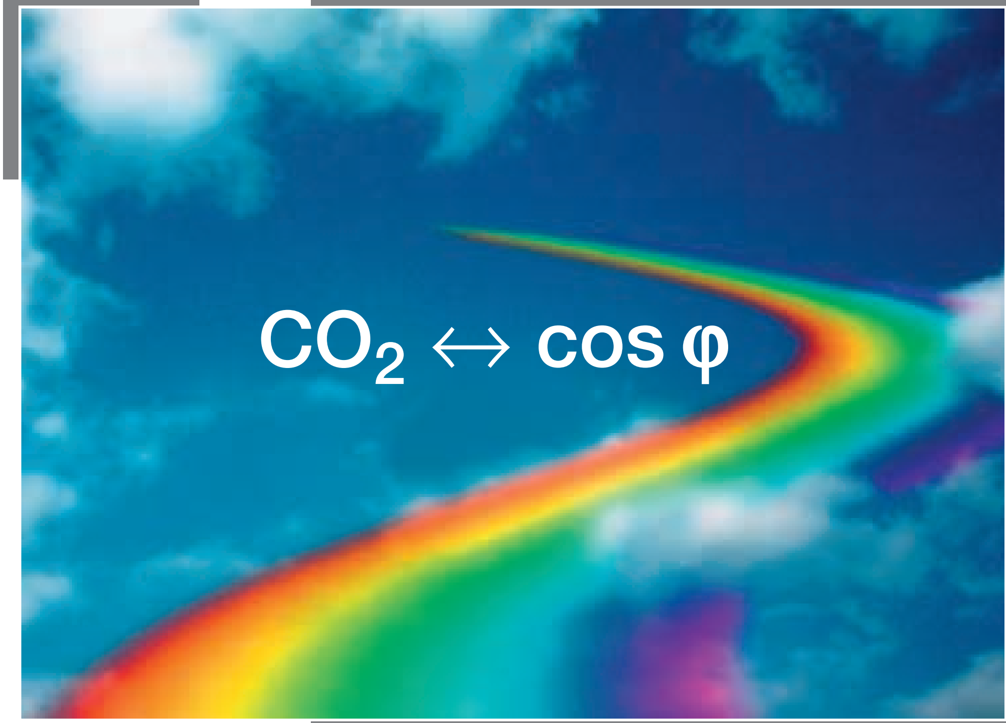
Zentralverband
Elektrotechnik- und
Elektronikindustrie e.V.

Protecting the Climate through Power Factor Correction



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Summary

The 1992 Convention on Climate Change which resulted from the Rio Earth Summit in that year sets goals for limiting the concentrations of greenhouse gases in the atmosphere, while the 1997 Kyoto Protocol prescribes targets for limiting and reducing emissions. Along with many other countries, the European Community and Germany have committed themselves to make significant reductions in the emissions of greenhouse gases, in particular of carbon dioxide (CO_2). Germany's commitments are set out in its National Climate Protection Programme and are being put into effect for proactive climate control through various statutory measures and the agreement between the German Federal Government and German industry.

For many years power factor correction units have been in operation in industrial installations and building utility systems in order to make more efficient use of electrical energy. One major economic advantage of this is that the consumer cuts down on energy costs. In addition, power factor correction reduces the amount of current flowing in the transmission and distribution networks. Reduced current levels mean lower power losses in the distribution network, savings in electrical energy and hence reduced CO_2 emissions. Calculations show that in 1999 the power factor correction systems then installed in Germany reduced network losses by about 9 billion kilowatt-hours. Expressed in terms of the energy source mix conventionally applied to Germany, this is equivalent to some 5 million tonnes of CO_2 emissions that were thus avoided. This saving is approximately four times greater than that achievable by using the „green" electricity currently being promoted.

Some power traders have a tendency to waive the charges for reactive power, thus making power factor correction less attractive for the final consumer. This marketing strategy may well be used to gain competitive advantage or to make use of surplus capacity, but is counterproductive in terms of climate protection.

The active contribution to climate protection made by power factor correction should be consolidated and expanded. This technology offers the potential for a further reduction in network losses of some 4.3 billion kilowatt-hours from present-day levels, equivalent to cutting CO_2 emissions by about 2.5 million tonnes per annum, or approximately 10% of the reduction in emissions for the energy and industry sector called for by Germany's National Climate Protection Programme.

