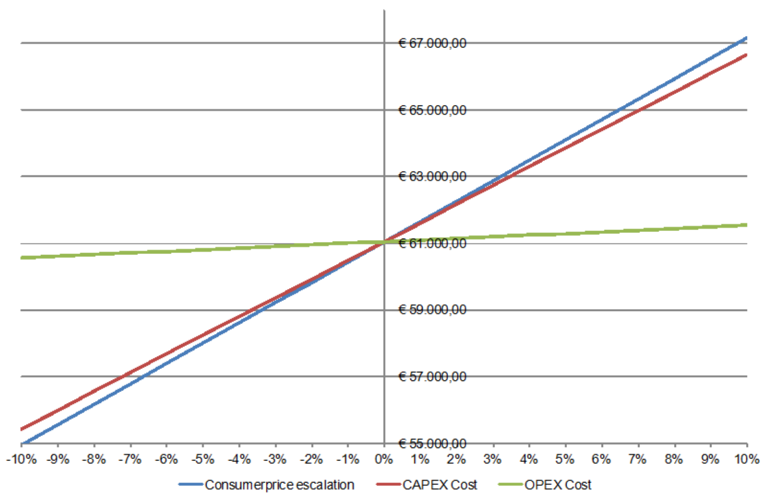


Figure 53: Scenario 1 / Sensitivity analysis (own calculation)

In the profit and loss analyse the influence of the installation on the tax related profit. The calculation includes the point that an installation is done in the second half of a year, the depreciation can only be set half in the profit reducing calculation. The depreciation in the calculations for the electrical infrastructure is set to 20 years; the communication infrastructure is according to information from Salzburg Netz AG between 10 (active) and 15 (passive equipment) years, in the scenario for simplification it is set to 10 years.

Phase 1 has in this scenario less impact on tax reduction of the company profit; it includes only the depreciation and the operational costs of the electrical infrastructure of the low voltage distribution grid.

Phase 2 includes the depreciation and operational costs of the electrical infrastructure and the first time the half depreciation of the communication infrastructure. Here the profit reducing value is €18,761.00

Phase 3 includes the full depreciation for electrical and communication infrastructure and the inflation-adjusted operational costs. From this point the profit reducing value starts with € 35,131.00

All three phases are shown in Figure 54: Scenario 1 / Impact on profit and loss:

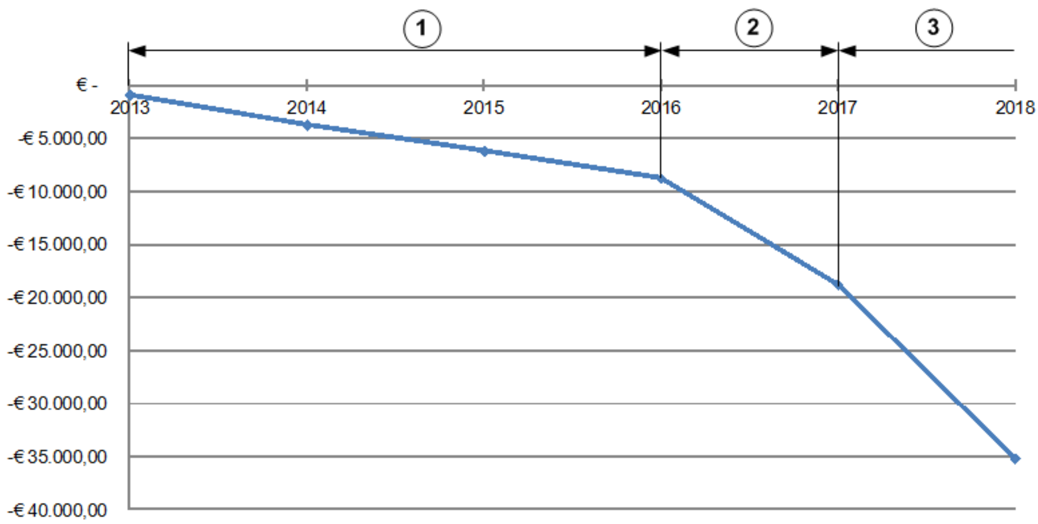


Figure 54: Scenario 1 / Impact on profit and loss (own calculation)

The Cash Flow analysis shows the following behaviour on this configuration (see Figure 55: Scenario 1 / Impact on cash flow

In Phase 1 a constant low cash out for the construction and maintenance with around € 30,000.00 influence the liquidity

In Phase 2 the high construction costs and the constant maintenance costs influence the liquidity with €168,683.00.

In Phase 3 it starts with low cash out for the inflation-adjusted yearly maintenance costs.

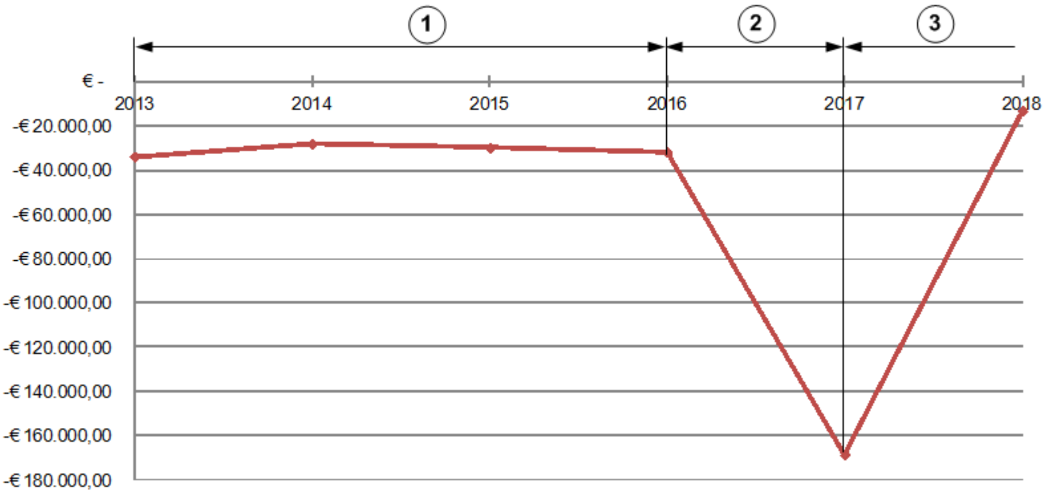


Figure 55: Scenario 1 / Impact on cash flow (own calculation)

5.2 Scenario 2: Enhanced grid expansion

Scenario 2 represents an enhanced low voltage distribution grid expansion, which is a mix between a classic and a full smart solution. In these versions main preparations on the infrastructure is taken in the realisation step by using of a different technology. The outcome in the end is the same as in scenario 1 and 3.

5.2.1 Assumptions for Scenario 2

In the calculations of scenario 2 project costs the electrical and communication infrastructure are included. One main infrastructure element, the costs for the construction of low voltage grid transformer station is not taken in consideration.

The scenario has as scenario1 three phases of the realisation which are:

1.) Realisation of the electricity infrastructure and the duct structure for the communication infrastructure in the year 2013, 2014, 2015 and 2016
2.) Finalizing of the communication infrastructure in the year 2017
3.) Up 2018 only maintenance of the infrastructure.

The costs for the first phase are the construction cost, electrical cabling material, the fibre optic ducts and implementation of the interconnection point. The construction costs in the beginning are oriented on the situation that the scenario is on new established real estate area, where the cable construction can be done with a plug. The typical costs are in this phase between € 50 to € 100/m. For the calculation €75/m were used.

The required transformer is in this scenario a 3-tap transformer with 240kVA, which costs 3 times more than a legacy transformer, around €24.000 and is calculated in the first phase of the implementation. The used cabling material is on the grid site a 4x150 cable.

For the communication infrastructure a duct structure is installed in the first construction activities. This reduces the costs by the expansion of the grid infrastructure with fibre optic cables from the costs of an again needed construction work. The required fibre optic cables will be blow-in with high pressure in sub-ducts to interconnection points.

The metering infrastructure will be in this scenario the first time intelligent meters, which can be extended with Ethernet modules for using the full range of functionality after realising the communication infrastructure.

In the second phase the costs for the implementation of the fibre optic cable, Ethernet switches and the additional network modules for the metering infrastructure are calculated. For the communication network only four fibres are as minimum requirement needed and calculated. The infrastructure offers additional reserves for later needed fibre optic connections.

The third phase includes no changes in the infrastructure only work based on maintenance.

5.2.2 Electrical characteristic of Scenario 2

The low voltage distribution grid electrical configuration of scenario 2 is defined only to use cables of type 4x150.

