# ECONOMIC EVALUATION OF CONTROLLABLE DEVICES IN THE SLOVENIAN ELECTRIC POWER SYSTEM – A CASE STUDY

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***Keywords: PST, liberalized electricity markets, economic valuation, discounted cash flow (DCF)***

**Abstract - This paper presents a case study on how controllable devices – two Phase Shifting Transformers (PST) – located in Slovenia could be valuated with economic tools. The motivation for the installation of these devices is the interest of Slovenian power producers and network operators to be able to transfer more power from cheap production units to Italy where electricity prices are notoriously higher than in the rest of Europe. The case study shows the possible approach on such an evaluation and gives qualitative results about the sensitivity of input parameters.**

## 1 INTRODUCTION

THE operators of power transmission networks are more and more forced to optimize their assets for economical efficiency. Together with higher electricity consumption this leads to an increased utilization of the physical components such as transmission lines. Even in highly meshed networks – as it is the case in Europe – this adds to the risk of local congestions in certain transmission lines or in links consisting of several lines. These congestions in turn can produce significant price differences between the areas around these congestions. Eliminating congestions by means of installing new transmission lines is normally difficult, if not impossible. It can take decades from evaluating a new line to the time it is installed. Political and environmental regulations further add to the difficulties improving the physical network.

This paper presents a qualitative case study installing Phase Shifting Transformers (PST) in the transmission lines between Slovenia and Italy. To estimate the effect of these devices power flows in the UCTE network are determined using detailed network data. Power generation and load consumption is taken from a typical Thursday beginning of year 2003 at 10.30 am. The flows are calculated using the UCTE network including approximately 5000 nodes, 7300 transmission lines and 1200 transformers (see section 2). The information from this detailed calculations is then used to determine the effective transfer limitations between the different countries surrounding Slovenia. For the economic evaluation a simplified model of the network is used implementing transmission limits determined from the detailed calculation (see section 3). This then enables the calculation of the price differences in the different areas resulting in the cash flow for the company owning the PSTs. The cash flow is produced by multiplying the enhanced power flow times the price difference between the nodes of the lines where the PSTs are installed (see section 4).

## 2 DETAILED POWER FLOW CALCULATION

### *2.1 Base Case*

Fig. 1 shows the power flows using the same generation and load situation assuming synchronous operation of UCTE zones I and II [1]. The power balance in Slovenia is almost zero. The exported energy to Italy is solely the result of transferring power from Austria and Croatia, whereas Croatia is importing large amounts from Hungary and Bosnia and Herzegovina (not shown in the figure). Italy is importing most energy directly from France and through Switzerland, a significant amount from Slovenia, and only a minor part from Austria. The link from Slovenia to Italy is loaded very high, surpassing the NTC value set by UCTE by some 150%. To prevent these excessive power flows PSTs could be installed in two lines between these countries.

### *2.2 Future Development*

As more production units with low incremental costs are available in the east of the newly synchronized UCTE parts, it will be attractive for Slovenian power companies to transmit more energy from Hungary to the high price zone Italy. Additional lines are planned to be built between Slovenia and Italy, Slovenia and Hungary, and Austria and Slovenia [2].

Fig. 2 shows the power flows using the same situation as above, but with major new 400 kV lines installed between Slovenia, Italy, Hungary, and Austria and two PSTs between Slovenia and Italy. One PST with a rating of approximately 400 MVA is installed in the 220 kV line connecting Slovenia and Italy, a second in the 400 kV line with a rating of approximately 2100 MVA. These PSTs control the power flow to Italy to stay within the NTC.

The economic value of the PSTs can be determined by first calculating the income cash flow for the company owning the devices. The price difference between Slovenia and Italy has to be multiplied with the increased transfer capacity between the countries in comparison with the base case above. In addition to the investment costs of the PSTs the investment costs for the new lines between Slovenia and the surrounding countries have to be included into the initial costs of the project.