This brochure is directed at electricity users, energy suppliers, network operators, power traders and politicians alike. It provides information on

- the economic advantages of power factor correction
- the benefits of power factor correction for climate protection.

The brochure should also inspire recommendations for taking concrete action:

- Power consumers should make full use of the potential for energy savings offered by power factor correction systems, thereby minimizing their own network losses, optimising the network load and stabilizing the network voltage.
- Network operators should insist on the rigorous implementation of existing technical rules in order to reduce losses in the transmission and distribution networks and to increase transmission capacities.
- Power suppliers must continue to charge for reactive energy, in order not to counteract the goals of climate protection.
- The power industry should exploit the potential for reducing CO_2 emissions offered by the more widespread use of power factor correction.
- Politicians and industry associations should encourage and support the active contribution to climate protection provided by power factor correction.

These recommendations are for concrete measures to help Germany's contribution to preventive action against climate change. If Germany sets a good example, this can also provide inspiration for European and international initiatives aimed at a common goal.

Climate protection is everybody's concern

Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) [1] forms the basis for the worldwide effort to combat global warming. It was open for signature at the Rio Earth Summit in 1992 and has as its ultimate objective „stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [i.e. caused by human activities] interference with the climate system. Such a level should be achieved with-in a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Parties to the Convention on Climate Change
Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America.

Kyoto Protocol

The Kyoto Protocol to the United Nations Framework Convention on Climate Change [2] supports the international effort to combat climate change. This Protocol, adopted by consensus at the third session of the Conference of the Parties to the Convention in December 1997, prescribes the (developed) countries listed in Annex 1, after ratification, legally binding targets for limiting and reducing emissions for the years after 2000.

The developed countries have committed themselves to reducing their joint emissions of 6 key greenhouse gases by at least 5% (by 2008/2012). This group objective will be achieved by the individual countries effecting reductions to differing extents.

To this end Switzerland, most central and eastern European states and the European Union will reduce their emissions by 8%, the individual EU member countries being assigned differing rates of reduction as part of the burden sharing agreement. Germany has pledged to achieve a reduction of 21%.

The six Kyoto Protocol greenhouse gases
CO_2 carbon dioxide
CH_4 methane
N_2O nitrous oxide
HFCs hydrofluorocarbons
PFCs perfluorocarbons
SF_6 sulphur hexafluoride

Climate protection targets of the Kyoto Protocol and EU burden sharing

Greenhouse gases	Emissions in the base year 1990	Reduction target in the period 2008/2012
Worldwide	18,147 million tonnes	by 5% (Annex I countries)
EU	4,208 million tonnes	by 8%
Germany [3]	1,209 million tonnes	by 21% (EU burden sharing)

Germany's National Climate Protection Programme

The German Federal Government's 1999 annual report on the greenhouse gas inventory [4] revealed that emissions of carbon dioxide fell by 13% from 1990 to 1998.

When broken down by sectors, the CO_2 reduction achieved was due to clear cutbacks in the following two areas:

- Industry (31% less)
- Power generation/conversion (16% less).

On the other hand, two sectors showed significant increases in emissions:

- Private households (6% more)
- Transport (an even more pronounced increase of 11%) [5].

The development anticipated after taking into account measures already implemented makes it clear that further efforts will be necessary to attain the objectives of the German Federal Government's National Climate Protection Programme [6]:

- Reduction in carbon dioxide emissions of 25% from the 1990 levels by 2005
- Reduction in emissions of the six greenhouse gases by 21% in the period 2008 – 2012.

The German Federal Government has decided on various measures in order to make up for the present shortfall of some 50 – 70 million tonnes needed to achieve the above 25% objective. They impact particularly on the following sectors [7]:

- Private households and buildings 18 – 25 million tonnes
- Energy and industry 20 – 25 million tonnes
- Transport 15 – 20 million tonnes

