University of Zielona Góra

UNIWERSYTET ZIELONOGÓRSKI

Grzegorz BENYSEK

Institute of Electrical Engineering www.iee.uz.zgora.pl

Improvement in the efficiency of the distributed power system

NOWOCZESNE SPOSOBY INTEGRACJI ODNAWIALNYCH ŹRÓDEŁ ENERGII

Zielona Góra, 3/04/2009

General Contents

Introduction

Limitations of the Transmission Systems

The limitations of the transmission system can take many forms and may include one or more of the following characteristics:

- voltage magnitude;
- transmission capacity;
- transient and dynamic stability;
- reliability

The transmission area is for arrangements known as Flexible Alternating Current Transmission System (FACTS), where the latest power electronic devices and methods are used to control the transmission side of the network.

Introduction

Interest in Power Flow Control

There are a number of reasons for this:

- In a meshed power system, there can occur a situation where a low impedance line carries much more power than originally designed for, while parallel paths are underutilized;
- When, among others, private companies operate transmission lines and sell energy to interested parties, the load flow will have to be controlled;
- Voltage and reactive power control issues — low voltage at heavily loaded transmission lines as well high voltage at lightly loaded lines are undesirable occurrences in transmission lines, therefore corrective actions have to be taken. The corrective actions with utilization of selected FACTS devices include correcting the power factor and compensating reactive losses in lines by supplying reactive power;
- Transient and dynamic stability control issues. In the first as well as the second situation, active power flow control can be a solution.

Introduction

Interest in Distributed Generation (DG)

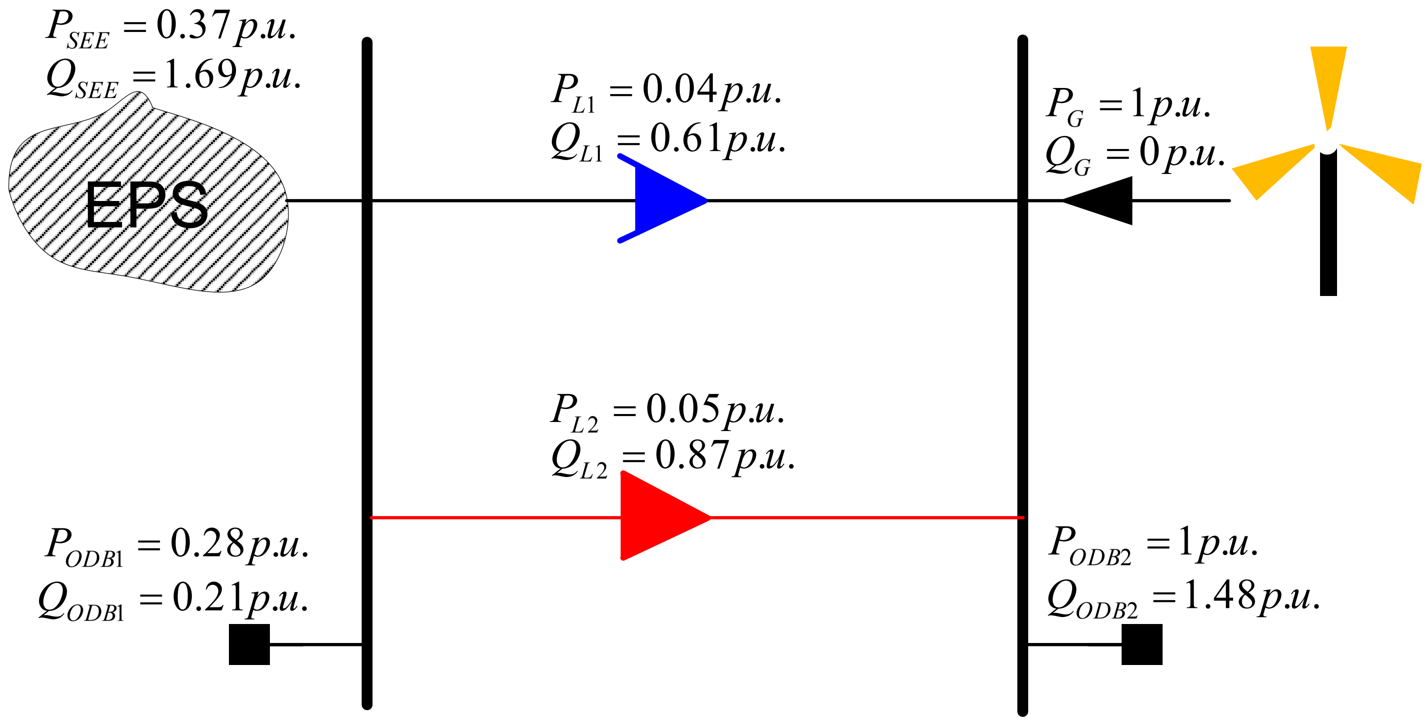
These new energy injections can have some benefits in the operation on the whole EPS:

- The production of energy near the load reduces the losses of the grids, because energy is generated where it is consumed;
- Normally voltage control is carried out by means of manually operated or automatic tap changers, or by utilization of capacitor banks. In both cases, the existence of DG units could be an important way to increase the voltage; the insertion of a DG in a bus raises its voltage;
- End-users who place DG can benefit by having backup generation to improve reliability; they may also receive compensation for making their generation capacity available to the grid in areas where power outages are possible.

