

Determining the Value of Controllable Devices in a Liberalized Electricity Market: A New Approach

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Abstract—This paper describes a method of assessing the value of controllable devices such as Flexible AC Transmission Systems (FACTS) in a liberalized electricity market.

A sophisticated algorithm using an optimal power flow (OPF) is often unnecessarily detailed for the purpose of valuating such projects. Input parameters such as expected future generation mix is hard to guess and error prone. Therefore a simplified model of the underlying electricity system was chosen for this evaluation.

The suggested method is based on a model that uses area constraints and aggregated generation in each area coupled with a double auction market model, based on the production costs of generators. A Discounted Cash Flow methodology is then used to estimate the value of this project.

In different case studies the influence of various parameters on the value of the controllable device is determined. Typical parameters are: Investment costs, running costs, relocatability etc. Also the impact of transmission congestions on electricity prices, consumer, producer and society profit is studied.

Keywords—liberalized electricity market, investment opportunities, FACTS, optimization, discounted cash flow (DCF).

I. INTRODUCTION

IN a liberalized electricity market, the transmission capability of an electrical network – which usually is regarded as a natural monopoly – is of economic value to the network operator. Due to various constraints due to security considerations and network topology, lines can often only be utilized significantly below their physical limits. To improve customer benefit one possibility is to raise the economic value of the transmission lines by increasing the power transfer capability of these lines. Additionally, there will be a gain in overall market efficiency since more energy trading can take place between competing regions with different price structures. Instead of installing new transmission lines, Flexible AC Transmission Systems (FACTS) devices can also increase the overall utilization of an electrical power network by directly controlling the power flow.

Since installations of FACTS devices require substantial investments, with costs that could be similar to new transmission lines (see [1]), it is very important to investigate all different aspects of such a device: For example not only the increased transmission capacity, but also the fact that such a device can be built in such a way that it can be relocated. The device can then be moved to an optimized location in the network. This can be based on seasonal differences in the generation pattern due to uneven distribution of hydro power or on changes in the installed capacity over longer periods of time. The liberalization of the

electric power market has already shown e.g. in the United Kingdom that important changes in the local installed generation capacity can occur. Also future, unpredictable load changes may create the need to relocate the device.

The biggest issue before investing in such a project often is the limited knowledge of its efficiency and, related to that, the financial benefits it can generate over its lifetime. Therefore appropriate valuation tools are needed. This paper tries to show one possible approach by using a market model to calculate expected price differences in regions that are connected via congested links. The results of the model are then fed into a financial analysis tool.

The paper presents results of an ongoing research project in the area of the value of controllable devices in a liberalized electricity market. The model is based partly on the work described in [2].

II. OPTIMIZATION CRITERIA

In this paper, the markets are assumed to be perfectly competitive and the market clearing process (or price adjustment procedure) to be instantaneous. In such a market, “an equilibrium price is achieved at the point where quantity demanded equals quantity supplied” [3].

When producers sell a good on the market their benefit is clear: it is their profit. In economics this profit is known as **producer surplus**. The producer surplus formally is defined as the difference between the income received by the sale of a good and its production cost. If producers behave rationally, they will only sell goods on the market if they can derive a profit or producer surplus equal or greater than zero. Under the assumption of perfect competition, producers adapt their production to demand and price their goods at a price equal to their short run marginal costs. The marginal cost is defined as the cost of producing one extra unit.

For the consumers, defining the benefits derived arising from a purchase is more challenging. Economists have proposed the concept of consumer surplus. The **consumer surplus** is defined as the difference between the value the consumer is prepared to pay and what he actually pays. It is assumed that the consumers behave rationally, in that they do not purchase any good that has a higher price on the market than the benefit he would derive from it.

Under the assumption of perfect competition both consumers and producers have a surplus. Consumers and producers being the only economic actors present, they represent the society as a whole. The aggregate of these two quantities is known as the total value of the market, other terms used by economists are **society profit** and **welfare**.