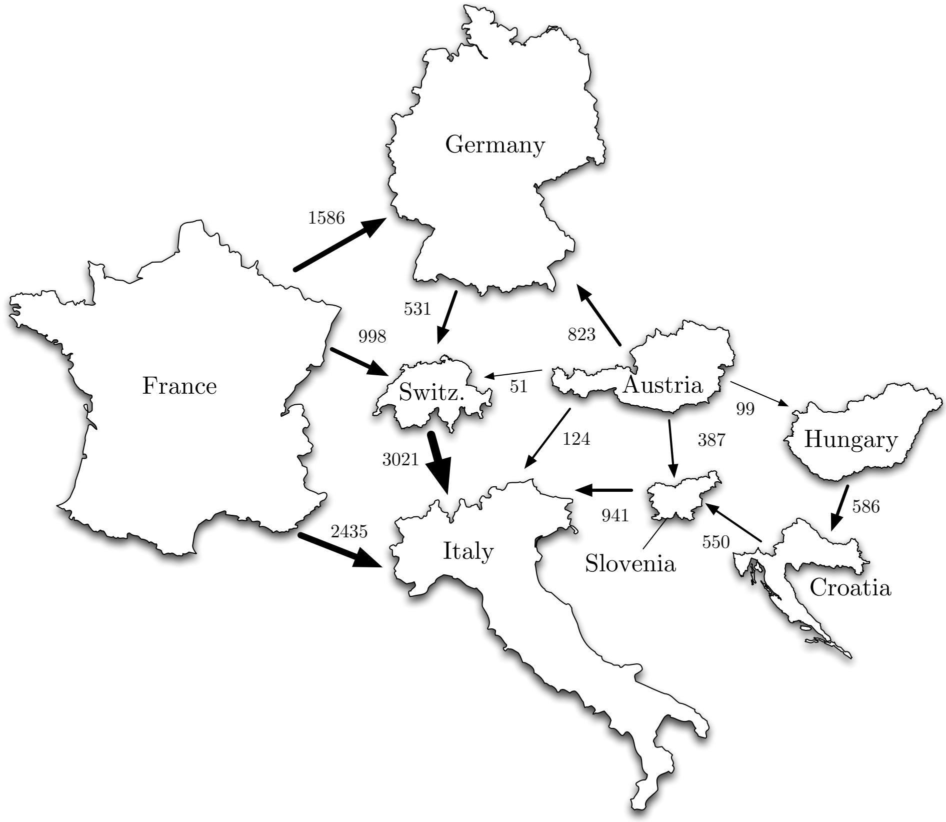


**Figure 1:** Power flows in Europe after the synchronization of UCTE zones I and II.

## 3 PRICE AND CASH FLOW CALCULATION

As said above, a simplified model of the electric power system is used for modeling electricity prices. The system is divided into regions with limited transfer capabilities between them. The physical networks in those areas – also known as Super Nodes – are not modeled [3]. However, transmission constraints between these areas are limiting the power transfer. Such a "Copper Plate Model" is shown in Fig. 3 for three regions. Region A, for example, has the export limit of $E^A$ and the import limit of $I^A$. The import and export limits are normally set to the same value for one region ($E^z = I^z$ for region $z$) [4].

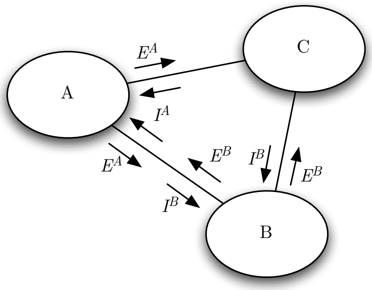


**Figure 3:** "Copper Plate Model" using Super Nodes

### *3.1 Optimization*

The behavior of the electricity market is modeled by optimizing for social welfare. The modeled price differences for different scenarios are utilized for the actual valuation of the controllable devices. In this study a perfectly competitive market is assumed, where all participants behave rationally, have full and free access to market information and producers bid their marginal cost curves.

The reasoning behind this assumption is that liberalized power markets are moving towards full competition, if a sufficiently long period of time is considered. Even if competition is not perfect looking at a time span of e.g. one year, market mechanisms will move the system towards maximum social welfare over several years. Thus, applying a model, which optimizes for social welfare, is appropriate for studying future behavior of electric power systems.