Introduction

Limitations of the Transmission Systems

Problem: transmission line overloaded

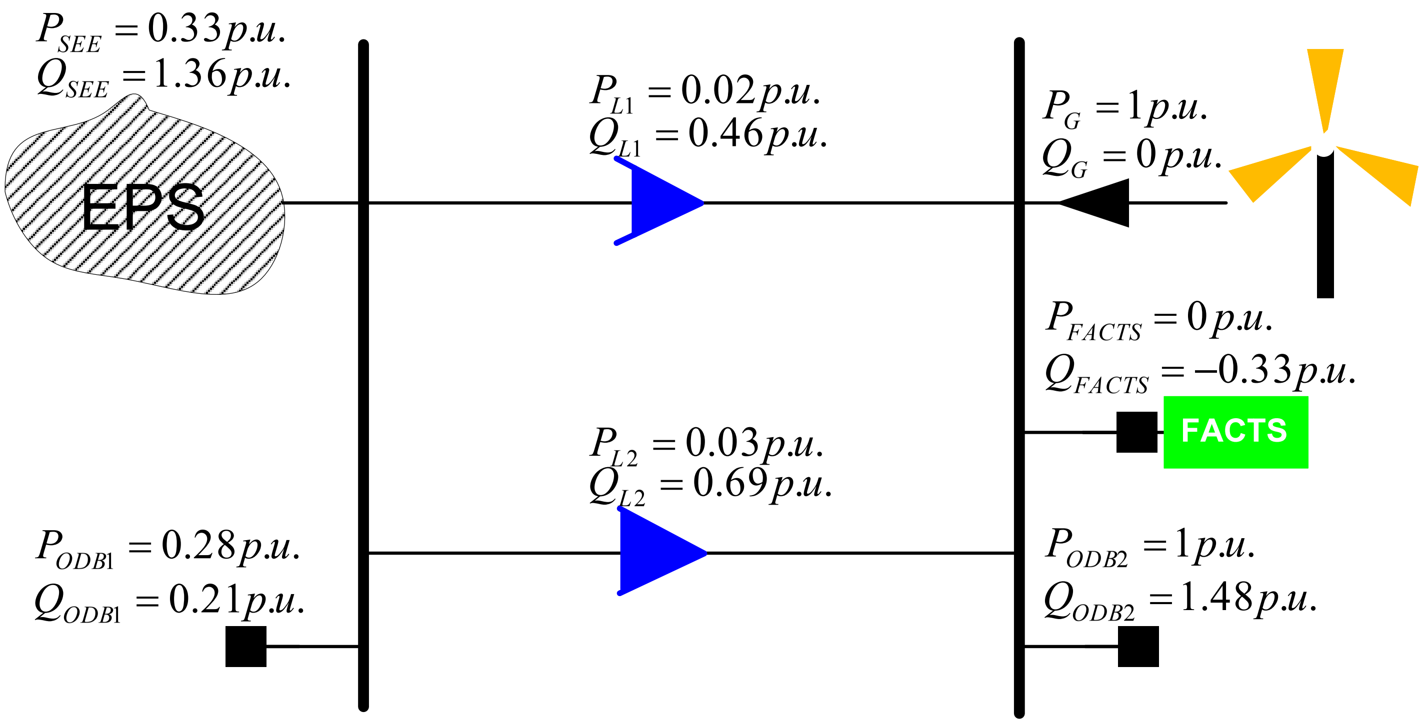


Different parameters parallel transmission lines

Introduction

Limitations of the Transmission Systems

Solution: parallel FACTS

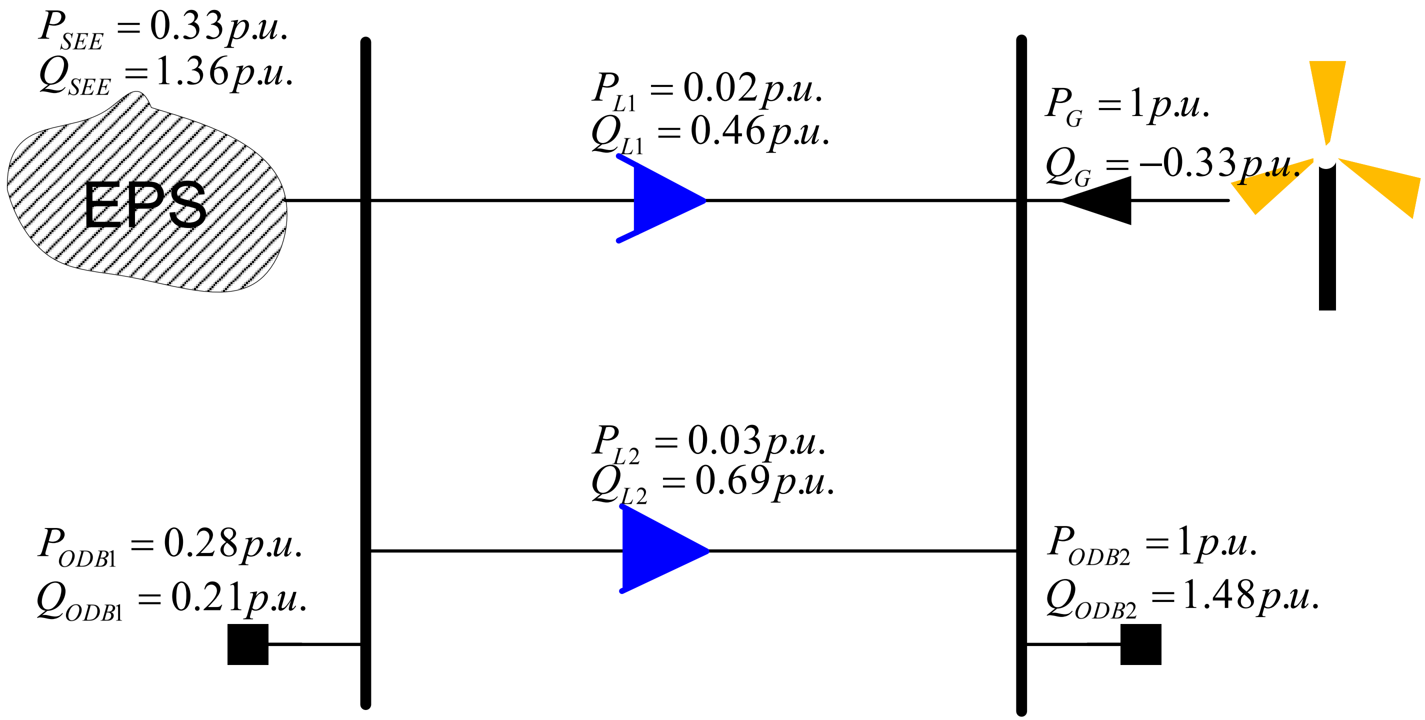


Different parameters parallel transmission lines

