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Trilateral angle on Outage Costs

The liberalization of the electricity market in the Czech Republic were finished in 2006 and it has brought about some major changes for distribution and trading in electrical energy and in the form of the Czech energy market. There are three major players in electricity market in Czech Republic, Customers, Holders of License for electricity trading and Holders of License for electricity distribution according to total unbundling of Czech electricity market. In case of electricity outage there are rising damages for all of three major electricity market players. In this article we analyzed outage costs for three major electricity markets participants.

Keywords: Outage costs, Customer, Holder of License for electricity trading, Holder of License for electricity distribution

I. INTRODUCTION

Through all European countries liberalization of electric energy market was finished. It brings new Technical, Economical and Legislation problems. One of these problems is relationship between customers and suppliers and standardization of quality of electric power supply.

II. RELIABILITY AND QUALITY OF POWER SUPPLY

Most of European countries use SAIDI, SAIFI, MAIFI, CML, AIT and ENS for reliability measurement and analysis:

- SAIDI - „System Average Interruption Duration Index

$$SAIDI = \frac{\sum Customer\ Interruption\ Duration}{Total\ Number\ of\ Customer\ Served} \quad (1)$$

$$SAIDI = \frac{\sum \lambda_i \cdot \tau_i \cdot N_i}{\sum N_i} \quad (2)$$

where:
λ_I - Failure rate
τ_i - Mean Failure Duration
N_i - Number of Customer served

- SAIFI – "System Average Interruption Frequency Index"

$$SAIFI = \frac{\sum Total\ Number\ of\ Customer\ Interruption}{Total\ Number\ of\ Customer\ Served} \quad (3)$$

$$SAIFI = \frac{\sum \lambda_i \cdot N_i}{\sum N_i} \quad (4)$$

- CML – "Customer minute Lost"
- AIT – "Average Interruption Time"
- ENS – "Energy not Supply" (more detailed in next chapter)

III. ENERGY NOT SUPPLY (ENS)

We use ENS for reliability analysis in Czech Republic Power Energy environment. During electric power supply outage we have no any information about electrical power energy consumption (See Figure 1).

We found out that the best for energy not supply estimation is to use standardized load curve (See Fig.2) and some additional information like start (8 a.m.) and finish (2 p.m.) of outage. Very important is to know type of outage day because there is essential difference in load curve in working days and weekends especially in industry.

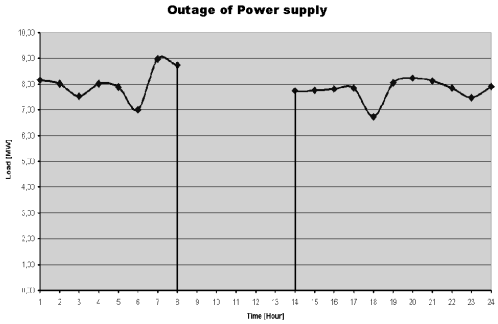

Figure 1. Example of Power supply Outage

We set 4 types of outage days in analyzed industrial enterprise:
Working days (Tuesdays, Wednesdays, Thursdays)
Weekend (Saturdays, Sundays)
Day before weekend (Fridays)
Day after weekend (Mondays)

Each type of outage days has different standardized load curve.

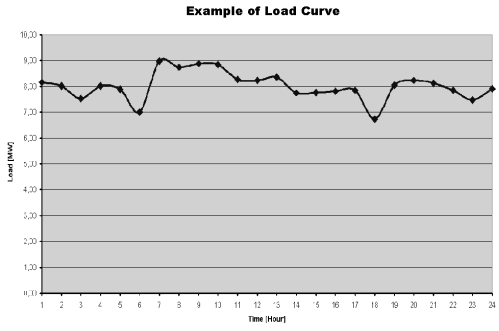

Figure 2. Example of Load Curve (Working Days)

We calculate Energy not supply using formula (5) according to Figure 3.

