

# Power Quality Application Guide



## Costs

### *Investment Analysis for PQ Solutions*

2.5



# Costs

## Investment Analysis for PQ Solutions

Angelo Baggini & Franco Bua

Università di Bergamo & Engineering Consulting and Design

July 2004



This Guide has been produced as part of the Leonardo Power Quality Initiative (LPQI), a European education and training programme supported by the European Commission (under the Leonardo da Vinci Programme) and International Copper Association. For further information on LPQI visit [www.lpqi.org](http://www.lpqi.org).



### Copper Development Association (CDA)

Copper Development Association is a non-trading organisation sponsored by the copper producers and fabricators to encourage the use of copper and copper alloys and to promote their correct and efficient application. Its services, which include the provision of technical advice and information, are available to those interested in the utilisation of copper in all its aspects. The Association also provides a link between research and the user industries and maintains close contact with the other copper development organisations throughout the world.

CDA is an IEE endorsed provider of seminar training and learning resources.



### European Copper Institute (ECI)

The European Copper Institute is a joint venture between ICA (International Copper Association) and the European fabricating industry. Through its membership, ECI acts on behalf of the world's largest copper producers and Europe's leading fabricators to promote copper in Europe. Formed in January 1996, ECI is supported by a network of eleven Copper Development Associations ('CDAs') in Benelux, France, Germany, Greece, Hungary, Italy, Poland, Russia, Scandinavia, Spain and the UK.

### Disclaimer

The content of this project does not necessarily reflect the position of the European Community, nor does it involve any responsibility on the part of the European Community.

European Copper Institute, Università di Bergamo, Engineering Consulting and Design and Copper Development Association disclaim liability for any direct, indirect, consequential or incidental damages that may result from the use of the information, or from the inability to use the information or data contained within this publication.

Copyright© European Copper Institute, Università di Bergamo, Engineering Consulting and Design and Copper Development Association.

Reproduction is authorised providing the material is unabridged and the source is acknowledged.

**LPQI is promoted in the UK by members of the Power Quality Partnership:**

**FLUKE**®

Fluke (UK) Ltd

**LEM**

LEM Instruments

**MGE**  
UPS SYSTEMS

MGE UPS Systems Ltd

**Rhopoint Systems**

Rhopoint Systems Ltd

## Investment Analysis for PQ Solutions

### Introduction

Poor power quality (PQ) can have a significant economic impact on the operation of many different types of facilities and a wide range of technologies exists for either mitigating the consequences or solving the resulting problems. The financial benefit of these technologies can be evaluated by estimating the improvement in the performance of the production facilities and the resulting cost reduction.

In order to take investment decisions, it is crucial to evaluate the economic impact of poor PQ and to compare it to the costs of the various alternative improvement measures. In other words, it is necessary to perform a cost benefit analysis between different solutions.

The process of evaluating these investments can be described in four basic steps:

- ◆ Characterise the present system's power quality (PQ) performance
- ◆ Estimate the costs associated with poor PQ
- ◆ Characterise the different solutions in terms of their cost and effectiveness
- ◆ Perform a comparative economic analysis of the different solutions.

This note is intended to give guidance on this process and, in particular, on the use of appropriate economic decision-making tools for comparing the different solutions. The focus will be on the review of different methods for performing comparative investment analysis.

For the sake of simplicity, in the following chapters we will refer to investments in technologies for mitigating or solving PQ problems as 'PQ investments'.

### Investment analysis

Companies have many choices about how to spend capital in order to produce a return on their investment (there are always at least two: invest in a project or put the money into an investment account).

Each option, including PQ investments, must compete with other investment opportunities for scarce capital. Therefore, the economic analysis of PQ investments should be conducted in the same way as the analysis of other capital investments, so that all options can be compared on an equal basis. This decision making process is called *capital budgeting*.

A particular problem arises for PQ investment, which is typical for any investment in cost reduction. In the capital budgeting process, some investments are earmarked as 'strategic', i.e. they are needed for the survival and growth of the enterprise, and hence receive priority. Another group of investments is required by law; they have little or no return on investment, and the enterprise would never undertake them on economic criteria. Typical examples are investments to reduce environmental impact of operations. Once the needs of strategic and legislative investments have been met, there is usually very little capital budget remaining for cost reduction measures, such as PQ investments. These investments have then to be undertaken by business units, using operating income rather than capital. This results in a very short time perspective, so PQ investments are required to achieve 1-2 year payback, equivalent to a 50-100% return rate, much higher than the average return on assets. Therefore, the scarcity of capital for PQ investments and the requirement to finance from operating income lead to sub-optimum performance, and present an opportunity for third party financing.

