Economic Evaluation of Cycling Plants – An Approach to Show the Value of Operational Flexibility

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1 Introduction

Since the beginning of power market's liberalization in the mid 1990ies, the power plant business has been changing fundamentally. Nowadays operators of power plants find themselves in a much more challenging market environment with the presence of strong competition, higher fluctuation of fuel prices and missing long term power purchase agreements. But apart from these new challenges, market's liberalization also comes along with new business opportunities: Utilization of market price fluctuations for operation and maintenance optimization, participation in ancillary service markets and short term trading to mention a few can contribute to improve significantly the operating margins. By knowing how to approach these opportunities significant higher profits compared to a long term power purchase agreement can be achieved.

The changed market conditions have an influence on the operating profile of every power plant in order to be dispatched. Combined cycle power plants often do not strictly operate in a base load-like regime running 8000 hours per year. Many units are operating in a daily start-stop regime with units starting up to two times a day. In this market environment, an economic model that incorporates only a certain amount of base load hours with fix power revenues will not describe the full picture, additional earnings from the above mentioned market opportunities would not be considered. To be more accurate, an extended approach for evaluating a cycling plant with high flexibility is necessary. Key parameters for operational flexibility are for example start-up time, standby operation and shut-down time. This paper describes an approach for evaluating flexibility for combined cycle cycling power plants.

2 Market environment

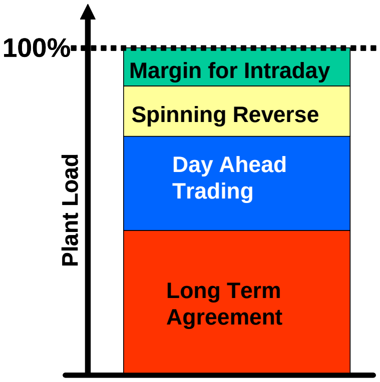
In the thirties of last century, the German steam turbine manufacture AEG (today a part of Siemens Power Generation) focused in one of its advertisements on operational flexibility - short start-up times and high part load efficiency – of its products (Figure 1).

Figure 1: AEG Advertisement

Today, seventy years later, the topic operational flexibility is still very much up-to-date. In highly competitive liberalized markets, operational flexibility is one key issue for economic success. Many plants nowadays do not have a power purchase agreement that guarantees long term and stable revenues. They are more likely to operate as merchant plants according to market conditions in direct competition with other power plants on the most favorable dispatch rank. Energy traders have various markets with different opportunities to place the power output. Examples are bilateral OTC contracts, power exchanges or markets for ancillary services. Each of these markets itself can be accessed with a variety of products. In this context one share of the power output can be placed with a long term contract, giving planning security for longer periods for lower margins, while other shares of the power output can be sold with short term agreements, on the day or even hour ahead spot market, offering higher margins linked to higher risks. Apart from the idea to participate in the market by splitting up the power output there are yet other ways to achieve higher revenues in liberalized energy markets by offering ancillary services. For spinning reserve for instance an allowance is paid just for the capability to provide power on request. In case of being dispatched, the power must be provided within minutes and an additional utilization fee will be paid. The plants capability to do so is first of all a criteria for qualifying to this market, but can be evaluated as it brings extra earnings in the next step.

Main characteristic of all products of the mentioned markets (OTC, power exchanges, ancillary markets) is the time span between contract signature and delivery and the dynamic requirements during delivery. A short time span increases the plant owner's risk, knowing only at short term under which load and revenue conditions he operates, but widening the opportunities for higher earnings. For long term agreements signed well ahead of the delivery date it works vice versa. For products with high dynamic requirements like spinning reserve normally revenues are achieved well above power exchange prices.

The challenge placed is simple in theory: optimizing plant operation between these two extreme positions and defining the right mix of products in order to achieve the highest return on investment for each plant or a plant portfolio with the desired risk level (Figure 2).



- Power Plant owner has different alternatives for selling plant output
- Resulting that power from one plant is paid differently
- Goal: optimization of sales strategy over plant lifetime

Figure 2: Market Opportunities

Keeping this in mind it is evident, that a power plant with high operational flexibility will perform better under these market conditions and therefore outperforms a plant with more technical constraints on operational flexibility if the additional flexibility comes at a adequate cost. The optimum position for the individual portfolio has to be carefully evaluated taking all technical and economical factors into account.