$$ENS = \int_{t_2}^{t_1} P(t)\,dt \quad (5)$$

where:
P - Power Load Function
t_1 - Begin of Outage
t_2 - End of Outage

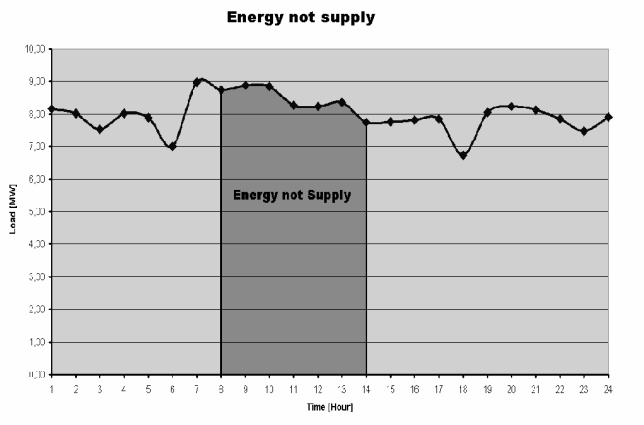

Figure 3. Example of Energy not Supply Calculation

We use load curve set by MS EXCEL table of numerical values in real industrial calculations. Load data interval is usually 1 minute but we can also use interval 1 second or 15 minutes (15 minutes interval is important for regulation of power flows in accordance with energy markets in Czech Republic).

Some examples of Energy not supply decreasing possibilities:
- oDecreasing of failure rate
  - oConnection into two independence substation
  - oConnection to higher voltage level
  - oOverhead lines change to cable lines
- oDecreasing of outage duration
  - oInstallation of remote controlled switch or recloser
  - oOptimizing of service teams availability
  - oInstallation of stand by power sources

IV. GENERAL EXPRESSION OF OUTAGE COSTS

In consequence of power supply outage, damages occur on the side of customer as well as on the side of Holders of License for electricity trading and Holders of License for electricity distribution. The total damages caused by a power outage can be then expressed mathematically as a sum of damages suffered by the customer and damages suffered by the Holders of License for electricity trading and Holders of License for electricity distribution.

$$C_{TOTAL}=C_{CUSTOMER}+C_{TRADING}+C_{DISTRIBUTION} \quad (6)$$

Where
C_{TOTAL} – Total Outage Costs
$C_{TRADING}$ – Holders of License for Electricity Trading Outage Costs
$C_{DISTRIBUTION}$ – Holders of License for Electricity Distribution Outage Costs

V. THE ANALYSIS OF DAMAGES SUFFERED BY THE CUSTOMER

If we consider merely damages suffered by the customer, it is necessary, for convenience, to distinguish the damages according to the time when the damage concerned happens in the course of outage. As the basic division of damages on the side of customers, the following division into two groups can be regarded:

- -Direct damages suffered by the customer – damages occurring immediately after interrupting the power supply (at the beginning of outage)
- -Indirect damages suffered by the customer – damages that may happen in the course of outage, or after power supply restoration.

This division can be expressed by the relation given below

$$C_{CUSTOMER} = C_{DIRECTC} + C_{INDIRECTC} \quad (7)$$

Where
$C_{DIRECTC}$ – Direct Customer Outage Costs
$C_{INDIRECTC}$ – Indirect Customer Outage Costs

Direct Costs Incurred by the Customer Due to the Outage

Direct costs incurred by the customer can consist of several basic items, e.g. costs of damaged products (half-finished products), costs of waiting time of employees, costs of the restoration of production, costs arising from lost production, costs of the alternative to production lost, costs of penalty payment, or in some cases other direct costs, which are typical of the given branch of industry, incurred by the customer.

These partial direct costs incurred by the customer can be expressed by the following relation

$$C_{DIRECTC} = C_{DP} + C_{WI} + C_{RP} + C_{LP} + C_{APL} + C_{PEN} + \Sigma C_I \quad (8)$$

Where
C_{DP} - Costs of damaged products
C_{WI} - Costs of waiting time of employees
C_{RP} - Costs of the restoration of production
C_{LP} - Costs arising from lost production
C_{APL} - Costs of the alternative to production lost
C_{PEN} - Costs of penalty payment
C_I - Other relevant direct costs specific of the given customer.

Relation (8) can be modified (extended) if applied to real industrial conditions due to different damages in different industrial branches.

Costs of the Restoration of Production

Among the costs of production restoration, the costs of restoration of whole production equipment if damaged in the course of outage and the costs of equipment restarting can be ranked. The costs of production restoration can be expressed by a relation as follows

$$C_{RP} = C_{COR} + C_{START} \quad (9)$$

Where
C_{COR} – Costs of Production equipment correction
C_{START} – Costs of equipment starting

Costs to Alternative to Production Lost

In case that the power supply outage does not affect the whole premises of the plant (e.g. in case of power supply to a part of the premises from another source), it is possible that the customer will maintain production by securing (buying) some parts, half-finished products or services from another producer (supplier).