Agreement on preventing climate change

The „Declaration by German industry on global warming prevention" of March 1996 agreed to a reduction in specific CO_2 emissions of 20% by the year 2005. Numerous actions taken already achieved a reduction in specific CO_2 emissions of 23% by 1999. In the „Agreement between the Government of the Federal Republic of Germany and German industry on climate protection" of November 2000, the participating industry associations renewed and reinforced their voluntary commitment to continue to make special efforts to lower their specific CO_2 emissions and the emissions of other greenhouse gases [8]. The goal is to reduce the specific emissions of all six greenhouse gases addressed by the Kyoto Protocol by an aggregate figure of 35% from their 1990 levels by 2012, and in the years leading up to 2005 to make additional efforts to reduce specific CO_2 emissions by 28% from their 1990 levels. The German Federal Government and German industry expect that the volume of emissions in 2005 can thus be reduced by an additional 10 million tonnes of CO_2, and in 2012 by a further 10 million tonnes of CO_2 equivalent, beyond the previous voluntary commitments.

Protecting the climate through power factor correction

A technique that has been used for many years to promote the efficient use of electrical energy is power factor correction (PFC).

By decreasing the electrical losses in the transmission and distribution networks, and hence reducing the emissions of CO_2, this technology is today already making an active contribution to protecting the global climate.

Power factor correction

= Decreased power losses

= Reduced CO_2 emissions

= Active climate protection

The principle of power factor correction

How reactive power originates

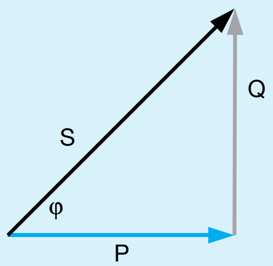
Many electrical devices, such as AC single-phase and 3-phase motors, require both active power and reactive power. The active power is converted into useful mechanical power, while the reactive power is needed to maintain the device's magnetic fields. This reactive power is transferred periodically in both directions between the generator and the load.

Effects of reactive power

Vector addition of the active power P and the reactive power Q gives the apparent power S.

Power generators and transmission network operators must make this apparent power available and transmit it. This means that generators, transformers, power lines, switchgear, etc. must be sized for greater power ratings than if the load only drew active power.

Power supply companies are therefore faced with extra expenditure on plant and additional power losses. They therefore make additional charges for reactive power if this exceeds a certain threshold. Usually a certain target power factor cos φ of between 1.0 and 0.9 (lagging) is specified [9].



Apparent power
$S^2 = P^2 + Q^2$

Active power
$P = S \cdot \cos \varphi$

Reactive power
$Q = S \cdot \sin \varphi$

Example: 3-phase motor

Active power	500 kW
Reactive power	510 kVAr (ind)
Resulting apparent power	714 kVA

Although the motor's mechanical power output only calls for 500 kW, the supply network loading is an apparent power of 714 kVA, i.e. it has to transmit 143% of the active power.

Definitions as set out in GridCode 2000 [10]

Active power is the electric power available for conversion to a different form of power, e.g. mechanical, thermal, chemical, optical, or acoustic power.

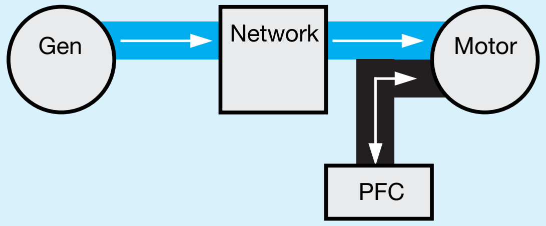
Reactive power is electric power required for the generation of magnetic fields (e.g. in motors or transformers) or electric fields (e.g. in capacitors). In a chiefly magnetic field, reactive power is inductive; in a chiefly electric field, it is capacitive.

Apparent power is the geometric sum of the active and reactive power. It is crucial to the design of, for example, electrical installations.

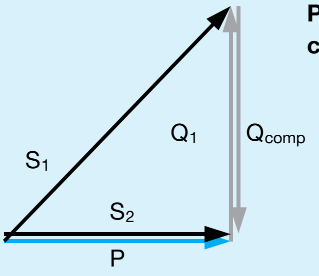
The power factor cos (is the quotient of the active power and the apparent power.

Power factor correction

If the lagging power factor is corrected, for example by installing a capacitor at the load, this totally or partially eliminates the reactive power draw at the power supply company. Power factor correction is at its most effective when it is physically near to the load and uses state-of-the-art technology.



The inductive reactive power Q_1 is compensated for totally or partially by the capacitive reactive power Q_{comp}, the apparent power thus being reduced from S_1 to S_2.