In this chapter a brief definition of capital budgeting principles and a short review of useful definitions will be given.

# Investment Analysis for PQ Solutions

---

## Capital budgeting

The decision whether to accept a project depends on the analysis of the cash flows resulting from the project. A capital budgeting decision process should satisfy the following criteria:

- ◆ It must consider all of the project's cash flows (including working capital)
- ◆ It must consider the time value of money
- ◆ It must always lead to the correct decision when selecting from mutually exclusive projects over different investment horizons.

The entire capital budgeting process relies on precise cash flow estimates and it is very important for the decision maker to obtain the most accurate forecasts possible. In order to do so, he must do two things:

- ◆ Identify all the variables that affect cash flows and determine which of those variables are critical to the success of the project
- ◆ Define the degree of forecasting accuracy required.

In the following sections the most relevant capital budgeting decision rules will be presented with a clear distinction between *deterministic* and *stochastic* methods. An evaluation method is considered deterministic if each cash flow can be precisely estimated, whilst it will be defined stochastic when cash flows vary over a range and thus introduce a degree of uncertainty.

The focus will be on deterministic methods, leaving in-depth coverage of stochastic methods to another section of this Guide.

## Project classifications

When dealing with capital budgeting, projects can be classified as either *independent* or *mutually exclusive*.

An independent project is a project where cash flows are not affected by the accept-reject decision of any other projects. Thus, all independent projects that meet the company's capital budgeting criteria should be accepted.

Mutually exclusive projects are a set of projects from which only one will be accepted, for example, a set of projects which each accomplish the same goal. Thus, when selecting from mutually exclusive projects, more than one project may satisfy the company's capital budgeting criteria, however, only one, i.e. the best project, can be accepted.

## Cost of capital

Discounted cash flow methods, described in the following paragraphs, measure cash flow in terms of a required rate of return (hurdle rate) to determine their acceptability. This hurdle rate can be taken as the company's cost of capital. But how is the cost of capital defined?

The company's cost of capital is the discount rate which should be used in capital budgeting. The *weighted average cost of capital* (WACC) reflects the company's cost of obtaining capital to invest in long term assets and is a weighted average of the company's cost of debt (long-term and short-term) and cost of equity (preferred stock, common stock).

In other words, the cost of capital represents the cost of funds used to acquire the total assets of the firm. Generally it refers to the rates of return expected by those parties contributing to the financial structure: preferred and common shareholders, as well as creditors. Thus, it is generally calculated as a weighted average of the costs associated with each type of liability included in the financial structure of the enterprise.

With reference to capital budgeting, the concept underlying the definition of the cost of capital is that a company must manage its assets and select capital projects with the goal of obtaining a yield at least sufficient to cover its cost of capital. Financial management separates the investment decision from the financing decision. A company's financial structure is considered as fixed, and yields a WACC figure.

# Investment Analysis for PQ Solutions

---

Sometimes, the required rate of return for investment opportunities can be risk adjusted, i.e. low risk projects have a lower hurdle rate, whereas high risk projects must produce a return well above the WACC.

Another consideration is the debt-to-equity ratio. Companies may not wish to carry too much debt compared to equity, as this increases their exposure to risk. So projects may not be pursued, even if they provide an attractive return, because the firm needs to limit or reduce debt. Again, such a situation presents an opportunity for third party financing.

## The time value of money

A given amount of money on hand today is worth more than the same amount to be received in the future, because money available today can be invested to earn interest to yield more than the same amount in the future. The *time value of money* mathematics quantify the value of a given amount of money over time. This, of course, depends upon the rate of return or interest rate that can be earned on the investment.

The time value of money concepts can be divided into two categories:

- ◆ *Future value* - describes the process of finding the extent to which an investment today will grow in the future.
- ◆ *Present value* - describes the process of determining what a given amount of money to be received in the future is worth in terms of today's money.

## Future value of a single cash flow

The future value of a single cash flow represents the amount, at some time in the future, by which an investment made today will grow if it is invested at a specified interest rate. For example, if you were to deposit € 100 today in a bank account to earn an interest rate of 10%, paid and compounded annually, this investment will grow to € 110 in one year.