This configuration shows on these short distances, one segment is maximum 196m, in a synchrony load situation without decentralised generation, based on the different load profiles on the reference days the following behaviour:

At the 28/1 the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.2% on a daily trend (see Figure 56: Scenario 2 / Total voltage deviation on a daily trend (28/1)).

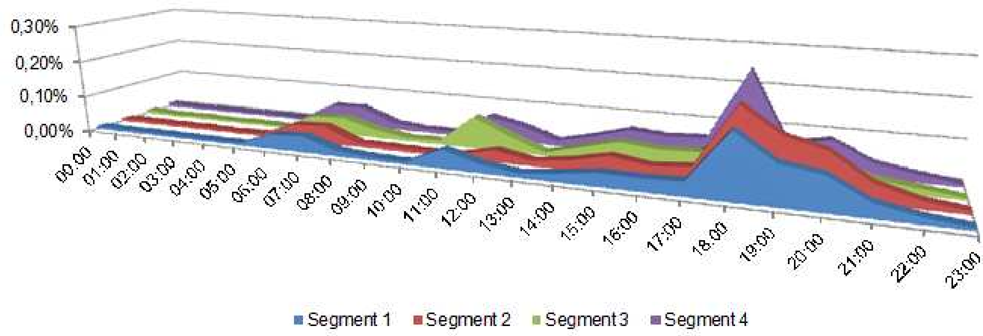


Figure 56: Scenario 2 / Total voltage deviation on a daily trend (28/1) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 06:00pm 83,9A (see Figure 57: Scenario 2 / Electricity deviation per segment on a daily trend (28/1)).

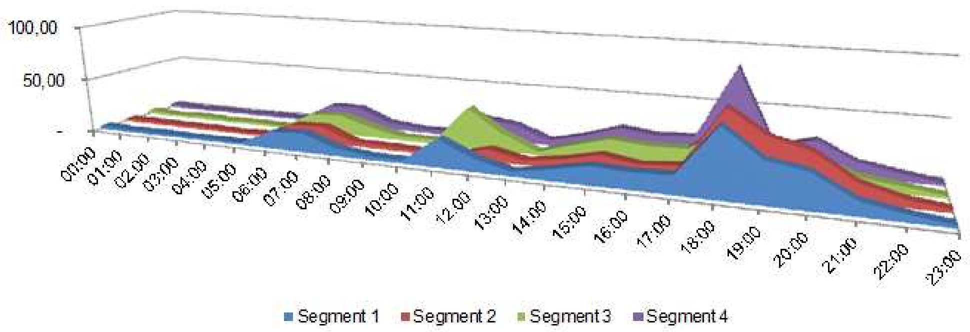


Figure 57: Scenario 2 / Electricity deviation per segment on a daily trend (28/1) (own calculation)

At the 21/6 the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.11% on a daily trend (Figure 58: Scenario 2 / Total voltage deviation on a daily trend (21/6)). Based on the used load profiles there are two peek points at around 11:00am and 06:00pm.

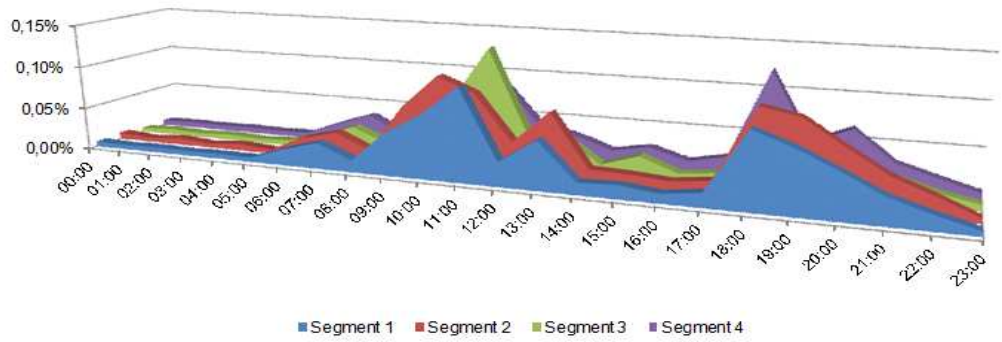


Figure 58: Scenario 2 / Total voltage deviation on a daily trend (21/6) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 11:00am 55A (Figure 59: Scenario 2 / Electricity deviation per segment on a daily trend (21/6)).

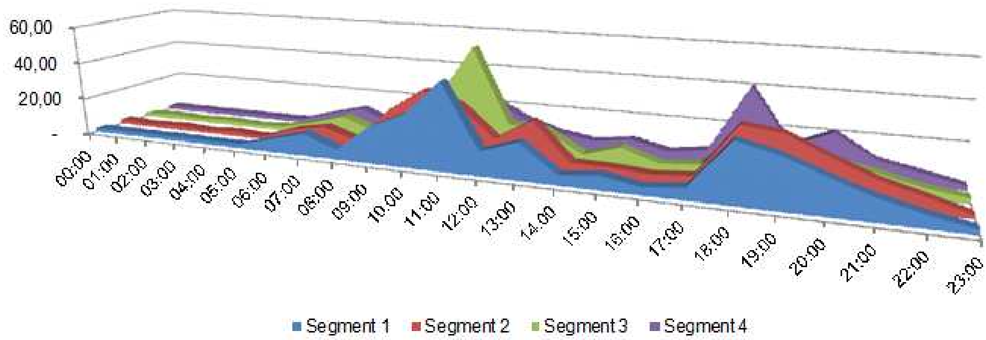


Figure 59: Scenario 2 / Electricity deviation per segment on a daily trend (21/6) (own calculation)

At the 16/10, where the used profiles shows the highest loads, the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.37% on a daily trend (see Figure 60: Scenario 2 / Total voltage deviation on a daily trend (16/10)).

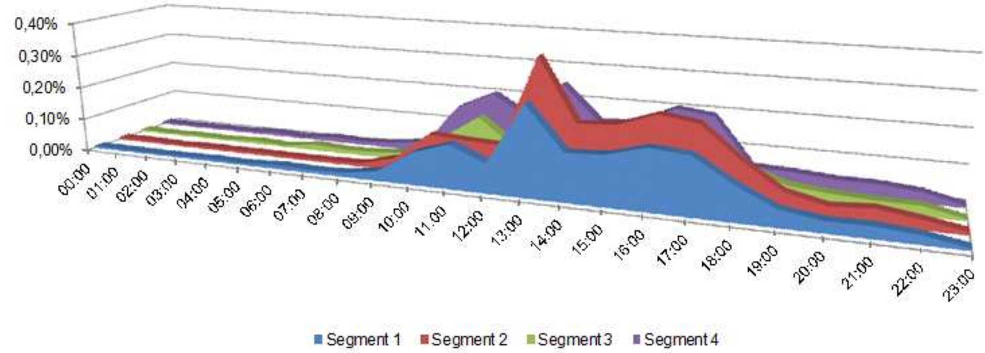


Figure 60: Scenario 2 / Total voltage deviation on a daily trend (16/10) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 01:00pm 118A (see Figure 61: Scenario 2 / Electricity deviation per segment on a daily trend (16/10)).

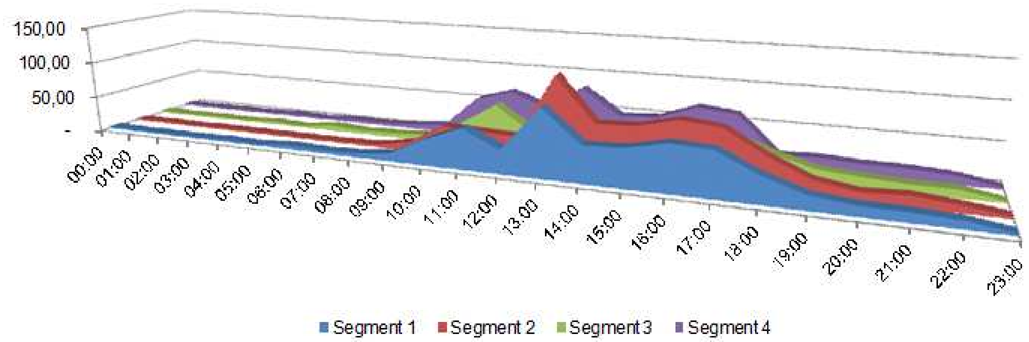


Figure 61: Scenario 2 / Electricity deviation per segment on a daily trend (16/10) (own calculation)

5.2.3 Commercial analysis of Scenario 2

In the commercial analysis only the costs of the scenario for a time period of 5 years is taken in consideration. The costs include in this time period the implementation costs and the maintenance costs in the defined operation time.

