

## WEATHER SENSITIVITY OF ELECTRICITY SUPPLY AND DATA SERVICES OF THE GERMAN MET OFFICE

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**Abstract.** The topics of this chapter are weather sensitivity related to electricity supply and data services of the National Meteorological Service of Germany (DWD). First, the weather sensitivities of electricity generation (thermal power plants, run-of-river power plants and wind energy plants) are shown. Then, atmospheric influences on overhead lines and underground cables, as well as on transformer and switching stations are examined. Second, the way in which the DWD supports electric companies by offering tailored data is illustrated. One conclusion of the chapter is that the inclusion of environmental parameters (like air and water temperatures, wind speeds, discharge amounts) is of great importance for a number of business actions in electricity companies. In order to ensure efficient research with useful results for electricity companies, the great amount of relevant information (from national meteorological services, planning offices, catastrophe service and as much as possible from companies) needs to be collected and compiled.

**Keywords:** Weather; climate change; electricity supply; data services; Deutscher Wetterdienst

### 1. Introduction

Electricity supply is always affected by weather and climate. Therefore, electricity companies have developed various weather and climate risk management tools over the years.

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Nevertheless the current debate about the impacts of climate change on companies has stimulated an increasing public interest concerning the weather sensitivities of electricity suppliers. The content of this chapter is to explore these sensitivities. Secondly, data services of the Deutscher Wetterdienst (National Meteorological Service of Germany; DWD) are presented for important weather parameters in order to better use these services for improved weather risk management. The purpose of this chapter is to contribute to an enhanced transfer of knowledge between energy experts and weather/climate scientists.

## 2. Generation of Electricity

In this section weather sensitivities of electricity generation will be identified. It is divided in the subsections thermal power plants, run-of-river power plants and wind energy plants.

### 2.1. THERMAL POWER PLANTS

Weather related interferences occur rarely at thermal power plants (especially coal-fired, gas turbine and nuclear power plants). Hence, the frequency of weather incidents occurs less from material loss, but rather due to several restrictions, such as a diminished operational availability. Some possible impacts are specified below with special reference to Germany (Rothstein and Parey, 2009).

#### 2.1.1. *Water Temperatures and Cooling of Thermal Power Plants*

Thermal power plants need water for their cooling processes. In order to protect bodies of water, legal constraints regulate the water usage of every site. These water quality requirements regulate not only the supply and release but also the evaporation and the warming rate of the body of water in case of low water.

In Germany, basic principles for the assessment of cooling water released into bodies of water have been devised by LAWA<sup>1</sup> (e.g. the maximum allowed warming of cooling water is 10 K). Due to the ecological water protection, 28°C is the limit for cooling water release into a river. To ensure this, regular measurements are taken at every thermal power plant at 30 min intervals (EnBW, 2004).

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<sup>1</sup> Bund-Länder-Arbeitsgemeinschaft Wasser; German Working Group on water issues of the Federal States and the Federal Government.

Climate change impacts on thermal power plants result from two possibly simultaneous reasons: legal constraints for both warming and maximum water temperatures, as well as constraints on the amount of water extracted during low water situations to ensure that a minimum discharge is maintained (Rothstein and Parey, 2009).

The cooling method has a considerable influence on the legal constraints for thermal power plants. The various restrictions are often connected and can intensify one another. In certain atmospheric conditions, problems with maximum temperature or low water situations dominate, as was the case in the winter of 2005/2006. Often, as in the hot summer of 2003 in central Europe, high temperatures and low water situations occur together. At the Neckar River (Southwest Germany) the hot summer of 2003 led to the restriction that only power plants with a cooling tower were allowed to operate (LfU, 2004).

Furthermore, the inlet and purification of cooling water at thermal power plants may be affected by weather and climate change. A low water situation can lead to a cooling water shortage in the power plant. The inlet to the corresponding building can be dredged, but this must be requested and decided on a case by case basis (Rothstein and Parey, 2009).

