

# BUYING THE LOWEST TOTAL COST OF OWNERSHIP (TCO)

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**Abstract** - When a Petrochemical end-user builds a new plant, almost all the end-users have specifications with a preferred vendor list. For the competition the end-users put more than one brand on the preferred vendors list. The Engineering, Procurement, and Construction (EPC) contractor will buy the cheapest brand of the vendors list. This means selection is based on minimizing the Capital Expenditures (CAPEX) rather than minimizing the Total Cost of Ownership (TCO), being the sum of CAPEX and Operating Expenditures (OPEX). Analyzing the TCO it becomes clear the OPEX can be divided into two segments. The first one is the controlled OPEX which can clearly be calculated. The a second segment of OPEX however is not that clear and is depending on Risk. Risk is defined as the product of a probability a situation during lifetime of the product will take place and the consequences it will have for the process in which the product is fulfilling it's role. Controlling risk means reducing the probability or limiting the consequences. Some tools out of the field of asset management used by utilities are applied for a Low Voltage Motor Control Centre (MCC) to give guidance how decisions can be argued. As will be found limiting the consequences can be translated into mandatory and preferred specifications that can be used in a tender. But what will happen when one of the brands on the preferred vendor list has a product development that will increase the CAPEX and will reduce the TCO, e.g. will reduce the risk. To take specific manufacturer specifications into account, it will demand that the purchase process find a way to take this into account, by having more aspects as CAPEX only to make the decision to which vendor the project will be granted.

*Index terms* – Total cost of ownership, asset management, risk, switchgear, form of internal separation, internal arc.

## I. INTRODUCTION

Erecting a large installation the purchase process of installation parts follows a more or less standard way. First of all based on the specifications a tender is made. Next to the tender almost all end-users in the petrochemical area have a vendor list with several brands. The Engineering, Procurement, and Construction (EPC) contractor will select the brand with the cheapest CAPEX price. This very simple description of the purchase process has some drawbacks:

- In many cases where TCO is considered and taken as much as possible into account in the specifications. However the tender shall be written in such a way that several brands of the vendor list are capable to deliver a product. This means that specifications that can be met only by one vendor alone will be omitted or at least be generalized to

such an extent that the added value of such a specification is limited.

- Vendors who claim to have a solution with a low TCO but a high CAPEX are in a position of having a reduced change to get the order as long as selection of the vendor is based on the lowest CAPEX and the added value of the specific solution is not included in the specifications. In case such a lower TCO is based on specific product developments the end-user will not value the product development and will wait till more than one preferred vendor has made the same product development. After that, the specifications can be updated and more than one preferred vendor can compete on the lowest CAPEX price.
- Vendors who claim to have a solution that:
  - Reduce the risk of interruptions of the supply
  - Increase the quality and lifetime of the product
  - Increase the safety of the product
  - Limits the consequences of a disturbance or malfunction to an as small as possible part of the MCC

are facing the problem how to get these standard translated into specifications and how to have them weighted in the purchase process. They all have a limiting effect on the occurrence of disturbances or on the consequences of disturbances, where costs (loss of production) is strongly depending on the specific process of the plant and hard to get into general objective specifications.

- Vendors are focusing on cost out projects for lower CAPEX prices instead of smarter TCO developments. Minimizing the TCO and minimizing the risks means they shall be taken into account in the purchase process. This means the specifications in the tender shall deal with it. As explained later on in this article aspects as quality and reliability of the product versus the risk of malfunction are hard to translate to practical specifications in the tender.

The aim of this article is to discuss how and to what extent optimisation of the costs and risks can be obtained and how it shall be taken into account in the specifications and in the purchase process.

## II. TOTAL COST OF OWNERSHIP (TCO)

### A. Definition and calculation models

TCO means 'Total Costs of Ownership'. One of the area's the term TCO as initially used is evaluation of IT products. In 1987 TCO was introduced in this area. It turned out that the CAPEX for hard- and software was only 20% of the total costs during lifetime. For IT products several models for TCO can be found in literature; however they are all specific for the IT area.