The first analyse base on the discounted cash flow method and shows the planned costs of the implementation for the next 5 years.

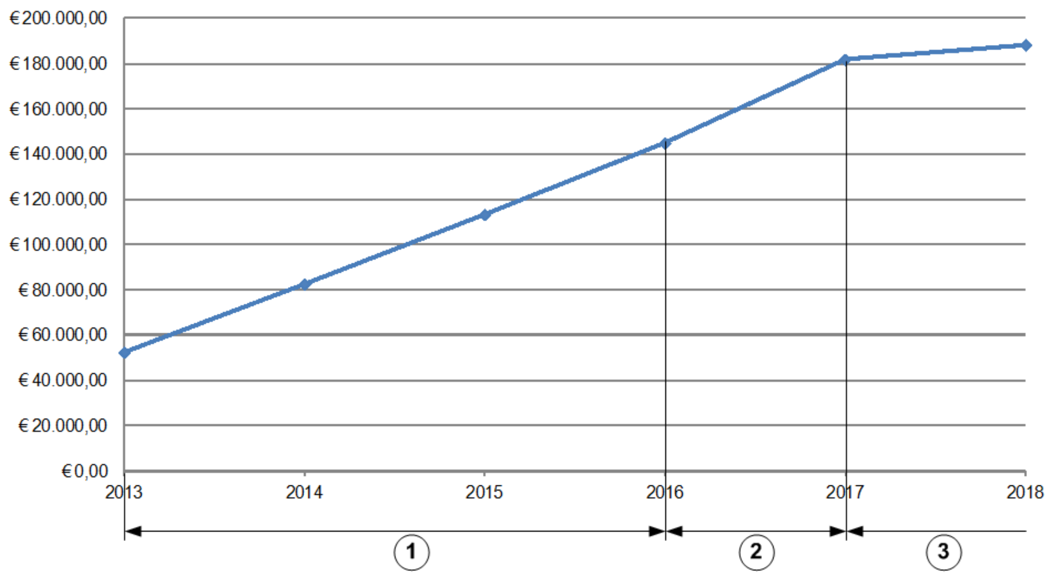


Figure 62: Scenario 2 / cumulated discounted cash flow (own calculation)

By analysing the cumulated discounted cash flow chart (see Figure 62: Scenario 2 / cumulated discounted cash flow) the three phases of the installation are visible again. The phases are with their dependencies:

Phase 1 includes only costs for the implementation of the electrical low voltage distribution grid, the duct structure for the communication network and the interconnection points. The costs contains with the year 2014 a part of maintenance costs, where the percentage in total is increasing year per year (Figure 63: Scenario 2 / total cost distribution between implementation and maintenance).

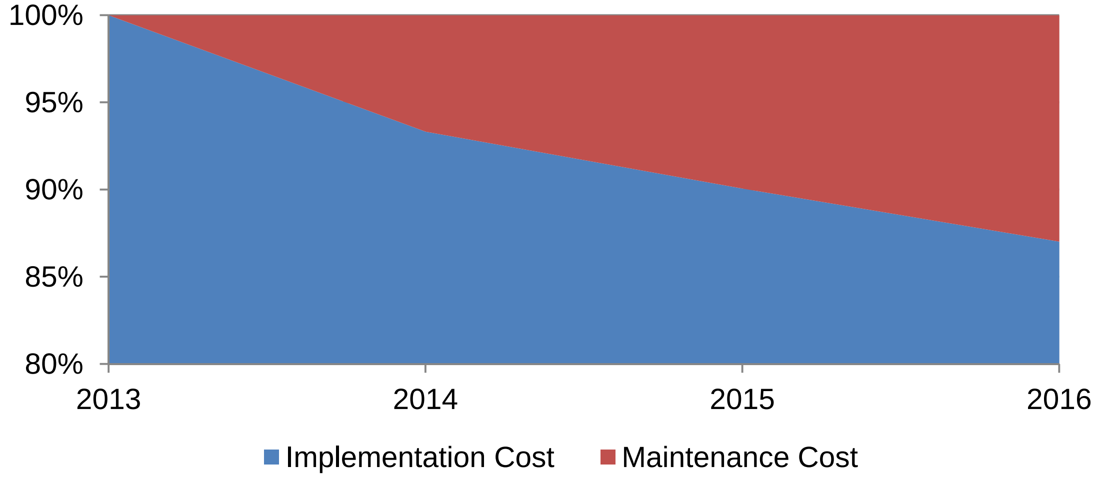


Figure 63: Scenario 2 / total cost distribution between implementation and maintenance (own calculation)

In phase 2 the low voltage distribution grid will be expanded with the required communication infrastructure. This cost increase in 2017 with €44,151.46 is based on the additional implementation costs of the fibre optic infrastructure, which is 52% of the total cost in this year. The rest are electrical infrastructure and communication base infrastructure maintenance 14%, hardware costs of adding the network modules to the existing smart meters 4% and the switches and implementation 31%.

With Phase 3 only inflation-adjusted maintenance costs are included.

By calculating all the discounted cash flows with a discount rate from 4.5% there is a cost annuity by a 5 year period of €42,885.25. The sensitivity analysis based on this calculated annuity shows that the changes on the operational costs has less influence , then changes in the investment costs or the consumer price index (see Figure 64: Scenario 2 / Sensitivity analysis **(own calculation)**).

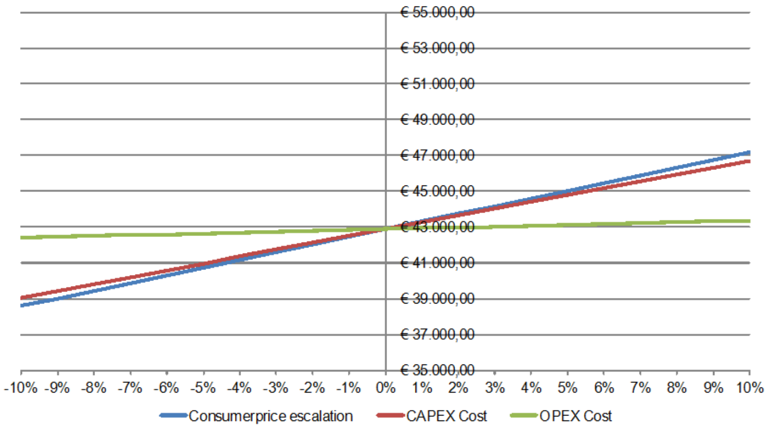


Figure 64: Scenario 2 / Sensitivity analysis (own calculation)

In the profit and loss analyse the influence of the installation on the tax related profit. The calculation includes the point that an installation is done in the second half of a year, the depreciation can only be set half in the profit reducing calculation. The depreciation in the calculations for the electrical infrastructure is set to 20 years; the communication infrastructure is according to information from Salzburg Netz AG between 10 (active) and 15 (passive equipment) years, in the scenario for simplification it is set to 10 years.

Phase 1 in this scenario has full impact on tax reduction of the company profit; it includes the depreciation and the operational costs of the electrical infrastructure of the low voltage distribution grid and the basic duct infrastructure for the communication network.

Phase 2 includes the depreciation and operational costs of the electrical infrastructure and duct infrastructure and the first time the half depreciation of the additional fibre optic based communication infrastructure. Here the profit reducing value is €15,196.99.