Introduction

Limitations of the Transmission Systems

Solution: modern interface Distributed Generation



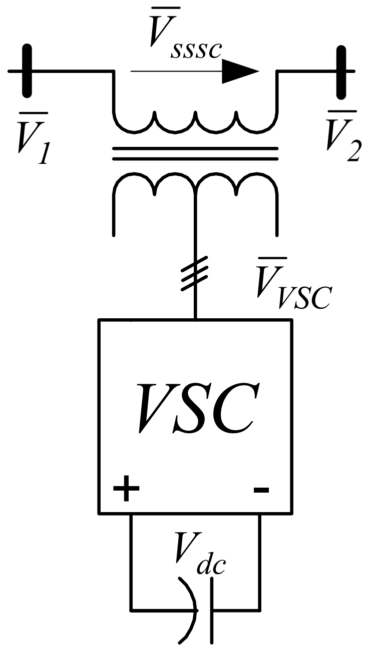
Different parameters parallel transmission lines

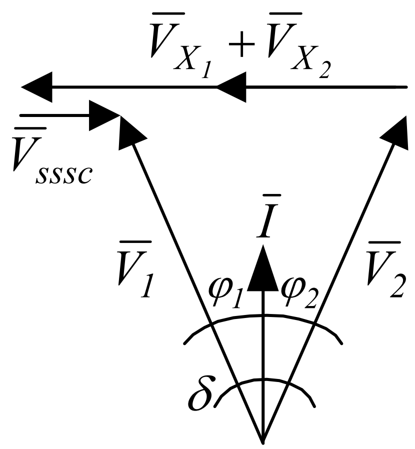
General Contents

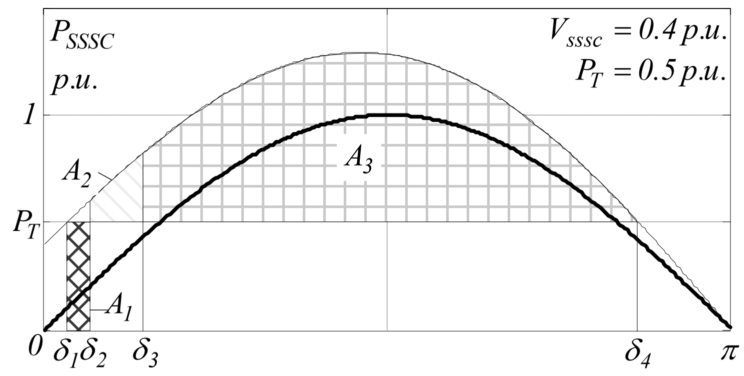
Flexible Alternating Current Transmission Systems