#### 2.1.2. *Sufficient Water Level for Inland Navigation and Coal-fired Power Plants*

Coal-fired power plants can only be operated economically if their location is in close proximity to the coal district or if the supply of hard coal can be shipped cost-effectively via waterways. Three million tons (t) of coal is transported to the different power plants in Baden-Wuerttemberg (South-West Germany) over the Rhine River every year. In comparison with the Ruhr area (North-West Germany), Baden-Wuerttemberg has a serious disadvantage in location due to the higher transport costs of coal (WM, 2004). The risk of extreme water levels, which can degrade the reliability and security of the inland water navigation, adds to the high transport costs (Rothstein et al., 2009).

In order to point out the importance of coal transport, a power plant at the Neckar River is considered more closely. The plant needs more than 200 t hard coal per hour, which adds up to a daily use of 3,000–5,000 t of hard coal. This equals two to four shiploads a day or three to four trainloads, respectively. A trainload consists of 20–25 wagons with 1,000–1,400 t of coal in total. A cargo ship on the Neckar can transport around 1,200–1,600 t. Seventy percent of the coal to the power plant arrives by cargo ship and 30% by train; in the future, however, ships will take a more dominant role. Because of high costs, truck transport is generally not suitable for coal supply (Rothstein and Parey, 2009).

Water-levels have always changed due to climate variability. The debate on climate change has raised the question of whether or not the current strategies that are used by the authorities responsible for management of inland waterways and industrial managers will be suitable to cope with future conditions (Rothstein and Parey, 2009). These questions are dealt with in the framework of the research program KLIWAS,<sup>2</sup> which is initiated by the Federal Ministry of Transport, Building and Urban Affairs.

### 2.1.3. Air Temperature and Gas Turbines

For gas turbine power plants, the net degree of efficiency can be specified at 38%. The efficiency of gas turbines depends primarily on the compressor and the power that is necessary to densify the air that is sucked in. The higher the temperature of the air, the larger the compressor power  $p$ :

$$p = c_p T_1 \left[ \left( \frac{p_2}{p_1} \right)^{\frac{R}{c_p \eta_p}} - 1 \right] \quad (1)$$

The parameters are the specific heat capacity  $c_p$ , the ambient temperature  $T_1$ , the air pressure at entering  $p_1$  and exiting the turbine  $p_2$ , the efficiency of the turbine  $\eta_p$  as well as the specific gas constant  $R$  (Kaltschmitt et al., 2006).

An increase in ambient temperature of 10°C causes the turbine output to drop approximately 8–10% (Leopold, 1984). Additionally, gas turbine power plants are particularly affected by air temperatures; they have lower efficiency in summer than in winter.

Water can be added to the air string in order to reduce the efficiency loss incurred by warmer temperatures. Consequently the enthalpy of evaporation lowers the entering temperature (Hermening and Klingemann, 2005). Furthermore, the mass flow in the gas turbine can be increased. As a result the air conditions of a clammy day are artificially created, with its higher gas turbine efficiency in comparison to hot and dry days. Another possibility for increasing efficiency is the use of a heat exchanging device to withdraw heat from the entering air without the use of water (Johnke and Mast, 2002).

Gas-steam power plants are sensitive to ambient temperatures in the same way that gas turbine power plants are. The gas process is more dependent upon environmental influences than the steam process. In a 250-MW-block

<sup>2</sup> KLIWAS – Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt in Deutschland; Consequences of climate change for navigable waterways and inland navigation in Germany.

for example, a 30 K lower ambient temperature results in an increased power of 30 MW in the gas turbine but only 3 MW in the steam process (Rothstein and Parey, 2009; Johnke and Mast, 2002).