Phase 3 includes the full depreciation for electrical and communication infrastructure and the inflation-adjusted operational costs. From this point the profit reducing value starts with € 19,133.00

All three phases are shown in Figure 65: Scenario 2 / Impact on profit and loss:

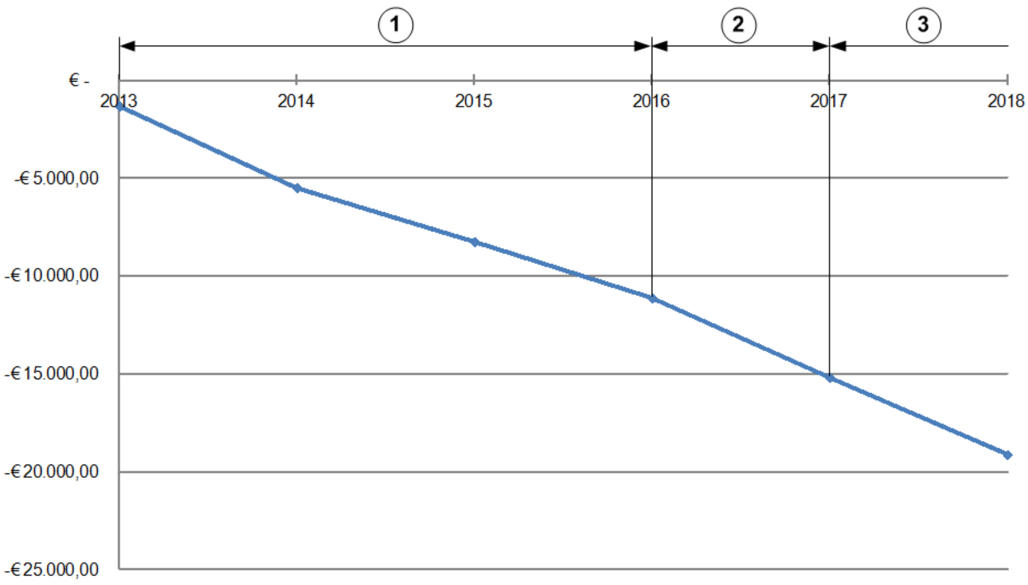


Figure 65: Scenario 2 / Impact on profit and loss (own calculation)

The Cash Flow analysis shows the following behaviour on this configuration (see Figure 66: Scenario 2 / Impact on cash flow)

In Phase 1 the cash-out starts with a higher payment for the construction of the electricity infrastructure of the low voltage distribution grid and the duct network for the later installed fibre optic network. With the new 3 tap transformer these costs influence the liquidity with €52,507.72. The three following years the cash-out is between €31,463.26 and €35,798.88 for the construction of the other segments and maintenance

In Phase 2 the additional fibre optic installation with fibre blow technology, the implementation of the active communication infrastructure and the constant maintenance costs influence the liquidity with €44,151.76.

In Phase 3 it starts with low cash out for the inflation-adjusted yearly maintenance costs.

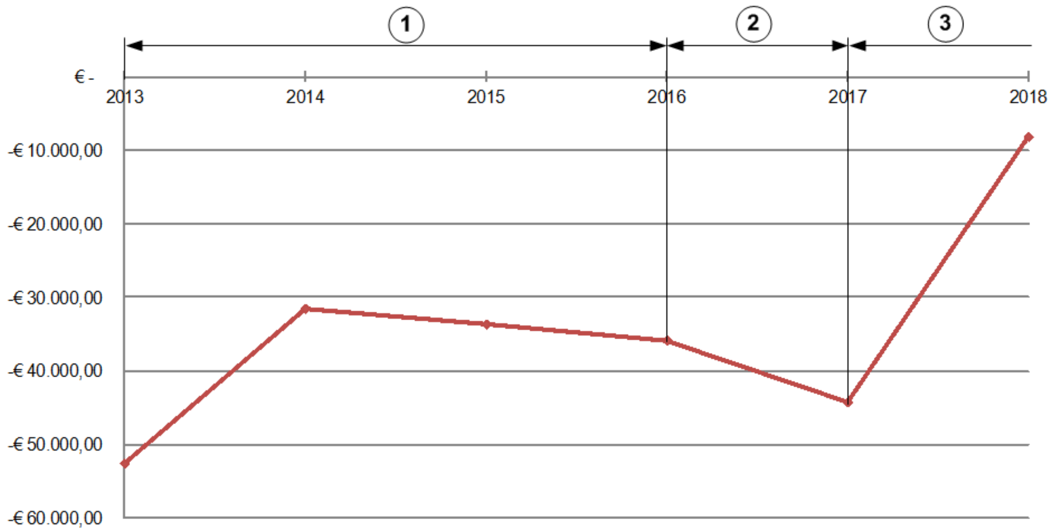


Figure 66: Scenario 2 / Impact on cash flow (own calculation)

5.3 Scenario 3: Full smart solution

Scenario 3 represents the full smart solution, where the electricity and communication infrastructure has to be built in the same step. The electrical configuration is equal to scenario 2.

5.3.1 Assumptions for Scenario 3

In the calculations of scenario 3 project costs the electrical and communication infrastructure are included. One main infrastructure element, the costs for the construction of low voltage grid transformer station is not taken in consideration.

The scenario has two phases of the realisation which are:

1.) Realisation of the electricity infrastructure in the year 2013, 2014, 2015 and 2016
2.) Up 2017 only maintenance of the infrastructure.

The costs for the first phase are the construction cost, cabling material and implementation of the interconnection point. The construction costs in the beginning are oriented on the situation that the scenario is on new established real estate area, where the cable construction can be done with a plug. The typical costs are in rural areas between € 50 to € 100/m. For the calculation €75/m were used.

The required transformer is in this scenario a 3-tap transformer with 240kVA, which costs 3 times more than a legacy transformer, around €24.000 and is calculated in the first phase of the implementation. The used cabling material is on the grid site a 4x150 cable and on the communication infrastructure again a 4 pair Single Mode fibre optic cable. Further the calculation includes all the pigtails, splices, pipe couplings, racks, the fibre optic switch and a Smart Meter with Ethernet interface.

The second phase includes no changes in the infrastructure only work based on maintenance.

5.3.2 Electrical characteristic of Scenario 3

The low voltage distribution grid electrical configuration of scenario 3 is defined only to use cables of type 4x150, same as in scenario 2.

This configuration shows on these short distances, one segment is maximum 196m, in a synchrony load situation without decentralised generation, based on the different load profiles on the reference days the following behaviour:

At the 28/1 the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.2% on a daily trend (see Figure 67: Scenario 3 / Total voltage deviation on a daily trend (28/1)).

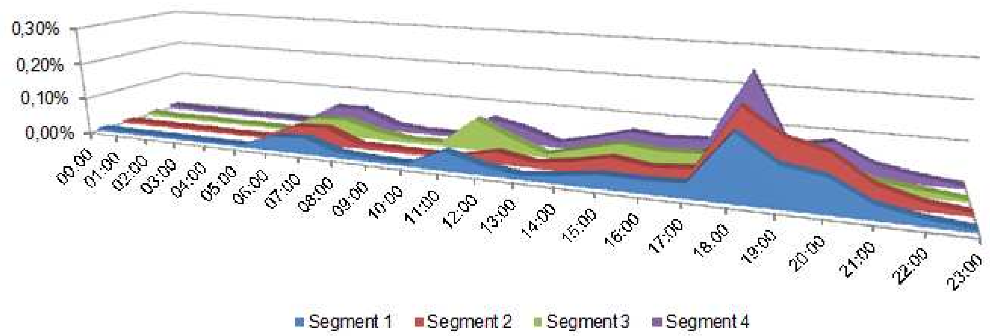


Figure 67: Scenario 3 / Total voltage deviation on a daily trend (28/1) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 06:00pm 83,9A (see Figure 68: Scenario 3 / Electricity deviation per segment on a daily trend (28/1).

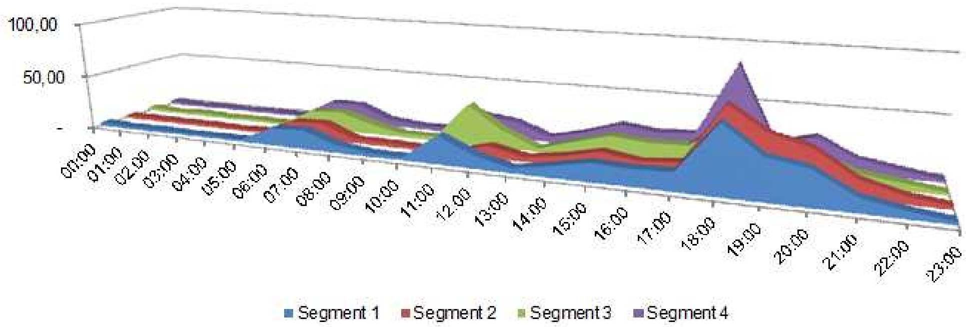


Figure 68: Scenario 3 / Electricity deviation per segment on a daily trend (28/1) (own calculation)

At the 21/6 the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.11% on a daily trend (Figure 69: Scenario 3 / Total voltage deviation on a daily trend (21/6)). Based on the used load profiles there are two peek points at around 11:00am and 06:00pm.