TCO can be defined as the total costs during the lifetime of a product taking into account costs of erection

(CAPEX), costs of operation (OPEX) and costs of end of life (EOLEX). In formula:

$$TCO = C_e + \sum_{y=1}^n \left[ \frac{C_{pm} + C_{cm} + C_{op} + C_{sd} + C_r}{(1+i)^{y-1}} \right] + \frac{C_{eol}}{(1+i)^n}$$

With:

$C_E$  = costs of erection (components, installation, infrastructure)

$C_{pm}$  = preventive maintenance costs / year

$C_{cm}$  = corrective maintenance costs / year

$C_{op}$  = operational costs / year

$C_{sd}$  = shut down costs / year

$C_r$  = repair costs / year

$C_{eol}$  = end of life costs

$i$  = inflation / year

The calculation is using the net present value. Net present value (NPV) is defined as the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting, and widely throughout economics, it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met.

End of life costs ( $C_{eol}$ ) are practically not taken into account in the TCO for electrical installations. They typically are not known as even the moment of end of life is not known in practice. For the purpose of this article they are omitted in the examples.

### B. TCO and the purchase process

Making the statement that minimizing the TCO would be most beneficial for an organization appears to be logical, however in practice it isn't.

A typical example of how it works in practice is visualized by Fig. 1.

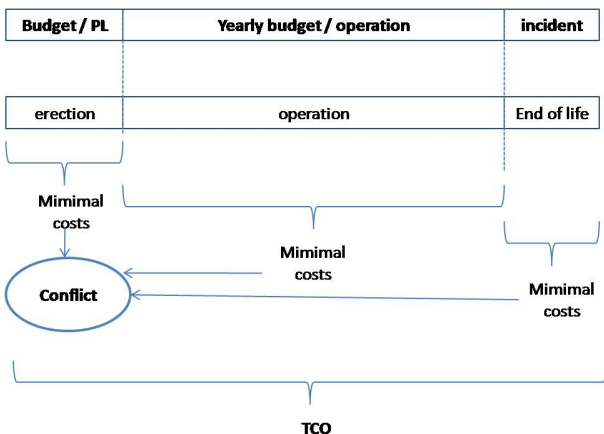


Fig. 1. Purchase practice versus TCO

Erection of the installation is a project of its own, done by a project leader from an end-user and/or EPC contractor. The erection has its own budget and is not connected to the future operation budget. The erection project leader gets the credits when he stays within the limits of his budget or even better: he is able to minimize the actual expenses. Of course he is responsible for a technically seen correct installation according to the set specifications, however minimizing the costs during

operation (OPEX) is not his responsibility.

So, first of all, the buying process should be open to consider an optimisation of the TCO and the responsible project leader for erection shall be judged in such a way it's attractive for him to take TCO into account in the buying process.

In Fig. 2 the different aspects of TCO are split out into 'controlled' items and 'uncontrolled' items.

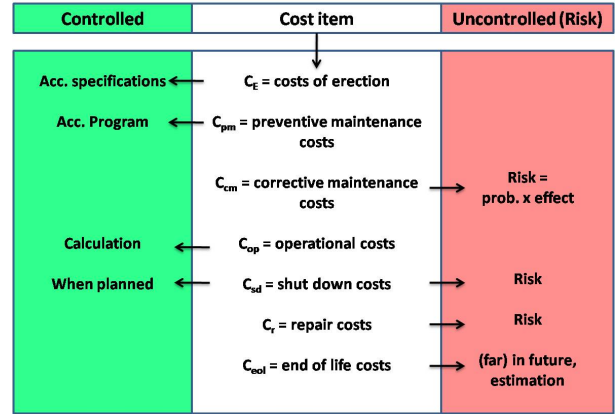


Fig. 2. Controlled and uncontrolled cost items

'Controlled' means that the specific cost item can be calculated in detail and is not affected by speculations or opinions. These items can be integrated in a calculation model to determine the impact on the TCO. To give an example: preventive maintenance is indicated in fig 2 as a controlled item. In case a manufacturer advises to execute preventive maintenance once a year and the costs are known it's clear how to take it into account in the TCO.

'Uncontrolled' means the cost item is mainly influenced by a change or probability something goes wrong during the lifetime of the product and when so, the disturbance will have a minor or mayor effect on the production process. In the worse case the disturbance will even lead to a complete shutdown of the process, were even for a short duration costs can be up to millions of euro's. These 'unplanned' interactions during the operation are difficult to assess. As indicated in the table items as corrective maintenance, repair costs and (unplanned) shut down costs are the risk factors.

Both 'controlled' items as 'uncontrolled' items will be assessed in 2 cases to be dealt with further on in this article:

- One case of cable selection where the TCO can be calculated in detail
- One case of selection of a MCC that is mainly depending on uncontrolled items.

