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Energy network regulation and management

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Abstract :

In a world where electricity is everywhere, new production techniques as renewable energy and a constant growing consumption tend to make energy production difficult. The supply and demand balance needs to be satisfied and different methods have been developed. The best way to give the production needed is to forecast the demand. Those forecasting techniques are continuously changing as the production become more and more variable. In another way, government takes decision to force people to consume energy when they are producing it thanks to wind turbines and photovoltaic panels. Those decisions avoid the network to store the exceeding energy in a poor efficient manner. Raising awareness of people will allow to safe money to everyone because a lack of energy needs to be filled with border countries trading.

Résumé :

Dans un monde où l'électricité est partout, les nouvelles techniques de production comme les énergies renouvelables et une consommation en constante augmentation tendent à rendre la production d'énergie difficile. L'équilibre entre l'offre et la demande doit être satisfait et différentes méthodes ont été développées. La meilleure façon de fournir la production nécessaire est de prévoir la demande. Ces techniques de prévision changent constamment, car la production devient de plus en plus variable. D'autre part, les gouvernements prennent la décision de forcer les gens à consommer leur énergie lorsqu'ils en produisent grâce aux éoliennes et aux panneaux photovoltaïques. Ces décisions évitent au réseau de stocker l'énergie supplémentaire de manière peu efficace. La sensibilisation de la population permettra à chacun de gagner de l'argent car le manque d'énergie doit être comblé par le commerce avec les pays frontaliers.

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Preface

A good practice at the end of a degree is to write a thesis. This master thesis allow me to keep learning things. Those things are very interesting and profitable for my career as it will allow me to have a better understanding of team management and business management.

This degree will also be an extra string to my bow and will enable different career orientations. Moreover, and that is what I like in this degree, all those courses will help me in my day to day life : negotiating a house price, investing in financial products, optimizing process and even psychology.

Energy network management is a complex subject with different dimension : demand and supply, trading, forecast and governmental regulations. Some parameters as variable production, weather condition and consumer randomness tend to make it even more complex.

Hopefully, this master and my technical knowledge will help to understand and identify methods of energy management. As energy consumption is in a constant growing, those methods will always need to evolve and enhance.

Chapter 1

Introduction

Electric network is a very complex subject. It involves a good knowledge of electricity and of other concepts as the voltage, the current and the resistance. It is also necessary to know about power and energy: how it is produced and where the losses are. A small reminder will be available at the beginning of this paper.

The global energy consumption is continuously growing. Almost every object we are using need electricity : cars, ring-bells, alarm clocks, lights, tools, electrical hobs, computers, smartphones and so on. As a consequence, the demand and the offer remain difficult to balance due to the variability of the consumption. In addition, more and more household install photovoltaic panel or even wind turbine generators. Those generators have a variable production depending on the weather forecast. The forecasting of the energy production needed is then even harder than ever.

To smooth those uncertainties, some techniques have been developed. Indeed, storage techniques like pumped hydro are in place to absorb all the non-used energy and store it. This energy can be used when needed. Storage techniques still contain losses of energy and are not ideal to avoid wasting. Another smoothing technique is to the trading between countries. So, when there is a lack of energy, a country can buy energy and avoid a blackout. Of course, trading has a cost and is not profitable neither for the buying country nor for households among it.

Electricity is a critical challenge as it is used to supply hospitals, traffic lights, phones and soon a lot of vehicles [1]. The electricity production is as critical as difficult to forecast because of the variability and randomness of the consumption. This paper will try to explain how power can be managed.

[1] More and more people choose an electric car and more and more public transport use electricity as fuel.

Chapter 2

Electrical basis

It is interesting to have an overview of what is the voltage, the current, the power, the energy, etc... Before talking of the energy network management.

2.1 Voltage, current and resistance

Voltage [V] expressed in Volt (V) is the cost of energy needed to move a charge between two potential. Voltage can be direct or alternative. In this paper, we will mainly talk about alternative voltage as it is the one used in the grid.

Current [I] expressed in Ampere (A) is the flow of electric charge passing through a conductor. As the voltage, the current will be used in grid application as alternative current (AC).

Resistance [R] expressed in Ohm (Ω) is the ratio of current to voltage $\frac{V}{I} = R$. Resistance can be considered as a load. For example, an electric heater is a resistance subjected to a voltage and then a current. But at the end, even a wire is a resistance (even if very small). [Horowitz and Hill, 1989]

The interaction of the voltage, the current and the resistance is shown in Figure 2.1. As mentioned for voltage and current, those are alternative in the grid and house. The alternative electricity is used because of the transport efficiency in the grid. Indeed, with alternative voltage we can reach lower loss on cable. The waves have a frequency of $50\,\mathrm{Hz}$ in Europe (Figure 2.2) and of $60\,\mathrm{Hz}$ in other countries.

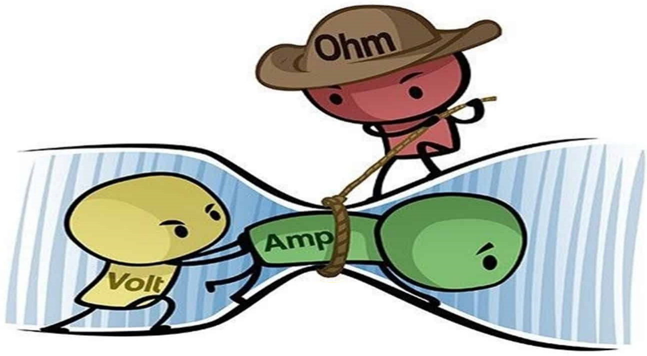

FIGURE 2.1: Illustration of how electricity works [Thegeekpub]

This frequency is very important for the network and nothing below or above this frequency should go in the grid. For example, wind turbines produce alternative electricity with a frequency equal to the rotor speed. This speed is never equal to $50\,\mathrm{Hz}$. This involve that the voltage and current need to be rectified by electronics and then alternate again.