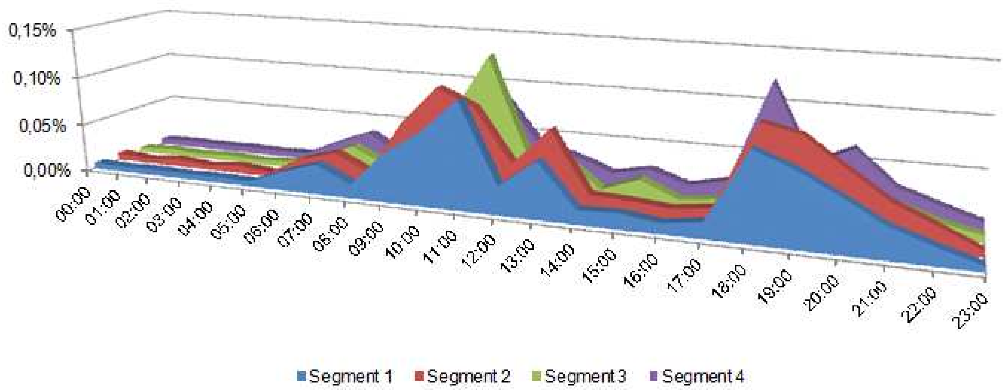


Figure 69: Scenario 3 / Total voltage deviation on a daily trend (21/6) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 11:00am 55A (see Figure 70: Scenario 3 / Electricity deviation per segment on a daily trend (21/6)).

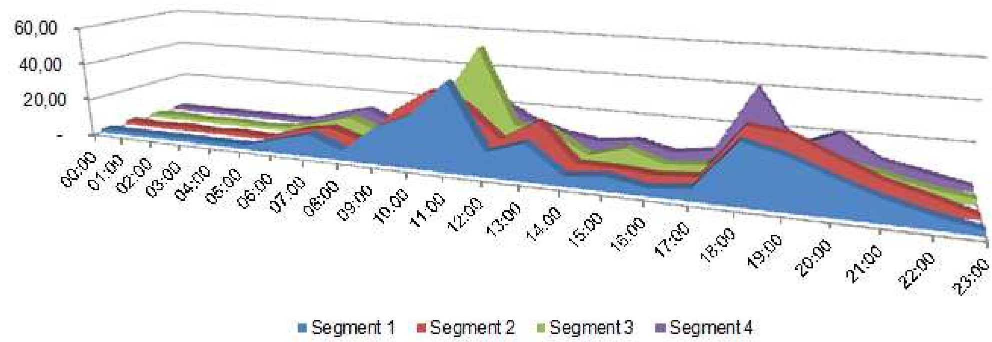


Figure 70: Scenario 3 / Electricity deviation per segment on a daily trend (21/6) (own calculation)

At the 16/10, where the used profiles shows the highest loads, the deviation of the maximum and minimum voltage in a segment is in total between 0.01% and 0.37% on a daily trend (see Figure 71: Scenario 3 / Total voltage deviation on a daily trend (16/10)).

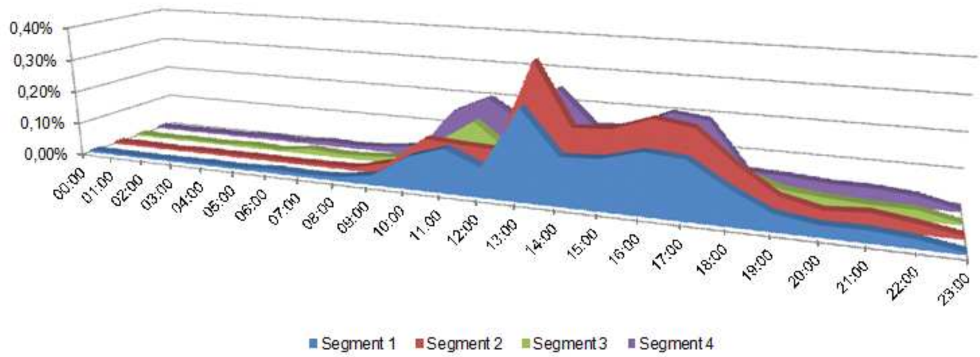


Figure 71: Scenario 3 / Total voltage deviation on a daily trend (16/10) (own calculation)

The maximum electricity, which has to be transported in the start point of the segment, is around 01:00pm 118A (see Figure 72: Scenario 3 / Electricity deviation per segment on a daily trend (16/10)).

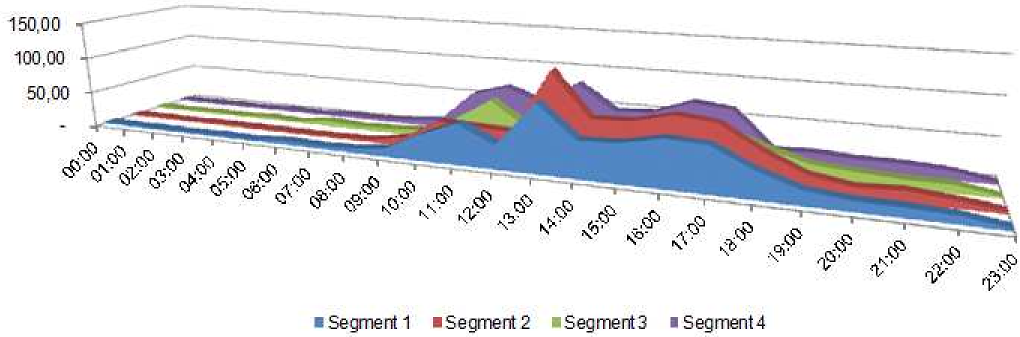


Figure 72: Scenario 3 / Electricity deviation per segment on a daily trend (16/10) (own calculation)

5.3.3 Commercial analysis of Scenario 3

In the commercial analysis only the costs of the scenario for a time period of 5 years is taken in consideration. The costs include in this time period the implementation costs and the maintenance costs in the defined operation time.

The first analyse base on the discounted cash flow method and shows the planned costs of the implementation for the next 5 years.

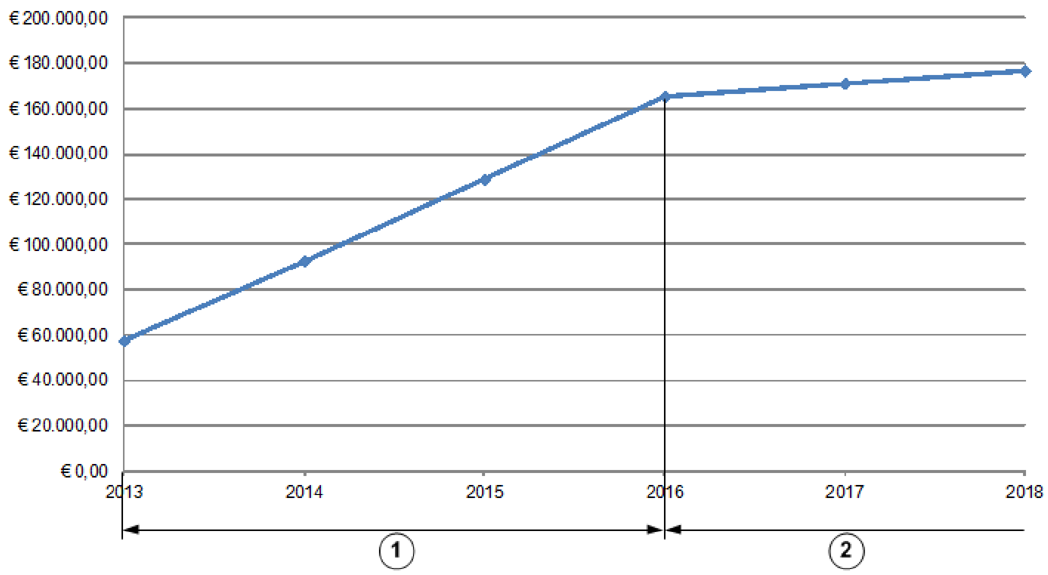


Figure 73: Scenario 3 / cumulated discounted cash flow (own calculation)

By analysing the cumulated discounted cash flow chart (see Figure 73: Scenario 3 / cumulated discounted cash flow) the two phases of the installation are visible again. The phases are with their dependencies:

Phase 1 includes the costs for the implementation of the electrical low voltage distribution grid and the complete communication infrastructure. The costs contains with the year 2014 a part of maintenance costs, where the percentage in total is increasing year per year (Figure 74: Scenario 3 / total cost distribution between implementation and maintenance).