This can be shown as follows:

$$\text{€ } 100 (1 + 10/100) = \text{€ } 110 \qquad \text{Year 1}$$

In the second year the account pays 10% interest on both the initial principal of € 100 and the € 10 of interest earned in the first year, giving a balance of € 121 after two years:

$$\begin{aligned} \text{€ } 110 (1 + 0.10) &= \text{€ } 121 \text{ or} && \text{Year 2} \\ \text{€ } 100 (1 + 0.10) (1 + 0.10) &= \text{€ } 121 \text{ or } \text{€ } 100 (1 + 0.10)^2 = \text{€ } 121 \end{aligned}$$

Notice that the investment earned € 11 in interest during the second year, whereas, it only earned € 10 in interest during the first year. This occurs because the interest rate in the example is a compound interest rate.

If the money was left in the account for one more year, interest would be earned on € 121 and the balance in the account at the end of year three would be € 133.10:

$$\begin{aligned} \text{€ } 121 (1 + 0.10) &= \text{€ } 133.10 \text{ or} && \text{Year 3} \\ \text{€ } 100 (1 + 0.10) (1 + 0.10) (1 + 0.10) &= \text{€ } 133.10 \text{ or} \\ \text{€ } 100 (1 + 0.10)^3 &= \text{€ } 133.10 \end{aligned}$$

The future value of an initial investment at a given interest rate compounded annually at any point in the future can be found using the following equation:

$$FV_t = CF_0(1+r)^t \qquad (1)$$

# Investment Analysis for PQ Solutions

---

where:

$FV_t$  = the future value at the end of year  $t$

$CF_0$  = the initial investment

$r$  = the annually compounded interest rate

$t$  = the number of years.

## Present value of a single cash flow and a cash flow stream

Present value describes the calculation of what a cash flow to be received in the future is worth in today's money. Therefore, the present value of a future cash flow represents the amount of money which, if invested today at a particular interest rate, will grow to be the same value as the future cash flow at that time in the future. The process of finding present values is called *discounting* and the interest rate used to calculate present values is called the *discount rate*. For example, the present value of € 100 to be received one year from now is € 90.91 if the discount rate is 10% compounded annually.

This can be demonstrated as follows:

$$€ 90.91 (1 + 10/100) = € 100 \text{ or } € 90.91 = € 100 / (1 + 0.10)$$

Notice that the future value equation was used to describe the relationship between the present value and the future value. Thus, the present value of € 100 to be received in two years can be shown to be € 82.64 if the discount rate is 10%:

$$€ 82.64 (1 + 0.10)^2 = € 100 \text{ or}$$

$$€ 82.64 = € 100 / (1 + 0.10)^2$$

The following equation can be used to calculate the present value of a future cash flow given the discount rate and number of years in the future that the cash flow occurs <sup>1</sup>:

$$PV = \frac{CF_t}{(1+r)^t} \quad (2)$$

where:

$PV$  = present value

$CF_t$  = future cash flow which occurs  $t$  years from now

$r$  = the interest or discount rate

$t$  = the number of years.

The present value of a cash flow stream is equal to the sum of the present values of the individual cash flows:

$$PV = \sum_{t=0}^T \frac{CF_t}{(1+r)^t} \quad (3)$$

where:

$PV$  = the present value of the cash flow stream

$CF_t$  = the cash flow which occurs at the end of year  $t$

$r$  = the discount rate

$t$  = the year, which ranges from zero to  $T$

$T$  = the last year in which a cash flow occurs.

<sup>1</sup> Note that this equation can be obtained algebraically from the future value equation.

## Deterministic approach to PQ investment analysis

The economic analysis of investments is one of the fundamental steps in any decision process because cost reduction is the main target for PQ investments.

The main elements of an investment to be investigated are:

- ◆ The capital cost or initial investment
- ◆ The cost of capital
- ◆ Cost reduction
- ◆ Operating and maintenance expenses for the investment
- ◆ The economic life of the investment.

Several evaluation methods can be used, according to the company's internal evaluation criteria for investment. More or less sophisticated methods can be used depending on the importance of the investment.

A distinction can be made between evaluation methods that use life cycle costing and those that do not. Evaluation methods that use life cycle costing are based on the conversion of investment and annual cash flows at various times to their equivalent present values. In other words the whole life span of the investment is taken into consideration. Typical examples of life cycle costing methods are *net present value* (NPV) and *internal rate of return* (IRR).