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The society profit is used as the objective function that is maximized:

$$\text{Maximize } W = \sum_i B_i(l_i) - \sum_j C_j(g_j) \quad (1)$$

Where:

- W is the Total Welfare or Society Profit
- B_i is maximum price the consumer i is prepared to pay
- l_i is the quantity of power consumed by load i
- C_j is the generator j 's cost of production
- g_j is the quantity of power produced by generator j

The generators are limited by a minimum and maximum output capacity modeled with additional inequality constraints.

III. MARKET MODEL

A simplified model of the electric power system is used: The system is divided into regions with limited transfer capabilities between them. The physical network inside those areas is not modeled. This represents a ‘‘copperplate model’’ in the different areas with transmission constraints between these areas (also known as ‘‘super node’’ model).

The idea behind this model is that an algorithm using optimal ac power flow (OPF) is often unnecessary complex for the purpose of valuating investments in new projects. The amount of data needed for an exact and complete OPF is immense and often not available at all or not available in the accuracy needed.

It should be noted here that the results obtained should therefore not be taken absolute numbers. What is shown here is a qualitative evaluation of which parameters are critical for the success of such a project and which parameters are less sensitive. For a concrete project much more effort would need to go into the determination of the input parameters.

The approach chosen for modeling electricity prices is cost based. The market structure is bilateral also known as double auction. On the supply side generators bid-in their respective cost curves, the demand being modeled by demand-curves. The **market clearing price** is determined by calculating the intersection between the aggregated supply curve with the aggregated demand curve. Over-the-counter trades are currently not modeled but will be introduced in the future.

A. Assumptions

- *No transmission costs*: Usually transmission costs are added ex post as overhead costs, based on a number of factors such as delivery zones and transmission volume. The model could however be amended to take into account the specific costs of using certain power transmission links. Each transmission link would have a cost function associated with it.
- *Line impedances are neglected and replaced by zonal constraints*

- *No losses*: Losses are usually a function of transmission so these are billed as part of transmission costs as ancillary services.

B. Transmission Constraints

The method chosen to model transmission constraints is based on defining import-export limits on each zone which represent the *maximum transmission capacities*. This approach is similar to looking at the macro economic flow of goods between countries. A country exporting more than it imports has a trade surplus, another one importing more than it exports has a trade deficit. This image can be applied to electricity markets by defining zones which act as separate ‘‘regions’’ or ‘‘countries’’, each with an import-export value. Intuitively, each zone will import when prices are lower in another zone and export if it can benefit from re-selling electricity in another area at a higher price.

To model these zones mathematically, the initial problem formulation is expanded to include these *maximum transmission capacities*.

$$\text{Export constraint: } \sum_j g_j^z - \sum_i l_i^z \leq E^z \quad (2)$$

$$\text{Import constraint: } \sum_i l_i^z - \sum_j g_j^z \leq I^z \quad (3)$$

Where:

- E^z is the export limit or maximum
- I^z is the import limit or maximum
- the superscript z indicates the zone in which the generator g_j^z or load l_i^z is located.

The areas are chosen according to natural separations of the electric power system in question: This can be control areas, countries or areas with limited exchange capacities. For the results presented in section V we used the congested connection between Italy and France to build the border between two areas.

C. Relocatability

FACTS devices can be installed in such a way that they are relocatable: E.g. all power electronics and needed auxiliary components are installed in a movable container, whereas high voltage connectors, transformers etc. are installed fixed on-site. This opens the possibility to move the device according to the ideal placement in the power system. Typical applications would be to optimize the placement for seasonal changes or for future changes in generator patterns in different regions.

Another type of application is the installation of relocatable static VAR compensators. This enables the grid companies to act accordingly if generator patterns change and therefore the need for reactive power compensation increases at certain points in the grid. (See e.g. [4])

A case study is carried out where it is shown how the additional investment costs for building a movable device and the expenses for the relocations each year balance against the improved revenues by the ideally placement.