Power factor correction

Example: 3-phase motor with power factor correction (PFC)

Active power	500 kW
Reactive power	510 kVAr (lagging)
Power factor correction	510 kVAr (leading)
Resultant reactive power	0 kVAr
giving apparent power	500 kVA

The motor draws an active power of 500 kW as before, but its reactive power is fully compensated for and the supply network needs to transmit an apparent power of 500 kVA, i.e. 100% of the active power. Power factor correction in this case therefore reduces the transmission load by 43% of the nominal active power (i.e. from 143% to 100%).

Economic benefits of power factor correction

Saving the costs of reactive energy

As an example we can take an industrial company with an average power of 500 kW, operating for 4000 hours per annum at an average cos φ of 0.7. The power supply tariff allows the user to draw 50% of the active energy as reactive energy at no extra charge, corresponding to a target cos φ of 0.9. Without power factor correction, the company pays the power supply company € 9,964 annually for reactive power.

A capacitor rating of 268 kVAr is necessary to correct the power factor to 0.9. It is usual, however, to select the next largest capacity, in this case a 300 kVAr system.

The payback time of less than one year illustrates the economic viability of power factor correction.

Part of an annual energy bill

Energy at normal tariff	2,000.000 kWh
Reactive energy at normal tariff	2,040.408 kVArh
Reactive energy at no charge	1,000.000 kVArh
Chargeable reactive energy	1,040.408 kVArh
x 0.009 €/kVArh	€ 9,364
Required PFC capacity	**268 kVAr**
Installed PFC capacity	300 kVAr
Investment cost incl. installation	€ 7,700
Payback period	**0.8 years**

Additional savings through reduced active power losses

The company taken as example has power losses in its own distribution network, and, like every other consumer, must pay the cost of the active energy lost.

The use of power factor correction reduces the apparent power in the company network, and hence also the power losses and the costs for active energy. An evaluation of the net benefits must also take into account the internal losses in the power factor correction system.

In addition to saving reactive energy costs, the power factor correction system in this example also reduces the costs for the active power expended on network losses by € 788 annually.

Analysis of losses and costs

Transformer power rating	800 kVA
Installed apparent power	714 kVA
Transformer and line losses (without PFC system)	10.0 kW
PF correction system	**268 kVAr**
Apparent power compensated	556 kVA
Transformer + line losses (with PFC system)	6.8 kW
Reduction in losses, gross	3.2 kW
Losses in PFC system	0.6 kW
Net reduction in losses	2.6 kW
Cut in active energy losses	10,232 kWh p.a.
Active energy costs incl. taxes etc.	0.077 €/kWh
Reduction in costs due to losses	€ 788 p.a.

Reduction in investment costs

Our company is planning to extend its facilities, and increase its power demand by 200 kW from the present level of 500 kW. The existing transformer with a rating of 800 kVA has been adequate to date, but would be overloaded after the plant expansion, making it necessary to extend the power infrastructure, with a transformer, switchgear, cabling, distribution board, etc. In this case the apparent power can be reduced by means of power factor correction so that the existing infrastructure is still adequate. In this project the power factor correction system involves a considerably smaller investment than an expanded infrastructure, means a cost saving of € 30,000.

Investment costs for expanded infrastructure

Installed active power	500 kW
Power factor	0.7
Installed apparent power	714 kVA
Transformer power rating	800 kVA
Transformer load factor	89%
Active power after extension	700 kW
Power factor	0.7
Apparent power after extension	1000 kVA
Transformer power rating	800 kVA
Transformer load factor	125%
Investment in new infrastructure	€ 40,000
Power factor correction system	**375 kVAr**
Active power after extension	700 kW
Apparent power after extension	778 kVA
Transformer load factor	97%
PF correction system	400 kVAr
Investment incl. installation costs	€ 10,000
Reduced investment compared with expanding infrastructure	**€ 30,000**

Power factor correction reduces both energy costs and investment costs.

Reducing power losses through power factor correction: Status quo and potential in Germany

Power factor, current loading, network losses

Power factor correction reduces the apparent power in a network, and thus the current loading in the same proportion.