Costs of Penalty Payment

In the industrial environment, all supplies are usually secured on the basis of contracts; the contracts usually include clauses regarding penalization, or allowances in case that the producer is not able, for various reasons (production failure due to an interruption in power supply to the production plant), to supply the goods. The total amount of costs of penalty payment depends on many factors, and the main factor is mostly the period of delay in delivery (here, a relation between the delay in delivery and the duration of outage is obvious in case that production equipment is utilized fully (100%) and the manufacturer uses make-to-stock production).

Indirect Costs Incurred by the Customer due to the Outage

Total indirect costs incurred by the customer can be expressed as a sum of individual partial indirect losses as follows:

$$C_{INDIRECTC} = \Sigma\, k_{IC} \,.\, C_{IC} \quad (10)$$

Where
C_{IC} – Partial Indirect Customer Outage Costs

Coefficients k_{IC} express a possibility that the damaged customer can decrease the total costs, e.g. by putting emergency plans prepared in advance into operation. The more detailed specification of indirect costs incurred by the customer is very complicated and in the majority of cases, only professional estimates are done. That is why we do not consider any indirect costs in our analyses at present.

Total Costs Incurred by the Customer

Total costs incurred by the customer can be expressed by inserting relation (9) into relation (8), and subsequently modified relation (8) and relation (10) into relation (7). Thus we shall obtain the resultant relation for the total costs incurred by the customer in the following form

$$C_{CUSTOMER} = C_{DP} + C_{WI} + C_{COR} + C_{START} + C_{LP} + C_{APL} + C_{PEN} + \\ + \Sigma\, C_I + \Sigma\, k_{IC} \,.\, C_{IC} \quad (11)$$

C_{DP}, C_{WI}, C_{COR}, C_{START}, C_{LP}, C_{APL}, C_{PEN} are functions of many variables and their mathematical expression is difficult. However, we can simplify the situation by regarding these functions as functions of a single variable, namely the duration of outage.

These theoretical relations are general and universal.

VI. COMPOSITION OF ELECTRICITY PRICE [9]

First of all we must analyze structure of electricity prize to describe aftereffects of electric power supply outage. After electricity prize analysis we can divide aftereffects between Holders of License electricity trading and Holders of License for electricity distribution.

Since the start of 2006, there has been a change in the manner of billing electricity payments for households. In connection to the unbundling of sales and distribution activities, the related payments have also been separated.

According to the requirements of the Energy Act, the price for electricity is divided into regulated payments for transmission of electricity to your household (i.e. payments for use of the energy network) and payments for the actually consumed electricity ("power"). The value of regulated payments is stipulated annually based on a proposal from the regulated entities by resolution of the Energy Regulation Office, while the price of power is determined by the situation on the electricity market.

The said payments are also divided into partial components, which are listed individually in the electricity price list and in the final billing of consumption.

Payment for power (payment for actually consumed electricity)

The price of electricity is composed of two parts:

- Fixed monthly price – the value of which differs depending on the product series of customer
- Price per consumed megawatt hour (MWh), which for some electricity rates are divided into the price in the low (LT) and high (HT) tariff band.

Regulated payments for electricity transmission

These payments are stipulated annually by the Energy Regulation Office based on a proposal from the regulated entities, and include the following components:

- Price for distribution (electricity distribution to individual customers) includes:
  - Monthly fee for power input according to the nominal current value of the main circuit breaker before the electrometer; this is a sum that evolves from the current value of the main circuit breaker in household (expressed in amperes – A) and covers the fixed costs of the distribution system operator. It is paid at a fixed monthly rate regardless of how much electricity customer consumes.
  - Price per transmitted MWh – this may again be divided into a price with a high (HT) and low (LT) tariff.
- Price for system services covers the costs of the energy transmission system operator to purchase auxiliary services from individual electricity producers. For simplicity, these services may be considered the necessary standby of power plants that work as backup facilities in the case of outages in production or sudden increases in electricity consumption.
- Price for support of electricity buyout from renewable sources (RES) and combined electricity and heat production. In connection to joining the EU, the Czech Republicundertook to support this type of production with regards to its ecological benefits. The production costs for these facilities are higher, which is why they are covered from this fee.
- Price for accounting activities of the Electricity Market Operator (OTE) covers the costs of this company, which among other things ensures processing of balances of the electricity supply offer and demand, and accounting of discrepancies between the planned and actually supplied volume of electricity between individual participants on the electricity market.

Electricity tax

From 2008, the price of electricity also includes the newly stipulated electricity consumer tax – one of the newly introduced ecology taxes arising from our obligations towards the European Union. The tax is paid by the electricity supplier to the Customs Administration in bulk for all customers, meaning that you have no additional worries. The tax is the same for everybody and is equal to CZK 28.30/MWh.