We are, however, not looking at where exactly the ideal placement in an existing network would be because this is – even of quite an importance – out of the scope for this evaluation. Many studies have been carried out investigating this problem. (See e.g. [5], [6])

IV. VALUATION METHOD

To perform the actual valuation of the FACTS one needs to find a framework suitable for this special kind of project. Here a so-called Special Purpose Vehicle company (S.P.V) is used: This company is a separate legal entity from the power producer but is – in our study – fully owned by the power producer. This is necessary to comply with the regulation that generating companies need to be financially separated from companies working in the field of electricity transmission. The S.P.V borrows the full amount it needs to fund the project from the power producer. It then buys electric energy in the low price zone and re-sells it in the high price zone. The cash flow is in the opposite direction: it gets paid from the consumers in the high price zone and gives back the profit to the power producer company (see Fig. 1).

A different approach could be to evaluate the FACTS project as a completely independent company which sells the improved transmission capacity as a *service* to the market participants.

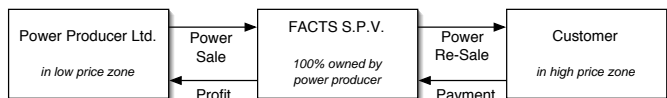


Fig. 1. A Special Purpose Vehicle (SPV) is used as business model

The method used to carry out the valuation is known as the Enterprise Discounted Cash Flow (DCF) model. This method is suitable for this specific project because only little financial market sensitive information is required in the case of a debt only financed company.

The value of an investment is simply equal to the future benefits minus the costs. Copeland in [7] defines the value of operations as the “discounted value of expected future free cash flows”. The free cash flow (FCF) is the total cash amount available to debt and equity holders. A formal definition: “Free cash flow is equal to the after tax operating earnings of the company, plus non cash charges, less investments in operating working capital, property, plant and equipment and other assets” [7].

The value of future cash flows has to be discounted to take into account the opportunity cost associated with investing in this specific project. In practice the future cash flows are split into two periods. A first period, of some five to ten years, which usually can be more accurately forecasted, a second period, of indefinite length, known as the “continuing value” (CV). For the case studies it is assumed that the FACTS have a limited lifetime of ten years ($T = 10a$) and a continuing value of zero. This is a conservative assumption.

For calculating the cash flows, the following formula is used [7]:

$$Value = \sum_{t=1,2,\dots}^T \left(\frac{NOP_{(t)} + NCI_{(t)}}{DF_{(t)}} \right) - I \quad (4)$$

- T is the total project duration, here 10 years.
- DF stands for discount factor. The discount factor is different for each year t and grows with the years.
- NOP stands for Net Operating Profit
- NCI stands for non cash items (mainly depreciation)
- I is the initial investment

To simplify the choice of the discount factor the project is assumed to be financed entirely through debt.

The formula used is the following:

$$DF_{(t)} = (1 + (1 - TR) * COB)^t \quad (5)$$

- COB stands for Cost of Borrowing
- TR stands for tax rate. Interest expenses are in most cases tax deductible, which reduces the cost of borrowing.

A. Valuation Parameters

The input parameters used for the valuation are given here:

TABLE I
GENERATION COSTS PROJECTIONS FOR 2005-2010

France	Euro cents / kWh
Nuclear	2.87
Coal	4.13
Gas	4.22

TABLE II
INSTALLED PRODUCTION CAPACITY IN FRANCE AND ITALY

1999 in GW	France	Italy
Nuclear	63.2	-
Conventional Thermal	26.2	52.4
Hydro	25.2	20.4
Total	114.6	72.8

- *Installed generation*: the values shown in table I and II are used.
- *Transmission capacity enhancement*: the FACTS device was assumed to increase the link capacity by 10%, in the base case. This figure is was chosen based the results in [8], which is a study of FACTS devices.