## 2.2. RUN-OF-RIVER POWER PLANTS

### 2.2.1. *Discharge and Generation of Electricity*

The following section refers merely to river power plants in order to keep within the scope of this work. In general, the head (the difference of the water levels) defines the generation of electricity in a run-of-river power plant. The mechanical power of a turbine  $P_T$  is calculated under consideration of the degree of efficiency  $\eta_T$  of the turbine, the density  $\rho_W$  of the water, the acceleration of gravity  $g$ , the water discharge  $q_W$ , and the useable head  $h_{useable}$  (Kaltschmitt et al., 2006):

$$P_T = \eta_T \rho_W g q_W h_{useable} \quad (2)$$

At extreme low water events the plant may have to be shut down because the turbines function only with a minimum discharge. There is no consistent limit, however, as it depends on the particular power plant. In the German state of Baden-Wuerttemberg, the so called hydro power order (“Wasserkrafterlass”) has been regulating the identification of the minimum discharge for small hydro power plants (up to 1,000 kW) since 1993 (LfU, 2005).

With rising discharge the production can be increased until the maximum limit of the turbine is reached. At high water and flood events, the generation of electricity may also be shut down and the weir opened (Kaltschmitt et al., 2006; BUWAL et al., 2004). Here, a consistent limit is missing as well. Moreover, run-of-river power plants work as regulators for flood waves by means of the corresponding adjustment of the weir (Rothstein and Parey, 2009; EnBW, 2005).

Efficiency losses can also occur due to drifting ice and other drifting substances, which are found especially after storms or floods. Rakes, skimming walls, and floating devices are installed for protection against these substances. Their usage is connected with a loss in generation of electricity, but the degree of loss depends on the amount of items stuck in the rakes. On average, they restrict flow by 5–10%. However, at extreme events, like ice drift, storms, or floods, the restriction is much higher; the protection facilities may become damaged and the plant may have to be shut down (Giesecke and Mosonyi, 2005). According to damage statistics, broken rakes, barrages, etc. make up 25% of all the damage taking place at river power plants (Kasper, 1984).

Ice formation is not necessarily a threat for the plant, even if it is a close ice crust, as long as there is a regular discharge beneath the ice. On the contrary, ground-ice and grease ice are more damaging. Reliable forecasts of the ice development and the creation of a close ice crust through a temporary shut-down can be a solution in this case (Giesecke and Mosonyi, 2005).

### 2.2.2. High Water/Flood

All run-of-river hydro power plants (as well as most thermal power plants) are built in close proximity to a river. Therefore, flood control measures are essential as, otherwise, buildings and plant components can get damaged through flow resistance, flooding or sediment discharge (Ritz et al., 2005). There is no consistent threshold value for flood events, since the flooding depends on the actual location of the plant. Hence, for the development of parameters, it is better to stick to common threshold values like the “100-year events” or the “mean high water”. It is differentiated between measures that have to be presented to the officials for the authorization of a new plant and such measures that ensure the authorization to operate during the flood events (Rothstein et al., 2008). These measures can not be discussed in detail but instead some basic aspects are covered briefly.

River hydro power plants are designed for a certain mean water quantity. Water levels higher than the mean water quantity lead to the reduction of generation of electricity (just like very low water levels); the plant may have to be shut down in extreme cases. Hence, annual load duration curves for discharge prognosis are of interest for river power plants. The significant question is whether the future yearly discharge will change in comparison to the current rate, and when these differences will occur. Then it can be deduced for the particular power plants when the situation is becoming critical (Rothstein et al., 2008).

## 2.3. WIND ENERGY PLANTS

### 2.3.1. Wind Speed and Generation of Electricity

The wind power  $P_W$  resulting from an air stream depends on the density of the air  $\rho_A$ , the wind speed  $v$  and the rotor circular area  $F$  (Kaltschmitt et al., 2006):

$$P_W = \frac{1}{2} \rho_A v^3 F \quad (3)$$

The wind speed affects the usable wind power immensely, namely with a power of three. A bisection of the wind speed  $v$  then leads to an increase in usable wind power  $P_w$  by one eighth.

A defined power output is associated to every prevailing wind speed. At wind speeds higher than 25–30 m/s, wind energy plants are normally switched off to ensure the safety of the plant. As small changes in wind speeds substantially influence the usable wind power, the danger of damage increases as well. The damage symptoms are torn rotors and broken pylons (Rothstein, 2007).