### C. Asset management utilities

Utility companies have adapted the principles of Asset Management for a long time. Although wider in practice, key performances of Asset Management are:

- to make proposals for investment programs
- to make investment decisions
- to make the balance between performance, finance and risk.

Actually an Asset Manager is the spider in its web dealing with sometimes conflicting aspects. Balancing between technical experts looking for the cheapest total solution versus financial experts looking for the cheapest

incremental solution. Such as long term and TCO versus short term, cost cutting and capital deferment. Having a holistic approach: complete overview on technical, financial, performance related and stakeholder related topics. And in this whole field there is one term being of mayor importance: RISK.

Generally risk can be defined as:

$$\text{Risk} = \text{probability} \times \text{consequences}$$

The definition as such might be simple, the practice isn't. Both probability as well as consequences needs to be assessed in detail. And when done so there needs to be a common way of communication and decision making.

One of the tools asset managers are using is the so called Risk assessment matrix. This matrix (Fig. 3) shows the overall consequences versus the probability. The level of risk is indicated as Very High, High, Moderate, Low, and Neglected.

Probability of occurrence		Consequences			
	Frequency [1/year]	Catastrophic	severe	serious	moderate
daily	1000	VH	VH	VH	H
weekly	100	VH	VH	H	M
monthly	10	VH	VH	H	M
yearly	1	VH	H	M	L
Frequently	0,1	VH	H	M	L
Probable	0,01	H	M	L	N
Possible	0,001	H	M	L	N
Not likely	0,0001	M	L	N	N
Almost impossible	0,00001	L	L	N	N

Fig. 3. Risk assessment matrix.

Utilities do assess the consequences in more detail. They typically take into account so called 'hard factors' as well as 'soft factors'. Hard factors are direct measurable: financial damage, quality of supply, safety (amount of victims) and legal penalties. Soft factors are only indirect measurable: quality image, environmental image, relation with authorities. In the risk assessment matrix all consequences are summarized.

How to deal with TCO in purchase processes where more than price alone is taken into account. As an example a specific utility company takes the following criteria into account in a tender for HV switchgear and controlgear assemblies used in its service area. The granting criteria used in order to determine the most economical situation are given in table 1.

Table 1.

Item	Weighting factor (total 100%)
CAPEX and controlled cost items	35%
Quality (uncontrolled cost items)	20%
Technical preferences (uncontrolled cost items)	35%
Terms and conditions	10%

Only 35% of the total TCO is based on the CAPEX price of the switchgear and controlled cost items. For example a controlled cost item in this case is the space needed for the switchgear. This will influence the CAPEX price of the building.

20% of the total TCO is based on the quality of the product and production process. High quality means low risk of failures. Low risk of failures means low uncontrolled cost items (uncontrolled cost items=risk\*consequences).

35% of the total TCO is based on technical preferences. Beside the mandatory technical specification the utility company has a list of technical preferences. The technical preferences are identified switchgear items that lower the risk or consequence after a failure (uncontrolled cost items=risk\*consequences).

10% of the total TCO is the fully acceptance of the term and conditions of the utility company. With the fully acceptance of the term and conditions the switchgear manufacturer has to pay when a uncontrolled cost item will arise.

### III. CASE 1: TCO OF CABLES

Dealing with TCO of cables IEC 60287-3-2 (calculation of current rating – part 3: sections on operating conditions – section 2: economic optimization of power cable size) gives detailed guidance. As clarified in the standard the purpose is to combine the purchase and installation costs with the costs of energy losses arising during the economic lifetime of a cable. In order to make correct comparisons, the standard takes into account to relate all cost values to the same point in time.

The formula to calculate the total costs (CT) is taking various factors into account.

$$CT = CI + CJ$$

CI = installed costs of the length of cable being considered

CJ = present value of the cost of joule losses during N years'

$$CJ = (I_{max}^2 \cdot R \cdot l \cdot N_p \cdot N_c) \cdot (T \cdot P + D) \cdot \frac{\sum_{n=1}^N [r^{n-1}]}{(1 + i/100)}$$

I<sub>max</sub> = maximum load in the first year i.e. the highest hourly mean value [A]

R = cable AC resistance per unit length [Ωm]

l = cable length [m]

N<sub>p</sub> = number of phase conductors per circuit

N<sub>c</sub> = number of circuits carrying the same type and value of load

T = operating time at maximum joule losses [h]

P = cost of 1 Wh [currency]

D = demand charge each year [W.year]

i = discounting rate used to compute present values [pu]

N = economic life [number of years]

$$r = \frac{(1 + a/100)^2 \cdot (1 + b/100)}{(1 + i/100)}$$

a = annual increase in I<sub>max</sub> [pu]

b = annual increase in P, not covered by inflation [pu]

Although this formula looks complex, it's very straight forward to use. To give an example.