VII. THE ANALYSIS OF DAMAGES SUFFERED BY THE HOLDER OF LICENSE FOR ELECTRICITY TRADING

According to Customer Outage Costs we also divide these Outage costs into two groups:

1. Direct damages suffered by the Holder of License for electricity trading – damages occurring immediately after interrupting the power supply (at the beginning and during of outage)
2. Indirect damages suffered by the Holder of License for electricity trading – damages that may happen in the course of outage, or after power supply restoration.

This division can be expressed by the relation given below

$$C_{TRADING} = C_{DIRECTT} + C_{INDIRECTT} \quad (12)$$

Where
$C_{DIRECTT}$ – Direct Holders of License for electricity trading Outage Costs

$C_{INDIRECTT}$ – Indirect Holders of License for electricity trading Outage Costs

Direct Costs Incurred by the Holder of License for electricity trading Due to the Outage

The main partial direct outage costs are composed mainly by loss from undelivered Power Energy ($C_{UNDELIVERED}$) (Kč/MWh). It is energy unconsumed by end user.

Indirect Costs Incurred by the Holder of License for electricity trading Due to the Outage

Economical expression of these indirect outage costs is very difficult and it is not possible to describe detail technical economical analysis in this article. We can include to this outage costs group for example change of Electricity trading License Holder or License Holder stock decreasing.

VIII. THE ANALYSIS OF DAMAGES SUFFERED BY THE HOLDER OF LICENSE FOR ELECTRICITY DISTRIBUTION

We also divide Holder of License for Electricity Distribution Outage costs into two groups:

-Direct damages suffered by the Holder of License for electricity Distribution – damages occurring immediately after interrupting the power supply (at the beginning and during of outage)

-Indirect damages suffered by the Holder of License for electricity Distribution – damages that may happen in the course of outage, or after power supply restoration.

This division can be expressed by the relation given below

$$C_{DISTRIBUTION} = C_{DIRECTD} + C_{INDIRECTD} \quad (13)$$

Where

$C_{DIRECTD}$ – Direct Holders of License for electricity distribution Outage Costs

$C_{INDIRECTD}$ – Indirect Holders of License for electricity distribution Outage Costs

Direct Costs Incurred by the Holder of License for electricity Distribution Due to the Outage

Direct Holder of License for Electricity Distribution Outage Costs we can divide into:

- Distribution Network Correction Costs ($C_{NETWORK}$) – Total value of these costs depends for example on cause and range of Outage.
- Manipulation Costs ($C_{MANIPULATION}$) – Total value of these costs depends for example on number of remote controlled switching elements connected in affected distribution network.
- Undistribution Costs ($C_{UNDISTRIBUTION}$) – It is composed by loss from untransmitted MWh
- Losses Costs (C_{LOSSES}) – It is profit for decreased losses costs.

Indirect Costs Incurred by the Holder of License for electricity trading Due to the Outage

The main part of these indirect costs is costs for penalization payments ($C_{PENALIZATION}$). There are set some guaranteed standards and penalization for standards overrun.

Some of the guaranteed standards

- Distributor's fuse
- Restoration of Supply
- Estimate of Charges

IX. GENERAL EXPRESSION OF TOTAL OUTAGE COSTS

Total outage costs we can express like a summation of customer outage costs, holder of License for electricity trading outage costs and Holder of License for electricity distribution outage costs according to (6).

$$C_{TOTAL} = C_{DP} + C_{WI} + C_{DOR} + C_{START} + C_{LP} + C_{APL} + C_{PEN} + \Sigma C_I + \Sigma k_{IC}.C_{IC} + C_{UNDELIVERED} + C_{INDIRECTT} + C_{NETWORK} + C_{MANIPULATION} + C_{UNDISTRIBUTION} - \Delta C_{LOSSES} + C_{PENALIZATION} \quad (14)$$

This expression is general and it is possible to use them in any type of reliability analysis. It is possible to modify this formula during reliability analysis and add or remove partial outage costs according to real situation.

CONCLUSION AND RECOMMENDATION

In this article, common reliability indices and other reliability parameters are described. Theoretical relations to the calculation of costs due to the outage suffered by the customer are summarized.

These theoretical relations are general and universal. Description of energy not supply was presented in theoretical part of article.

The knowledge of total costs due to a power outage is important especially to planning investments in measures leading to an increase in power supply reliability.

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