The non-linearity of the power flow equations, the cost curves of generators result in an optimization problem that has a non-linear objective function as well as non-linear constraints. The model is optimized for social welfare, subject to transmission constraints, and generation limits. The mathematical setup is of the form:

$$\begin{array}{lll} \text{minimize} & f(x) & x \in \mathbf{R}^n \\ \text{subject to} & Ax - b = 0 & \\ & Cx - d \leq 0 & \\ & g_i(x) = 0 & \\ & h_j(x) \leq 0. & \end{array} \quad (1)$$

where $f(x)$ is the *objective function*, $Ax - b = 0$ the linear equality constraints, $Cx - d \leq 0$ the linear inequality constraints, $g_i(x) = 0$ the non-linear equality

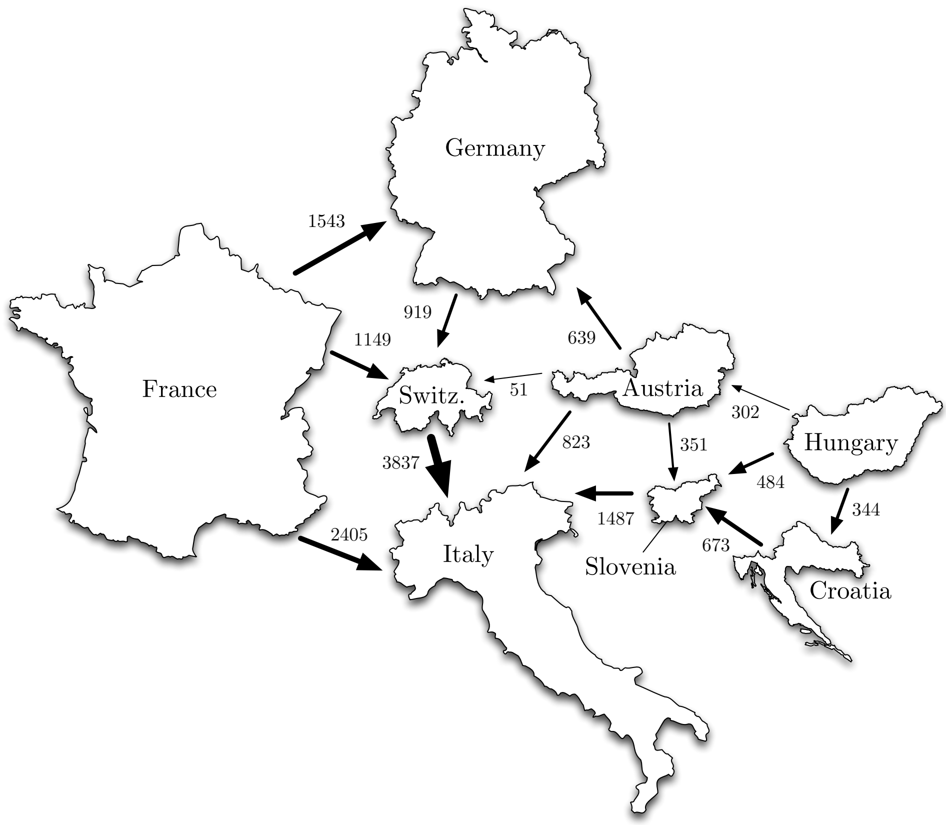


**Figure 2:** Power flows in Europe after the synchronization of UCTE zones I and II, with new lines and PST installed.

constraints, and $h_j(x) \leq 0$ the non-linear inequality constraints.

### 3.2 *Objective Function*

The methodology described here is similar to what was applied in [5] and is based partly on [6]. Social welfare is used as the objective function. It is defined as:

$$SW = \underbrace{\sum_i B_i(P_{L_i}) - \lambda \cdot P_\lambda}_{CS} + \underbrace{\lambda \cdot P_\lambda - \sum_j C_j(P_{G_j})}_{PS} \tag{2}$$

where:

- $SW$ is the social welfare,
- $B_i$ the amount the consumer $i$ is willing to pay for the power $P_{L_i}$,
- $P_{L_i}$ the power consumed by load $i$,
- $C_j$ the generator $j$'s cost to produce the power $P_{G_i}$,
- $P_{G_j}$ the quantity of power produced by generator $j$,
- $\lambda$ the price at the intersection of the consumers' and producers' aggregated marginal cost curves.
- $P_\lambda$ the power at the intersection of the aggregated marginal cost curves.