An ordinary low voltage cable is characterized with a length of 150m, protected by a fuse 250A, installed on an open cable tray. The typical load current is 200A for a duration of 4400h a year. Prize level (Cu) Jan 2009 is used.

Depending on the insulation material the cross section of the cable is minimal 70 mm<sup>2</sup> (XLPE 90oC) or 95 mm<sup>2</sup> (PVC 70oC). As function of the amount of years (horizontal axis) it's found the economic optimal cross section of the cable is increasing with an increasing life time (Fig. 4).

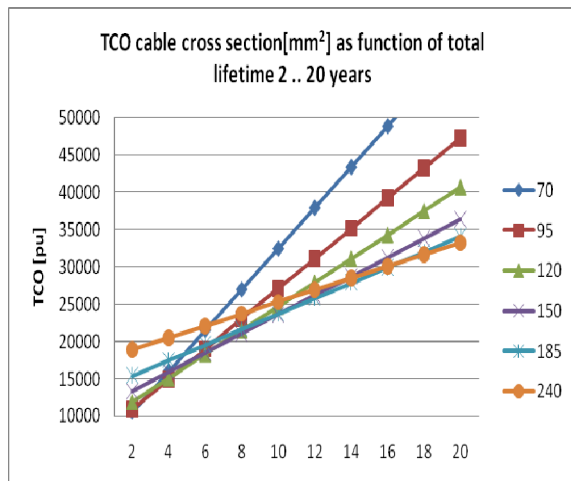


Fig. 4 TCO for different cable cross-sections

As can be seen with increasing lifetime the optimal cross section increases too: 6 years 120mm<sup>2</sup>, 8 years 150mm<sup>2</sup> and 10 years 185mm<sup>2</sup>.

#### IV. CASE 2: TCO OF MCC'S

Typically a MCC can be described as a switchgear and controlgear assembly meant for switching protecting and controlling motor loads in various industrial processes. Physically these systems can be big and rather large parts of an industrial process can be fed out of one MCC. A MCC is characterized by its specifications. Assumed the MCC is in accordance with the international standard IEC / EN 60439-series (or new IEC 61439-series), the specifications are partly mandatory as laid down in the standard.

Most of the specifications have a direct impact on basic safety, such as insulating properties and forms of separation, or the ratings, such as the rated currents.

##### A. Controlled cost items

In the specifications for a MCC there are some for which the costs can be clearly defined:

- Dimensions in relation to the required amount of square meters floor surface
- Preventive maintenance program and required time interval

Taking into account preventive maintenance for 3 examples the total costs have been calculated (table 2). This example and the ones following is calculating the net present value and is based on euro's, For other

currencies the relations between the different cost items will be the same. Dimensions have been taken into account in the initial investment. The total lifetime has been set to 10 years.

Table 2.

	example 1	example 2	example 3
initial investment [euro]	40000	70000	80000
form	1	3b	4a
Inflation [%]	4	4	4
preventive maintenance [euro yearly]	1750	2000	1500
total costs over 10 years [euro]	54194	86222	92166

Based on this limited background example 1 is far cheaper as examples 2 and 3. However, it does not take into account any of the uncontrolled cost items.

##### B. Uncontrolled (Risk) cost items

There are specifications which should be taken into account to judge the costs, or as will be explained the risks, during operations, such as:

- Lifetime
  - Quality
  - Preventive maintenance (frequency, costs, costs shut down)
  - Expected level of modifications / extensions
  - Set up of the installation, redundancy
  - High form of internal separation and alignment with safe working procedures according EN 50110
  - Additional functions / specifications: e.g. internal arc
- For the purpose of discussion the initial example will be extended step by step taking into account uncontrolled risk factors. Three further cases are evaluated:
- The failure of a device, e.g. a contactor and the safety of making changes
  - A failure resulting in an internal arc inside the MCC
  - The difference between a single or a double supply
- Before dealing with these some general considerations of risk will be discussed.