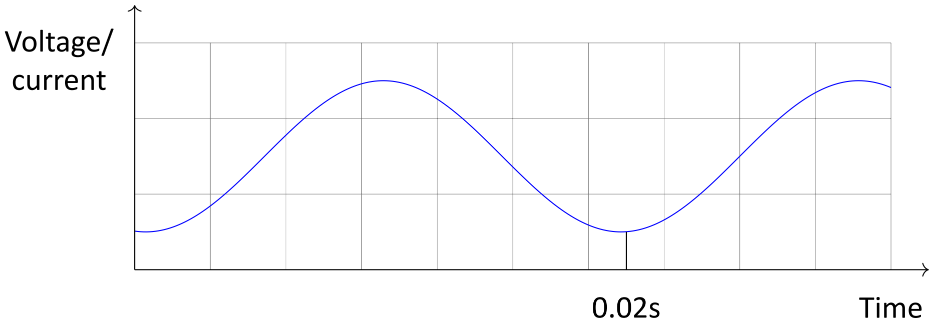

FIGURE 2.2: Evolution of voltage and current at $50\,\mathrm{Hz}$

2.2 Power and energy

Power expressed in Watt [W] is the current times the voltage $V \cdot I = P$. For example, a $1\,000\,\mathrm{W}$ toaster in a house will need $\frac{1000W}{162V} = 6.17$[1] A.

Energy expressed in Joule [J] but commonly expressed in Kilowatt-hour $\mathrm{kW\,h}$ in the electric world. The energy is simply the power through the time expressed as the integration of the power $\int_{t_1}^{t_2} P\,dt$. Which simply means that to toast

[1] As the voltage is a 230 V alternative, we need to take the rms value which is equal to $\frac{230V}{\sqrt{2}} = 162V$

a bread during $5\,\mathrm{min}$ we need $1000W \cdot \frac{1}{12} = 83.33\ \mathrm{W\,h}$ which is equal to $0.083\,33\,\mathrm{kW\,h}$

With those two statements, it is important to mention that what is consuming a lot is not always the more powerful devices. Indeed, a $4\,000\,\mathrm{W}$ device that is used during $1\,\mathrm{h}$ will consume $4\,\mathrm{kW\,h}$ whereas a $500\,\mathrm{W}$ device will consume $12\,\mathrm{kW\,h}$ during $24\,\mathrm{h}$. That is why the main consumption of a household is the cooling part. Indeed, it is powerful device working all the time. The same statement is applied to device standby, it is a very low consumption but always ON which means that it will be a high consumption at the end of the year [Bertoldi and Atanasiu, 2007].

2.2.1 Joule effect

As illustrated in Figure 2.1, resistance will slow the current whereas the voltage will to push it. This resistance will induce losses and as even a wire is a resistance losses will be everywhere. Those losses are transformed in heat. Those losses are called "Joule effect", the calculation of those losses is:

$$P_{lost} = R \cdot I^2 \tag{2.1}$$

We will try to reduce as much as possible the resistance (R parameter) of a wire to reduce the loss of power. Moreover we will try to reduce the current through the resistance as it is a squared parameter in Equation 2.1.

2.3 Electricity production

To have a better understanding of the different manners to produce electricity, we will briefly talk about how it works and the different type of production.

2.3.1 Power plant

Power plant are as shown in Figure 2.3 mostly nuclear and thermal (gas) and represent 83.8% of the power production in Belgium in 2019. The principle of those power plant is quite the same. They are using an energy source as nuclear and gas and use it to heat water. When this water became steam, it goes through a turbine which will start spinning and produce electricity thanks to an alternator [2]. Hydro energy is also used to produce electricity. The difference with nuclear and gas is that it is the water who goes through the turbine to produce electricity. This kind of production is small in Belgium (≈1.1%) because it is very specific to a place. Of course the bigger the turbine, the bigger the production. That is why power plant are today the main electricity source. However, an important point to mention is that the bigger the turbine, the harder it is to make it turn. Which means that we are not able to increase or decrease the production as fast as we would like due to inertia[3].[Köpp, Mettenheim, and Breitner, 2013]

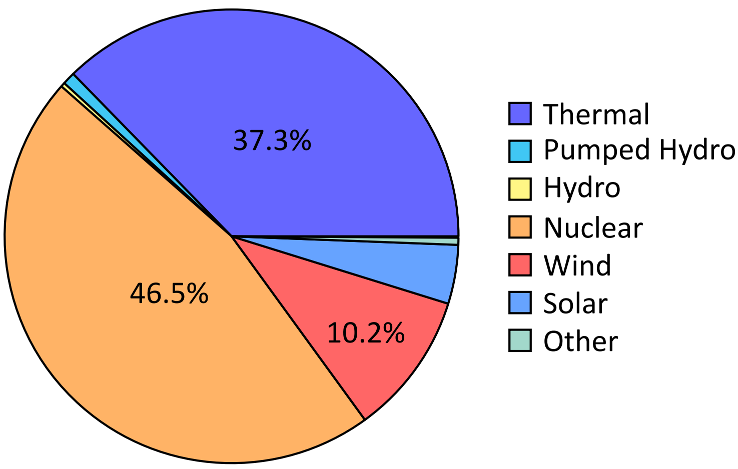

FIGURE 2.3: Pie chart of the power production in Belgium [Febeg]

When the electricity is produced, it is send to the network with very high voltage to limit the losses ($P = V \cdot I^4$). As the cable are closer to houses and factories, the

[2]An alternator is similar to an electric motor, the only difference is that a motor is turning while there is a voltage on it and an alternator produce voltage whereas it is spinning.

[3]Inertia is the trend of body to maintain its speed. A big wheel will be hard to move but also hard to stop while it is moving.

[4]High current gives high losses in wires. As the power send to the network is fixed, we can reduce the current value by increasing the voltage.

voltage will be decrease step by step.

2.3.2 Renewable energy

The most common renewable energy are solar and wind. Wind turbine is quite similar to a power plant working as it is a turbine spinning thanks to the wind instead of water in power plant. For the solar energy, we are using photovoltaic cells (pv cells) who are electronic components that produce a voltage when it is exposed to the light. These pv cells produce a DC voltage which needs to be alternate to be sent to the network. The major problem of those renewable energy is that we are not able to control them. Indeed, we need light and or wind for those devices to work. As you can see in Figure 2.3 wind energy is 10.2% and solar 4.2% for a total of 14.4%. The trend of government is to promote those kind of energy to reduce nuclear and gas production. This will involve uncertainties on the power production and will bring to power trading between countries.

Chapter 3

The grid

3.1 How the network works

The electrical network (Figure 3.1) is composed by 3 types of elements :

- Generator;
- Load;
- Storage.