The term $CS$ represents the consumer surplus and the term $PS$ the producers' surplus (their profit).

Typical optimization algorithms minimize the objective function. Thus, the objective function to be minimized is:

$$f(P_{L_i}, P_{G_i}) = \sum_i B_i(P_{L_i}) - \sum_j C_j(P_{G_j}) \tag{3}$$

The cost curves of the generators are defined as quadratic functions. It is assumed that the suppliers bid continuous marginal cost curves. The demand is considered to be fixed.

### 3.3 *Constraints*

The linear inequality constraints ($Cx - b \leq 0$ in Eq. (1)) are defined by the upper and lower production limits of the generators and the upper and lower consumption limits of the loads.

$$P_{G_i}^{min} \leq P_{G_i} \leq P_{G_i}^{max} \tag{4}$$

$$P_{L_i}^{min} \leq P_{L_i} \leq P_{L_i}^{max} \tag{5}$$

The non-linear inequality constraints ($h_j(x) \leq 0$ in Eq. (1)) are given by the transmission capacity of the transmission lines as described in section 3.

The non-linear equality constraints ($g_i(x) = 0$ in Eq. (1)) contain the power flow equations for each node in the network: the sum of the injected power flowing into a node has to match the power consumed by the loads and flowing out of the node through the transmission lines.

For each equality constraint a marginal price is calculated for a specific solution of the optimization problem formulated. This leads to marginal prices for each node of the network. Thus, by using the optimization method described in the preceding paragraphs it is possible to calculate Locational Marginal Prices (LMP) in the network. The differences in these prices together with the increase in transmitted power is used to calculate the cash flow produced by the controllable devices installed in the electric transmission system. Schweppe describes in [7] the theory of spot pricing of electricity, which forms the theoretical basis for LMP based methodologies.

The LMPs consist of three parts: the marginal costs for production, the marginal costs for losses and the marginal costs for congestion at a specific node. If there are no losses and no congested transmission lines in a network, the LMPs are equal for each node. In this case the total amount of earnings of the producers and the total amount of payments by the loads is equal too.

If the system has constrained transmission paths[1] the LMPs are no longer equal throughout the network. This results in higher energy prices at nodes with limited import capacity from areas with cheap production.

In such a situation the total payments made by each load $i$ are:

$$CF_L = \sum_i P_{L_i} \lambda_i \tag{6}$$

Compared with the total earnings made by each generator $j$

$$CF_G = \sum_j P_{G_j} \lambda_j \tag{7}$$

they are always equal or larger[2]:

$$CF_L \geq CF_G \tag{8}$$

The difference

$$CF_C = CF_L - CF_G \tag{9}$$

is called Congestion or Transmission Charge. In a pool market it can be collected by the TSO.

Part of this congestion charge is used to pay the company running the controllable devices. The amount paid to the company is the price difference between the nodes where the enhanced capacity is installed times the amount of additional energy transported towards high price areas due to the controlled power flow.

[1] or losses, which are not taken into account in this paper

[2] the term $CF$ stands for cash flow

## 4 ECONOMIC VALUATION

The evaluation of the controllable devices will be carried by considering a special company, a so-called Special Purpose Vehicle (SPV). Its sole purpose is the operation of the device. The company will produce cash flows by reselling the additionally transfered energy from a low price area into a high price area. A Discounted Cash Flow analysis is then carried out to determine the value of that company at present [8]. (A similar valuation using a "Copper Plate Model" is presented in [3]. )

### *4.1 Input Parameters*

This section presents the parameters used for the economical simulations. The input parameters influencing the economical valuation of the project are:

- *Transmission Network*: The system is modeled using a "Copper Plate Model". The "Super Nodes" are chosen as shown in Fig. 4. The links between Italy and the other countries is congested most of the time. The cheap production units cannot export as much energy as they want into Italy. The introduction of a controllable device in Slovenia helps pushing more energy over this link and thus decreases the prices in Italy.

