T&D Europe
The European Association of the Electricity Transmission and Distribution Equipment and Services Industry

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Network Infrastructures &
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Study on Criteria for the Quantification of how modern T&D-systems help accomplish the EU 20/20/20 targets

First general report
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16/11/2009

Revision: 2.2

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This report is the outcome of a collaboration between T&D Europe[1] and N.I.C.E.S. Lab[2].

Industrial expertise in design, testing and installation of electric power components, as well as relevant control and protection systems, has been combined with expertise in basic and applied research in order to perform a scientific analysis of how much products and systems from the electric industry contribute to the European Union's (EU) efforts to mitigate climate change.

Electricity is an efficient and environmental friendly infrastructure for the delivery of energy from power plants to end users. Pollution from power plants and from the use of energy is primarily associated with prime movers, non electrical loads, and components for energy conversion.

There are however opportunities for improvement of the electrical power infrastructure worldwide, and in particular in the rational management of energy resources.

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Executive Summary

Worldwide, measures are taken to lower the environmental impact of energy supply systems, in particular with regard to climate change. The European Union has established targets for 2020 on efficiency, CO_2 reduction and renewable energy.

T&D Europe, the European Association of the Electricity Transmission and Distribution Equipment and Services Industry, has studied how, and to what extent, the electric power infrastructure could contribute to meet these goals.

The Electra initiative and several position papers, underline the importance of T&D Europe's role in the development of new guidelines for design, construction and operation of power system components and related devices, with low environmental impact.

In March 2009, a designated task force on Environmentally Friendly Products, in T&D Europe's WG1 on Energy Policy and Energy Efficiency, developed a "Tender document for a study on the environmental benefits of modern T&D products and systems".

The document contained the following elements:

- A background analysis to demonstrate the need for the study
- Presentation of the initial work and preliminary results presented in a matrix indicating efficiency potentials
- The scope of the study and examples of measures that will be analyzed during the study (e.g. T&D state-of-the-art technologies) and the expected outcome of the study

The main element of the tender document is a survey of how the electrical power industry can pursue production with lower environmental impact by, for example:

- Substitution and/or renovation of power system components
- Integration of additional power system components of the recent generations
- Modification of management and control strategies in T&D networks
- Developments in ICT infrastructures in order to enhance grid strength and reliability

The tender document contains a qualitative analysis of the impact of the measures above with regard to the EU targets, including remarks on investment costs, quality of electric service and customer acceptance.

The study is made in collaboration with universities, since there is a need to use scientific methods to quantify the effects of the proposed solutions, to assess possible side effects, and eventually establish a method to rank the solutions. This way it will be possible to orient industrial production towards more environmentally beneficial solutions, and to suggest the best mixture of multiple market available solutions.

The resulting activity is organised in two subsequent steps:

- Step one, where a methodology is proposed to assess the benefits of T&D state-of-the-art technologies (the results from this part of the study are presented in this report).

- Step two, where the performance indices, proposed in step one, are calculated for each family of T&D state-of-the-art technology in standardised model grids. This work is split in multiple parallel tasks and performed by research teams at different European universities.

The first report is focused on the following topics:

A critical literature review of scientific papers and project reports that were issued by European bodies, including manufacturers, utilities, research centres and universities. The purpose of the review was to search for analogous, quantitative comprehensive studies and for modelling procedures of conventional and state-of-the-art technologies. As a result, several useful elements and contributions were found in a high number of contributions, but without a comprehensive approach. This strengthened the conviction that a comparative study that addresses several different objectives is needed.

In a second stage, performance indices, which are in line with the EU 20/20/20 targets, are proposed. As an additional element, power quality indices are introduced, evaluated at the transmission and distribution level, and distinguishing between static and dynamic behaviour.

The following assumptions and simplifications were made in the study to reduce complexity and avoid a combinatorial explosion of test cases:

- The analysis is fully deterministic and investment costs are not taken into account.
- Customer demand is considered fixed in the steady-state analyses. However, at least two load levels (heavy / light) should be examined; alternatives in load location are considered, for the selected level of the total amount.
- Market models are ignored to avoid particular procedural and conceptual constraints.
- Only electrical transmission and distribution systems are considered.