Evaluation methods that do not use life cycle costing are, for instance, *payback time* (PBT) and *break-even analysis*. They do not take into consideration the life of the investment, they merely indicate how long it will take to recover the money spent on the project.

## Discounted cash flow methods

### Net present value (NPV)

The net present value (NPV) of a project indicates the expected impact of the project on the value of the company.

Projects with a positive NPV are expected to increase the value of the company. Thus, the NPV decision rule specifies that all independent projects with a positive NPV should be accepted. If NPV is greater than zero the project is valid, since the revenues are enough to pay the interest and recover the initial capital cost before the end of the life of investment. When NPV equals zero, the balance occurs at the end of the life, and the investment is scarcely attractive.

When selecting from mutually exclusive projects, the project with the largest (positive) NPV should be chosen.

The NPV is calculated as the present value of the project's cash inflows minus the present value of the project's cash outflows. This relationship is expressed by the following formula:

$$NPV = \sum_{t=0}^T \frac{CF_t}{(1+r)^t} = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_T}{(1+r)^T} \quad (4)$$

where:

$CF_t$  = net cash flow at time  $t$

$CF_0$  = the initial investment

$r$  = the cost of capital

$t$  = the number of years

$T$  = life of the project.

# Investment Analysis for PQ Solutions

The example in Table 1 illustrates the calculation of net present value and shows the cash flows yielded by projects A and B over their five year lives. The cost of capital for the project is 10%.

Thus, if projects A and B are independent projects, then both projects should be accepted. On the other hand, if they are mutually exclusive projects, then project A should be chosen since it has the larger NPV.

The NPV considers all of the project's cash flows and the time value of money.

Projects can also be compared by taking as a parameter the ratio between the present worth of the project and the related investment (NPV/I).

	Project A	Project B
Year	Cash Flow (€)	Cash Flow (€)
0	-1000	-1000
1	500	100
2	400	200
3	200	200
4	200	400
5	100	700
NPV	121.89	103.92

*Table 1 - Example illustrating the calculation of NPV (refer to Excel file [6])*

## Net Present Value (NPV) in brief

### What is it?

NPV is a measure of how much value is created or added today by undertaking an investment, i.e. the difference between the investment's market value and its cost.

### How do you calculate NPV?

Estimate future cash flows. Calculate the present value of those cash flows minus the initial cost.

### The NPV Rule

For independent projects: An investment should be accepted if the net present value is positive and rejected if it is negative .

For mutually exclusive projects: The project with the largest positive NPV should be selected.

### Work it out yourself (and if you need help refer to Excel file [6])

You plan to buy a UPS that will cost € 20 000 today and will produce cash flows of € 3 000 in each of the next 10 years. The salvage value will be zero. The cost of capital is 5%. Should you buy the UPS?

## Internal Rate of Return (IRR)

The internal rate of return (IRR) of a project is the discount rate at which the NPV of a project equals zero. The IRR decision rule specifies that all independent projects with an IRR greater than the cost of capital should be accepted. When selecting from mutually exclusive projects, the project with the highest IRR should be chosen as long as the IRR is greater than the cost of capital.

$$NPV = 0 = \sum_{t=0}^T \frac{CF_t}{(1+IRR)^t} = CF_0 + \frac{CF_1}{(1+IRR)^1} + \frac{CF_2}{(1+IRR)^2} + \dots + \frac{CF_T}{(1+IRR)^T} \quad (5)$$

where:

$CF_t$  = the cash flow at time  $t$

$T$  = life of the project

# Investment Analysis for PQ Solutions

---

The example in Table 2 illustrates the determination of IRR and shows the cash flows yielded for projects A and B over their five-year lives. The cost of capital for both projects is 10%.

Thus, if projects A and B are independent projects then both projects should be accepted since their IRR are greater than the cost of capital. On the other hand, if they are mutually exclusive projects then project A should be chosen since it has the higher IRR.

	Project A	Project B
Year	Cash Flow (€)	Cash Flow (€)
0	-1000	-1000
1	500	100
2	400	200
3	200	200
4	200	400
5	100	700
IRR	17%	13%

*Table 2 - Example illustrating the calculation of IRR (refer to Excel file [6])*

## Internal Rate of Return (IRR) in brief

### What is it?

The internal rate of return is the discount rate that makes the NPV of a project equal to zero.