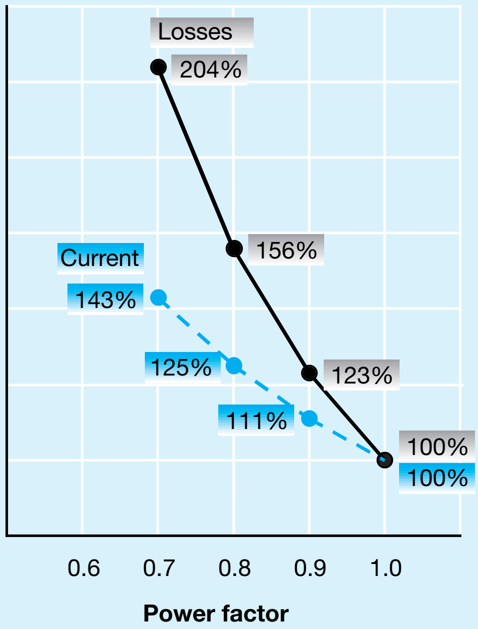
Network power losses are proportional to the square of the current:

5% less current = 10% lower losses.

Power factor is an indication of the proportion of reactive power in a network. The graph on the right illustrates how the current loading and network losses depend on the power factor, with the case when cos φ equals 1 (i.e. with full power factor correction) being defined as 100%. The lower the power factor, the higher are the reactive power, current loading and network losses.

This applies just as much to the power consumer's (special contract customers) own distribution network as to the general transmission and distribution networks for the supply of electric power.

Current loading and network losses as a function of power factor



Network losses in Germany

Network losses occur in the network operators' transmission and distribution systems but also in the distribution networks of special contract customers.

Power factor correction impacts on the current-dependent losses. A calculation of the losses that are dependent on current (see Appendix) for the transmission and distribution networks of the network operators together with the distribution networks of special contract consumers results in a total figure of 27.4 billion kWh.

Power factor correction brings double benefits for special contract customers: firstly, the power losses and therefore the energy costs in the consumer's own distribution network are reduced, and secondly, the losses in the network operators' transmission and distribution networks are also reduced.

Current-dependent network losses

Network operators	24.4 billion kWh
Special contract customers	3.0 billion kWh
Total	27.4 billion kWh

Power factor correction reduces network losses in Germany

The effect of power factor correction on the magnitude of network losses (see Appendix) is analysed by examining three scenarios:

Scenario 1: No PF correction

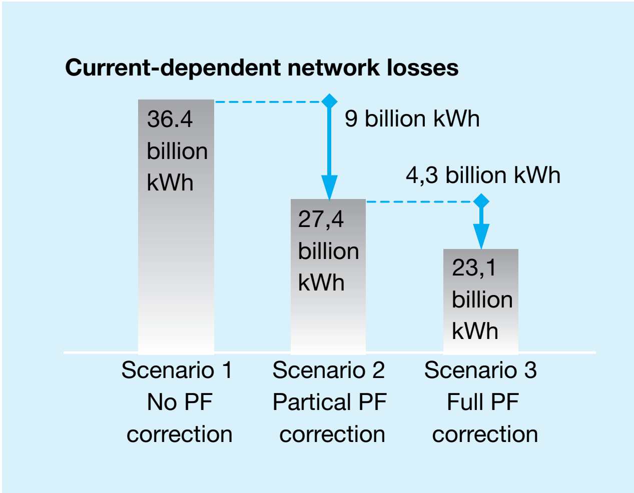
How high would the network losses be without power factor correction (i.e. without the power factor correction systems already in existence)?

Scenario 2: Partial PF correction

This scenario represents the status quo with power factor correction to a cos φ of 0.90.

Scenario 3: Full PF correction

How high would the network losses be with the maximum possible use of power factor correction (i.e. target PF = 1.0)?



A comparison of Scenario 1 with Scenario 2 shows that:

– The existing power factor correction systems already installed reduce annual network losses by 9 billion kWh.

  This is roughly equivalent to the energy generated by 6 coal-burning power stations or the electricity consumption of 2.7 million households.

Power factor correction reduced network losses in 1999 by 9 billion kWh.

Comparison of Scenario 3 with Scenario 2 shows that:

– With the maximum possible use of power factor correction, there is the potential for a further reduction in network losses of 4.3 billion kWh.