SSSC

Basic Principles



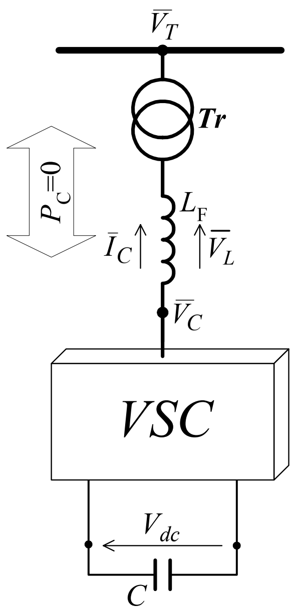


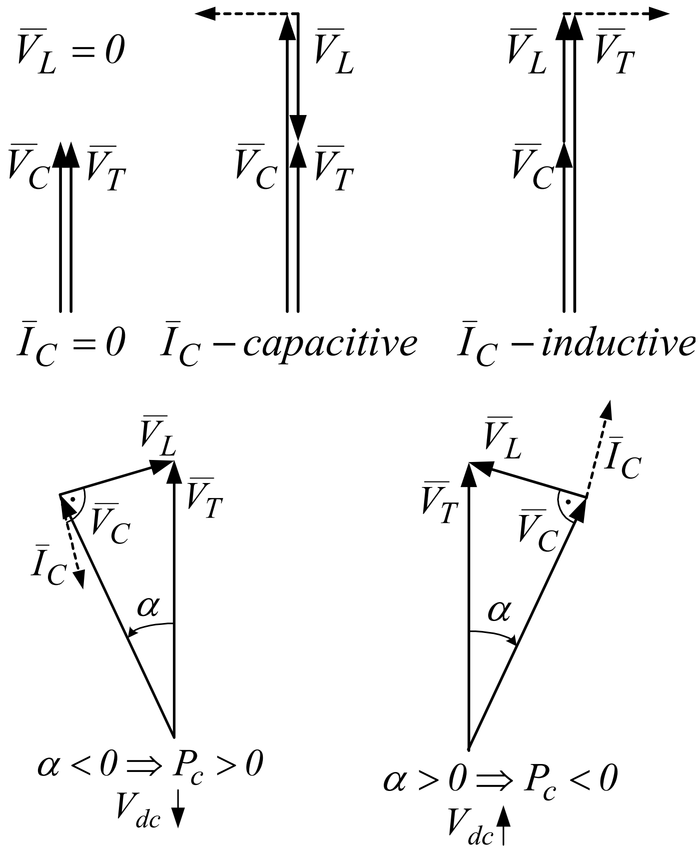


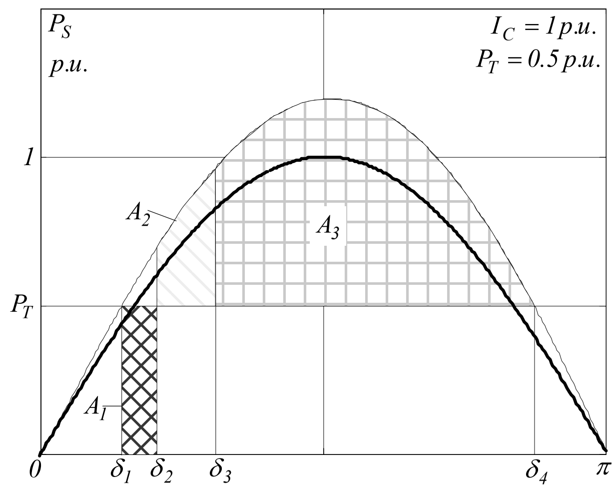
SSSC: left. its equivalent circuit; middle. vector diagram; right. stability capabilities

STATCOM

Basic Principles







STATCOM: left. its equivalent circuit; middle. vector diagrams; right. stability capabilities

Paul Sweet Substation

Problem:

The Paul Sweet Substation (Silicon Valley), serves residential, commercial, and hospital customers plus an emerging high-tech manufacturing sector (which require high-quality power with minimum voltage deviations). Voltage deviations of as much as 12% during the course of a day caused damage to transformer LTCs due to excessive switching (over 2,000 tap changes/month on average). In addition, some of the high-tech customers' UPS systems were operating frequently.

Possible solutions:

(1) convert the existing 115kV double-circuit line to 230kV; (2) install synchronous condensers; (3) install a SVC.

Paul Sweet Substation

STATCOM Implementation

Solution:

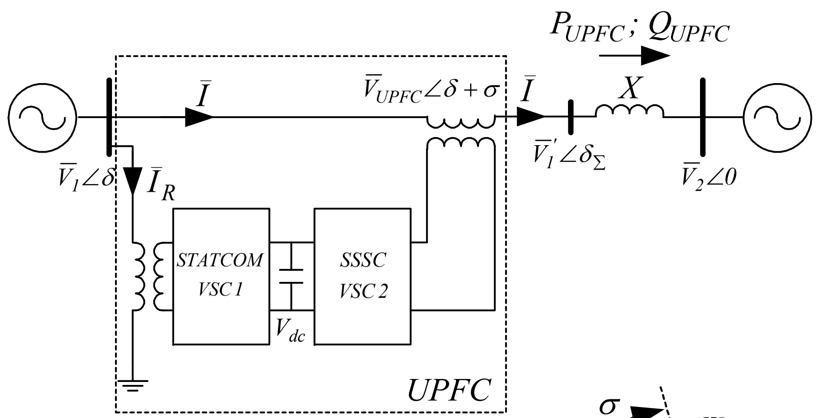
The SVC provides the best voltage regulation, with fast-action. The "next best" alternative of the 230kV line conversion would have taken too long to implement and at a much higher cost. However after all bids were evaluated, the STATCOM was implemented. STATCOM offers several advantages over the SVC: small footprint (less than 1/2 the size of the SVC) and ability to deliver the full range of reactive compensation at reduced operating voltages versus the reduced reactive compensation output from the SVC.