### How do you calculate IRR?

Set NPV equal to zero and solve for interest rate. The interest rate that yields an NPV of zero is the IRR.

### The IRR Rule

An investment is acceptable if the IRR exceeds the required rate of return. It should be rejected otherwise.

### Work it out yourself (and if you need help refer to Excel file [6])

You plan to install an active filter that will cost € 5 000 today and produce cash flows of € 1 000 in each of the next 10 years. The salvage value will be zero. The cost of capital is 5%. Should you install the active filter?

## Annual equivalent

If we assume the same cash flow every year, i.e.  $CF_0 = CF_1 = \dots = CF_T$ , we can simplify equation (3) to:

$$PV = \frac{CF * ((1+r)^T - 1)}{r(1+r)^T} \quad (6)$$

The above equation can be used to calculate *annualised cash flows* (ACF) resulting from an investment made. For example, if we make an investment, I, in PQ mitigation, this investment is effective if the *annual cost savings* (ACS) are higher than the ACF plus *operating & maintenance expenses* (OME).

$$ACF = \frac{I * r * (1+r)^T}{(1+r)^T - 1} \quad (7)$$

The *annual cost of ownership* (ACO) for this investment is ACS – OME – ACF and the investment decision should be positive if ACO > 0. A variant of this method is used in Section 5.5.1 of this Guide, where the annual cost of poor power quality is added to annual investment and operating and maintenance costs for various mitigation approaches and the minimum cost solution is proposed.

# Investment Analysis for PQ Solutions

---

ACO can be converted to *total cost of ownership* (TCO) by re-use of equation (3):

$$TCO = \frac{ACO * ((1+r)^T - 1)}{r * (1+r)^T} \quad (8)$$

## Comparison of discounted analysis methods

Both NPV and IRR decision rules consider all of the project's cash flows and the time value of money.

The NPV and IRR decision rules differ with respect to their reinvestment rate assumptions. The NPV decision rule implicitly assumes that the project's cash flows can be reinvested at the company's cost of capital, whereas the IRR decision rule implicitly assumes that the cash flows can be reinvested at the projects' IRR. Since each project is likely to have a different IRR, the assumption underlying the NPV decision rule is more reasonable.

In general, engineering economic analysis presents NPV as the most correct method for making investment decisions. IRR has particular problems – for example, equation (5) does not always give a unique solution for IRR. In addition, for a project with a high IRR, for example 40%, the assumption that the company will be able to earn a 40% return on the proceeds from the project is flawed. In today's information age, with the power of desktop computing available, there is no reason not to use NPV systematically for making investment decisions.

## Non-discounted cash flow methods

### Payback time (PBT)

The payback time represents the amount of time that it takes for a project to recover its initial cost.

The use of the PBT as a capital budgeting decision rule specifies that all independent projects with a PBT less than a specified number of years should be accepted. When selecting from mutually exclusive projects, the project with the shortest payback is to be preferred.

The calculation of the PBT is best illustrated with an example. Consider Project A, which yields the cash flows shown in Table 3 over its five-year life.

To begin the calculation of the PBT for Project A, let's add an additional column to this table which represents the *net cash flow* (NCF) for the project in each year (Table 4).

Note that after two years the NCF is negative (-1000 + 500 + 400 = -100) while after three years the NCF is positive (-1000 + 500 + 400 + 200 = 100). Thus the PBT, or break even point, occurs sometime during the third year. If we assume that the cash flows occur regularly over the course of the year, the PBT can be computed using the following equation:

$$PBT = Y_{LN} - \left( \frac{NCF(Y_{LN})}{CF(Y_{LN+1})} \right) \quad (9)$$

where:

$Y_{LN}$  = last year with a negative net cash flow (NCF)

$NCF(Y_{LN})$  = net cash flow in that year

$CF(Y_{LN+1})$  = total cash flow in the following year.

Year	Cash Flow (€)
0	-1000
1	500
2	400
3	200
4	200
5	100

Table 3 – PBT Project A

Year	Cash Flow (€)	Net Cash Flow (€)
0	-1000	-1000
1	500	-500
2	400	-100
3	200	100
4	200	300
5	100	400

Table 4 – PBT Project A (NCF)

# Investment Analysis for PQ Solutions

---

Thus, in the example above, the last year with a negative net cash flow is year 2; the value of the net cash flow in that year is equal to -€ 100; the total cash flow in the following year (year 3) is equal to € 200; therefore the project will recoup its initial investment in  $2 - (-100/200) = 2.5$  years.