  This is almost equivalent to the energy generated by 3 coal-burning power stations or the electricity consumption of 1.3 million households.

Power factor correction reduced Germany's carbon dioxide emissions in 1999 by 5.1 million tonnes.

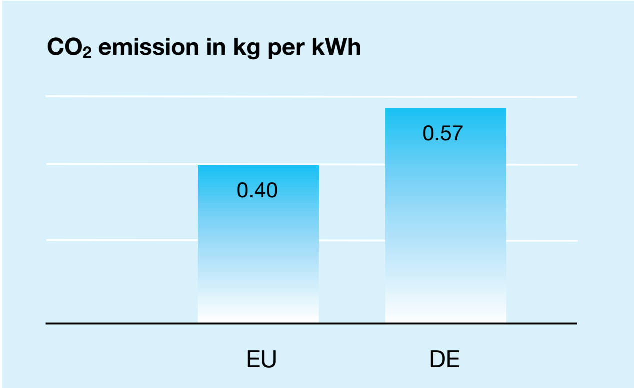
Protecting the climate through power factor correction: Status quo and potential in Germany

Reducing losses means protecting the environment and our climate

The use of fossil fuels to generate electrical energy means that the greenhouse gas carbon dioxide CO_2 is released to the atmosphere.

The emission of carbon dioxide attributable to each unit of electric power generated can be calculated on the basis of the energy source mix in Germany.

Owing to the high percentage of power stations that burn fossil fuels, this figure for Germany in 1999 was 0.57 kg CO_2 per kWh [11], while for the EU as a whole it was 0.40 [12].



Power factor correction already makes an active contribution to climate protection today

In Germany in 1999 power factor correction reduced network losses by some 9 billion kWh, roughly equivalent to 5 million tonnes of CO_2 emissions.

Some power traders have a tendency to waive the charges for reactive power, thus making power factor correction less attractive for the final consumer. This marketing strategy may well be used to gain competitive advantage or to make use of surplus capacity, but is counterproductive in terms of climate protection.

The active contribution to climate protection made by power factor correction should be consolidated and expanded.

Power factor correction reduced Germany's carbon dioxide emissions in 1999 by 5.1 million tonnes.

Power factor correction offers further potential for climate protection

There is a further potential for reducing carbon dioxide emissions by 2.4 million tonnes per annum through the use of power factor correction over and above the extent it is employed today.

Power factor correction offers the potencial for reducing CO_2 emissions by a further 2.4 million tonnes.

Reduction in CO2 emissions compared with other protective measures

The National Climate Protection Programme of the German Federal Government features a variety of measures for reducing CO_2 emissions. Some are already in place, while with others their introduction is still under discussion. Several of the measures are being promoted by financial incentives or are required by law.

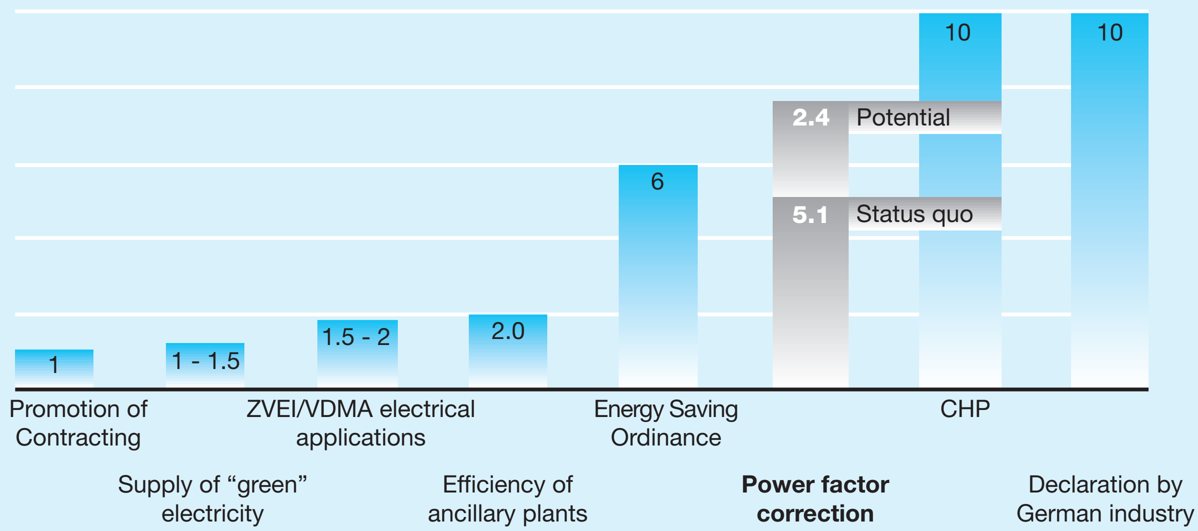
For the industry and small consumer sector, seven measures have been stated, together with their anticipated impact in millions of tonnes of reduced CO_2 emissions by 2005 [13]:

- Promotion of contracting — 1.0
- Supply of "green" electricity — 1.5
- Statement by the ZVEI/VDMA on electrical applications — 1.5 - 2
- Increasing the efficiency of so-called ancillary plants — 2.0
- Energy Saving Ordinance for industry and small consumers — 6
- Long-term combined heat and power (CHP) generation programme — 10
- Further development of the "Declaration by German industry on global warming prevention" — 10

Comparison with Germany's National Climate Protection Programme shows that power factor correction, with a reduction in carbon dioxide emissions of some 5 million tonnes per annum, offers a significant contribution to climate protection, with an additional savings potential of about 2.5 million tonnes.

Power factor correction offers a significant contribution to climate protection.

Measures in Germany's National Climate Protection Programme to reduce CO_2 emissions by 2005
Comparison with "Protecting the climate through power factor correction" in millions of tonnes



Outlook

Status quo

Power factor correction is already making a significant contribution to reducing CO_2 emissions today.

Some power traders have a tendency to waive the charges for reactive power, thus making power factor correction less attractive for the final consumer. This marketing strategy may well be used to gain competitive advantage or to make use of surplus capacity, but is counterproductive in terms of climate protection.

The active contribution to climate protection made by power factor correction should be consolidated and expanded.

Making full use of potential

The additional potential for reducing network losses and CO_2 emissions can still be exploited, because the value of cos φ of 0.9 specified for power factor at the present time still does not represent the limit that is technically possible or economically viable. It is possible to correct the power factor until cos φ = 1, i.e. compensating for the reactive power completely. Some power suppliers already require this measure. Other technical aspects must also be taken into account, however, for example possible overcompensation through cable networks or due to slow-acting power factor correction systems.

It is important that discussions take place between power suppliers, network operators and power factor correction specialists to determine to what extent specifying high values of cos φ makes sense technically and can be put into practice in today's market.

Additional approaches

An additional positive effect can be achieved by the application of de-tuned power factor correction systems and filter circuits. These have the property of suppressing harmonics. This effect enhances the quality of the power supply, since the desired sinusoidal waveforms are achieved for voltage and current, and no harmonic currents then flow in the distribution and transmission networks. Less current flowing in the networks therefore means further reduction in power losses and CO_2 emissions. This beneficial effect must be investigated and quantified by further studies.

Addressing the subject of climate protection through power factor correction in Germany can also encourage initiatives at European and international levels.

Appendix

Current-dependent network losses in Germany in 1999

Network losses occur not only in the network operators' transmission and distribution systems but also in the distribution networks of special contract customers. Power factor correction impacts on the current-dependent losses.

According to the VDEW [14], losses in the networks of German operators amounted to some 28 TWh in 1999.

According to a study by the EU [15] to assess the current-dependent losses, it was first necessary to distinguish between line and transformer losses. The transformer losses were then subdivided into copper losses and iron losses, taking as typical example a transformer of average power rating and loading.

The assessment revealed current-dependent losses of 24.4 TWh in the transmission and distribution systems of the network operators.
(1 TWh equals 1 billion kWh)

Losses in the network operators' transmission and distribution networks

Line and transformer losses

Total losses in Germany in 1999	100%	28.0 TWh
Proportion as line losses	57%	16.0 TWh
Proportion as transformer losses	43%	12.0 TWh

Transformer iron and copper losses
Example: 1600 kVA at 60% load (16)

Iron losses no load	2.8 kW	
Copper losses full load	17.0 kW	
Iron losses 60% load	2.8 kW	30%
Copper losses 60% load	6.1 kW	70%
Total losses 60% load	8.9 kW	100%

Current-dependent losses

Line losses	100% x 16 TWh	16.0 TWh
Transformer losses	70% x 12 TWh	8.4 TWh
Current-dependent losses		24.4 TWh

The losses in the distribution networks of special contract customers are not included in the losses assessed for network operators.