The idea of an electrical network would allow a balance between the produced electricity (*Generator*) and the consumed electricity (*Load*). Nevertheless, this balance is difficult to reach because :

- The load is not entirely predictable;

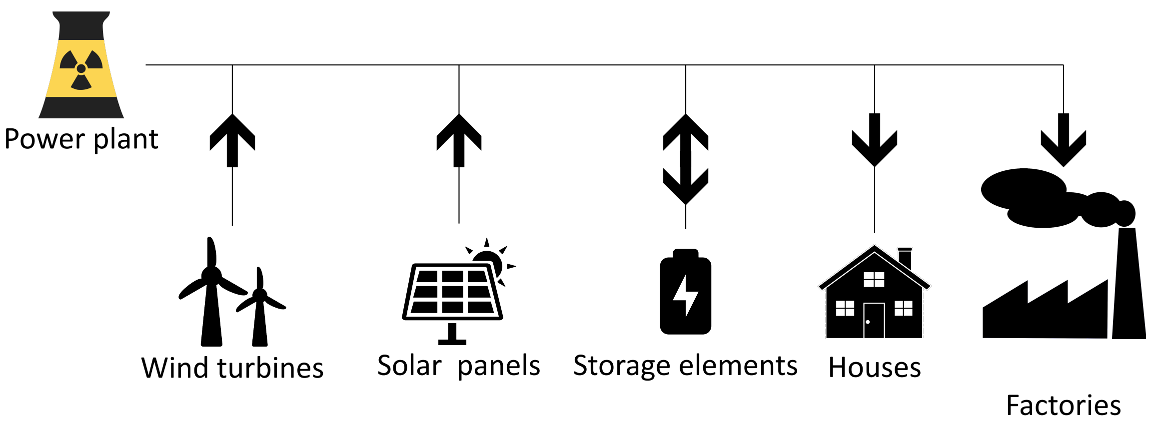

FIGURE 3.1: Illustration of a grid with generators, loads and storage.

- A part of the generated electricity varies because of the energy produced by the wind-turbines, photovoltaic panels, etc...;
- Changing the power output of a controlled generator takes time.

In the light of the above, a balance is not possible. That is the reason is why the production is always higher than the consumption.

Furthermore, the storage is there to absorb the degree of uncertainty. Unfortunately, this storage technique is not really efficient and costs a lot.

3.2 Micro grid within the Grid

A micro-grid is a reduced version of a grid. The energy is shared by and with multiple users. Some users produce energy with photovoltaic panels, or with wind turbines and others stored the energy. The micro-gird is a subsystem connected to the main grid. The idea of this connection is to prevent a breakdown [Milczarek, Malinowski, and Guerrero, 2015]. Micro-gird is of course a way to limit the main network dependency in an energetic and economic point of view. Today in Belgium, there is no real micro-grid as people with solar panels or wind turbines are unable to have an energetic independency and only have an economic advantage. Indeed, if there is a breakdown and if you have solar panels or a wind turbine you do not have electricity either. This is because the solar electricity producer never consumes its own electricity. This electricity is injected in the network. Moreover, in a domestic installation, inverters [1] and rectifiers [2] are supplied by the network. As a consequence, when there is a breakdown, domestic productions are off which proves that domestic producers are not energy independent.

[1] Inverters are electronic components used to oscillate voltage and current . Indeed, the electricity used on the network is alternative current (AC) and this current is oscillating at $50\,\mathrm{Hz}$ in Europe.

[2] Rectifiers are electronic components used to change an alternative current (AC) to direct current (DC). This component is mainly used by wind turbine who produced unstable AC.

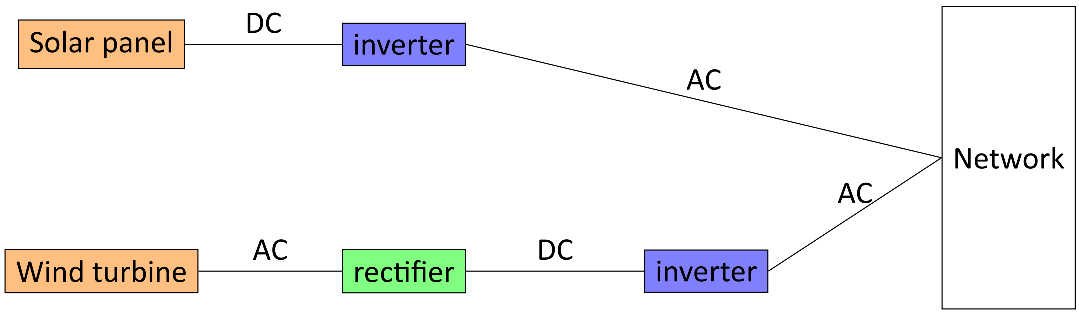

FIGURE 3.2: Schematic view of the electronic needed to connect an installation to the grid.

In Figure 3.2, we can see inverters and rectifiers used to connect solar panels and wind turbines to the grid. Wind turbines produce unstable AC current that needs to be rectified and oscillated to match the $50\,\mathrm{Hz}$ of the network.

3.3 Why is energy management difficult?

Below is a non-exhaustive list of difficulties in the energy network management. All of these points will be approached in this section.

1. Growing consumption
2. Instable DR
3. Blackout
4. Variable production
5. Infrastructure
6. Storing energy

3.3.1 Growing consumption

Each year, the global electric consumption is growing. On the one hand, there are every day new electrical devices (eg: electric cars). And on the other hand, there are also more and more people. This naturally leads to a higher electric consumption.

Application	Consumption [TWh]
Heating	8,61
Lighting	17,32
Refrigerators freezers	19,36
Washing machines	9,08
Cooking dishwasher	8,90
Hot water	6,06
Consumer Electronics and stand-by	11,36
Miscellaneous	5,84
Total	86,53

TABLE 3.1: Electricity consumption in Europe per year [Bertoldi and Atanasiu, 2007]

For example, in Europe between 2003 and 2004 there was an increasing of ≈ 2 %. [Bertoldi and Atanasiu, 2007].

As we can see in Table 3.1, the biggest part of the electricity is consumed by lighting, freezers and stand-by electricity. Those consumptions are quite simple to manage because they are static consumptions. Freezers are always on, as well as stand-by consumption. The lights are usually on by night, so this consumption can be considered as fixed. This fixed amount of energy is important because it can be considered as a fixed production.

3.3.2 Instable demand response

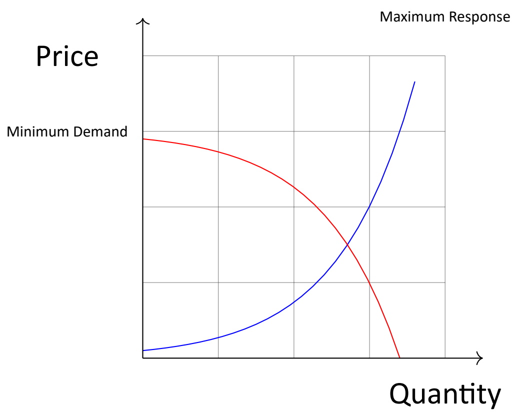

FIGURE 3.3: Demand response diagram

As every product on the market, the electricity is also governed by the law of supply and demand. The goal of the energy producers is to maintain a balance between demand and response. As seen in the subsection 3.3.1 there is a fixed amount of energy that is consumed by the freezers, the lights and consumer electronics. So we know that we will always have a minimum demand as shown in Figure 3.3. What remains of the consumed energy is going to be randomly used.