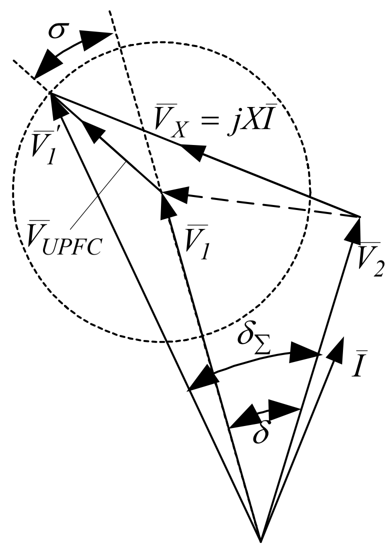
Performance:

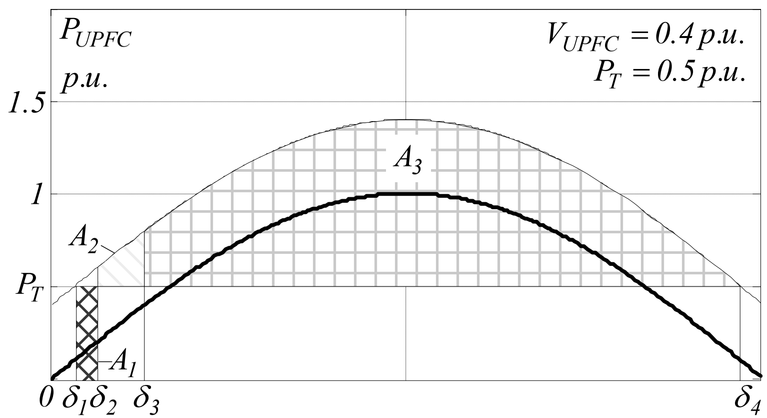
The +/-40MVAr STATCOM began operation in 1998, to provide accurate and fast response voltage regulation. The controlled voltage, is "*rock solid*". The STATCOM's dynamic voltage control has reduced the LTC switching of voltage regulators by 60%.

UPFC

Basic Principles







UPFC: <u>left</u>. its equivalent circuit; <u>middle</u>. vector diagrams; <u>right</u>. stability capabilities

INEZ Station

The First UPFC Ever (1996)

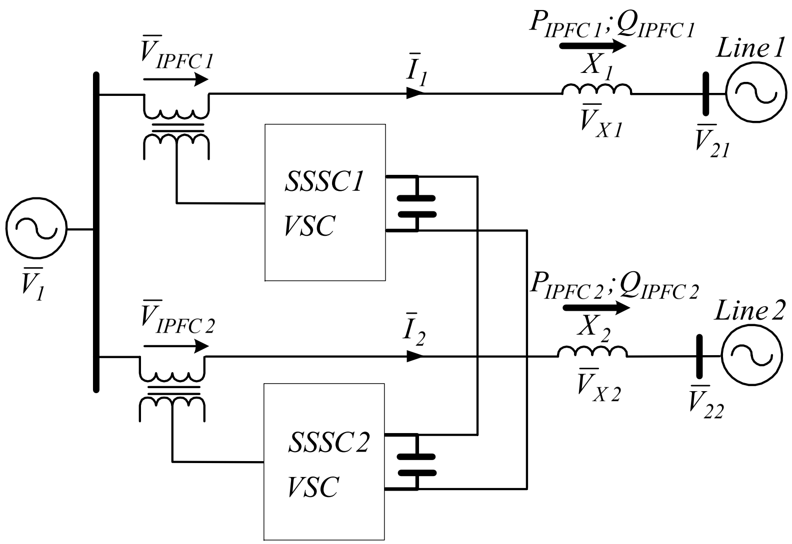
System is flexible and the following configurations are possible:

- **single STATCOM (+/- 160MVAr);**
- **double STATCOM (+/- 320MVAr);**
- **STATCOM + SSSC;**
- **SSSC;**
- **double SSSC.**

This is possible to control voltage, improve stability and independent power flow control.