- *Supply*: The parameters of the generators are set as shown in table 1. Generators 1, 2, and 3 are located in node 1, generators 4, 5, and 6 in node 2, generators 7 and 8 in node 3, generators 9, 10, and 11 in node 4, and generators 12, 13, and 14 in node 5 as indicated in Fig. 4. Each generator in a node represents an aggregated type of generation with its characteristic cost parameters [3]: Generators 1, 4, 9, and 12 represent nuclear generation, generators 2, 5, 7, 10, and 13 hydro generation and generators 3, 6, 8, 11, and 14 conventional thermal generation. Their peak output is set as found in [9]. Generator 8 represents expensive production in Italy. Generators 15 and 16 represent additional cheap production units in Bosnia and Herzegovina (15) and in Czechoslovakia (16).

- *Demand*: The demand is modeled using the following values for the yearly demand: In the first year the demand is considered to be in the range between 60% and 70% of the peak load in each country in 2002 [9] in quantification steps of 2%. The duration of the steps is equally distributed resulting in a total of 8760 hours. For the following years the minimum demand is assumed to increase by 0.5% per year and the maximum demand by 1% per year. This approximates an increase in demand similar to what is seen in recent years in Italy [10]. The peak load for each node results to the values shown in table 2 and is set as found in [9].

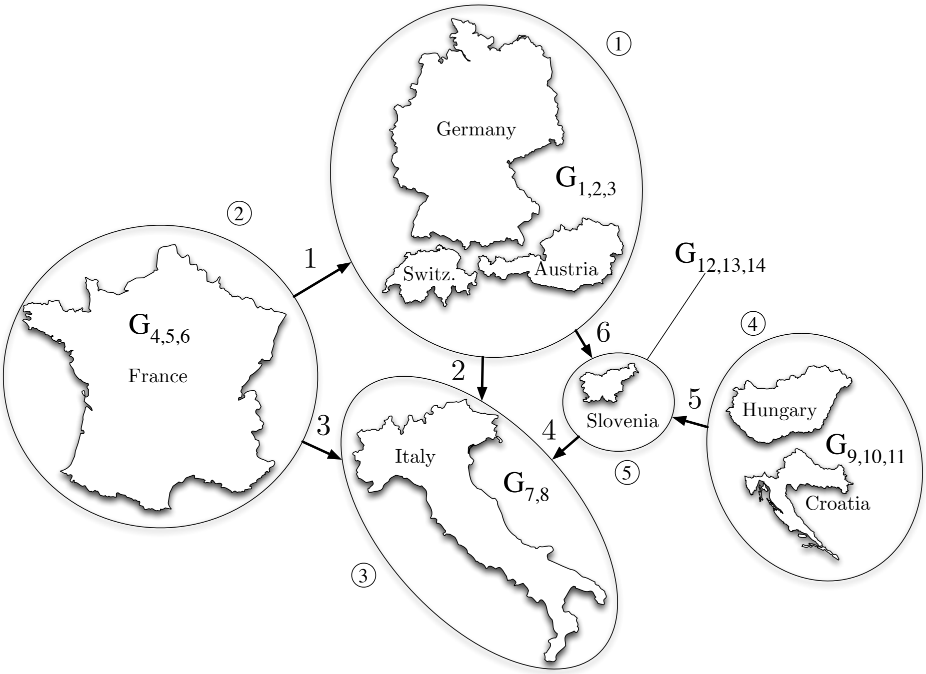


**Figure 4:** "Copper Plate Model" representation of the system.

- *Enhanced Power Flow*: The transmission paths between the nodes are set as shown in table 3. The PSTs are considered to allow a 40 % increase in power transfered from Slovenia into Italy. These values are derived approximately from the results of the detailed simulations of section 2.

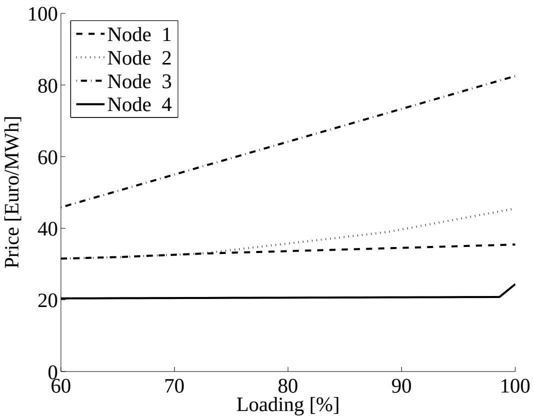


**Figure 5:** Nodal prices at nodes 1, 2, 3, and 4 for the base case without additional power transfer.

Varying the demand from 60 to 100 % of the peak load results in the LMPs as shown in Fig. 5, which shows the high prices in Italy (node 3) and the increasing prices in France (node 2) for higher loads. The kink in the prices of node 4 is due to the limited transfer capacity between node 4 and 5.