This consumption can be forecast thanks to previous data and mathematics. There are multiple methods to forecast demand. The most promising method is software based. The best software based method will be the neural network or artificial neural network. This method is used in a lot of applications as the principle is to learn from its experience. The advantages of artificial intelligence (AI) is that it is very powerful, but it needs a lot of data to be efficient. Moreover, each neural network needs to be trained. And this training takes a lot of time [Singh et al., 2013].

Hopefully, the means of communication are constantly improving and will allow to gather a lot of data that will be processed. This type of grid is called a smart grid. As shown in Figure 3.4, a smart grid is a grid with a communication system between all the element of the grid. This communication allows the forecast system to improve their responses. In that way, energy producer can adapt its production to avoid waste and blackout.

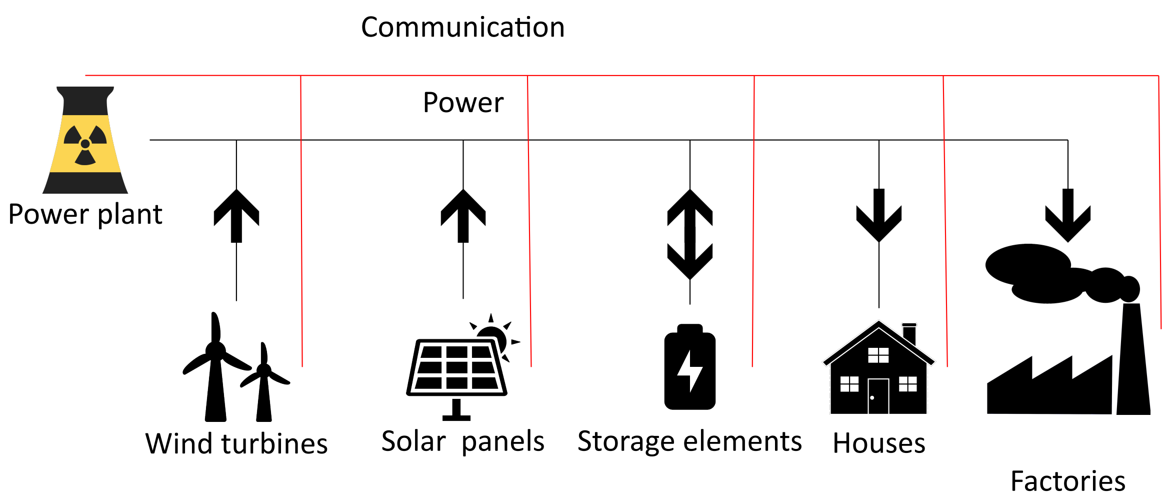

FIGURE 3.4: Smart grid

The problem of energy is that we've almost lost the control of response. Indeed, the energy offer can be controlled when the generator is a nuclear plant or fossil plant [3] . Unfortunately, renewable energy has included variable production that induces sometimes too much energy for the demand. If the demand decreases and the offer increases, the market needs to reduce its price. When both trends diverge, the price needs to be reduced sometimes until negative price. To absorb the amount of energy, producers are selling energy at a negative price which means that consumer is paid to consume energy. This transaction is often done between producers and the industry consumers. The renewable energy generators or uncontrollable energy generators with a big production capabilities are really dangerous for the energy network management.

For example, the original alarm clock that was mechanical became electric. This means that, instead of consuming $0\,\mathrm{W}$ a classic alarm clock consumes now $\approx 15\,\mathrm{W}$ which is not a lot. Now, if we take the european population of 446 Million where $\approx \frac{2}{3}$ use an electric alarm clock, the global consumption become $4\,460\,000\,\mathrm{W}$. This consumption is equal to 3 nuclear plants.

This example shows a part of the problem. We will need 3 more nuclear plants more each time European people increase their consumption of $15\,\mathrm{W}$. It is difficult to construct more and more electrical plants. In another way, devices tend to be more and more ”eco”. Indeed, yesterday, a classical light bulb was consuming $\approx 50\,\mathrm{W}$ whereas today it is only $4\,\mathrm{W}$. Hurray! We saved 60 nuclear plants for European people.

This is all the challenge in managing energy. One day you need a few electric plant working and the day after you need a lot more electric plants.

Today, to manage variable consumption we have the variable and manageable generators (nuclear, gas, coke). If every house and every factory generated its part of the power, electric plants would only be needed as backup.

[3] Power plant can be controlled and produce more or less but this production of energy has a low reactive response.

3.3.3 Blackout

A blackout is a crash of the power grid. If the power grid was a house, a blackout will be the circuit breaker activated because of a short circuit or too big consumption. If the power production is below the power consumption, this may induce a blackout. Nevertheless, blackout are more often due to weather disaster who destabilize the network. That is why the structure of the grid is looped. The Figure 3.5 shows the network structure. If a tree falls and cut the link between A and B, the power can still go through C and D to reach A.

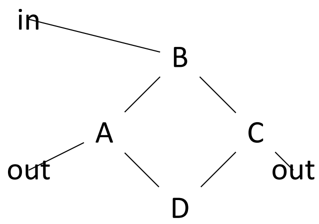

FIGURE 3.5: Structure of the grid

3.3.4 Storage

As mentioned in section 3.1, the main problem with the energy network is the balance between produced energy and consumed energy. It is wellknown that storing energy is not easy, cost money and energy and in some case is hazardous [Connolly et al., 2011].

An old way but still used method of storing energy is the pumping method [4]. Two lakes are needed, one higher than the other. During low use of electricity, the pump sends the water on the higher lake. When the demand is high, the water is sent to the lower lake through a turbine. This method costs mainly energy but can be lucrative. Indeed, the water is pumped up during the night when the electricity is at a low cost and returned when the price is higher. The two lakes energy storing technic can not be spread because it needs a specific localization and moreover the installation needs maintenance and human work load.

[4] 0.9 % in Belgium.