With regard to this final point, electric power infrastructure is split into two typical transmission and distribution subsystems, with the following boundary assumption:

- Each generation unit is accounted for at its interconnection with the electrical transmission grid, which implies that step-up transformers associated with generation units are not investigated
- For the transmission subsystem, the distribution grid is modelled as an equivalent load leaving evidence of the step-down interconnecting transformer
- Conversely for the distribution subsystem, the transmission grid is modelled as an equivalent utility grid at the primary HV windings, leaving evidence of the interconnecting transformer.

Table ES.1 contains a summary of the proposed performance indices for each objective.

Table ES.1: Matrix of objectives and relevant performance indices

Objective	Performance index
Efficiency	Network losses normalized to total load demand
CO_2 reduction	Total grid CO_2 emissions normalized to total load demand
Penetration rate of renewables	Total generation from renewables normalized to total load demand
Steady-state quality in transmission and distribution grids	Total mismatch from ideal uniform node voltage and branch rated current profile
Distribution harmonic power quality	Network total harmonic (node voltage, branch current) distortion factor, average or variance
Transmission dynamic quality	Network cumulative proximity to starting thresholds of line distance relays (voltage, current and angle phenomena) and load shedding relays (frequency phenomena)
Distribution dynamic quality	Network cumulative proximity to ideal voltage and current waveforms (dips, sags, swells) Network cumulative unsupplied energy (interruptions)

The general report also suggests sample systems, which are simple electric grid configurations, where numerical evaluations of the introduced indices can be made. These benchmarks are as reduced in complexity as possible in order to minimise the vast combinatorial multiplicity that may occur when covering all typical electrical components and state-of-the-art technologies. Reference is given to material available in the literature, where test configurations usually differ according to the examined sub-problem, and comprehensive solutions are finally proposed. The topological outcome is reported in Figure ES.1, showing the interconnection between meshed EHV/HV transmission grid with radial MV/LV distribution system.

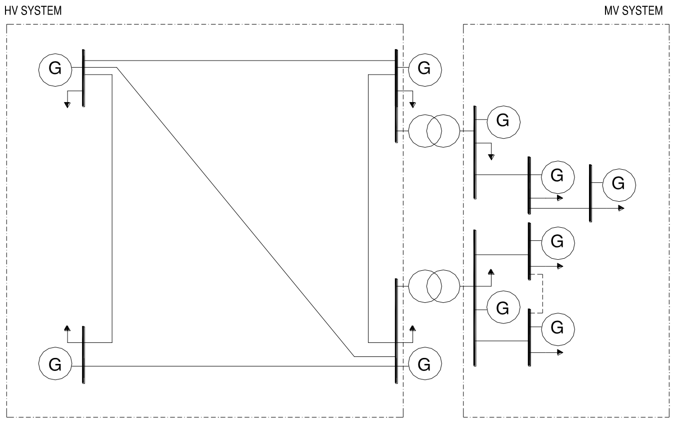

Figure ES.1: HV-MV sample network for the study of performance indices

From the simulation point of view, and depending on the specific problem analysed, equivalents can be introduced starting from the system shown in Fig. ES. 1 above, in order to decouple the transmission system from the distribution system. Thus, two sub-systems can be derived, each one accounting for an aggregation process of the currently non interesting section.

Another topic in the first general report is the effort to introduce aggregated models for different devices that influence the proposed indices. Static and dynamic formulations are therefore proposed, with the aim to minimize the risk of combinatorial explosions of cases to be considered and compared. Such an analysis proves efficient since it tries to generalize all the possible corrective interventions on the grid, being ready to comprehend future T&D technologies.

As an example in the steady-state domain, a comprehensive model was found quite general, as pictured in Figure ES.2.