Apart from that another reason for the need of flexibility lays in a shift of the general load regime over the plant's lifetime, which is contemplated often in practice. In the nineties of the last century gas fired combined cycle plants were designed for base load operational regime. Natural gas was – from a today's point of view - unrivaled cheap. But operating under current high gas prices conditions, these plants find themselves in a strong competition with coal fired plants and are being shifted to cycling or peaking operation. This is another driver that pushes older plants into cycling operation, running less operating hours as new, more economic and flexible plants are entering the market.

But not only liberalization and competition increase the need for flexible operation. There are also technical reasons defining higher demands on power plants like the influence of highly fluctuating wind power as seen in Germany and Spain or the uncertainties in operation caused by weak grids.

A flexible plant that can switch its load regime providing power with competitive electricity costs from 8000 h a year base load regime to a cycling mode two times a day helps to overcome these challenges. Short start-up time and peaking capability enables the participation in ancillary services. Plant operation can easily be adapted to market needs and the operating margins can be optimized. In the economic modeling of a plant that operates under mentioned market requirements, the more detailed contemplation of the market environment increases the accuracy of the investment calculation and thus allows identifying the benefits of flexible operation. Siemens Power Generation uses economic modeling for years to optimize the design of its Reference Power Plants. Recently, these models were extended by the implementation of operational flexibility.

3 Approach for economic evaluation and its implementation in the Reference Power Plant development

3.1 Investment Decision Drivers

At the end of the day, an investor's decision on whether to realize a specific project or not will be mainly based on economic facts such as life cycle cost, the project's net present value, its internal rate of return, the cost of electricity and the payback period which themselves highly depends on specific boundary requirements for the project. By identifying and understanding the most important drivers for optimized customer value, Siemens RPP development is focusing on life-cycle-cost optimization. The main parameters for evaluating plant profitability are efficiency, power output and availability while the initial investment costs, operating costs and environmental impact are considered as secondary drivers for successful projects (Figure 3).

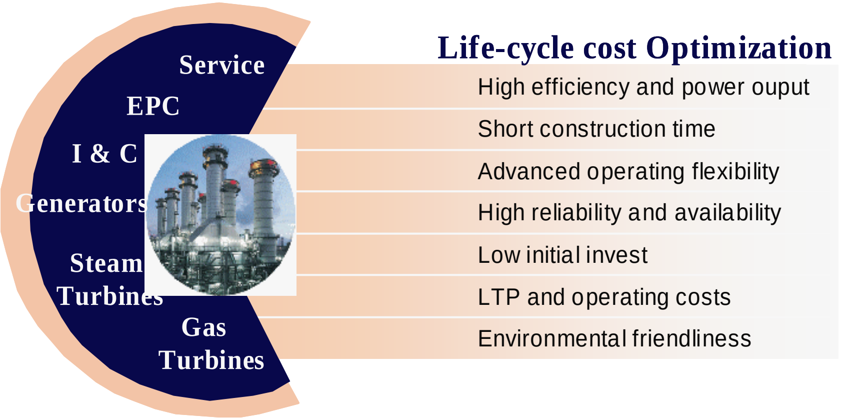


Figure 3: Influence Factors Life Cycle Costs

To calculate a project's NPV and IRR, a range of assumptions on the future market developments is necessary. Based on its wide experience base over many years in the power plant business and feedback from relevant markets all over the world, Siemens has set a range of assumptions that have been proven to reflect boundary conditions realistically. Examples for those parameters are the development of fuel prices, electricity revenues, financial boundary conditions and operating hours. Combined with detailed life cycle cost tools, Siemens is able to calculate a whole set of variants of its Reference Power Plants options and features in order to optimize life cycle costs. In the past, this process of optimization took place mainly for base load plants assuming approx. 7000 operating hours per year as seen in the markets. With the shift of combined cycle power plants to cycling operating, this approach was needed to be updated and enhanced by the consideration of other parameters like number of starts, load profile and standby cost. Paragraph 4 describes how these features are added.

3.2 Reference Power Plant Development Process

Siemens started the Reference Power Plant (RPP) development in the nineties. The modular RPP concept from Siemens enables the design of individually configured power plants applying standardized functional units with logical interfaces to allow flexibility in scope. The development from tailor made plants to standardized plants is shown in Figure 4.