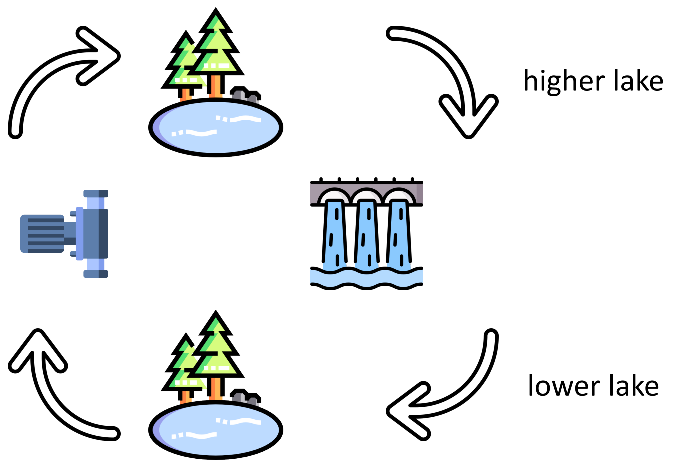

FIGURE 3.6: Water storage with 2 lakes, a pump and a turbine

This method of storing energy is ideal because it allows a fixed production. For example, a nuclear plant produces energy at a constant level. When nobody consumes the energy, the pump works to consume the exceeding energy. When people are consuming energy, the turbine is working to add power on the grid. In that case, we will need to know the peak power to be absorb and the average consumption of citizen. In Figure 3.7, we can see the solution illustrated. In red the average consumption produced by a plant. In blue, the consumption. When the blue curve is below the red line, energy is stored in the storage element. When the blue curve is above the red line, the storage element is delivering energy.

Of course, the red line in Figure 3.7 should be variable as well to be adapted to the consumption. In a perfect world, the storage element needed should be very low, almost zero because the consumption habit will fit variable production as solar and wind. The bigger the storage element the ineffectiver the grid.[Lavoie, 2018]

3.3.5 Network limitation

A classical installation of energy producer (solar panels or wind turbines) is connected to the network. Then, at the end, a family with solar panels will never use the energy they produce. All this power produced is directly send to the network. This topology implies two things :

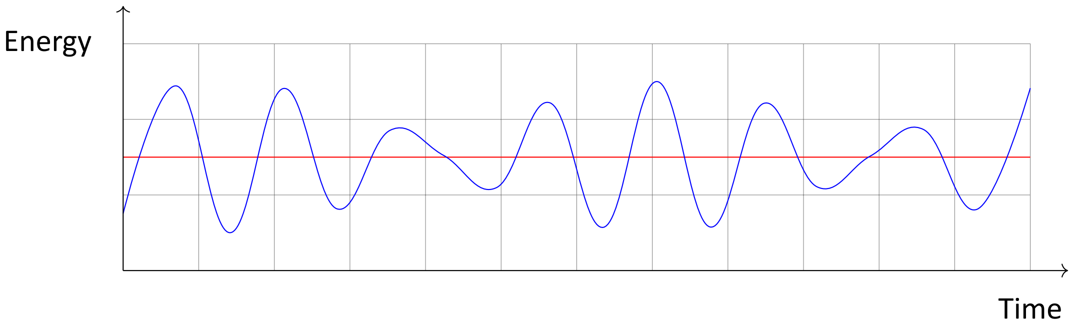

FIGURE 3.7: In red, a fixed energy production; in blue, the amount of energy stored or delivered depending on the demand

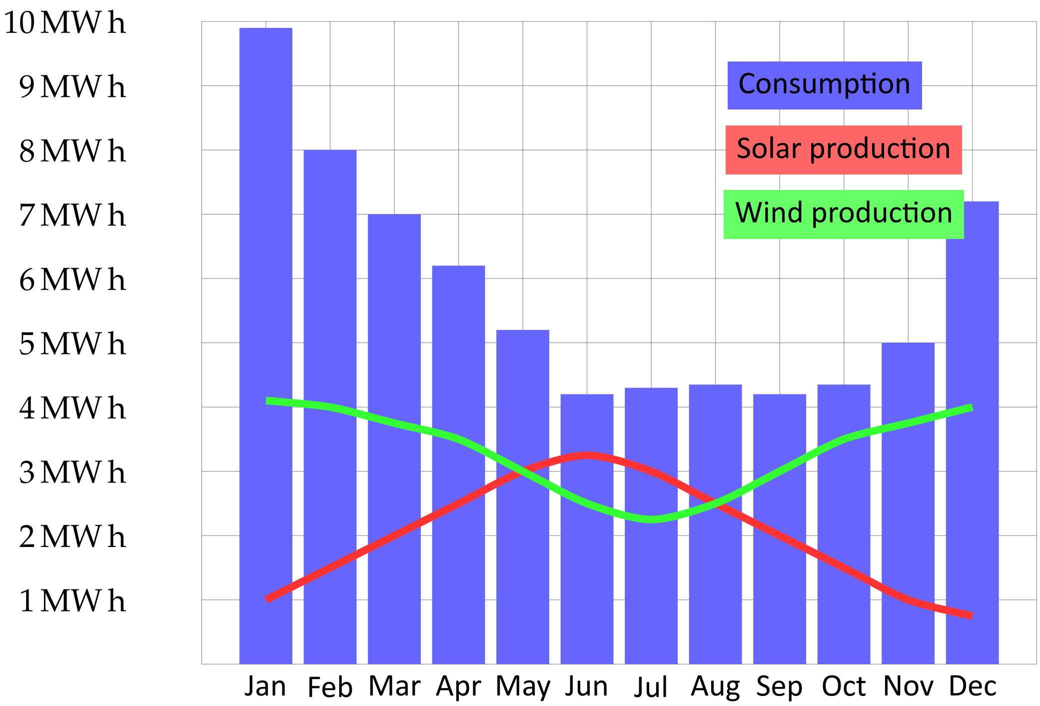

FIGURE 3.8: Evolution of the consumed energy and the wind and solar energy production in a year [Weatherspark]

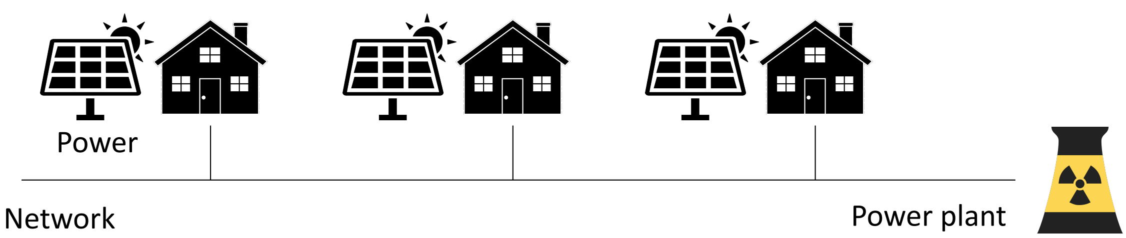

FIGURE 3.9: Network connection problem

1. **The wire section of the network is limited** as it can handle a limited amount of power. Indeed, each wire has its limitation in term of power acceptance. If all houses had solar panel, the network could not handle it. This point is of course the main implication of the network in micro-gid application. Because if the network provider is not able to handle all the production of energy of the micro grid, the micro grid will fail.