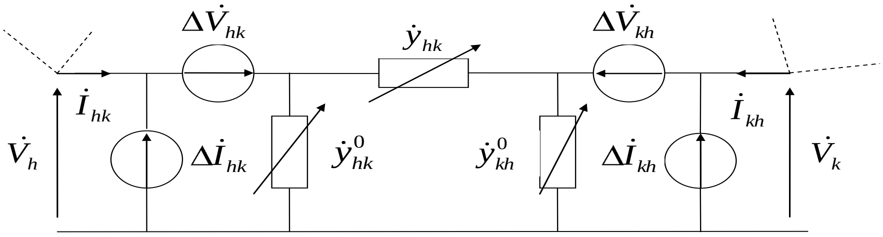

Figure ES.2: Generalization of state-of-the-art technologies: steady-state model

The most important part of the general report is the detail on the procedure for how to determine and compare the quantitative effect of each single corrective action. Emphasis is given to the different opportunities to build separated or aggregated judgements, as well as to distinguish between primary and correlated effects. The aim of this analysis is also to propose consideration of side effects and to advice on strategies for the implementation of corrective measure. The procedure set-up, which includes comparative, selective and flexible attributes, accounts for some main operating steps, shown in the flow chart of Figure ES.3.

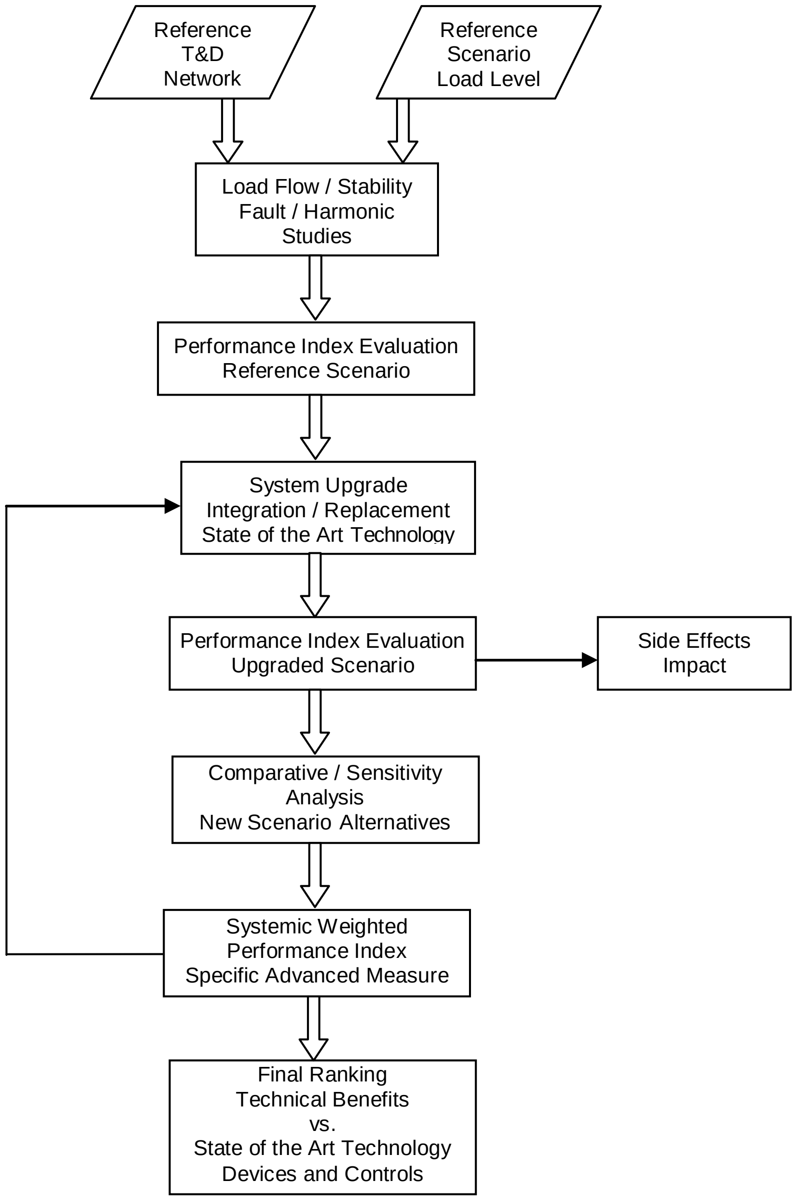

Figure ES.3: Performance Index Evaluation – Flow Chart of the Comparative Procedure

Finally, a review of the basic analyses that are required to size the benefits of state-of-the-art technologies in T&D networks is made. Several simulation codes, including extended libraries of component models, are needed. And so is an open environment to host user defined solutions. A proposal of a multi-purpose simulation environment is also made, in order to simultaneously collect the impact of each corrective intervention according to the examined sub-problem.