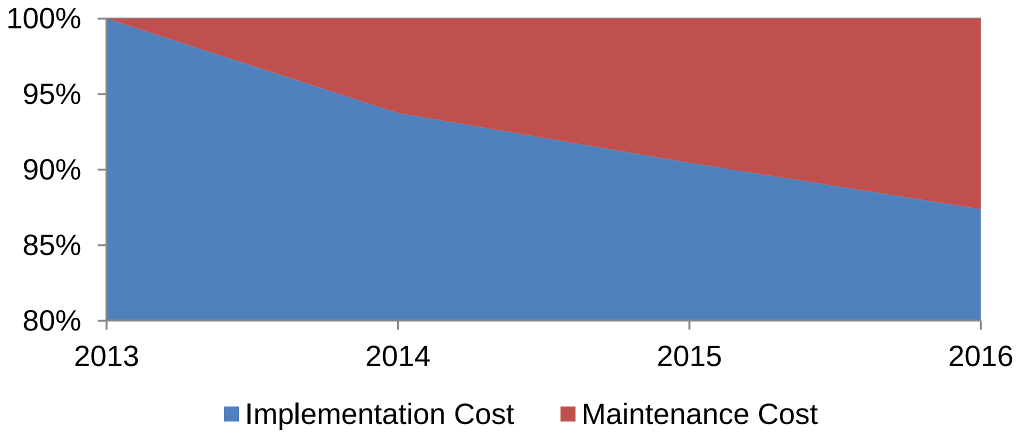


Figure 74: Scenario 3 / total cost distribution between implementation and maintenance (own calculation)

With Phase 2 only inflation-adjusted maintenance costs are included.

By calculating all the discounted cash flows with a discount rate from 4.5% there is a cost annuity by a 5 year period of €40,284.29. The sensitivity analysis based on this calculated annuity shows that the changes on the operational costs has less influence , then changes in the investment costs or the consumer price index (see Figure 75: Scenario 3 / Sensitivity analysis).

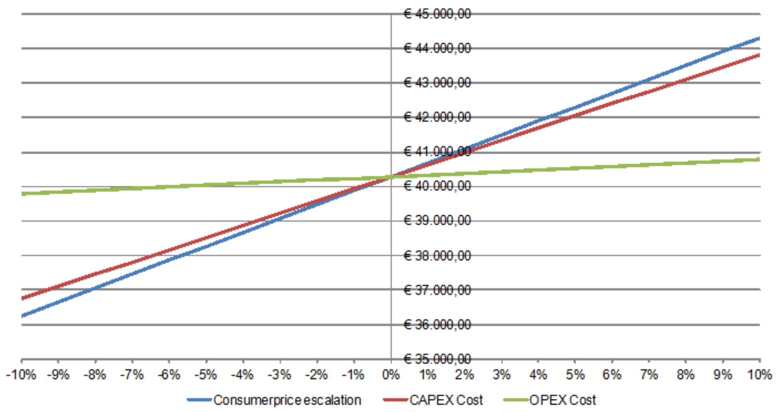


Figure 75: Scenario 3 / Sensitivity analysis (own calculation)

In the profit and loss analyse the influence of the installation on the tax related profit. The calculation includes the point that an installation is done in the second half of a year, the depreciation can only be set half in the profit reducing calculation. The depreciation in the calculations for the electrical infrastructure is set to 20 years; the communication infrastructure is according to information from Salzburg Netz AG between 10 (active) and 15 (passive equipment) years, in the scenario for simplification it is set to 10 years.

Phase 1 in this scenario has full impact on tax reduction of the company profit; it includes the depreciation and the operational costs of the electrical infrastructure of the low voltage distribution grid and the communication infrastructure.

Phase 2 is the raise of the last half of the depreciation of the infrastructure and the first time the inflation-adjusted operational costs.

Phase 3 includes the full depreciation for electrical and communication infrastructure and the inflation-adjusted operational costs. From this point the profit reducing value starts with € 16,209.88

All three phases are shown in Figure 76: Scenario 3 / Impact on profit and loss:

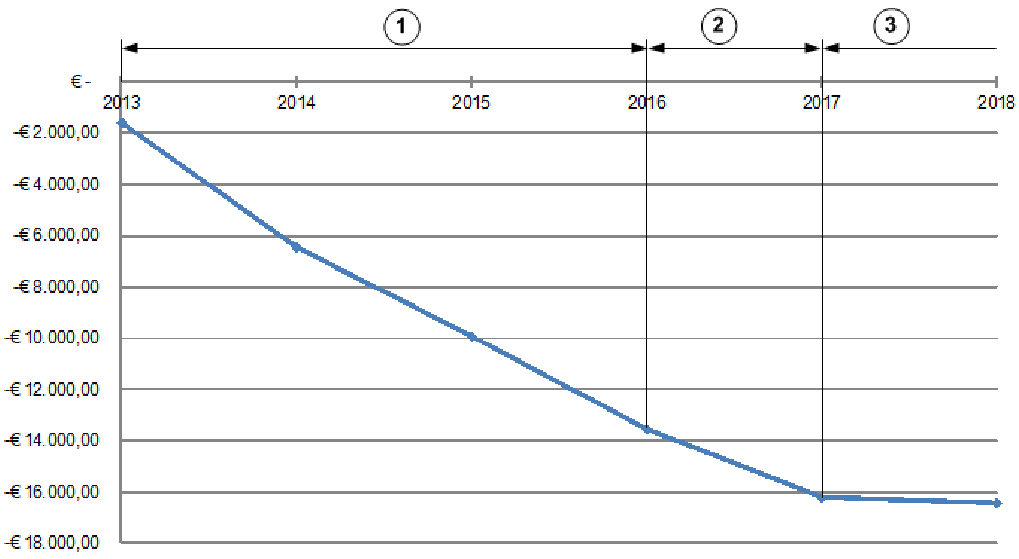


Figure 76: Scenario 3 / Impact on profit and loss (own calculation)

The Cash Flow analysis shows the following behaviour on this configuration (see Figure 77: Scenario 3 / Impact on cash flow)

In Phase 1 the cash-out starts with a higher payment for the first construction and the new 3 tap transformer and influence the liquidity with €57,487.00. The three following years the cash-out is around €40,000.00 for the construction of the other segments and maintenance

In Phase 2 it starts with low cash out for the inflation-adjusted yearly maintenance costs.

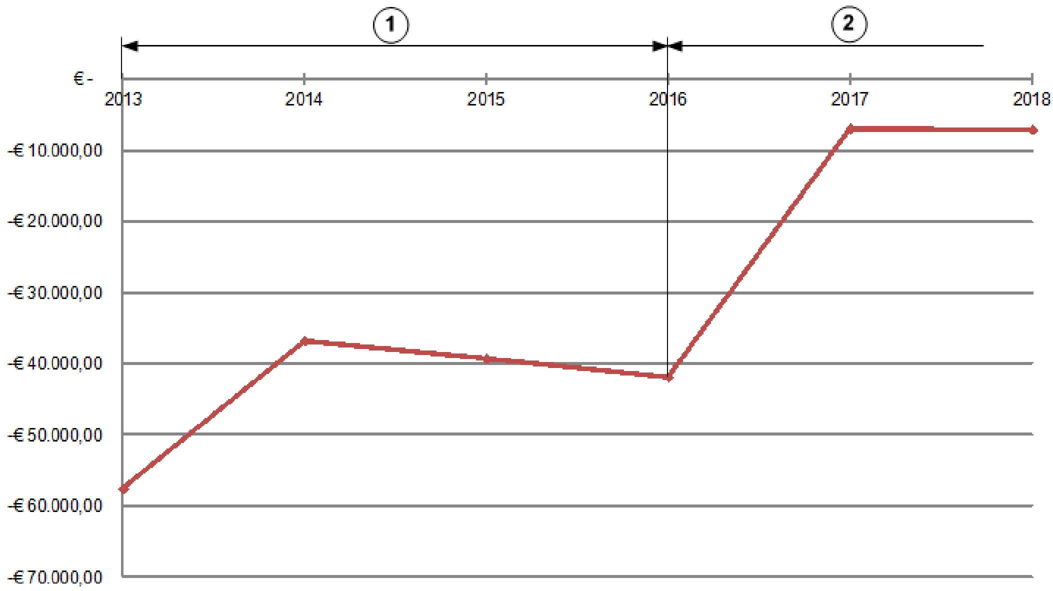


Figure 77: Scenario 3 / Impact on cash flow (own calculation)

6 Scenario comparison

After discussing the electro technical and commercial arguments of the three Greenfield scenarios of building a low voltage distribution network, the following section is concentrating to find out, based on the previous facts, which scenario helps the distribution network operator to fulfil the technical and legal requirements.