Although widely used, payback time suffers from several drawbacks. First, PBT assumes that € 200 received 1 year from today is equivalent to € 200 received 5 years from today; in other words, it does not consider the time-value of money. This issue can be resolved by calculating *discounted payback* (DPBT), where cash flows are discounted to their present value based on the discount rate, making DPBT consistent with life cycle costing methods such as NPV and IRR. The second flaw is that payback does not consider the effects of different lifespans of the alternatives, thus penalising projects that have long potential lifespans. For example, if alternative investments A and B each cost € 1 000 and save € 200 per year, then both would have a PBT of 5 years, making them seem equally acceptable. However, if investment A has an estimated useful life of 5 years and investment B has an estimated useful life of 10 years, investment B would obviously be the better choice. The third drawback is that the accept/reject criterion is often arbitrarily short. For example, many organizations require a 1 to 3 year payback period to consider a cost-saving project and place a higher priority on projects with a shorter payback time.

Therefore, the payback method will reject many interesting investment opportunities, while it may even accept projects that reduce the company's value. It was widely used in the 60s and 70s, before the computer era, because it is simple to calculate. Today, it should be avoided as much as possible. A recent survey [7] shows that NPV is by far the preferred tool among Fortune 1000 companies, with 85% of respondents using it always or often.

## Payback (PBT) in brief

### What is it?

The payback is the length of time it takes to recover the initial investment.

### How do you calculate PBT?

Assume cash flows are received uniformly throughout the year. Calculate the number of years it will take for the future cash flows to match the initial cash outflow.

### The Simple Payback Rule

An investment is acceptable if its calculated payback period is less than some pre-specified number of years.

### Work it out yourself (and if you need help refer to Excel file [6])

You plan to buy a flywheel that will cost € 200 000 today and produce a € 3 000 annual cash flow. The company only accepts projects with a payback of 4 years or less. Should you purchase the machine?

## Break even analysis

Break even analysis can be used for projects where there is a gradual build up of costs and benefits over time. For example, a production plant will need several years of investment in facilities, labour, training, and services. After a certain time, output of the plant will start and then rise gradually as experience grows and the product is sold onto the market. The point where accumulated costs equal accumulated benefits is called the break even point. It typically applies to complex projects, and rarely applies to PQ investments.

Most spreadsheet software packages, such as those included in OpenOffice, StarOffice and Microsoft Office, provide functions and help files to make these calculations simple.

## Stochastic approach to PQ investment analysis

PQ problems cause a negative cash flow – i.e. they result in a cost – either continuously (as for example, excess power loss in a transformer due to harmonics) or in discrete events (such as an unmitigated voltage dip or the failure of a transformer due to long term overload caused by harmonics).

A decision maker may therefore be faced with conditions of certainty, risk or uncertainty; these are differentiated as follows:

- ◆ *Certainty* indicates that the decision maker knows in advance the precise values of all the parameters which might affect the decision
- ◆ *Risk* indicates that the decision maker is aware of all possible states which may occur, and thereby affect relevant decision parameters, and he is able to place a probability of occurrence on each of these states
- ◆ *Uncertainty* indicates that the decision maker may not be aware of all the possible states that affect the decision and/or may not be able to place a probability on the occurrence of each.

When there is certainty about the nature and scale of the risk, deterministic methods are applicable. When faced with uncertainty, the first step should be to attempt to collect the additional data required to understand the range of possibilities and their probabilities so that the problem becomes one of risk. This usually involves collecting additional data, at some cost.

To deal with risk, it is necessary to adapt the deterministic evaluation methods described earlier. For example, if NPV and PBT were used when cash flows are deterministic,  $NPV^{\wedge}$  and  $PBT^{\wedge}$  would be used in stochastic analysis where cash flows are expressed in terms of their expected value.

Figure 1 – Example of use of deterministic and non-deterministic project evaluation criteria

		Short period	Long period
Stochastic	Deterministic	PBT	NPV
	Stochastic	$PBT^{\wedge}$	$NPV^{\wedge}$

For example, in conditions of risk, NPV can be reformulated as follows:

$$NPV^{\wedge} = \sum_{t=1}^T \frac{CF(t)^{\wedge}}{(1+i)^t} - I \tag{10}$$

where the symbols indicate the same quantities described earlier.