Below is a list of recommended common analysis tools for power system studies:

- Load flow
- Optimal power flow
- Transient stability analysis
- Fault analysis
- Harmonic analysis
- Electromagnetic transient analysis

The expected results of the study, as regards the general report, is a re-elaboration of the matrix on efficiency potentials proposed by T&D WG1 in March 2009, as reported in Table ES.2.

Table ES.2: Re-elaboration of matrix on efficiency potentials WG1

Impact on: / Action:	Efficiency	CO_2 Reduction	Renewables	Steady-state quality in T&D	Harmonic quality in distribution	Dynamic quality in transmission	Dynamic quality in distribution
Replacement/refurbishment of Power Components	Direct effect (lower losses)	Indirect effect (via more efficiency)	Indirect effect (removal of bottlenecks)	Direct effect (improved parameters)	Indirect effect (improved parameters)	Indirect effect (improved parameters)	Indirect effect (improved parameters)
WAMS/WACS & Upgrading Protection and Control Devices for Communication	Direct effect (flow rescheduling)	Indirect effect (via more efficiency)	Indirect effect (removal of bottlenecks)	Direct effect (regulation)	Indirect effect	Direct effect (improved strategies)	Direct effect (improved strategies)
Increase of Voltage Level of the Power Grid	Direct effect (lower losses)	Indirect effect (via more efficiency)	Indirect effect (removal of bottlenecks)	Indirect effect (reduced drops)	Direct effect (harmonic current sources)	Indirect effect	Indirect effect
Installation of Power Quality Devices (Distribution Networks)	Indirect effect	Indirect effect (via more efficiency)	Indirect effect (support volatile generation)	Direct effect (regulation)	Direct effect (as active filters)		Direct effect (as custom power)
HVDC (Line and forced commutated)	Direct effect (geographically dependent)	Indirect effect (via more efficiency)	Direct effect (removal of bottlenecks)	Indirect effect (regulation)	Indirect effect (side effect)	Direct effect (dedicated controls)	Direct effect (dedicated controls)
FACTS (Transmission Networks)	Direct effect (flow rescheduling)	Indirect effect (via more efficiency)	Indirect effect (removal of bottlenecks)	Direct effect (regulation)		Direct effect (dedicated controls)	

The indication of direct and indirect effects foresee a quantitative evaluation which can be reliably produced only after the second parts of the study.

An equivalent, but more explicit, presentation of the expected results of the studies is hereafter proposed by means of spider diagrams, reporting in Figures ES.4 – ES. 9 the effects of each introduced action on the seven targets considered so far.