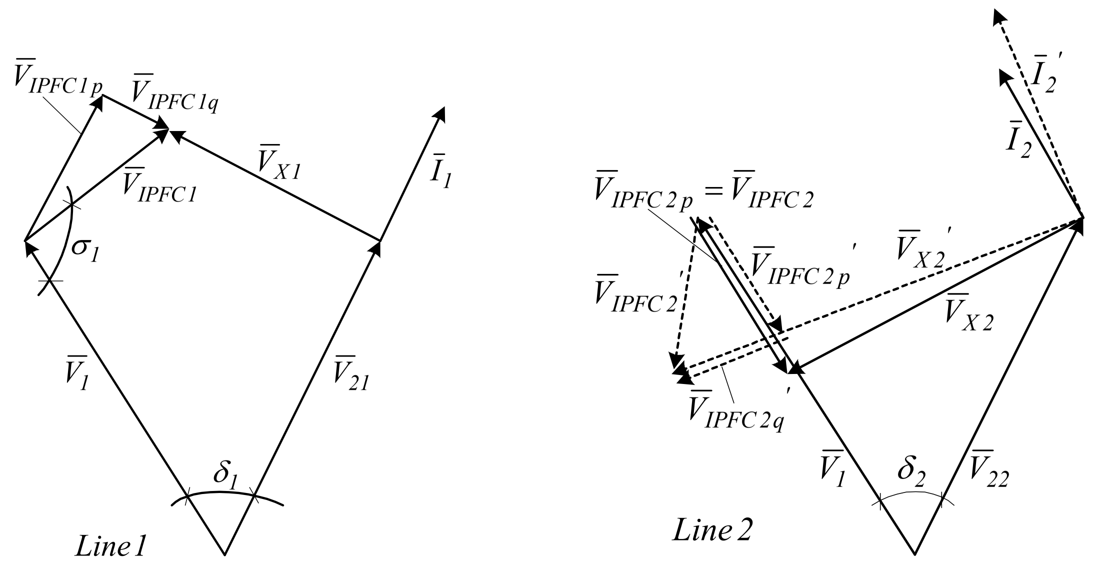
SSSC Based IPFC

Basic Principles



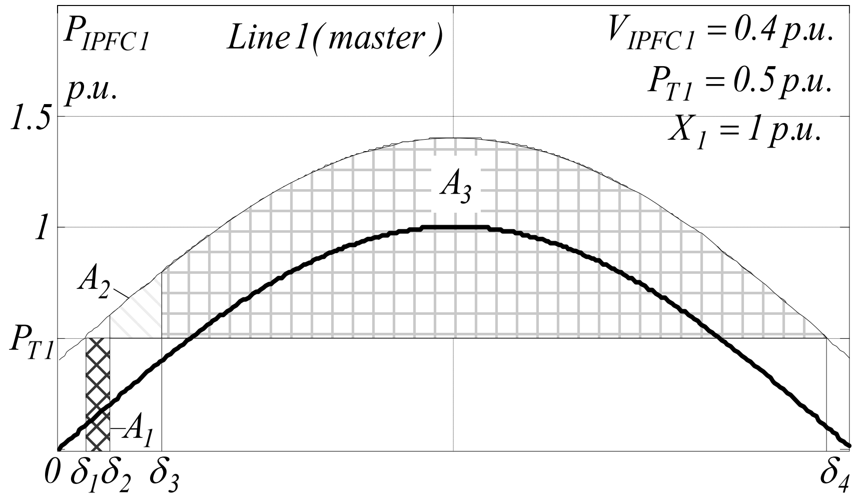
Single line diagram of an IPFC with two series VSCs

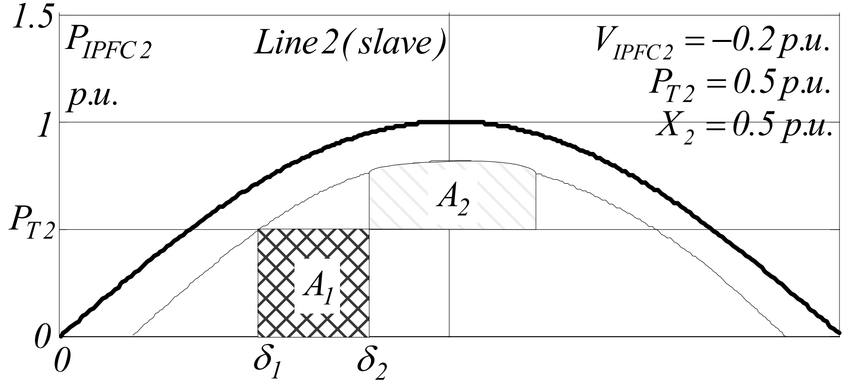
Possible vector diagrams



SSSC Based IPFC

Basic Principles





Transmission characteristics obtained for IPFC device compensating two transmission lines