| Nr. | $a_0$ [€] | $a_1$ [€/MW] | $a_2$ [€/MW$^2$] | $P_G$ [MW] |
|---|---|---|---|---|
| 1 | 0 | 24.3 | 0.00040 | 23900 |
| 2 | 0 | 6.9 | 0.00067 | 33500 |
| 3 | 0 | 29.1 | 0.00006 | 74400 |
| 4 | 0 | 24.3 | 0.00040 | 63200 |
| 5 | 0 | 6.9 | 0.00067 | 23900 |
| 6 | 0 | 29.1 | 0.00006 | 23500 |
| 7 | 0 | 6.9 | 0.00067 | 20400 |
| 8 | 0 | 40.0 | 0.00090 | 55100 |
| 9 | 0 | 24.3 | 0.00040 | 1800 |
| 10 | 0 | 6.9 | 0.00067 | 2100 |
| 11 | 0 | 29.1 | 0.00006 | 7100 |
| 12 | 0 | 24.3 | 0.00040 | 700 |
| 13 | 0 | 6.9 | 0.00067 | 800 |
| 14 | 0 | 29.1 | 0.00006 | 1100 |
| 15 | 0 | 20.0 | 0.00006 | 6700 |
| 16 | 0 | 20.0 | 0.00006 | 10500 |

**Table 1:** Parameters of Generators

| Nr. | $P_L$ [MW] |
|---|---|
| 1 | 93900 |
| 2 | 72900 |
| 3 | 50900 |
| 4 | 8500 |
| 5 | 1800 |

**Table 2:** Parameters of Loads

| Nr. | $P_{mn}^{max}$ [MW] |
|---|---|
| 1 | 1500 |
| 2 | 3500 |
| 3 | 2500 |
| 4 | 900 |
| 5 | 400 |
| 6 | 500 |

**Table 3:** Parameters of Lines

The economical parameters for the evaluation are:

- *Project lifetime*: is set to 20 years in the base case. This value is set this small, since the future development of the system cannot be predicted much further without sacrificing reliability of the results.
- *Risk free interest rate*: is set to the average of the 25 year yield of the US government bonds in 2003 which is approximately 5% [11]. This approach is recommended by Copeland in [12].
- *Cost of borrowing*: is assumed to be 1% over the risk free interest rates amounting to 6%. Investments in utilities are usually considered as low risk, so any bond issued by such a company would only have a slight premium over government bonds.
- *Cost of running the SPV*: is assumed to be 5% of gross turnover.
- *Initial investment*: the initial investment including installation costs for the PSTs per MVar are approximated similar to what is proposed in [13]. A value of 30 k€ / MVar is assumed. This leads to a total investment for the PSTs of 60 M€. An additional 60 M€ is assumed for the necessary transmission lines needed. This leads to a total of 120 M€ initial investment.
- *Variable Costs and Revenues*: the revenues are determined by multiplying the amount of additional transfered energy due to the PSTs by the nodal price in the high price area; the variable costs by multiplying the amount by the nodal price in the low price area. These numbers are needed to calculate the "Earnings Before Interest, Taxes, Depreciation and Amortization" (EBITDA).
- *Corporate tax rate*: this is assumed to be 25 %, which was the corporate tax rate for companies in Slovenia in 2004.
- *Working capital*: this is assumed to 1.5 M€ with an additional variable amount equal to 5% of revenues. The working capital is the cash required to pay salaries and other expenses in order to keep the company in operation.
- *Salvageable Working Capital at the End of the Project*: This is set to 25%.