Replacement / refurbishment of Power Components

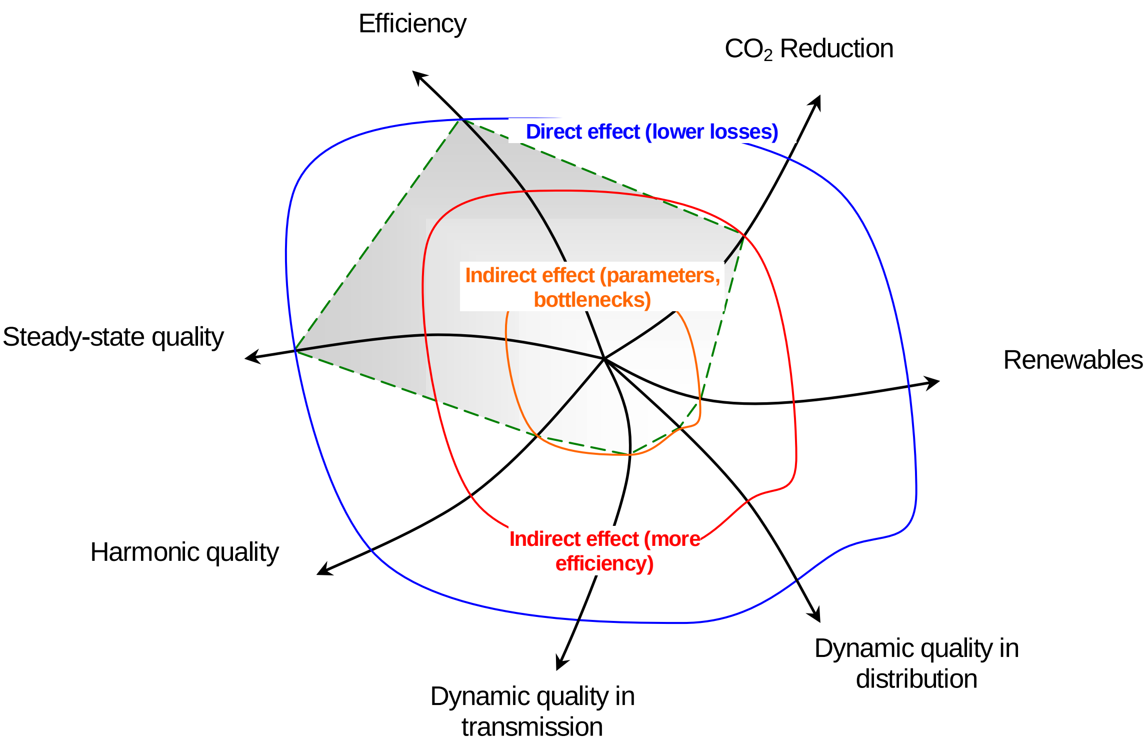

Figure ES.4: Spider diagram for the effects of replacement/refurbishment of Power Components

WAMS/WACS & Upgrading Protection and Control Devices for Communication

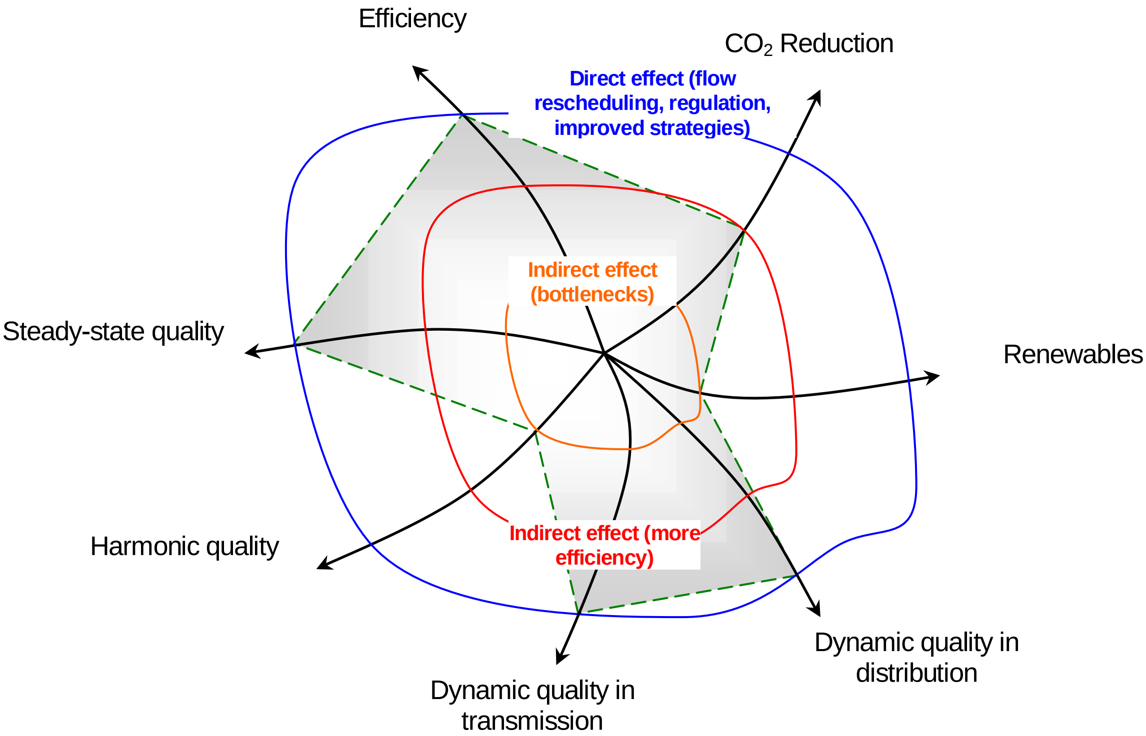

Figure ES.5: Spider diagram for the effects of WAMS/WACS & Upgrading Protection and Control Devices for Communication