##### 1. Risk: general considerations

The uncontrolled cost items are difficult to translate into hard figures: they are entering the area of risk. In case of lifetime the first thought is how long will the product be in operation fulfilling its function with the required level of reliability. In practice the planned lifetime of a whole plant can be short (less then 10 years), but very long lifetimes up to 20 to 30 years are no exception. As with every product aging will affect the product, e.g. detoration of insulation materials, terminations, switchgear and controlgear. A strongly influencing factor is the level of stress of the MCC, in particular the level of thermal stress. A way to control at least the initial quality of the MCC is to lay down in the specifications the way and proof how conformity to the standard has been verified. In case no type test has been performed the new IEC 61439 gives more dedicated design information which can be checked.

Lifetime and quality have a high level of interaction with preventive maintenance. Vendors should be invited to define the required periods and the required program of preventive maintenance. As preventive maintenance can be planned during the operation it can be combined with a general production stop for maintenance purposes.

Corrective maintenance, safe working procedures according EN 50110, expected level of modifications / extensions and additional functions / specifications are dealt with in combination with risk. As earlier defined risk is the product of probability and consequences.

A structured tool for a risk analyses is a FMEA, a failure mode effect analyses. Based on the different failure modes the effect on the functionality of the MCC and more important, the effect on the plant process is assessed to get an overview of the impact (see annex 1 for an FMEA of a failing component). A difficult item is missing information about the probability of failures such as malfunction of a component or a severe calamity such as an internal arc. This probability is on the one hand depending on the quality of the specific product itself, on the other hand depending on the way it is used: e.g. the level of stress, the environmental conditions the level of maintenance and, last but not least, the way humans are handling / operating it. However, large companies will have gathered historic information which can be used as an input. For assessing the results of an FMEA the principles as used for asset management can be used.

For the purpose of discussion 3 levels of consequences are defined for a MCC:

- Interaction on the process by interrupting one functional unit
- Interaction on the process by interrupting one panel
- Interaction on the process by interrupting the complete MCC

These 3 levels are highlighted in Fig. 5.

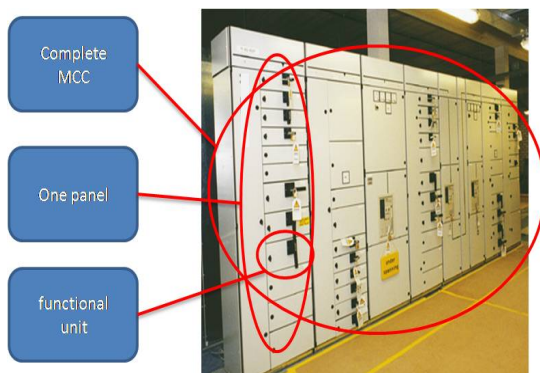


Fig. 5 Three levels of interaction on the process

The impact of the a, b, and c consequences on the process will be different and will depend on the specific process. Interruption of the complete MCC will result in a shutdown of a mayor part of the process. Costs will depend on the specific process and the time of the shut down, but can be in the order of millions of euro's. Interruption of only one functional unit will typically affect one load only and the consequences will be less.

As an example a full continuous plant process will be considered. The consequences translated into costs are:

- Interaction on the process by a short (2h) interruption of one functional unit → order  $10^3$  -  $10^4$  euro
- Interaction on the process by a 2h to 4h interruption of one panel of the MCC → order  $10^4$  -  $10^5$  euro
- Interaction on the process by a full interruption the complete MCC with various duration → order  $10^5$  -  $10^6$  euro

The consequences are visualized in the Risk assessment matrix (Fig. 6)

To 'control' the risk as much as possible there are 2 basic and principle options:

- Limit the probability up to the level of 'almost impossible'
- Limit the consequences to the smallest part of an MCC: one functional unit.

One way to reduce the risk in this example is to limit the consequences to the smallest part of the MCC. To realize this there are 3 important items:

- A high form of internal separation
- In case of a fault (even an internal arc) the consequences are limited to the compartment where the fault was initiated
- In case of a fault in the supply use a double redundant supply is used.

Probability of occurrence		Consequences			
	Frequency [/year]	>1000000 Eur	>100000 Eur	>10000 Eur	>1000 Eur
daily	1000	VH	VH	VH	H
weekly	100	VH	VH	H	M
monthly	10	VH	VH	H	M
yearly	1	VH	H	M	L
Frequently	0,1	VH	H	M	L
Probable	0,01	H	M	L	N
Possible	0,001	H	M	L	N
Not likely	0,0001	M	L	N	N
Almost impossible	0,00001	L	N	N	N

Annotations in the matrix:  
 - 'Whole MCC' points to the 'Almost impossible' row.  
 - 'Panel MCC' points to the 'Not likely' row.  
 - 'Functional unit MCC' points to the 'Possible' row.