In order to evaluate each single cash flow the following expression can be used:

$$CF^{\wedge} = n p \delta$$

where:

$n$  = frequency of the PQ event (cause of damage)

$p$  = probability of damage

$\delta$  = amount of damage.

# *Investment Analysis for PQ Solutions*

---

The frequency of the event can be evaluated on the basis of standards (for example EN 50160), the results from measurement campaigns or on historical data.

Probability of damage can be evaluated on the basis of literature and experience; an example is the Computer and Business Equipment Manufacturers' Association (CBEMA) curve for IT equipment.

The amount of damage is the value of losses arising from the PQ event under consideration. Its consequences vary with type of industry, site, type of production, market conditions, etc; average values can be found in the literature or survey reports such as [8]. For example typical losses related to PQ events are:

- ◆ Losses due to reduced equipment life
- ◆ Energy losses
- ◆ Production interruption or reduced throughput
- ◆ Data losses.

With this approach:

- ◆ Cash flows are determined with a risk assessment procedure
- ◆ Cash flow is no longer a deterministic variable but a stochastic variable and is expressed in terms of expected value.

The risk element in PQ investments can be accommodated in two ways:

- ◆ Setting a high hurdle rate: for example, if a company's WACC is 15%, risky investments may be required to yield a 20% return
- ◆ Requiring a rapid payback: a 2 year payback requirement implies a return of almost 50% per year. The short time period allows the company to get its money back 'before something can go wrong'.

However, these techniques to accommodate risk are quite crude. They do not take into account that operating assets are actually managed over their lifetime, and that managers can take corrective action.

## **References and bibliography**

[1] D V Lindley: *'Making Decisions'*, Wiley, London, 1985

[2] J Clark, T Hindelag, R Pritchard: *Capital budgeting, planning and control of expenditures*, 3<sup>rd</sup> Edition, Prentice-Hall, 1989

[3] R Brearly, S Myers: *Principles of corporate finance*, 4<sup>th</sup> Edition, McGraw Hill, 1991

[4] Colli, Franzone: *'Teoria generale dei processi decisionali'*, Giuffrè, Pavia, 1992

[5] Cherubini, Dalla Lunga: *'Matematica finanziaria'*, McGraw Hill, Milano 2002

[6] [http://www.copperinfo.co.uk/power-quality/downloads/pqug/2\\_5-examples.xls](http://www.copperinfo.co.uk/power-quality/downloads/pqug/2_5-examples.xls)

[7] P Ryan: *'Capital budgeting practices of the Fortune 1000: how have things changed'*, *Journal of Business and Management*, Winter 2002

[8] CEIDS: *The cost of power disturbances to industrial & digital economy companies*, 2001

# *Notes*

---

## Reference & Founding\* Partners

European Copper Institute* (ECI) <i>www.eurocopper.org</i>	ETSII - Universidad Politécnica de Madrid <i>www.etsii.upm.es</i>	LEM Instruments <i>www.lem.com</i>
Akademia Gornicz-Hutnicza (AGH) <i>www.agh.edu.pl</i>	Fluke Europe <i>www.fluke.com</i>	MGE UPS Systems <i>www.mgeups.com</i>
Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA) <i>www.citcea.upc.es</i>	Hochschule für Technik und Wirtschaft* (HTW) <i>www.htw-saarland.de</i>	Otto-von-Guericke-Universität Magdeburg <i>www.uni-magdeburg.de</i>
Comitato Elettrotecnico Italiano (CEI) <i>www.ceiuni.it</i>	Hogeschool West-Vlaanderen Departement PIH <i>www.pih.be</i>	Polish Copper Promotion Centre* (PCPC) <i>www.miedz.org.pl</i>
Copper Benelux* <i>www.copperbenelux.org</i>	International Union for Electricity Applications (UIE) <i>www.uiie.org</i>	Università di Bergamo* <i>www.unibg.it</i>
Copper Development Association* (CDA UK) <i>www.cda.org.uk</i>	ISR - Universidade de Coimbra <i>www.isr.uc.pt</i>	University of Bath <i>www.bath.ac.uk</i>
Deutsches Kupferinstitut* (DKI) <i>www.kupferinstitut.de</i>	Istituto Italiano del Rame* (IIR) <i>www.iir.it</i>	University of Manchester Institute of Science and Technology (UMIST) <i>www.umist.ac.uk</i>
Engineering Consulting & Design* (ECD) <i>www.ecd.it</i>	Katholieke Universiteit Leuven* (KU Leuven) <i>www.kuleuven.ac.be</i>	Wroclaw University of Technology* <i>www.pwr.wroc.pl</i>
EPRI PEAC Corporation <i>www.epri-peac.com</i>	Laborelec <i>www.laborelec.com</i>	