2. **Houshold producers do not have to carry when they are consuming energy.** This fact is a big advantages because producers do not have to think when they need to consume the energy they are producing. Indeed, a lot of energy consumption is very situational as : cooking, heating, lighting, etc...

This second point brings us directly to the next subsection 3.3.6.

3.3.6 Variable production

European government took, as a big part of the world, decisions about energy. A lot of countries are moving from big power plant (nuclear, gas) to renewable energy as wind and solar. This move will induce a bigger variable energy production. As we can see in Figure 3.10, the part of wind turbine production in Germany has considerably increased among the total electricity production 18% in 2013 [Nordensvärd and Urban, 2015]. On the histogram of Figure 3.10, the price of electricity is shown in red. We can see that this price is increasing since the wind campaign. Indeed, there are three cases with variable production :

1. A lot of wind and solar production and small consumption $\Longrightarrow$ Too much energy, the producer should sell electricity with negative price to factories.

2. A few wind and solar production and a lot of consumption $\Longrightarrow$ The producer does not have enough energy and should buy energy to bordering countries. The price will increase.

3. Balance between production and consumption $\Longrightarrow$ Price will probably increase to monetize new wind turbine infrastructure.

In those three case, only the first one is unprofitable for the producer. Indeed, he will pay some entities to consume energy. The consumer is always losing because price will increase in each case because selling energy at negative price will induce a recovery of producer who will increase their prices.

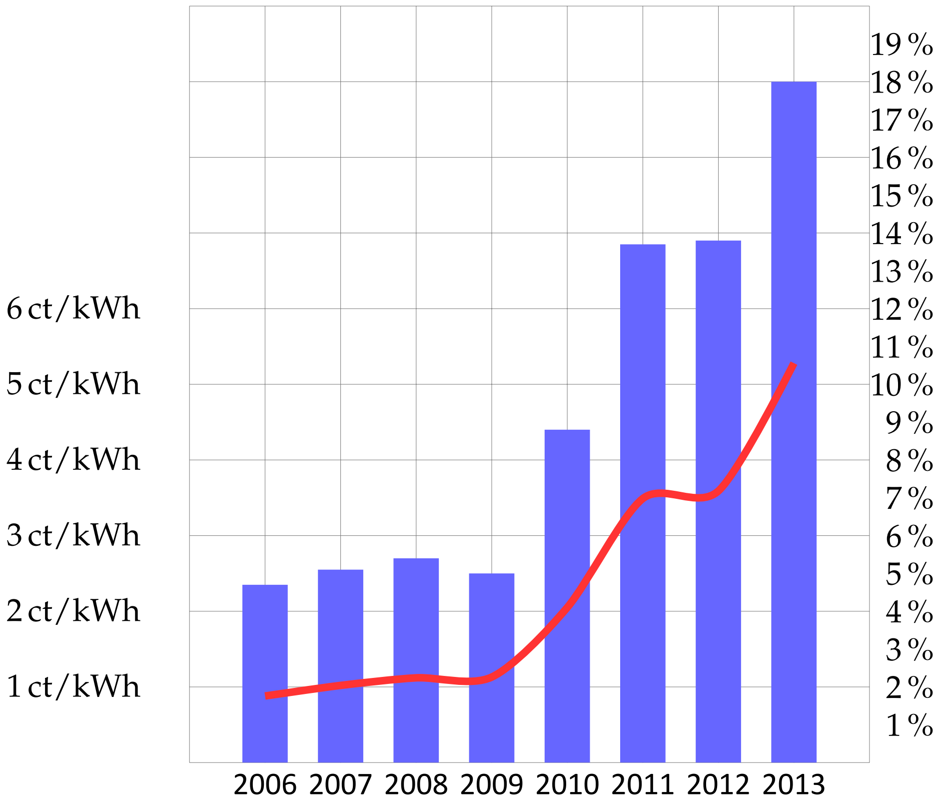

FIGURE 3.10: Increase in renewable energy surcharge in Euro ct/kWh (red) and increasing percentage of share of renewable (blue) [Nordensvärd and Urban, 2015]

Chapter 4

Management

To fight the different difficulties showed in section 3.3 we need to use some management techniques. The main goal of those techniques is to balance the demand and supply of energy.

4.1 Forecasting techniques

To optimize the energy production and as discussed on the subsection 3.3.2 to match the power demand, we need to predict the energy that will be consumed. We can achieve that by gathering past data regarding the energy consumption. Previous data can indicate what will be the demand in the future. There are many forecast techniques and almost all of them can be combined together. Forecast techniques are mathematical formula that use time series [1] to predict the future. Time series are moving in three main ways :

1. Randomness : unpredictable movement,
2. Trend : obvious way of moving,
3. Seasonality : repeated pattern during a period of time[2]

Those parameters are always susceptible to change, randomness can be bigger or smaller, trend can be up, down or stationary and seasonality can also vary. For

[1] Data through the time.

[2] The seasonality can be bigger than a year. For example, every four years, a lot of people will watch the football world cup and use their tv, additional fridge, etc...

example, it is common to think that energy consumption is seasonal because we are consuming more energy during winter as we are using more light, more heater and probably more TV. This seasonality is probably about to change a bit as people are more and more using air conditioning and then consume more electricity during summer [Lesage, 2020]. Also, those pattern can be combined or doubled as we can have multiple seasonality (Figure 4.1) with a growing trend. All of this explain in a way why data are important. To have the best forecast we need to collect a lot of data to catch different seasonality and different trends as randomness is unpredictable. [Singh et al., 2013]

4.1.1 Common forecasting techniques

- Moving average
- Weighted moving average
- Exponential Smoothing
- Linear regression

All of those previous method can be combined as in the work of Holt, 2004, they approach the forecasting with an exponentially weighted moving average. They claimed that this method should be used to smooth random fluctuations with the following properties declining weight for older data. Which is good for electricity consumption because as mentioned in subsection 3.3.1, the trend of electricity consumption is growing which means that the power consumption 10 years ago as less value that 1 year ago. The calculation of Holt, 2004 are based on a trend and a double seasonality. Those equations intend to give a short-term forecast. Indeed, the inspection of half hour time series gave a double seasonality within a day and within a week. This double seasonality is illustrated in Figure 4.1.