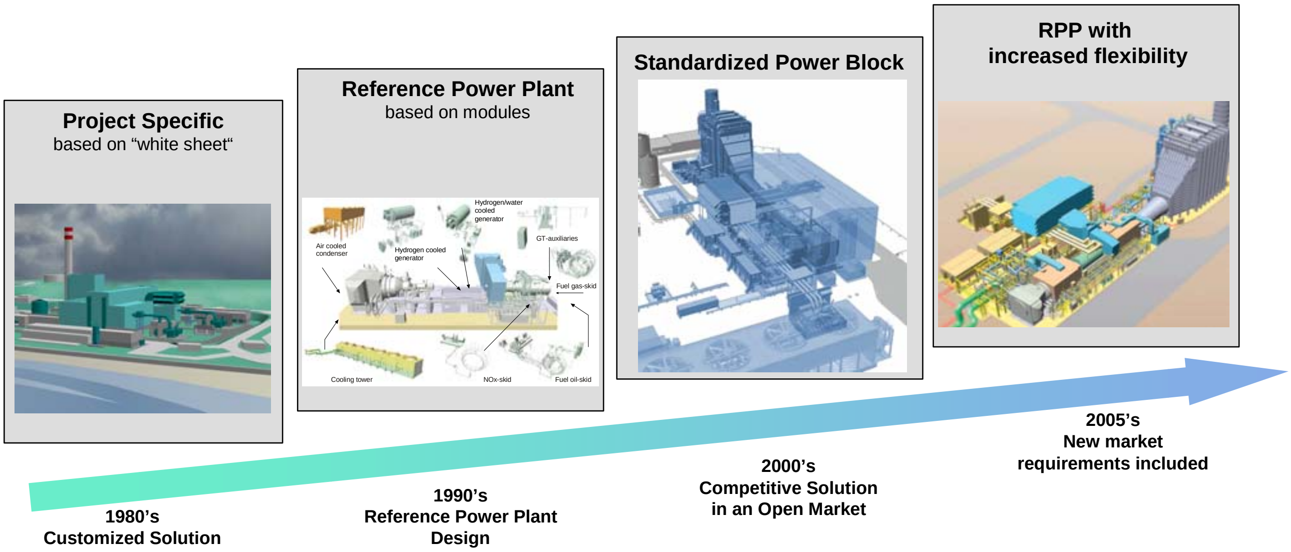


Figure 4: Power Plant Design Philosophy

Standardization and modularization are the main focus for increasing quality. The objectives of high quality, low costs, and short lead times can only be reached with pre-design and pre-engineered plants. It is a necessity that the RPP is as close as possible to the clients needs without requiring redesign of key plant components. Therefore, the RPP development takes place in close contact to our customers. In Quality Function Deployment (QFD) workshops, different design variants for certain features and requirements are discussed with customers. The needs of the customers are identified. The best solution which meets the demands regarding technical performance and best life cycle costs is selected and implemented in the RPP design. For the life cycle cost optimization variants of the power plant are modeled and analyzed under different economic conditions. The variant with the highest customer benefit is then chosen as the preferred solution. One example for this approach is the feedwater pump redundancy. A 2x100% feedwater pump configuration increases plant availability per 0.5% points compared to a 1x100% configuration. In South Europe, one percentage point availability increase is evaluated with approximately 2’5 Mio. €. A second pump would cost approx. 0’5 € and thus a 2x100% configuration represents the option with the highest customer value.

Another source for input to the RPP developments is the participation of customers in design reviews. During those reviews, customers give their input directly to the RPP development team. Through close contact to construction, commissioning and plant operation, lessons learned from executed projects flow back to the development. For example, the RPP SCC5-4000F Single Shaft incorporates the experience of more than 20 executed units (Figure 5).