### *4.2 Valuation Results*

Below the results of applying the valuation framework using the above input parameters are presented. The DCF analysis finally results in the valuation indicators as shown in table 4.

| | |
|---|---|
| Net Present Value (NPV) = | 478 M€ |
| Return Of Capital (ROC) = | 63 % |
| Internal Rate of Return (IRR) = | 34 % |

**Table 4:** Financial indicators of valuation.

These value are surprisingly high. The Internal Rate of Return (IRR) can be used to compare the project to investing the same amount of money as the initial investment into a bank account. Projects with an IRR over 10 % are normally considered to be financially attractive. The Return Of Capital (ROC) is similarly high. These values show the economical potential that lies in projects taking advantage of price differences between congested areas in an electric power transmission system. This values can, however, not be taken as absolute numbers. The amount of initial investment can vary significantly depending on the scope of the project, e.g. if the investment costs of additional lines need to be taken into account. Therefore it is very important to study the influence of parameter variations on the valuation results.

The influence of the project lifetime on the IRR is shown in Fig. 6. The numbers show that after a project lifetime of about 5 years the project can be financially attractive. The Net Present Value (NPV) shows a similar result (Fig. 7). After about 5 years the NPV is higher than the initial investment, which is indicated as a horizontal line.

As the initial investment is a very important factor, its influence on the IRR is shown in Fig. 8. Doubling the initial investment to 240 M€ reduces the IRR to about 17 %. Whereas reducing the amount significantly enhances the project value.

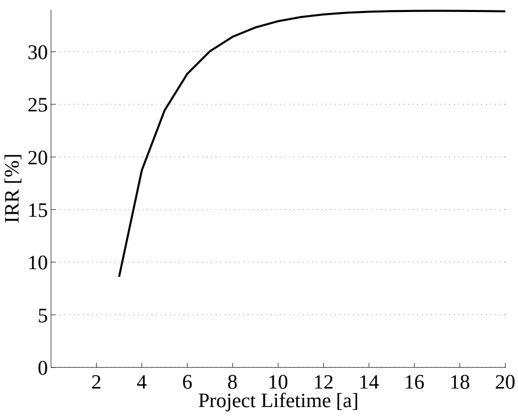


**Figure 6:** Internal Rate of Return (IRR) as a function of the project lifetime in years.

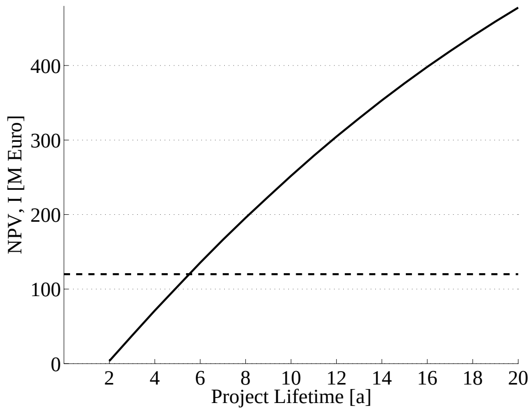


**Figure 7:** Net Present Value (NPV) and I as a function of the project lifetime in years.

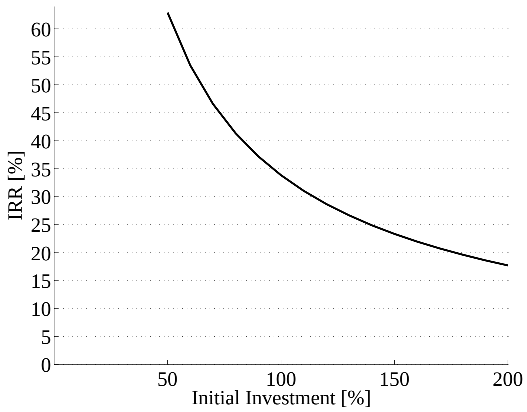


**Figure 8:** Internal Rate of Return (IRR) as a function of the variation of the initial investments.

## 5 CONCLUSIONS

This case study shows possible ways to valuate the installation of PSTs in Slovenia into the existing UCTE network. The framework shows how electricity prices can be forecasted using a "Copper Plate Model" without calculating detailed power flows in the network. The economic valuation indicates that it can be financially very attractive to increase the amount of power being transfered from Slovenia into Italy. Controllable device are needed to be able to limit the power transfer to secure levels. In this case, the investments into new lines and into PSTs have to be valuated as one project.

Extensive simulations would need to be carried out to be able to give a quantitative answer about the value of the project. Furthermore, the European TSOs have to agree upon an exact procedure to compensate for these kind of network services. The cash flow to the project owner has to come from collected congestion charges.

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