The main requirement is to build up an electro technical base infrastructure, which has enough reserves for the additional connection of decentralised generation's units and a high flexibility for future expansions. To the electricity grid a communication network is required, which is fibre optic based with rough type network switches for out-door use that provides an open IP-based platform for present and future smart grid applications. Additional to the two infrastructural requirements the metering infrastructure has to be according the metering law a smart meter solution.

Scenario 1 concentrates on an implementation method, which base on the standard method, used by the operators since the last years. For the connection of customers cables with different sections are used. This reduced in the past the costs for the implementation of consumers. Nowadays this implementation is critical for the connections consumers, who are producer in the same moment. The communication network is a 4 pair single mode fibre optic cable, were the implementation comes in the second phase.

Scenario 2 is the next step of the implementation, where a 3 tap transformer and one type of cable are used. The 3 tap transformer opens by finishing the complete communication network the possibility for an active control for balancing the low voltage distribution grid segment. The reductions to on cable type (4x150) moves the complete electrical segment to the same quality level and reduce the losses. This method, increase the cable price for the installation, but in the other side, there are possibilities to decrease costs by the procurement- and the logistic process. The installation of the communication network is split into two phases. In phase 1 empty duct are installed with the electrical infrastructure in the same construction process. In phase 2 the fibre optic cables were installed with high pressure in this duct network and finally the network elements and additional network modules for the smart meter.

Scenario 3 is the solution, which is the electrical infrastructure equal to solution 2, but in the same construction step the complete communication infrastructure, inclusive smart meter were installed.

Table 10: electrical characteristic of the scenarios

Scenario	Transformer type	Max. voltage deviation in the scenarios 28/1	21/6	16/10	Comments
Scenario 1	Classical transformer with no possibility to control the voltage deviation in standard operation of the low voltage grid	0.6%	0.32%	0.85%	This configuration has a higher power loss based on the cable infrastructure as scenario 1 & 2
Scenario 2	3 tap transformer offers 3 voltage outputs for the balancing of the low voltage grid in operation	0.2%	0.11%	0.37%	Combination of 3 tap transformer and high quality cable types
Scenario 3	3 tap transformer offers 3 voltage outputs for the balancing of the low voltage grid in operation	0.2%	0.11%	0.37%	Combination of 3 tap transformer and high quality cable types

After comparing the electrical characteristics scenario 2 and 3 are to favour for this area (summary Table 10: electrical characteristic of the scenarios). Additional has scenario 1 a limitation on the control of the transformer, and cannot provide an active control for the low voltage distribution grid.

In the next step the commercial aspects of these scenarios were compared. To get a clear picture it was needed to get a fourth scenario into consideration, it is the classic installation without communication infrastructure. This scenario is called “Scenario classic” and base on scenario 1 without the additional communication infrastructure.

The first comparisons are the annuity costs based on a 4.5% discount rate and 5 year period (see Figure 78: Annuity cost comparison). In this comparison the scenario 3 with the full installation is the cheapest version from the compared scenarios'. The reason for this is that scenario 1 needs additional construction and scenario 2 includes additional costs for the afterwards installed fibre optic infrastructure.

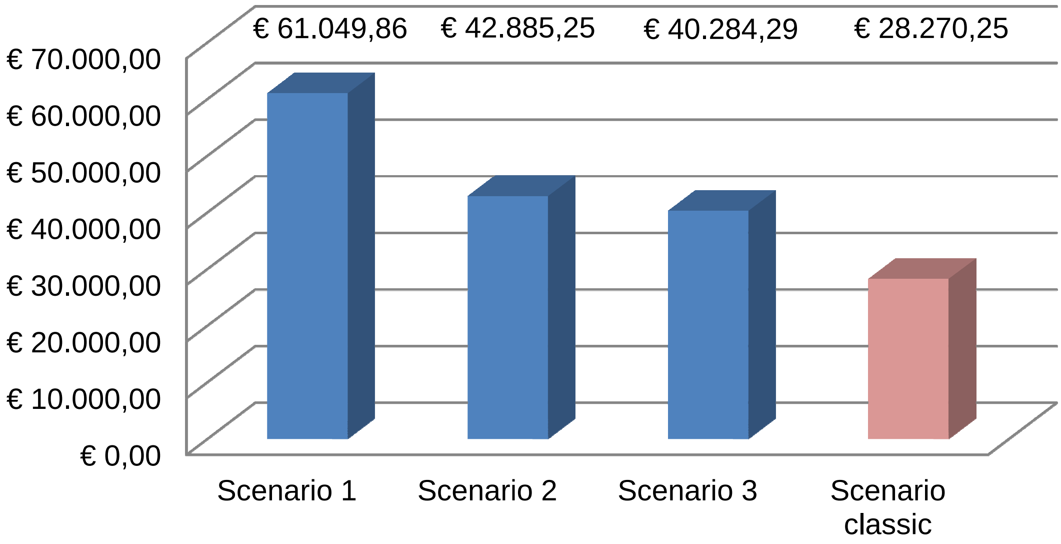


Figure 78: Annuity cost comparison (own calculation)

The comparison of the total costs against the classic scenario the full implementation costs 42% more than an installation without an infrastructure for smart solutions (see Figure 79: total cost compare against classic scenario).

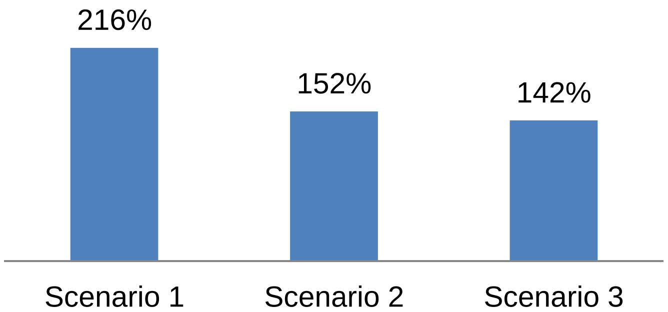


Figure 79: total cost compare against classic scenario (own calculation)

By analysing the cumulated discounted cash flow chart (see Figure 80: comparison cumulated discounted cash flows) three phases of the installation are visible again. The phases with their dependencies for the scenarios are:

In phase 1 the time period 2013 to 2016, all three scenarios have the main construction phase. The costs for the scenario 1 is this period the lowest, out of the reason, that only electrical installations were done and a standard transformer is used. Scenario 2 includes a 3 tap transformer and the duct structure. In Scenario 3 the costs include the 3 tap transformer and the complete communication infrastructure.

Phase 2 in the year 2017 includes the installation of the communication infrastructure in scenario 1 and 2. In scenario 1 these costs increase, based on the construction work in that way that it pass extreme the costs of scenario3. Scenario 2 has additional costs too, but in a limiter scale as scenario 1. Scenario 3 has its full range of functionality and has from this time only the inflation-adjusted maintenance costs.

In Phase 3 with start 2018, all scenarios have at this point the full range of functionality and only the inflation-adjusted maintenance costs.

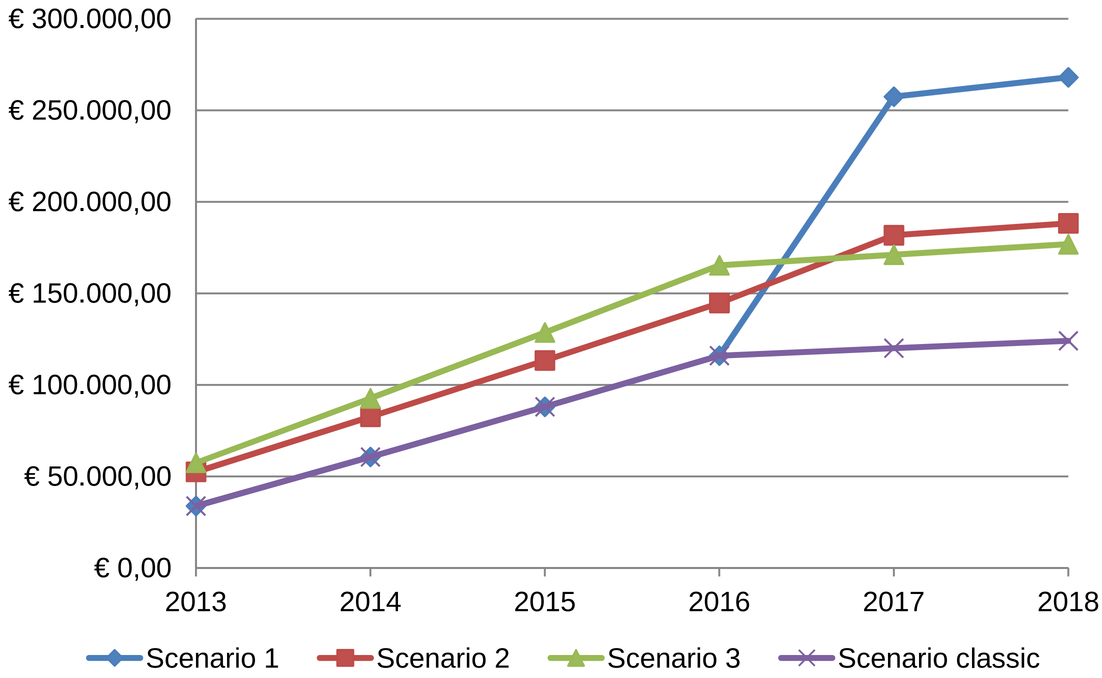


Figure 80: comparison cumulated discounted cash flows (own calculation)