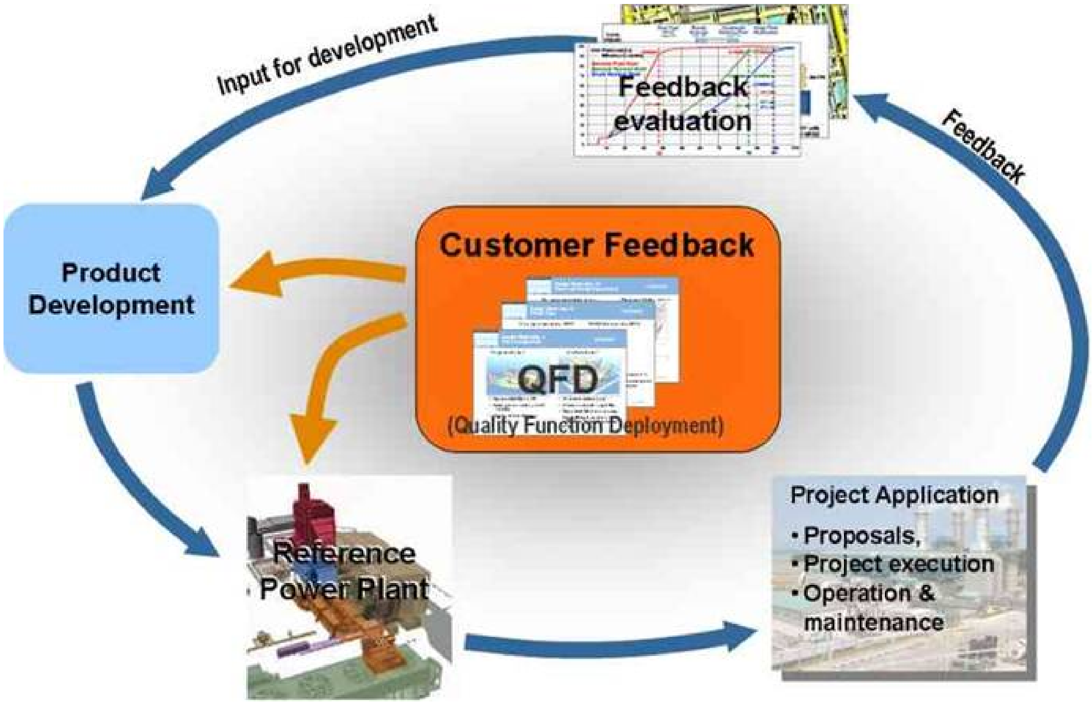


Figure 5: Feedback Cycle

Siemens established a Product Development Process based on the Six Sigma methodology to guarantee an excellent design quality. One important component of this process is a review of the work progress after every design stage like concept design, basic design or detailed design by all faculties along the development, sales, operating and service path. This close monitoring ensures on one hand that the RPP provides an optimal technical concept and on the other hand that it meets the market expectations. Further on, the process incorporates state-of-the art engineering methods like Failure Mode and Effective Analyze (FMEA). Hand in hand with the economic optimization, these efforts combined with the outstanding Siemens experience as an original equipment manufacturer (OEM) and turnkey contractor ensure highest customer value of Siemens Reference Power Plants.

The full advantages of the Reference Power Plant concept become evident during a real power plant project. The high degree of pre-planning and the pre-selection of mayor components result in short lead times and high quality during construction and commissioning. The consideration of operation and maintenance requirements in the design ensures trouble free production and short outage times (Figure 6).