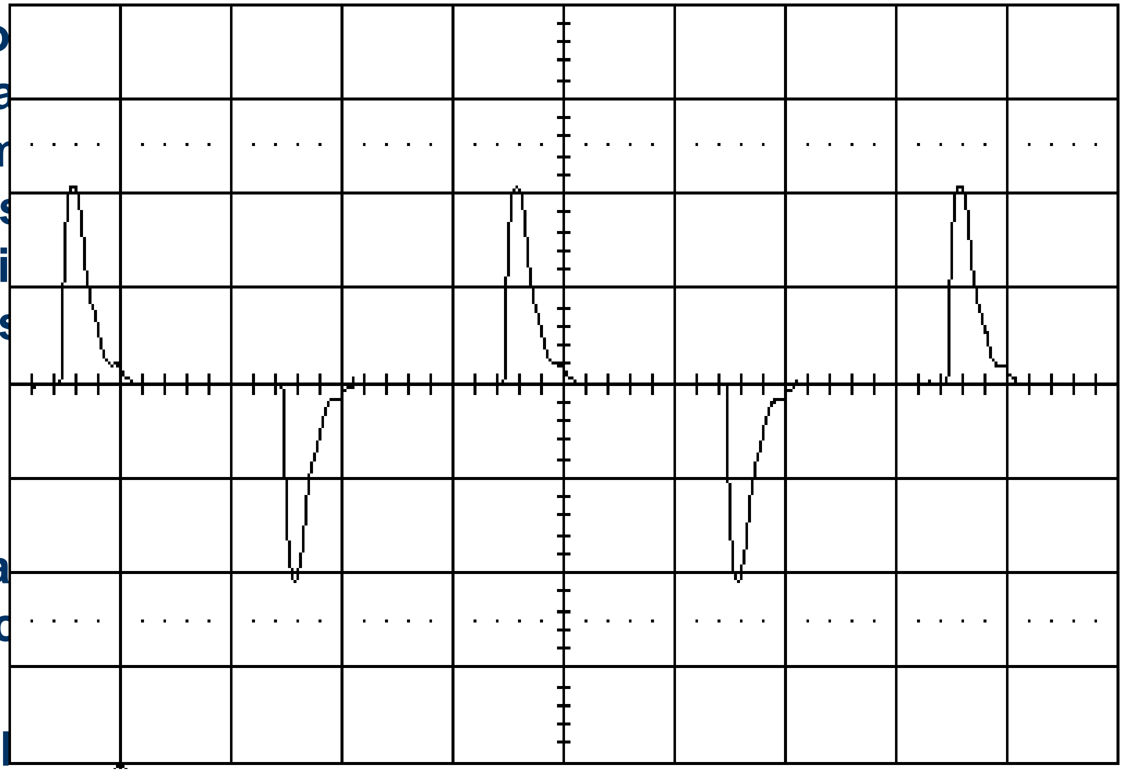
MARCY Station

The First IPFC Ever

Problem: overloaded lines.
Solution: two reconfigurable converters (cost of the new line is to high).

System is flexible and the following configurations are possible:
- STATCOM – 200MVAr;
- SSSC – 200MVAr;
- UPFC – STATCOM + SSSC;
- IPFC – SSSC + SSSC.

Introduction

From all kno  ER), it can be stressed tha include two aspects, nam oltage Quality part includes s, harmonics, interharmoni the reliability part involves interruptions, voltage dips y deviations.

This applica ower System (CUPS), whic e energy end-uses and is f poor power quality of su

Custom Power Systems

Compensating Type Custom Power Systems

Hybrid Active Power Filter

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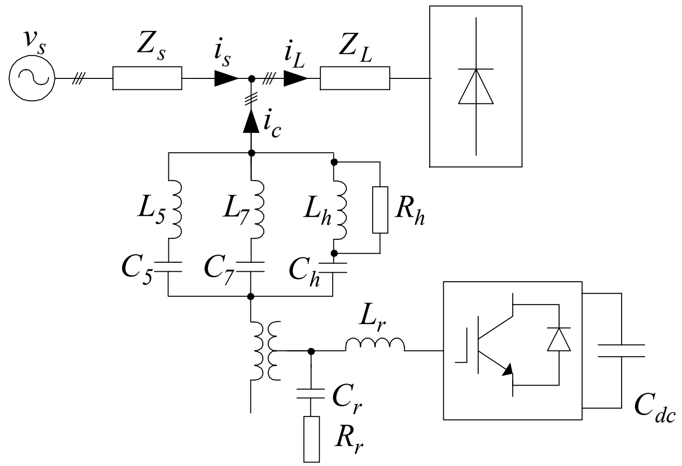
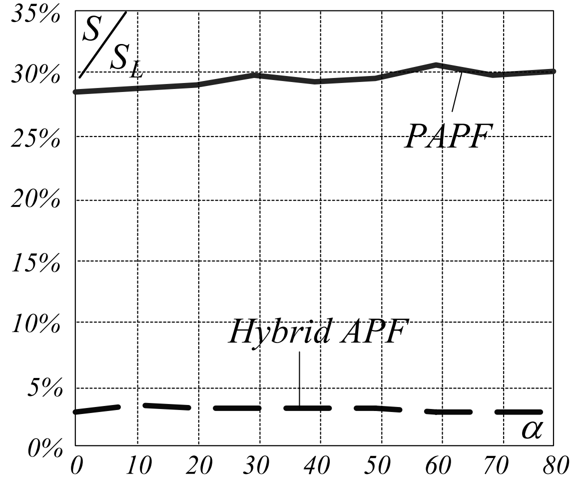
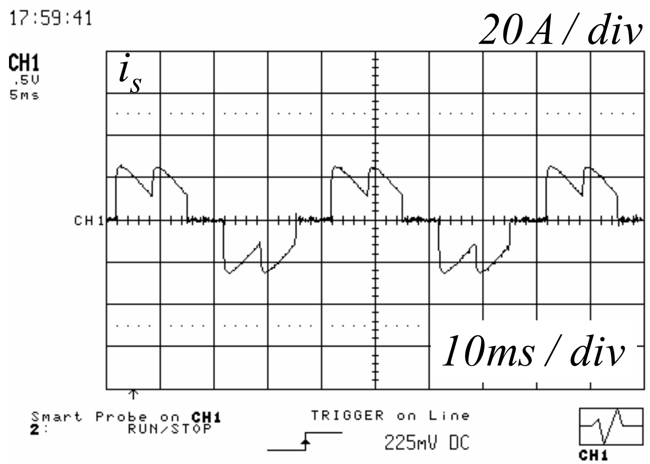
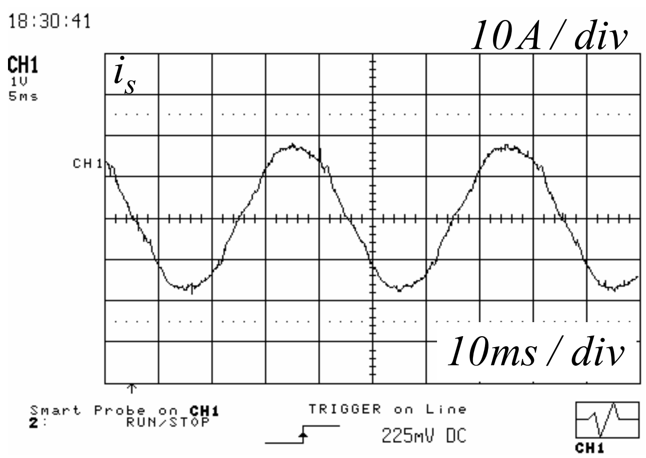