Fig. 6 Risk assessment matrix and levels of interaction on the process

- The failure of a device, e.g. a contactor and safety of making changes

The consequences of the failure of a device and making changes, e.g. replacement of a device or installing an additional functional unit and outgoing cable in a MCC are highly related to the form of internal separation. A high form of internal separation means that busbars, individual components and terminals for external conductors are separated from each other by barriers or screens. E.g. it means that an individual component is accessible without the possibility of touching any life parts of other components. This is important when working in an MCC for repair or cable connection purposes. In Europe the EN 50110 defines that working under life conditions is only allowed under very strict defined situations. In the Netherlands the exceptions are:

- In case of doing measurements where the voltage is essential
- In case stopping a process will lead to potential dangerous situations itself.

Economic reasons are **not** seen as a necessary reason to work under life conditions.

Looking at the specifications of the MCC the form is important to what extent a MCC needs to be disconnected from the mains to be able to work safely and according to the requirements:

Form	Part of the MCC to be disconnected from the mains
1	Whole MCC
2	One panel
3	One panel up to one functional unit
4	One functional unit

This means by specifying a high form of internal separation the consequences of corrective maintenance, repair or modifying an functional unit the consequences are limited to that functional unit itself. Of course a high level of internal separation (form 3b, 4ab) will increase the costs of erecting the installation, however it will limit the costs during operation considerably in case of a problem with a functional unit.

Based on the same 3 examples used earlier the total costs taking into account the form of internal separation have been calculated. For save working procedures the principles of EN 50110 shall be taken into account. In case of a contactor replacement in a form 1 system it has been taken into account that the MCC has to be made voltage free.

Based on our experiences in practice over the years the failure rate of an individual contactor has been set to once in 100 year, so 0,01 times a year. Based on a MCC containing 50 functional units with a contactor the probability that 1 or more contactors will fail is 0,39 times a year.

Table 3

	example 1	example 2	example 3
<i>initial investment [euro]</i>	40000	70000	80000
form	1	3b	4a
Inflation [%]	4	4	4
<i>preventive maintenance [euro yearly]</i>	1750	2000	1500
defect component FU [per year]	0,39	0,39	0,39
costs repair [euro]	500	500	500
costs shut down [euro]	25000		
<i>yearly risk [euro]</i>	9945	195	195
<b><i>total costs over 10 years [euro]</i></b>	<b>134857</b>	<b>87803</b>	<b>93748</b>

As can be seen in table 3 the benefits of a high form are clearly influencing the results of the total costs over 10 years.

In case of installing a new cable for a new functional unit in a form 1 and 3b system it has been taken into account that the MCC (form 1) or one panel of the MCC (form 3b) has to be made voltage free. The result in both cases is shutting down of a part of the plant process. Although the duration will be short, the costs can be considerable. The probability of placing a cable for a new functional unit is once every 5 years for a switchgear with 50 functional units.

Table 4

	example 1	example 2	example 3
<i>initial investment [euro]</i>	40000	70000	80000
form	1	3b	4a
Inflation [%]	4	4	4
<i>preventive maintenance [euro yearly]</i>	1750	2000	1500
defect component FU [per year]	0,39	0,39	0,39
costs repair [euro]	500	500	500
costs shut down [euro]	25000		
<i>yearly risk def. component [euro]</i>	9945	195	195
new cable [per year]	0,2	0,2	0,2
costs connection [euro]	250	250	250
costs shut down [euro]	25000	5000	0
<i>yearly risk new cable [euro]</i>	5050	1050	50
<b><i>total costs over 10 years [euro]</i></b>	<b>175817</b>	<b>96320</b>	<b>94154</b>

As can be seen in table 4 again the benefits of a high form are clearly influencing the results of the total costs over 10 years.

### 3. A failure resulting in an Internal arc.

An internal arc is the most dangerous failure mode of a switchgear assembly. The amount of damage to the assembly will be considerable to even total and in case operators are in the direct neighborhood the probability of severe injuries is high. Typical causes of an internal arc are mistakes made during maintenance activities, joint faults, working under voltage (!), overload and harmonics, pollution and malfunction of apparatus.