Another very popular method used in Lazos, Sproul, and Kay, 2014 is the ARIMA [3]. This method allows to use a randomness data behavior (stochastic forecast). Including randomness in the calculation is very interesting for a forecasting as energy consumption. Coupled with an exponentially weighted pattern as discuss previously can integrate double seasonality and give a robust system for forecasting.

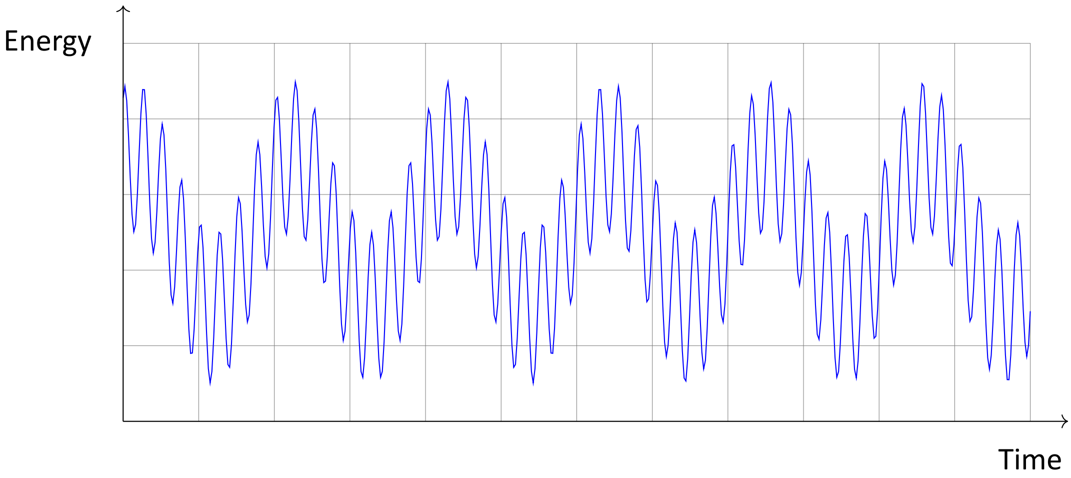

FIGURE 4.1: Double seasonality

Having a good short-term forecast is interesting but even if we know the demand, we need to supply the offer. As explained in section 2.3, producing electricity is not that easy because of turbine inertia of power plant and uncertainties of renewable energy. To smooth that uncertainty, network manager use :

- Weather forecast,
- Storage
- Trading

The best option is of course the weather forecast because managers will be able to anticipate big renewable production or poor one. The problem is that weather forecast is not always reliable. Then network managers use storage and trading to smooth the demand offer balance. If there are too much energy produced, we will store as much energy as we can thanks to pumped hydro system. If the production

[3] Auto-regressive integrated moving average

is too poor, we will trade energy with bordering countries. Those two options are expensive because a pumped hydro system consume energy and cost a lot in infrastructure and trading energy is expensive as boundary countries want to sell at a maximum price.

Network managers should use multiple forecast as energy consumption and weather forecast.

Wind turbines and photovoltaic panel have a maximum production rate. This production rate match a certain amount of sun or wind. In the same idea, the minimum produced power match an amount of light and wind. In Figure 4.2, we have represented the linearization [4] of the power versus wind and light. The forecast of the weather can easily give a weight. Translated to an equation we have Equation 4.1. This weight times the maximum power gives us the power produced Equation 4.2.

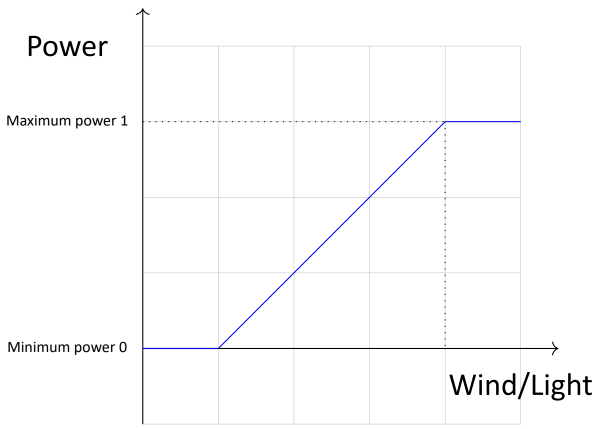

FIGURE 4.2: Linearization

$$F_{weath} \implies 0 \leq \mu_{weath} \leq 1 \tag{4.1}$$

$$\mu_{weath} \cdot P_{max} = P_{prod} \tag{4.2}$$

[4] The relation between the power versus weather condition is probably not linear but make it linear will give small error.

$$P_{prod} + P_{plant} \geq F_{cons} \tag{4.3}$$

When we have the power produce, we just need to add it to power produced by power plants and make the Equation 4.3 true. Naturally, we need to be the closest of the balance to avoid wasting of energy. Those forecasting will be a lot improved with the birth of smart-grid which will allow us to have consumption data of each household in real time.

4.2 Financial measures

The very next step in Belgium is to invoice prosumers [5]. Prosumers will be invoiced on the energy injected on the grid. For example, a prosumer with a solar installation will use the energy produced by its solar panel when he is consuming. But when he will produce energy and not consuming it, an additional counter will evaluate the amount of energy sent to the network and he will pay for the use of the network. This method is supporting the energetic independency of prosumers. However, this method is not adapted to the prosumer as he will consume more energy when he is not producing. Indeed, as shown in Table 3.1, the second main consumption is lighting who is used only when the sun is not giving light. Heating [6] is also used mainly during winter when there is less sun light. In Figure 3.8, the energy produced by wind energy is more important during winter which is a good thing because this is the most consuming period. However, the challenge is still the same : we need to consume when we are producing. The problem is that solar and wind energy production are variable generator. On one hand, this method will help network manager as prosumer will change his habits to pay less :

[5] A prosumer is a person or an entity who is both consuming and producing electricity.

[6] Heating is mainly achieved with fossil energy whereas if we want to use renewable energy, electric heating is needed.

1. Less power on the grid that can lead to more prosumer on the network (subsection 3.3.5);
2. The global power consumed during the day will be balanced, smaller peak power during evening.

On the other hand, this change of habit will falsify previous data and decrease the forecast veracity. Finally, this action of the government is very interesting for network manager as prosumer will pay for their use of the network. So even if it is not interesting in term of forecast and/or energy production, it will be financially beneficial.