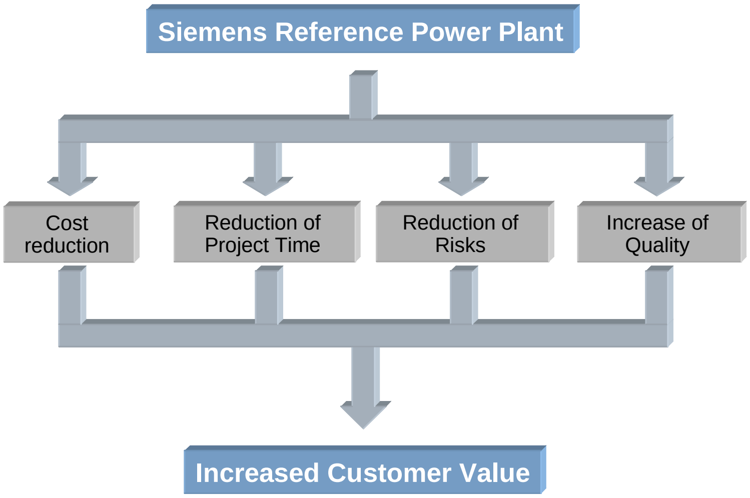


Figure 6: Advantages of Reference Power Plants

4 Adapting economic models to cycling plants

As discussed in the last paragraph, a comprehensive economic evaluation of a cycling plant plays a major role in the process of product optimization. Herein the quality of an enlarged set of parameters as input for the NPV-model is essential as small changes or wrong assumptions can lead to incorrect conclusions. For instance in order to detect benefits from fluctuations in electricity prices, estimation for every hour during the plant lifetime is required. For a first approach, modeling the differences between day and nighttime, week and weekends as well as within seasonal changes combined with an annual escalation leads to realistic and comparable results. Input parameters can be based on modified historical data or assumed scenarios for future price developments. Further improvement can be achieved by implementing statistical price variations, caused by weather changes, plant breakdowns, bank holidays or other events. For example the spot market prices in Germany's EEX may vary by a 100% during one day while occurrences like an operators strike at French nuclear power stations can result in even higher power price fluctuations. It is important to consider these circumstances, keeping in mind that they can have a major effect on the plants' operational income. Thus a potential revenue curve with short term variations during the plant's lifetime can be developed as a base for the NPV calculation.

For a more detailed calculation of a plants profitability and the evaluation of additional plant features an investigation of the following parameters is needed: Start-up costs, shut down costs, standby costs, cost of electricity for various loads (base load, minimum load, ect.), costs for load changes and costs for peaking power. Evidently, there are much more parameters as for a base load plant, for which start-up and shut down costs are marginal. Besides the costs, also technical restrictions have to be considered. Examples are start-up time depending on outage duration, minimum operation time, minimum load or peaking capability. These parameters allow the calculation of electricity production costs depending on the chosen load regime. Together with a price curve, plant operation can now be optimized in order to maximize the projects internal return (Figure 7).

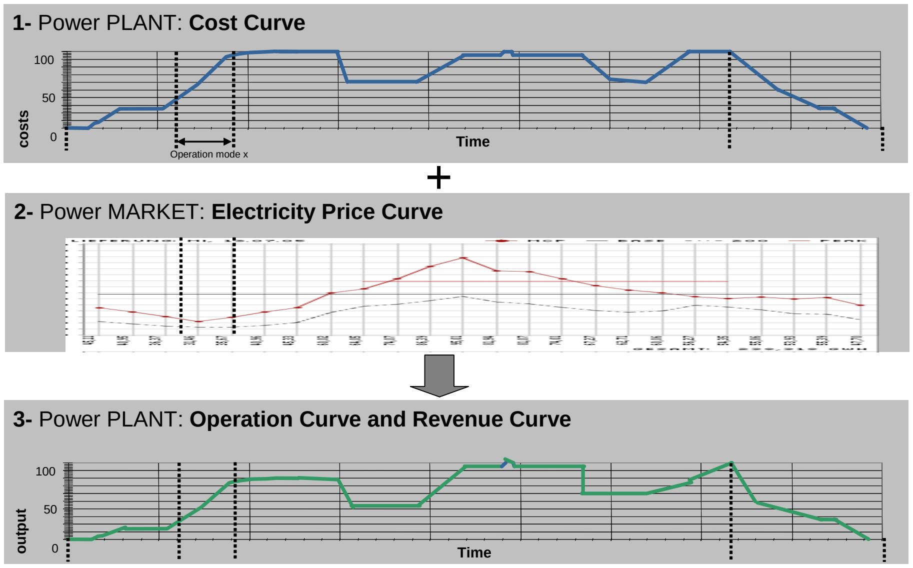


Figure 7: Evaluation Approach

Similar to the evaluation of a base load plant, different technical solutions with modified sets of parameter need to be analyzed. This approach allows to give flexibility features a value and to optimize plants operational capabilities according to customer needs.

5 Approaching the value of flexible plant features

Today, it can be contemplated that utilities begin to include operational flexibility into their evaluation models. Siemens is asked more and more often to guarantee flexibility criteria like start-up time or minimum load performance within invitations for tenders to current proposals or recently awarded projects. But so far, the value given to a feature shows great differences between different tenders as a sign of uncertainty on how to evaluate or penalize flexibility plant features. As an example the contract fine for a certain feature varies between a thousand Euros at one project up to some hundred thousand Euros for non compliance of the same parameter, while the influencing input data does not vary with the same magnitudes. Surely the cost of fuel or the different expectations on market appearances can present a certain variation in the customer’s view and evaluation of performance attributes and another part of the differences can be explained with different strategic approaches by different companies. But after all, the large discrepancy in the presented fines can not be explained. Another assumption therefore is that today there is no consistent market view of the value of flexibility. Within the evaluation of flexible plant features Siemens has been able to estimate more accurate as shown later

In response Siemens developed evaluation factors for key flexibility parameters. The parameters are suited for a specific Reference Power Plant design and are based on assumptions that were verified in the specific target market. As a conservative approach, the assumptions are always on the lower end of possible values.