Increase of Voltage Level of the Power Grid

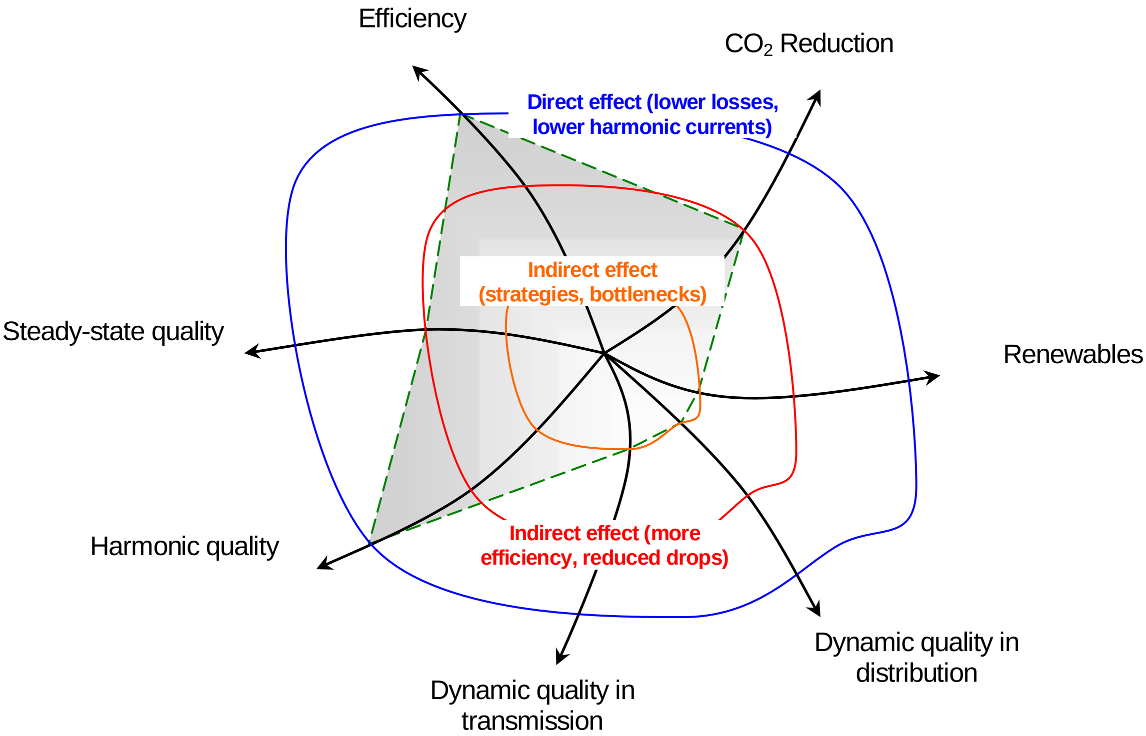

Figure ES.6: Spider diagram for the effects of Increase of Voltage Level of the Power Grid