### 2.3.2. *Mechanical Effects at Wind Power Plants*

The rotor blades of wind power plants are especially prone to mechanical effects (e.g. frost, ice, hail and thunderstorms). Possible consequences are cracks, fractures due to vibration, delaminations, and broken blades. Lightning strikes can even lead to a total loss.

For offshore plants the additional risk of damage comes from storm surges at the foundation, tower and rotor. At mountainous locations over 1,000 m, snow and frost can affect wind power plants more negatively than at locations in a more favourable climate (Rothstein, 2007; GDV, 2005).

## 3. Transport and Distribution of Electricity

Atmospheric influences on overhead lines, underground cables, transformers, and switching stations are covered in this section. Due to the stronger impacts of atmospheric parameters on overhead lines, these are considered on a larger scale than the other components of the electric mains.

### 3.1. ATMOSPHERIC INFLUENCES ON OVERHEAD LINES

Overhead lines are affected by atmospheric influences in several ways, such as failures by lightning, wind, additional loads (such as ice or snow), low temperatures, humidity and moisture.

Lightning is divided into direct strikes and induced over-voltage. The latter occurs when lightning strikes close to an overhead line. The high energy resulting from lightning strikes burns the conductor rope and demolishes the isolators, which are protective devices (EnBW, 2004). Additionally, strikes in pylons or underground cables cause a reverse flashover, which can damage transformers and switching devices.

Wind-induced failures depend on the wind speed  $V_R$  which, together with height  $h$  and air density  $\rho$  is used for the calculation of the dynamic pressure  $q_h$  (EN 50341-1, 2002):

$$q_h = \frac{\rho}{2} V_R^2(h) \quad (4)$$

A typical threshold for dangerous winds is circa 90 km/h. In addition to the direct wind loads, failures occur when branches or other foreign substances are directed into the circuit by wind. They bypass the conductor rope and cause short-circuits. Moreover, falling trees can damage pylons and conductor ropes especially at the comparatively low overhead lines of medium voltage (EnBW, 2004). Therefore, the density of wood around overhead lines is directly related to the magnitude of failure (Martikainen, 2005). Furthermore, the ropes of overhead lines often swing due to wind. The amplitudes transverse to the rope axis can reach up to half of the conductor spacing so that they can contact and short-circuit. This may cause the stability of the grid to be diminished (Kießling et al., 2001).

Failures caused by ice and snow loads (short additional loads) arise mainly from ice accretion, which is classified as ice from precipitation and ice from fog or clouds. The combination of additional loads and wind is regarded as having the highest impacts on overhead lines (Kießling, 2002). In this case, the ice loads enlarge the surface of the conductor ropes so that there is a greater contact surface for wind. Additional loads alone cause vertical loads as well as higher traction at the conductor ropes. The traction increases with dropping ambient temperatures, because the ropes contract tighter. Strong forces act especially on the pylons. The traction  $Q_i$  results from the weight spans  $L_{w1}$  and  $L_{w2}$  as well as from the ice and snow load  $I$  at the grid (EN 50341-1, 2002):

$$Q_i = I(L_{w1} + L_{w2}) \quad (5)$$

In the case that the load exceeds the load capacity of the pylons, they can twist or break. Furthermore, conductor ropes can snap. A further danger results from conductor ropes that sag due to ice and snow loads. Ropes could make contact with other ropes or lower lying objects, which causes short-circuits and short-circuits to earth. Particularly affected by sagging are guard wires at overhead lines of high and highest voltage, which do not carry warming electricity as a protection against ice and snow loads. Ice and snow covered trees in close proximity of overhead lines are also a danger when influenced by the wind (EnBW, 2004; Martikainen, 2005). Moreover, the swinging of ropes can also be caused by the changed aerodynamic shape of the grid in comparison to the original cylindrical shape without the ice

and snow loads. When the ropes swing for a long time, mechanical overloads of equipment as well as electric arcs can be observed (Kießling et al., 2001). Guidelines regarding the ice loads for pylons were created and partially modified in Germany. The guidelines divide Germany into three different zones (from zone 1, low ice loads, to zone 3, high ice loads).