As an example, the way to evaluate start-up times is given here.

For the calculation the following parameters are necessary to know in order to be able to economically evaluate changes in the start up process:

- Time of start time reduction [min]
- Fuel mass flow [MWh/min] during start
- Electricity production [MWh/min] during start
- Variable cost of start up process (mainly fuel cost to be considered [€/GJ])
- Cost and charges for life time consumption for each start and start type [€/eoh]
- Remuneration during start up time regarding expected or unexpected starts [€/MWh]
- The cost and revenues for balancing energy [€/MWh] (Important when participating in this market)
- The cost or revenues for CO2-certificates [€/tCO2]

Start time comprehends the time of a power plant to reach maximum plant load after a shut down. According to the duration of the shut down and the resulting component temperatures the plant needs different time periods to restart. The start-up times given in Table 1 underneath are considered as a baseline in this example here.

Definition of start-up time: The time between GT flame on to GT in OTC controller and the ST bypass closed.

Start type (tech.)	Downtime	Time to max. plant load
Hot Start	8h (e.g. night time)	50 min
Warm Start	64h (e.g. weekend)	3h
Cold Start	>120h	4-5h

Table 1: Start-up Times

For the monetary evaluation of variable start up times the fact that start up procedures occur expectedly or unexpectedly has a major impact due to the differences of magnitude and time periods of revenues obtainable. The difference between an expected and unexpected start-up is described in *) The economic benefit of the faster unexpected start results in a higher production of electricity during the start up process that does not have to be bought as balancing energy and thus can be considered as cost avoidance.

Other cases for unexpected starts may occur due to sudden request by the grid operator or whenever hour reserve capacity is charged. These cases are not considered.

Table 2 and Figure 8.

Start type (econ.)	Definition	Variable revenues	Effect of start time reduction
Expected Start	At certain time plant goes on grid with max. output	Electricity price is assumed to be lower (~75%) during start up time	Variation of time has no influence, only variation of avg. efficiency
Unexpected Start	Without preceding notice plant goes on grid in min. time (e.g. after trip)	Electricity revenue is assumed to not vary*)	Earlier operation with max. efficiency renders higher revenues*)

*) The economic benefit of the faster unexpected start results in a higher production of electricity during the start up process that does not have to be bought as balancing energy and thus can be considered as cost avoidance.

Other cases for unexpected starts may occur due to sudden request by the grid operator or whenever hour reserve capacity is charged. These cases are not considered.

Table 2: Definition of Start-up Type

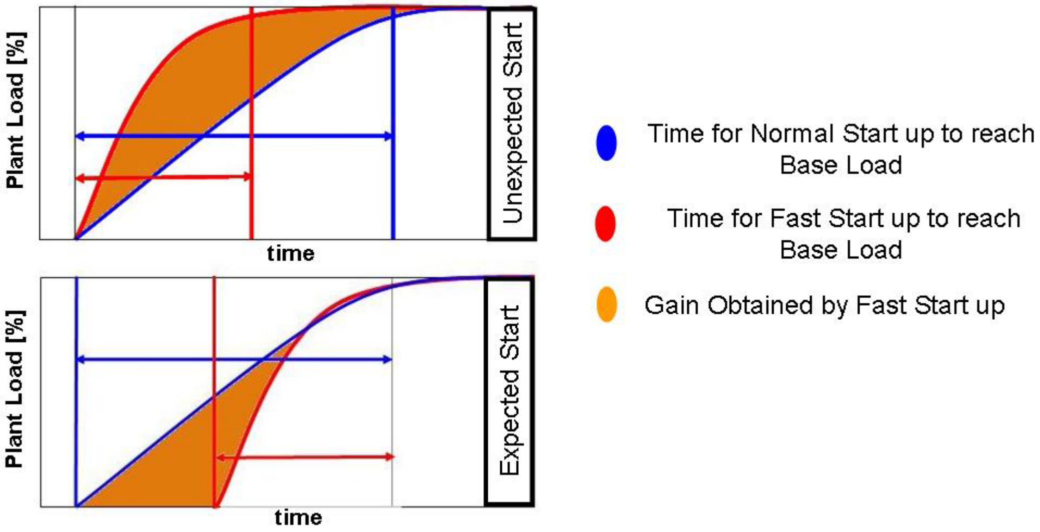


Figure 8: Difference between Expected and Unexpected Start-up

Costs during the start up process

For the evaluation of different start times, only the variable costs apply. Within these the major part is taken by the fuel cost considered for the different start up cases. Other variable costs are maintenance costs due to the different concepts and can mainly be considered by the charge for “equivalent operating hours”.