- *Project lifetime*: this was chosen to be ten years. There is one main reason for limiting the lifetime of this project: The behavior of the market is very difficult to guess into the future. Normally a forecast of only a few years is reasonable.
- *Project utilization*: it is assumed that the device is to be used 80% of the time six months of the year and 100% during the remaining six months.
- *Risk free interest rate*: this was chosen to be equal to the ten year yield of the US government bonds on the 02.04.2002¹ and is equal to 5.42%. This approach is recommended by Copeland in [7].
- *Cost of borrowing*: is assumed to be 1% over the risk free interest rates which amounts to 6.42% in the base case. Investments in utilities are usually viewed as low risk, so any bond issued by such a company would only have a slight premium over government bonds.
- *Cost of running the link*: this was assumed to be 5% of gross turnover, in the base case. As no similar projects are in commercial operation today, this parameter is an educated guess.
- *Initial investment*: this was assumed to be 80 million Euro. This assumption is an approximation for the total investment and break up as shown in table III.

TABLE III
INITIAL INVESTMENT

Cost Type	Amount in M Euros
Land and Infrastructure	5
Research and Development	10
Administrative and Legal	5
Device	60

These cost estimates were derived using as basis a the Hydro-Quebec interconnection project between Quebec and new England. This project is described in [9].

- *Net Operating Profit*: the profit is calculated using the market model described in section III. The area prices of electricity and the amount of production of all generators are calculated for one specific transmission constraint which is, in the base case, 10% above the limit without using FACTS. This yields to a net income for the S.P.V. From this the costs of running the company are deduced. This yields to the Gross Profit. To get the Net Operating Profit the financial Overheads or non production costs needs to be deducted which are, in this case, mainly depreciation costs.
- *Corporate tax rate*: this was assumed to be 37%, which was the average corporate tax rate in 2001 in France for large corporations.
- *Working capital*: this was assumed to 20 million Euros plus a variable part equal to 5% of revenues. This assumption is considered high as it amounts to over 25% of the initial investment. The working capital is the cash required

for the project to function, to pay wages and other expenses before the revenues flow in. The working capital is usually high in the first years of a project but then decreases over time as the project is then financed only through internal cash flows.

- *Growth rates*: revenues were assumed to drop significantly with time. This is to take into account two effects not modeled directly: (a) the initial drop in electricity prices which has been observed in liberalized electricity markets such as the UK or Norway; (b) the loop back effect caused by the additional transfer capacity, which will result in lower price differences between the areas. A drop in revenues of 7.5% the first year 5% in the second 4% in the third and 1% in the fifth year was assumed.

To calculate the additional value for making the controllable device relocatable we assumed the following parameters:

- *Additional transmission capacity enhancement*: It is assumed that the possibility to move the controllable device enhances the link capacity by an additional 2% to a total of 12% during the summer months. During the winter months the enhancements remains at 10% as described above.
- *Additional initial investment*: This was assumed to be 6% above the investment for a non-movable device in the base case. As there are no exact numbers available the results of a parameter variation will be presented below.
- *Additional fixed costs*: The costs for actually moving the device from one location to another was assumed to be 40'000 Euro. As this value is very small compared to the actual cash flows of the S.P.V it has a very limited influence on the overall valuation of the project.

V. VALUATION RESULTS

In this section the results of the valuation done for the FACTS S.P.V are presented. First, the primary input data is described, then the valuation results for a fixed FACTS installation and for a relocatable installation.

The market model described in section III yields the results shown in table IV for the link capacity without FACTS (2.5 GW), with fixed installed FACTS (2.75 GW) and with a relocatable device (2.8 GW).

TABLE IV
GROSS PROFIT FOR DIFFERENT LINK CAPACITIES

Link (GW):	2.5	2.75	2.8
Sales from Export	9.67	10.60	10.79
Cost of Sales	-6.15	-6.77	-6.89
Gross Profit	3.52	3.38	3.90

These values are entered into the financial valuation tool. The discount rate (DR) results to 4.04% with the input parameters described above. This gives the discount factors (DF) for each year (from 1 to 10) shown in table V.

¹source: Dow Jones

TABLE V
DISCOUNT FACTOR (DF) RESULTING FROM DISCOUNT RATE (DR)

DR	DF for years 1..10
4.04%	1.04 1.08 1.13 1.17 1.22 1.27 1.32 1.37 1.43 1.49

The financial tool has as output the total enterprise value or Net Present Value (NPV), the Discounted Cash Flow (DCF), which is the NPV minus the value of debt and the Return Of Capital (ROC), which are the earnings before interest and tax divided by the book value of the assets.