Further failures are caused by low temperatures, when the functionality of the equipment is reduced through cold and frost or gets damaged (e.g. when the design temperature is under-run). For instance, frost and other weathering signs crack isolators or ropes.

Power losses also occur in electricity transmission and distribution. These are called the corona discharge losses and losses due to high ambient temperatures. The length and sag of a conductor rope is also temperature-sensitive, since the circuits expand with rising temperatures. This aspect is particularly important for the selection and design of the grid and the projection of overhead lines.

Furthermore, transmission networks are exposed to humidity, which can creep into the equipment and lead to corrosion and wasting. In general, it can be distinguished between direct atmospheric influences (e.g. through precipitation or thaw) and results from high water levels (e.g. floods after heavy rainfalls or snowmelt). Frequent damage occurs to metal components degraded by corrosion and fouling at wooden pylons (Martikainen, 2005).

### 3.2. ATMOSPHERIC INFLUENCES ON UNDERGROUND CABLES AND ON TRANSFORMER AND SWITCHING STATIONS

Underground cables are also affected by atmospheric influences. During the hot summer of 2003 in France a number of failures with underground cables occurred, especially around the Paris area. These failures were analysed and corrected if necessary. Also, a study was produced by EDF that offers recommendations regarding droughts, heat, and the resulting limited conduction capacities. Furthermore, it is considered important to develop regulations for planning. Besides this, cable lines are uncovered, pylon fundamentals are washed out, and slumping and mudslides are initiated by rivers bursting their banks. The latter can cause damage to or even breaking of pylons (Rothstein and Parey, 2009; Rothstein, 2007).

The previously described atmospheric influences like lightning and temperature apply to transformer and switching stations as well. Moreover, floods are important because the equipment may be adversely affected. High waters may cause the flooding of transformer stations and their components to silt up, becoming damaged and often completely destroyed (Rothstein, 2007).

#### 4. Data and Services of the Deutscher Wetterdienst

The Deutscher Wetterdienst (DWD) is the National Meteorological Service of the Federal Republic of Germany. It is responsible for providing data and services for the protection of life and property in the form of weather and climate information. One of the main duties of the DWD – embodied in the Law on the Deutscher Wetterdienst – is the provision of meteorological services for the general public or for individual customers and consumers in the fields of traffic, trade and industry, agriculture and forestry, the building industry, public health, and water management, including preventive flood control, environmental protection, nature conservation and science. In fulfilling its statutory tasks, the DWD supports electric utilities and energy supply companies with data, services and expert opinions.

The DWD runs the National Climate Data Centre (NCDC) with its database of climate data for the whole country of Germany. The longest data series dates back to the eighteenth century. Today the observation network of the DWD comprises of about 2,200 stations. Statistical evaluations based on this climate data are the basis of planning purposes and risk management for energy supply companies.

The DWD supports the energy companies, in particular concerning wind power plants, with near real-time meteorological data (temperature, wind speed – mean value or strongest gust) from the manned or automatic weather stations. Providing a continuous supply of power and gas to consumers requires accurate predictions about the quantity of energy from wind energy plants, thermal power plants or solar plants that will be available in the next hours or days. On the basis of numerical weather models, the DWD offers the energy companies short-term forecasts for temperature, wind, solar energy, and precipitation. The local, very short-range numerical weather model COSMO-DE, with a grid length of 2.8 km, is even able to accurately represent shower and thunderstorm events. This high-resolution model belongs to the model chain of the DWD, which consists of the Global Model for the weather worldwide and the local models embedded in it for central Europe and Germany.

Seasonal forecasting is the attempt to provide useful information about the “climate” that can be expected in the coming months. The seasonal climate outlook of the DWD is a seasonal forecasting for 6 months, which is based on numerical weather prediction calculations made by the European Centre for Medium-Range Weather Forecasts in England. Even though this data is less accurate than short-time forecasts, it can be useful to energy companies.