Other variable costs then refer to consumable costs and are not considered because the start-up time reduction is assumed to be without major impact on the consumable costs.

Impact of CO2 values under the EU Emissions Trading Scheme

The impact of CO2 certificate charges, as they are introduced by the EU Emissions trading scheme, are considered as a fuel related CO2 cost adder to the variable cost. Although currently the allocation rules in EU 25 are under review for the next trading period 2008-2012 and final plans are not yet approved, there are clear signals, that new plants ("New Entrants") will be allocated on the basis of output related benchmarks without load related ex post correction. This definitely translates into the full integration of CO2 costs in the variable costs.

Nevertheless whenever CO2 emissions are being considered within a legal framework and are priced in, it is very likely to be favorable for the faster start up since less fuel is burnt at a higher heat rate.

Revenues during the start up process

According to utility companies the produced electricity during the start up process is sold irrespectively whether it is an expected start or an unexpected start.

- For unexpected starts (Figure 9) the obtainable revenues are estimated to be constant (black curve = revenues [€/MWh]; arrow = time of plant start):

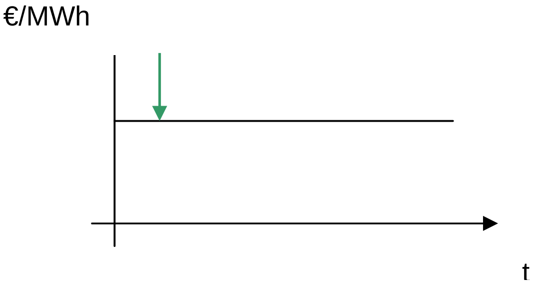


Figure 9: Revenues for Unexpected Starts

(The cost per MW for response energy is considered to be constant over the viewed period.)

- For expected starts (Figure 10) the revenues are estimated to jump from 75% of base load revenue to 100% for hot starts and from 50% to 100% for warm starts (black curve = revenues [€/MWh]; arrow = agreed time to be on grid):

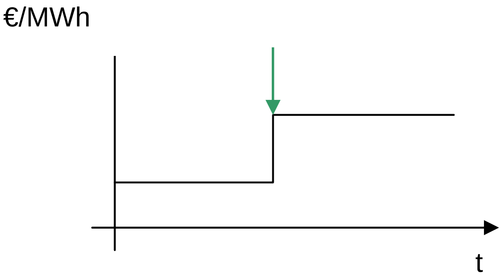


Figure 10: Revenues for Expected Starts

Results

The evaluated customer benefit of reducing the start time now varies largely according to the assumed operating regime of the plant and the market environment. Hence, specifying absolute figures would necessitate a detailed description of the boundary conditions.

But however, reducing the start time of a 400MW Single Shaft power plant, running in a cycling mode, can result in a six-digit number [€/min] customer benefit in a 20 years NPV model. Consequently, the reduction in start-up times can easily sum up to seven-digit numbers, when reductions of several minutes per start are achieved.

6 Conclusion

In the same way as presented for the calculation of the benefit of shorter start-up times other plant features that allow lowering the technical constraints of a power plant can be evaluated. As the major difference to the more commonly evaluated values of power or efficiency these estimations are more sensitive to the input parameters. The more flexible a power plant can operate in a technical sense on the market, the more complex the combination of achievable revenues get. In that sense the first limitation in detecting revenue opportunities is whether the revenues magnitude can be predicted or whether it is more subject to a market not fully developed. Characteristically the balancing market has to be modeled with certain probability functions. Whether the plant obtains revenue for balancing services does not only depend on the technical capability but also on certain market occurrences. Balancing energy will only be needed whenever the capacity of the grid is below demand and the offered balancing capacity is called up. The real value to be obtained is therefore hard to determine as we enter fields of predicting market scenarios. Approaches to ascertain a value, by statistical means or complex mathematical calculation derived from models of the financial world to value real options, can only give an idea. Evaluated benefits can only be translated into the market whenever the technical feature shows a clear advantage that is being paid for.