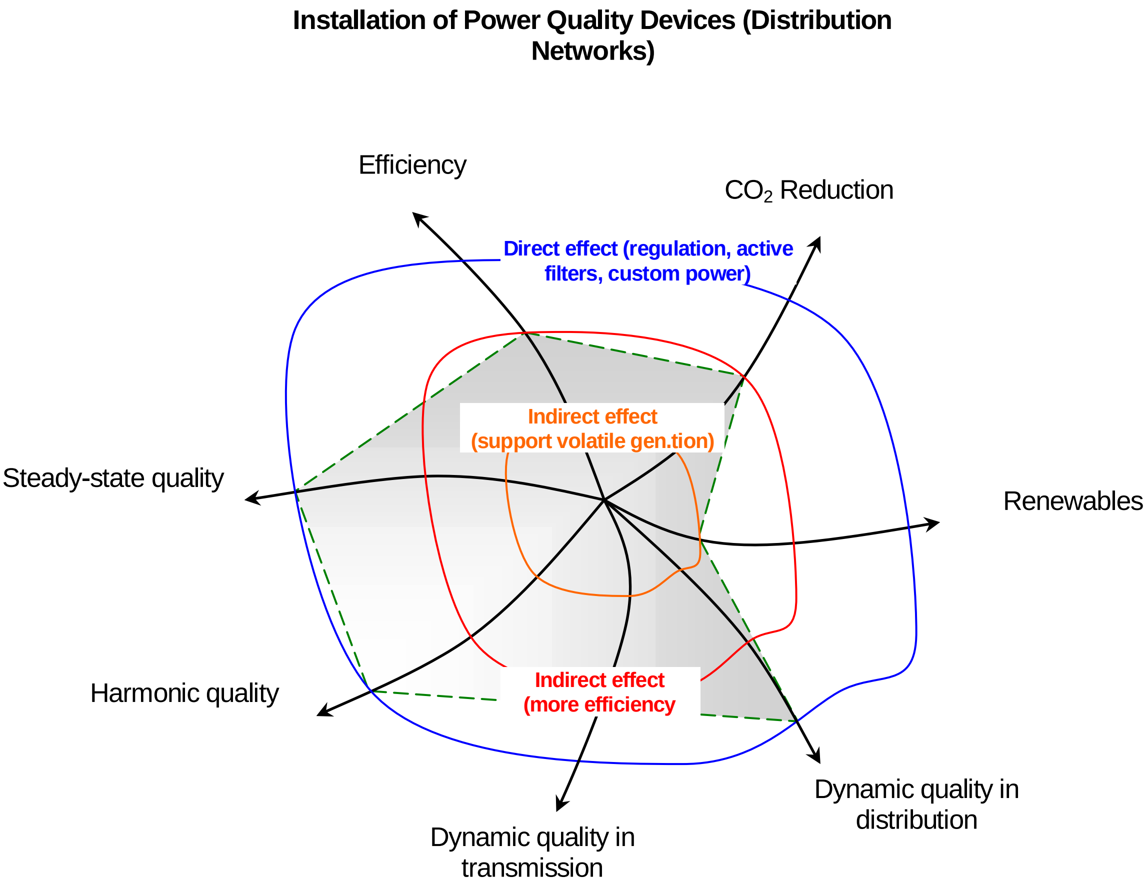

Figure ES.7: Spider diagram for the effects of Installation of Power Quality Devices (Distribution Networks)

HVDC (Line and Forced Commutated)