There is quite a lot of cooperation between experts from the DWD, various governmental water and energy management authorities, and power

and gas companies to develop and implement special meteorological services. Analysing heavy precipitation events is an important prerequisite even for the energy companies. The KOSTRA catalogue (Bartels and Malitz, 2006; DWD, 2005) contains statistical values of heavy precipitation events for different duration levels and recurrence periods. The values can be interpolated or extrapolated for individual raster cells as well as to average values for larger areas in Germany. Through findings from the KLIWA-project, the DWD further developed the KOSTRA catalogue to include the period 1951–2000 ([www.kliwa.de](http://www.kliwa.de)).

Long-term icing measurements have been carried out since 1965 at different stations in Germany. These measurements are carried out in order to improve the knowledge of regional differences, the height dependence of icing (icing climatology), to understand interrelationships between icing and other meteorological parameters, to supply data to special experts, and to produce icing maps of Germany (Wichura, 2007).

Other tools for risk management purposes or planning of the power and gas companies are forecasts for heating or cooling degree days, test reference years, wind data for users of wind energy plants, or maps of the solar radiation for solar plants.

The degree day number (sometimes called heating degree days) is a heating indicator. The heating energy consumption of buildings depends on many factors. They range from the heating and ventilation habits of the inhabitants, the thermal insulation, and the weather. These issues can be dealt with by the help of the degree day number, which is the difference in temperature between the room temperature of 20°C and the daily mean air temperature. When the outdoor temperature decreases, the degree days increase by the same amount as the heating energy consumption rises to keep the room at a temperature of 20°C. The industry uses degree days for the temperature adjustment of energy consumption figures. One of the quantities derived from the degree days, known as the climate factor, is used for issuing energy performance certificates for buildings in the framework of the German Ordinance on Energy Saving. The climate factor can be downloaded from the DWD website ([www.dwd.de/klimafaktoren](http://www.dwd.de/klimafaktoren)).

The DWD is getting increasingly involved in activities of the Intergovernmental Panel on Climate Change (IPCC) With this know-how and the aid of new results of global and regional climate projections, the DWD is providing advice on issues of climate impact assessment to decision makers in politics, business, administration and industry. In order to be able to assess the impact of climate change on the energy industry and peoples in urban areas, performance models (e.g. microscale urban climate models) will be used to determine how the changes in climate will affect concrete sectors of our society. Climate projections – which describe the development

of the climate over the coming decades – are filled with considerable uncertainties, and this is also true of the regional climate models for Germany. The DWD procedure, called ZWEK (a compilation of performance model input data sets for climate impact research), compares existing regional models with the aim of determining the probability and the impact of certain climate changes to be expected in Germany.

An initial application is the description of the future development of the heating degree days. Further calculations will help to answer the question whether, and to what extent, the rising temperatures due to climate change will lower the energy requirement (reduced heating in winter) or enhance the energy requirement (more cooling in summer), especially in urban areas.

## 5. Conclusion

As shown in the previous sections, many atmospheric and hydrological parameters influence electricity generation, transportation and consumption. The inclusion of environmental parameters (like air and water temperatures, wind speeds, discharge amounts) is of great importance for a number of business actions in electricity companies. Therefore, it is essential for several sub-processes of different business sectors in electricity companies to collect and to analyze this data.

Relevant atmospheric parameters are ground-level air temperatures, wind speeds, lightning strike locations, and rainfall. The most important hydrological parameters are the discharge amount and water temperature.

For some of these parameters (ground-level air temperatures, water temperatures), electricity companies have their own measuring systems from which the data is transmitted to the proper control station. Nevertheless, data services from DWD play an important role for many German electricity suppliers.

An enhanced exchange of data would certainly be useful for the improvement of regional climate forecasts, especially analysis about the occurrence probability of extreme events (e.g. low water periods, intense snowfall at high temperatures), and also accurate predictions regarding the further shift of means due to climate change are required.

In order to ensure efficient research with useful results for electricity companies, the great amount of relevant information (from national meteorological services, planning offices, catastrophe service and as much as possible from companies) needs to be acquired and systematically organised. Subsequently, a GIS-based company-specific risk mapping is possible. Based on this GIS, detailed information can be accessed and connected with information of different regional climate models.

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