An internal arc is more and more referred at in tenders. Most common is the wording: the assembly shall have been tested according IEC TR 61641 [2]. The IEC TR 61641 is a guide for testing under conditions of arcing due to internal fault. It's background is safety: in case of an internal fault resulting in an arc the operator standing in front of the assembly shall not be injured. In the new IEC TR 61641 edition 2 2008-01 the assessment criteria are divided in criteria 1-5 for personal protection and criteria 6-7 for assembly protection. By specifying criterion 6 the consequences of an internal arc is limited to a defined area and, in case fulfilling criterion 7, the assembly is suitable for (limited) continued operation. It is possible to choose one functional unit as defined area. Also new in this edition is the arc free zone. This is the part of the circuit within the assembly where it is not possible to ignite an internal arc without destroying of the insulation materials on conductors.

By making an estimate of the probability and the consequences (costs) the yearly risk can be calculated and the impact on the TCO can be made visible. The 3 examples used earlier have been extended with the risk of an internal arc.

Table 5

	example 1	example 2	example 3
<i>initial investment [euro]</i>	40000	70000	80000
form	1	3b	4a
Inflation [%]	4	4	4
<i>preventive maintenance [euro yearly]</i>	1750	2000	1500
defect component FU [per year]	0,39	0,39	0,39
costs repair [euro]	500	500	500
costs shut down [euro]	25000		
<i>yearly risk [euro]</i>	9945	195	195
new cable [per year]	0,2	0,2	0,2
costs connection [euro]	250	250	250
costs shut down [euro]	25000	5000	0
<i>yearly risk new cable [euro]</i>	5050	1050	50
Internal arc 61641 cr 1-5	no	yes	yes
Internal arc 61641 cr. 6-7	no	no	yes
Internal arc arc free zone	no	no	yes
probability internal arc [amount/year]	0,0002	0,0002	0,0001
costs repair [euro]	30000	50000	2500
costs shut down [euro]	2500000	2500000	20000
Probability person injuries	0,00004		
Costs severe bodily injuries [euro]	1000000		
<i>yearly risk [euro]</i>	546	510	2,25
<b><i>total costs over 10 years [euro]</i></b>	<b>180245</b>	<b>100456</b>	<b>94172</b>

About the probability of an occurrence of an internal arc in LV assemblies no statistics are available. Based on our experience the probability has been set to once in the

5000 year up to once in the 10000 year when provisions for an arc free zone have been made. Although the probability is low the consequences (costs) are very high. It shall be noted that in case of an internal arc the amount of damage to an assembly can be considerable. When no measures have been taken the assembly will be (automatic) switched off afterwards and damaged to such an extent, that partly renewal is necessary. In all cases it leads to a full shut down of the complete MCC and so the complete part of the plant process fed from the MCC.

In example 1 there is also no personal safety and a change that a person is in the surrounding of the switchgear and gets severe bodily injuries. The probability is even lower (set to 20% in case of an internal arc, so once in the 2500 year) but the consequences are disastrous.

As can be seen in table 5 the impact on the TCO of limiting the effects of an internal arc to one compartment only are considerable.

#### 4. Single supply versus double supply

To avoid problems with the supply the risk assessment matrix can be used again. If the supply fails the consequences are:

- Interaction on the process by interrupting the complete MCC in case of 1 supply
- Interaction on the process by interrupting a specific % of the MCC case of a double supply, but no full redundancy
- No interaction on the process in case of a double supply, having a full redundancy

It will be the combination between the expected probability of a failure versus the specific consequences of the interruption of a supply on which the decision can be based.

Assessing the investment costs it shall be taken into account that a double transformer needs a double space. About the probability of a failure of the transformer several investigations have been reported in literature [3, 4]. They differ from 0,1 / 100 years till 0,5 / 100 years. For specific situations even values of 2 / 100 years are reported, but these seem too high for standard applications. For the purpose of the example 0,2 / 100 years, so 0,002 times a year will be taken.