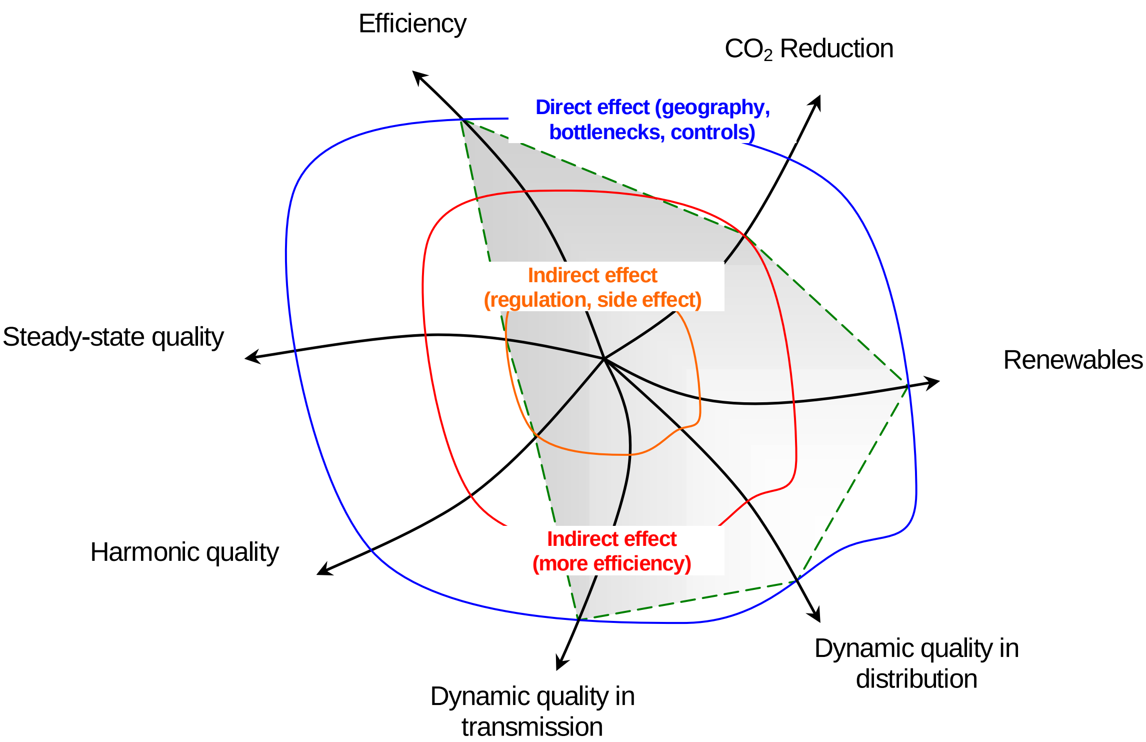

Figure ES.8: Spider diagram for the effects of HVDC (Line and Forced Commutated)

FACTS (Transmission Networks)

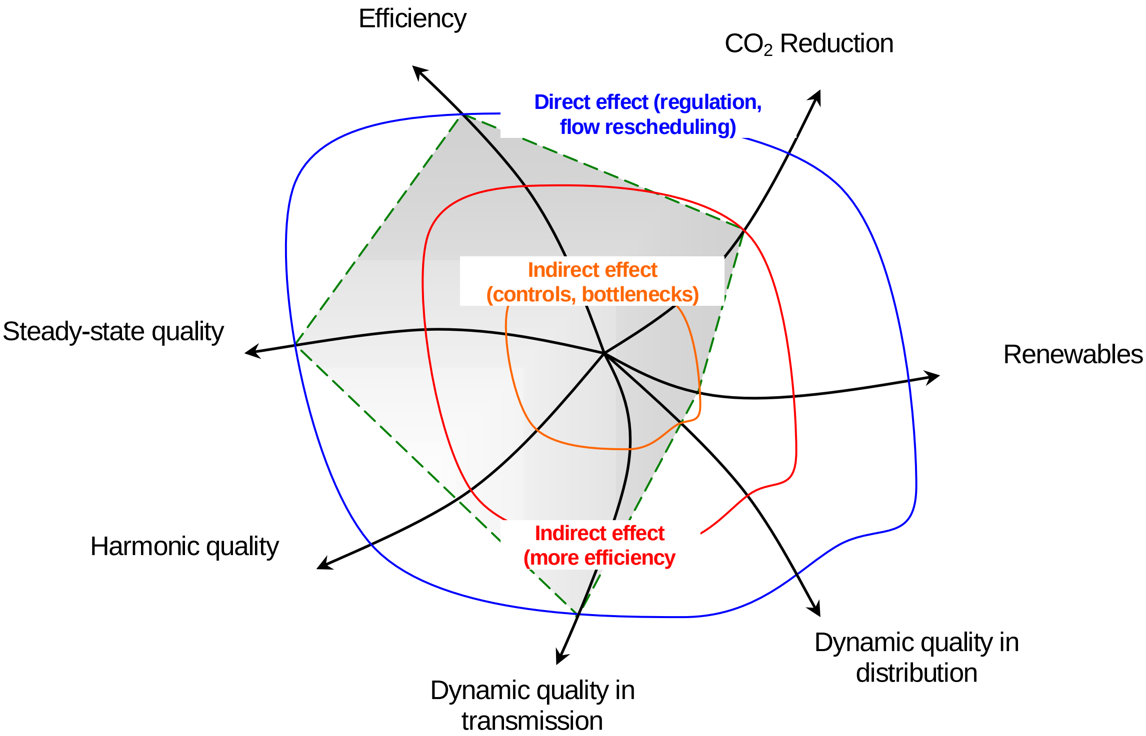

Figure ES.9: Spider diagram for the effects of FACTS (Transmission Networks)