The base case results in a net present value of 144 million Euros and an equity value (DCF) of 44.03 million Euros. The Return Of Capital is 14.42%.

A. Fixed Location FACTS

First we will look at how the project could perform for a fixed installation of the device. From the base case, a number of parameters are varied and their effect on the project valuation are presented.

In figure 2 the return of capital (ROC) and the project value (DCF) in million Euros – represented by the area of the circles – are shown for the variation of the estimated transmission capacity improvement by installing FACTS device. The base case in dark is for an improvement of 10%. We can easily see that the amount of improvement has a very large impact on these values. A 10% improvement is the lower limit for the project to remain financially attractive. Below the ROC is under 15% which is normally considered as the limit for investing in a project.

It is therefore clear that an exact evaluation of the actual performance of a considered FACTS installation needs to be carried out carefully. Under-performance of only a few percent have a significant impact on the projects value.

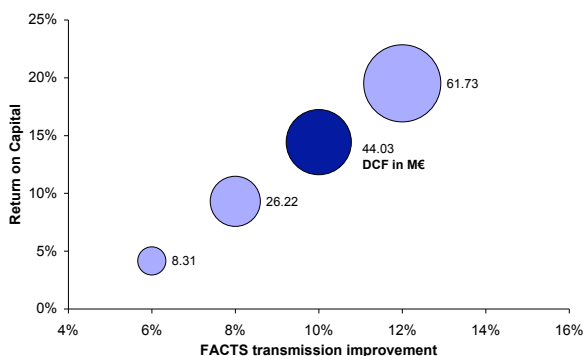


Fig. 2. Return on Capital and Discounted Cash Flow (area of circles) as a function of the estimated transmission capacity enhancement

The return of capital (ROC) and the project value (DCF) for specific expenses to run the link (in percentage of the revenue) is shown in Fig. 3. The base case (dark disk) is

for costs of 5%. The relationship between the expenses and the DCF is linear. A 1% drop in margin has an impact of 3.15 million Euros on the project value. An increase in running costs due to higher maintenance expenses than expected could therefore make the project unattractive. If running costs run over 5% of revenues it does not seem wise to make the investment. Once the exact running costs are determined, it is very important to determine the factors which can influence these and assess their probability of occurrence. This will help determine the risk associated with a rise in running costs.

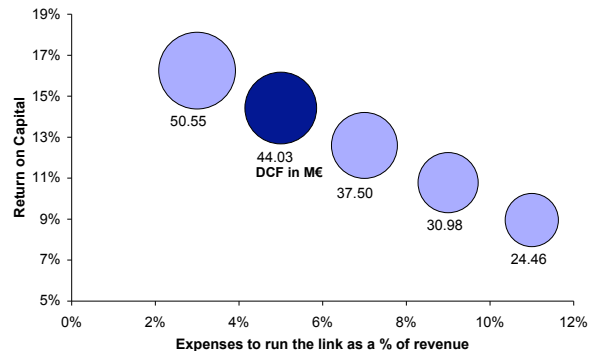


Fig. 3. Return on Capital and Discounted Cash Flow (area of circles) as a function of the expenses to run the link

The influence of cost of borrowing money on the enterprise DCF is shown in figure 4. The variation from the base case (displayed as the dark bar) is only moderate. This is partly due to tax benefits, which reduce the impact of borrowing money on the final valuation. A 1% increase of the cost of borrowing leads to a valuation drop of 2 million Euros. The cost of borrowing does not affect the ROC as this is an internal measure based on earnings before interest and tax.

B. Relocatable FACTS

The valuation tool was expanded to include the possibility of relocation of a controllable device. It was assumed that due to seasonal changes in the generation pattern between the two zones there is a potential to improve the link capacity during the winter month from 2.5 to 2.8 GW (instead of only to 2.75 GW with the fixed installation).

Figure 5 shows the sensitivity of the ROC and the DCF in million Euros – represented by the area of the circles – when varying the additional investments needed for providing the relocatability. The base case (marked with a bright disc) is fixed for an additional investment of 6%. This is also the upper limit for the project to be still above 15% for the ROC which is considered as the limit the project to be interesting for investment.