## Editorial Board

David Chapman (Chief Editor)	CDA UK	david.chapman@copperdev.co.uk
Prof Angelo Baggini	Università di Bergamo	angelo.baggini@unibg.it
Dr Araceli Hernández Bayo	ETSII - Universidad Politécnica de Madrid	ahernandez@etsii.upm.es
Prof Ronnie Belmans	UIE	ronnie.belmans@esat.kuleuven.ac.be
Dr Franco Bua	ECD	franco.bua@ecd.it
Jean-Francois Christin	MGE UPS Systems	jean-francois.christin@mgeups.com
Prof Anibal de Almeida	ISR - Universidade de Coimbra	adealmeida@isr.uc.pt
Hans De Keulenaer	ECI	hdlk@eurocopper.org
Prof Jan Desmet	Hogeschool West-Vlaanderen	jan.desmet@howest.be
Dr ir Marcel Didden	Laborelec	marcel.didden@laborelec.com
Dr Johan Driesen	KU Leuven	johan.driesen@esat.kuleuven.ac.be
Stefan Fassbinder	DKI	sfassbinder@kupferinstitut.de
Prof Zbigniew Hanzelka	Akademia Gornicz-Hutnicza	hanzel@uci.agh.edu.pl
Stephanie Horton	LEM Instruments	sho@lem.com
Dr Antoni Klajn	Wroclaw University of Technology	antoni.klajn@pwr.wroc.pl
Prof Wolfgang Langguth	HTW	wlang@htw-saarland.de
Jonathan Manson	Gorham & Partners Ltd	jonathanm@gorham.org
Prof Henryk Markiewicz	Wroclaw University of Technology	henryk.markiewicz@pwr.wroc.pl
Carlo Masetti	CEI	masetti@ceiuni.it
Mark McGranaghan	EPRI PEAC Corporation	mmcgranaghan@epri-peac.com
Dr Jovica Milanovic	UMIST	jovica.milanovic@umist.ac.uk
Dr Miles Redfern	University of Bath	eesmar@bath.ac.uk
Dr ir Tom Sels	KU Leuven	tom.sels@esat.kuleuven.ac.be
Prof Dr-Ing Zbigniew Styczynski	Universität Magdeburg	Sty@E-Technik.Uni-Magdeburg.de
Andreas Sumper	CITCEA	sumper@citcea.upc.es
Roman Targosz	PCPC	cem@miedz.org.pl
Hans van den Brink	Fluke Europe	hans.van.den.brink@fluke.nl



*Prof Angelo Baggini*



Università di Bergamo  
Via Marconi 5  
I-24044 Dalmine  
Italy

Tel: 00 39 035 2052353  
Fax: 00 39 027 00508311  
Email: [angelo.baggini@unibg.it](mailto:angelo.baggini@unibg.it)  
Web: [www.unibg.it](http://www.unibg.it)



*Dr Franco Bua*



Engineering Consulting and Design  
Via Cardinal Maffi 21  
I-27100 PAVIA  
Italy

Tel: 00 39 03 82 538934  
Fax: 00 39 027 00508307  
Email: [franco@ecd.it](mailto:franco@ecd.it)  
Web: [www.ecd.it](http://www.ecd.it)

## **Copper Development Association**

Copper Development Association  
5 Grovelands Business Centre  
Boundary Way  
Hemel Hempstead HP2 7TE  
United Kingdom

Tel: 00 44 1442 275700  
Fax: 00 44 1442 275716  
Email: [helpline@copperdev.co.uk](mailto:helpline@copperdev.co.uk)  
Websites: [www.cda.org.uk](http://www.cda.org.uk) and [www.brass.org](http://www.brass.org)



European Copper Institute  
168 Avenue de Tervueren  
B-1150 Brussels  
Belgium

Tel: 00 32 2 777 70 70  
Fax: 00 32 2 777 70 79  
Email: [eci@eurocopper.org](mailto:eci@eurocopper.org)  
Website: [www.eurocopper.org](http://www.eurocopper.org)