The comparison of the profit and loss shows between the three scenarios the same behaviour than by the discounted cash flow analyse. In the time period between 2013 and 2016, scenario 3 offers the highest profit reduction against the tax. With 2017 the scenario 1 offers the highest profit reduction (see Figure 81: comparison of the profit and loss impacts of the scenarios).

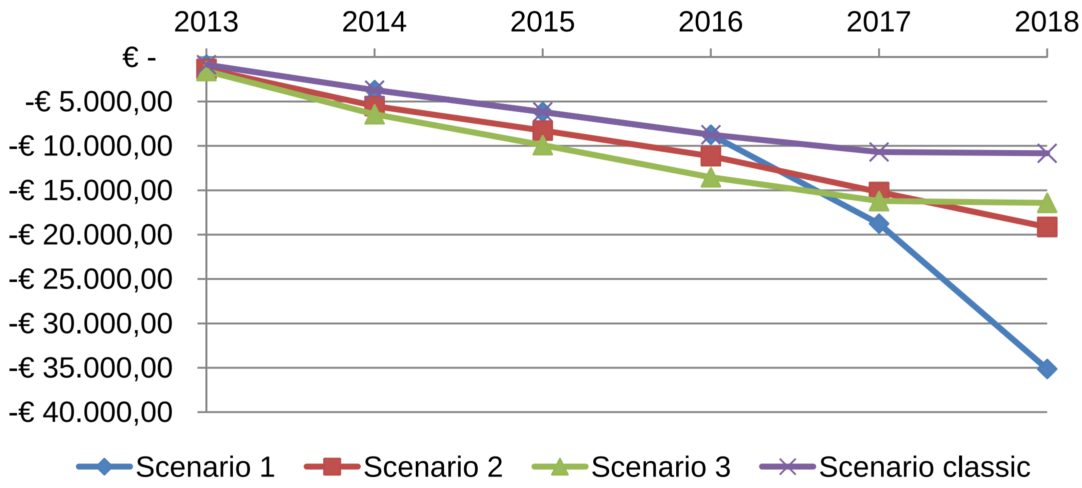


Figure 81: comparison of the profit and loss impacts of the scenarios (own calculation)

The Cash Flow analysis shows the following behaviour on the liquidity of the three scenarios (see Figure 82: comparison of the liquidity impacts of the scenarios)

In Phase 1, the time period between 2013 and 2016 the lowest cash out has the installation scenario 1. Scenario 2 starts, based on the installation of the 3 tap transformer, with a higher amount (€52,507.72) and is the rest of the time between €34,463.26 and €35,798.88. Scenario 3, which has in this time period the highest cash out, starts as scenario 2, based on the 3 tap transformer with a higher value (€57,486.84). The rest of the time period the cash out is between €36,790.92 and €41,873.58.

In Phase 2 the high construction costs and the constant maintenance costs influence the liquidity of scenario 1 with €168,683.00. Scenario 2 has only the cash out for the additional communication infrastructure. Scenario 3 reduces the cash out only to the inflation-adjusted maintenance costs.

In Phase 3 it includes only the cash out for all scenarios for the inflation-adjusted yearly maintenance costs.

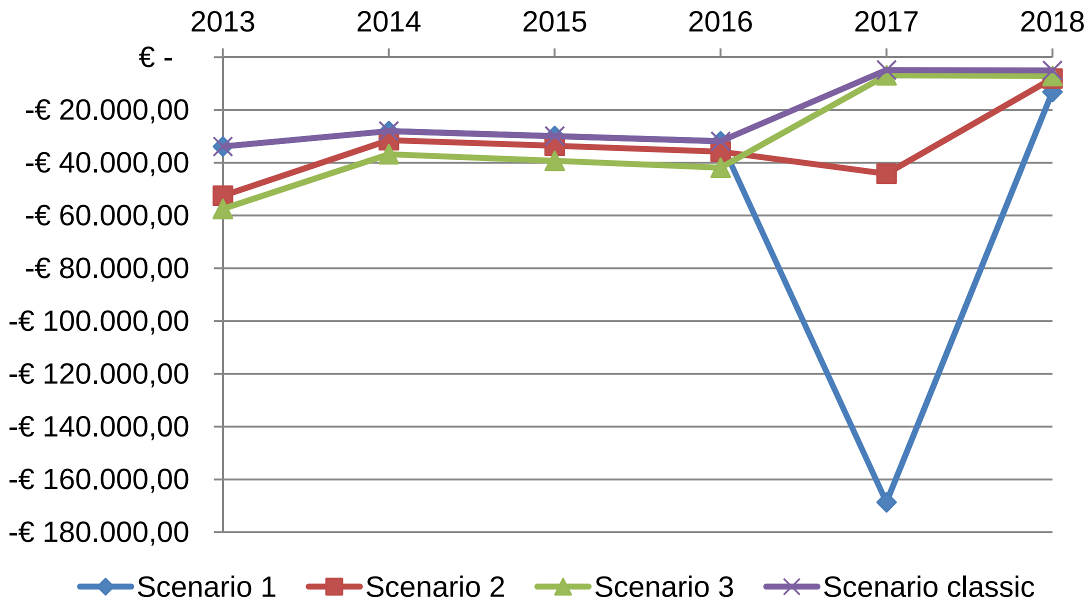


Figure 82: comparison of the liquidity impacts of the scenarios (own calculation)

7 Conclusion

To show the difference on one view between in the previous chapter described commercial comparisons, the following table gives a short summary of the most important key facts (Table 11: Summary commercial scenarios).

Table 11: Summary commercial scenarios

Scenario	Annuity costs	Discounted total costs	Total cost compare against classic scenario	Max. Cash Out
Scenario1	€ 61,049.86	€ 268,007.46	216 %	€ 168,682.83
Scenario 2	€ 42,885.25	€ 188,265.26	152 %	€ 52,507.72
Scenario 3	€ 40,284.29	€ 176,847.11	142 %	€ 57,486.84

After summarizing all technical and the commercial information, scenario 3 is the optimal solution for the implementation of a Greenfield smart distribution grid expansion. It shows that with this solution all the future requirements to the distribution grid operator can be fulfilled and this on a cost optimised base. The covered key requirements are:

1.) Higher capacity in the distribution grid infrastructure for decentralised generated energy

2.) High Bandwidth with this fibre optic network, for implementation of intelligent and real time control of the network
3.) Open platform for future smart grid applications

Additional to the main criteria the following issues are implemented too:

1.) Open communication IP-platform based on a fibre optic infrastructure – standard industrial products can be used
2.) Basic protection in the communication network structure
3.) Implementation of the new distribution grid transformer generation for active control
4.) Implementation of smart meters on Ethernet base

The operator have by implementing this type of smart grid infrastructure in the Greenfield area the possibility to share parts of the physical fibre optic infrastructure with telecom operator, this helps optimising the costs, or open a new business segment in the area of unbundling. Another possibility is to request subsidies for the building of broadband services like "Breitband Austria Zwanzigdreizehn" and build the infrastructure with telecom operators together

If a grid operator made a decision, not to invest in a full fibre optic based communication infrastructure in the beginning, as it is in scenario 3, he should minimum invest in scenario 2, were an additional adaption with fibre optic is possible with an reduced effort and costs.

Last a fibre based communication network of a smart distribution grid opens for the future developments of smart grid applications. Many companies out of the IT and Telecom industry shows now the first communication concepts in which direction the developments will go. All this concepts are built on a strong communication infrastructure and a high quality active controlled distribution network.

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