4.3 Energy trading

The forecasting techniques are used to buy energy on the market. Those markets are divided in three parts :

1. Day-ahead market;
2. Intra-day market;
3. Future market.

4.3.1 Day-ahead market

The day-ahead market is used to buy energy for tomorrow.

If the team has forecasted the Figure 4.3, the organization will buy this amount of energy before 2 pm the day after the forecast. This energy is sold at an interesting price[7] as it is bought in advance. Naturally, we are forced to adjust the consumption during the day.

[7] Price range vary between -500 €/ $\mathrm{MW\,h}$ and 3000 €/ $\mathrm{MW\,h}$

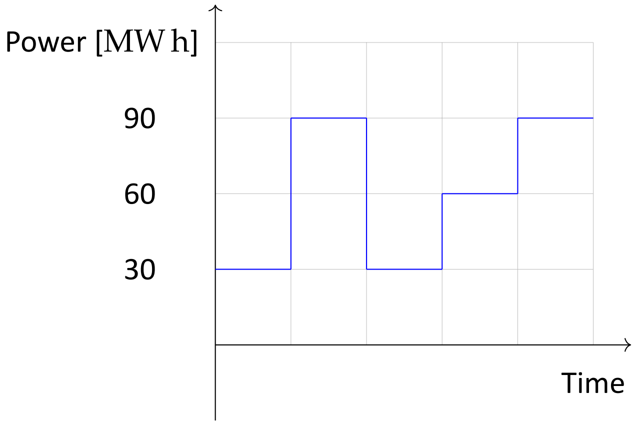

FIGURE 4.3: Consumption of tomorrow

The technique used to know if we are under or above the consumption/production balance is to measure the network frequency. As explained in section 2.1, the network frequency is at 50 Hz. If the frequency is below 50 Hz, it means that we are not producing enough energy. If the frequency is above 50 Hz, we are producing too much energy or we are not consuming enough (Figure 4.4). [European-commission, 2016]

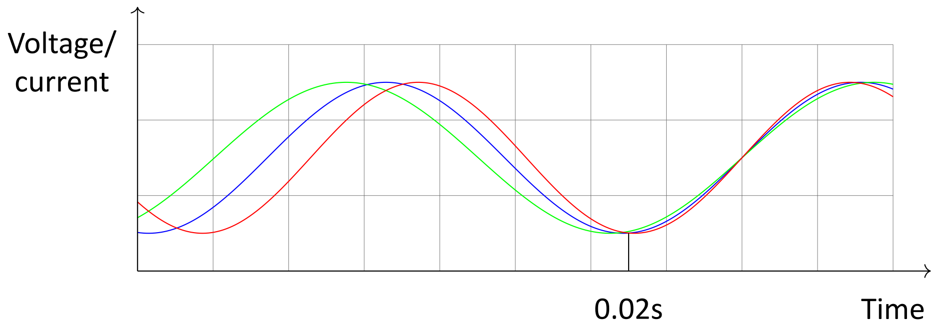

FIGURE 4.4: 50 Hz measurement; in blue the correct 50 Hz; in red less than 50 Hz, under production;in green more than 50 Hz, above the consumption;

4.3.2 Intra-day market

Intra-day market is the trading market within the day. Actually, the market is open the day before at 2 pm and is closed 5 minutes before the delivery. Of course, as the trading is continuous 24/7, the price will increase : between -9999.99 €/MW h and 9999.99 €/MW h.[European-commission, 2016] On the Figure 4.5, we can see an example of adjusted consumption in red. This small amount of energy will be bought with a higher tariff as it is a short-term trading.

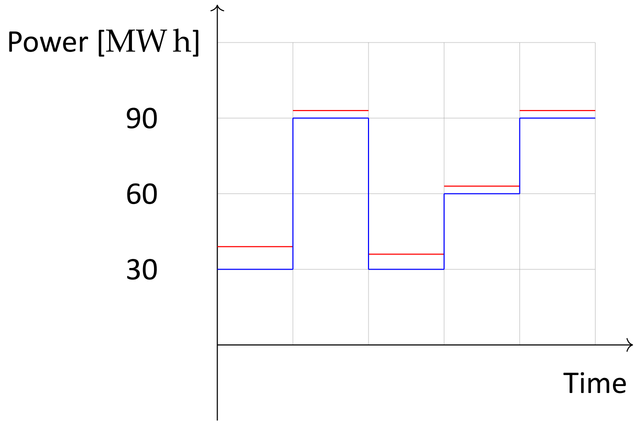

FIGURE 4.5: Consumption of tomorrow with error in red

4.3.3 International power trading

This trading is the last chance trade. The price will be of course higher [8] as it is an international trade and it includes more transport. The delivery can be done in 0-30 seconds delivery.

[8]This price is paid-as-bid and is discussed on time.

Chapter 5

Conclusion

This paper shown how complex energy management is as it use electrical concepts such as alternative voltage, current, energy and power.

As we discussed, there are multiple reasons on why energy management is difficult :

1. Growing consumption
2. Instable demand/supply
3. Blackout
4. Variable production
5. Infrastructure
6. Storing energy

All of this point have an impact on forecast and governmental decisions. The growing consumption (1.) induces a trend in the forecast and force to produce more. This addition amount of energy is mostly renewable energy who are variable production (4.). Of course, the variable production will make the demand/supply (2.) more and more difficult as we will need to forecast the production in addition to the demand. The complex demand/supply balance is getting worse if we include infrastructure (5.) which is limited in power capabilities and is subjected to weather disaster who can easily lead to blackout (3.). A first idea to smooth the demand/supply variability is to store energy (6.) but this option become quickly a problem because of its hazard, cost and technique feasibility.

As already mentioned, a solution for balancing demand and supply is the forecast. There are multiple method who can nearly forecast the exact consumption. Nevertheless, this forecast needs to be join by another one $\longrightarrow$ weather forecast. Indeed, as a part of the production is variable, the network manager needs to know in advance what he needs to produce in addition with power plants. As forecasting is not giving exact numbers, other concept needs to be used.

Every day, forecasters trades energy for tomorrow. The sooner they buy the energy, the smaller the price will be. There are 3 levels of trading, day-ahead, intra-day and real time trading. Network managers try to buy less power as possible during the international real time market as it is expensive. Network manager takes measure to regulate the market of prosumers. A new decision is to invoice prosumers for their use of the network. Prosumers should directly use the energy they produce. This will help network manager to smooth the electric consumption.

Electric production is always improving and the addition to variable generators force the network management to evolve and enhance. Hopefully, trading energy is efficient and allow us to have electricity day and night.

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