The model for calculating these losses comprised a power line in the medium voltage circuit, a transformer and a power line in the low voltage circuit, together with a power factor correction system to maintain cos φ at 0.90.

The assessment revealed current-dependent losses of 3.0 TWh in the distribution networks of special contract customers.

Losses in the distribution networks of special contract customers

MV line 20 m	at 100% load	0.1 kW
Transformer	10/0.4 kV	800 kVA
Iron losses	no load	1.9 kW
Copper losses	full load	8.2 kW
LV line 20 m	full load	1.8 kW
Load	active power	500 kW
	corrected power factor	0.90
	apparent power	556 kVA
	% of transformer rating	69%
Power line losses MV + LV		0.9 kW
Transformer copper losses		4.0 kW
Total current-dependent losses		4.9 kW
	% of load active power	1.0%
Power consumed by special contract customers including own power generation		307 TWh
Current-dependent losses	1.0%	3.0 TWh

Average power factor in Germany in 1999

The consumption of active energy is divided between special contract customers (SCC) and tariff customers (TC), and the average power factor is calculated for both groups of consumers.

Note:
„Normal“ power factor correction only influences the fundamental power and hence the displacement power factor cos φ_1. To simplify matters, however, the term power factor cos φ is used here.

Power consumption in Germany in 1999 [17]
Power factor (ZVEI Power Capacitor Product Division estimate)

		Power factor cos j	
Sector	Total consumption	No PFC	Partial PFC
Iron and steel	23 TWh	0.60	0.90
Chemicals	48 TWh	0.80	0.90
Other industries	160 TWh	0.70	0.90
Transport	16 TWh	0.80	0.90
Public amenities	37 TWh	0.80	0.90
Commercial SCCs	23 TWh	0.80	0.90
Total for SCCs	307 TWh	0.73	0.90
Agriculture	8 TWh	0.70	0.90
Households	129 TWh	0.90	0.90
Commercial TCs	42 TWh	0.80	0.90
Total for TCs	179 TWh	0.87	0.90
Grand total	486 TWh	0.78	0.90

Internal losses in power factor correction systems and the connecting cabling

When the reduction in network losses is calculated, the internal losses in the power factor correction system and the cabling to it must also be taken into account. The figures given here are based on power factor correction systems without filter reactors. Although filter reactors have higher losses, they do however suppress harmonic currents and therefore cause an additional reduction in network loading. A more exact evaluation is given in a separate technical article.

Internal losses in power factor correction systems and the connecting cabling	
PF correction system	1.5 W/kVAr
Connecting cable 10 m long	0.9 W/kVAr
PF correction system with cabling	2.4 W/kVAr

Power factor correction and network losses

Scenario 1: without PF correction

Without the power factor correction systems already installed

Scenario 2: partial PF correction

The status quo with partial PF correction to achieve cos φ = 0.90

Scenario 3: full PF correction

Full power factor correction to achieve cos φ = 1.00

Power supply company networks		Scenario 1 No PFC	Scenario 2 Part PFC	Scenario 3 Full PFC
Active energy	TWh	458	458	458
Power factor		0.78	0.90	1.00
Power factor correction	Tvar	-146	0	222
Network copper (Cu) losses	TWh	32.5	24.4	19.8
PFC system losses	TWh	-0.3	0.0	0.5
Network Cu + PFC losses	TWh	32.1	24.4	20.3
Special contract customers' networks		Scenario 1 No PFC	Scenario 2 Part PFC	Scenario 3 Full PFC
Active energy	TWh	307	307	307
Power factor		0.73	0.90	1.00
Power factor correction	Tvar	-139	0	149
Network copper (Cu) losses	TWh	4.6	3.0	2.4
PFC system losses	TWh	-0.3	0.0	0.4
Network Cu + PFC losses	TWh	4.2	3.0	2.8
Total network		Scenario 1 No PFC	Scenario 2 Part PFC	Scenario 3 Full PFC
Network Cu + PFC losses	TWh	36.4	27.4	23.1

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