Table 6

	single supply	partly redundancy	full redundancy
transformer 2 MVA [euro]	30000		
2 transformers 1,2 MVA + 6m <sup>2</sup> additional [euro]		54000	
2 transformers 2 MVA + 6m <sup>2</sup> additional [euro]			72000
cables 20 meter [euro]	11520	13824	23040
Inflation [%]	4	4	4
<b>total initial investments [euro]</b>	<b>41520</b>	<b>67824</b>	<b>95040</b>
<b>energy loss transformer(s) in 10 years [euro]</b>	<b>109620</b>	<b>146160</b>	<b>121800</b>
energy loss cables in 10 years [euro]	33320	27780	16660
probability defect transformer / supply [per year]	0,002	0,003992	0,003992
costs repair [euro]	30000	21000	30000
duration (partly) shut down [hours]	160	160	0
costs shut down [euro]	2500000	500000	0
<b>yearly risk [euro]</b>	<b>5060</b>	<b>2079,832</b>	<b>119,76</b>
<b>total costs over 10 years [euro]</b>	<b>213981</b>	<b>244809</b>	<b>211431</b>

Of course the determining factor is the assessment of the consequences: what will it cost when the supply totally fails' of what will it cost if only a part of the supply will fail. The estimates in table 6 are an example based on a specific situation. They cannot be used in general.

Due to the effect of a total failure of the supply (1 transformer only) in this example is very costly the most economical solution over 10 years will be a full redundancy of the supply. The differences however, are not huge in this example.

## V. CONCLUSIONS

Working with TCO has been discussed. Distinction has been made between controlled items and uncontrolled items. Controlled items have been defined as cost items which can be calculated clearly in detail without speculations and opinions. They can be applied in a uniform way. Uncontrolled cost items however are depending on risk factors. Risk has been defined as the product of a probability a situation during lifetime of the product will take place and the consequences it will have for the process in which the product is fulfilling its role. Controlling risk means reducing the probability or limiting the consequences. Some tools out of the field of asset management used by utilities have been applied for a Low Voltage Motor Control Centre (MCC) to give guidance how decisions can be argued. It has been showed limiting the consequences can be translated into mandatory and preferred specifications that can be used in a tender. To take specific manufacturer specifications into account, it will demand that the purchase process find a way to take this into account. Suggestions have been made to have more aspects as CAPEX and mandatory requirements alone on which the granting will be based. This could be realized by to invite vendors to supply specific information for TCO based on a defined amount of requirements and to introduce 'preferred specifications'. These are defines as specifications which, when met by the vendor, will be weighted in the granting process.

## VI. REFERENCES

- [1] IEC 60287-3-2 ed. 1.1 Calculation of current rating – part 3: sections on operating conditions – section 2: economic optimization of power cable size
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- [3] R.A.Walling and T.Ruddy, Economic optimization of offshore windfarm substations and collection systems. Fifth international workshop on large scale integration of wind power and transmission networks for offshore windfarms, Glasgow 2005
- [4] F.Roos and S. Lindahl, Distribution system component failure rates and repair times – an overview, Nordac 2004 – Nordic distribution and asset management conference 2004

## VII. APPENDIX

FMEA of a contactor.

failure	failuremode	reason	consequences	repair time	consequences plant
contactor	contacts welded	insufficient coordination (no type 2)	loss of functionality	4h	depending on process, 10 <sup>3</sup> - 10 <sup>4</sup> euro
			dangerous situation (emergency stop)		depending on process, 10 <sup>3</sup> - 10 <sup>4</sup> euro
	loss of contact force	aging	insufficient contact	1h - 4h	depending on process, 500 pu when detected before loss of functionality, 10 <sup>3</sup> - 10 <sup>4</sup> euro when undetected
			damage to load		depending on load, worse case new electrical motor
		overheating		depending on process, 500 pu when detected before loss of functionality, 10 <sup>3</sup> - 10 <sup>4</sup> euro when undetected	
		internal arc	4 h / 2 days	depending on damage and process: 10 <sup>4</sup> - 10 <sup>6</sup> euro	
	broken housing	aging	loss of functionality		depending on process, 10 <sup>3</sup> - 10 <sup>4</sup> euro
		short circuit	dangerous situation (emergency stop)	4h	depending on process, 10 <sup>3</sup> - 10 <sup>4</sup> euro
			damage to load		depending on load, worse case new electrical motor
		overheating		depending on process, 500 pu when detected before loss of functionality, 10 <sup>3</sup> - 10 <sup>4</sup> euro when undetected	
		internal arc		depending on damage and process: 10 <sup>4</sup> - 10 <sup>6</sup> euro	
	loose cable connection	aging	damage to load		depending on load, worse case new electrical motor
		oxidation	overheating		depending on process, 500 pu when detected before loss of functionality, 10 <sup>3</sup> - 10 <sup>4</sup> euro when undetected
		internal arc		depending on damage and process: 10 <sup>4</sup> - 10 <sup>6</sup> euro	

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## VIII. VITA

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