The DCF depends linear on the additional investment: A 1% increase leads to about 0.56 million Euros decrease

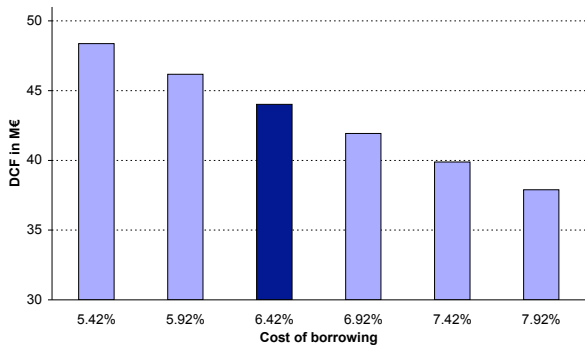


Fig. 4. Return on Capital and Discounted Cash Flow (area of circles) as a function of the he estimated transmission capacity enhancement

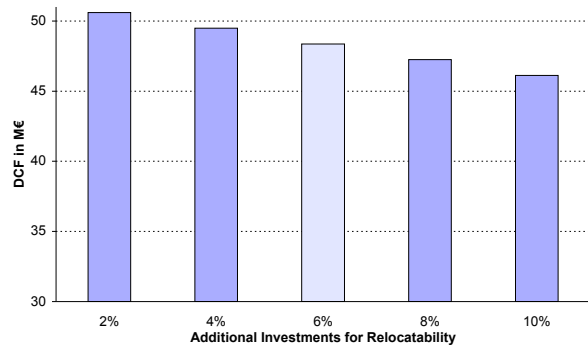


Fig. 6. Discounted Cash Flow as a function of the additional investments for relocatability

for the DCF. This is also shown in figure 6.

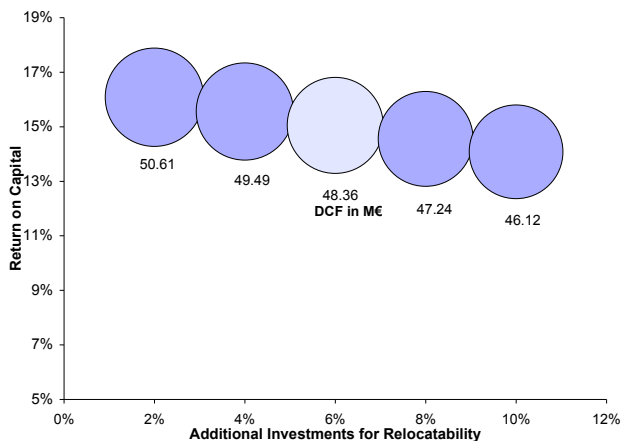


Fig. 5. Return on Capital and Discounted Cash Flow (area of circles) as a function of the additional investments for relocatability

Compared to the case with a fixed installation of the device it can be said that with an additional investment of 6% (for the base case) the value of the project calculated as the DCF increases from 44.03 to 48.36 – an increase of almost 10%. If the investments can be further reduced, the impact is even higher.

VI. CONCLUSIONS

This paper shows how engineering models for modeling electric power markets can be combined with financial instruments to determine the value of a controllable device in a transmission network.

It is shown how different parameters influence the value of a FACTS installation to improve the available transfer capacity (ATC) over a congested path between two network areas.

The results indicate that the value of the project is very sensitive to the ability of the device to improve the ATC. This means that in a concrete project further investigations to determine this value more accurately should be carry out.

The possibility to install relocatable devices will give an additional value to the project even with only moderate extra investment costs.

VII. OUTLOOK

It will be interesting to analyze the distribution probabilities of the most important input parameters to gain more knowledge on how an appropriate risk analysis method could be implemented. More detailed market scenarios would need to be simulated in order to get more data.

Also the question of transmission pricing is not yet included in the models.

A third improvement would be to perform more detailed network calculations using AC or DC Optimal Power Flow.

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