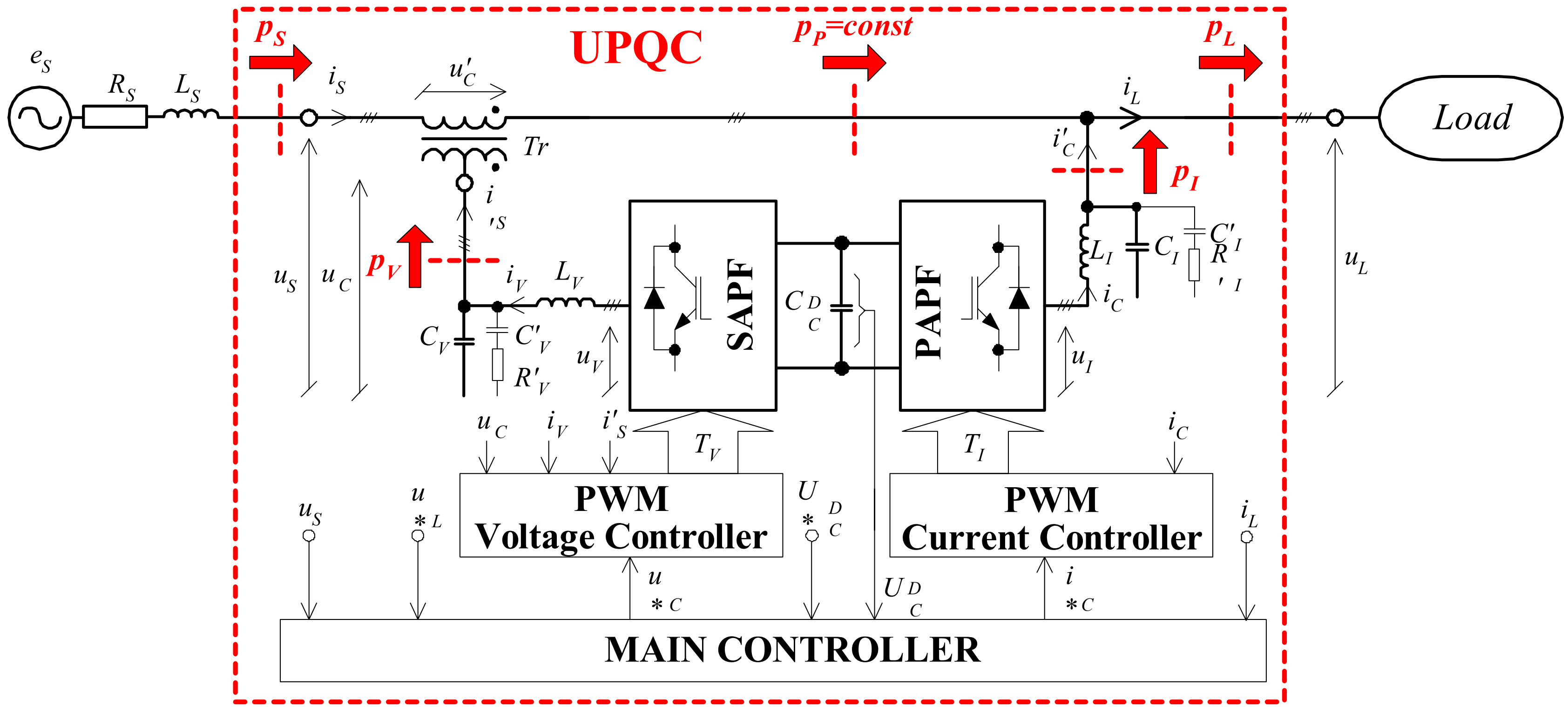
Configuration and operation principles of a hybrid APF





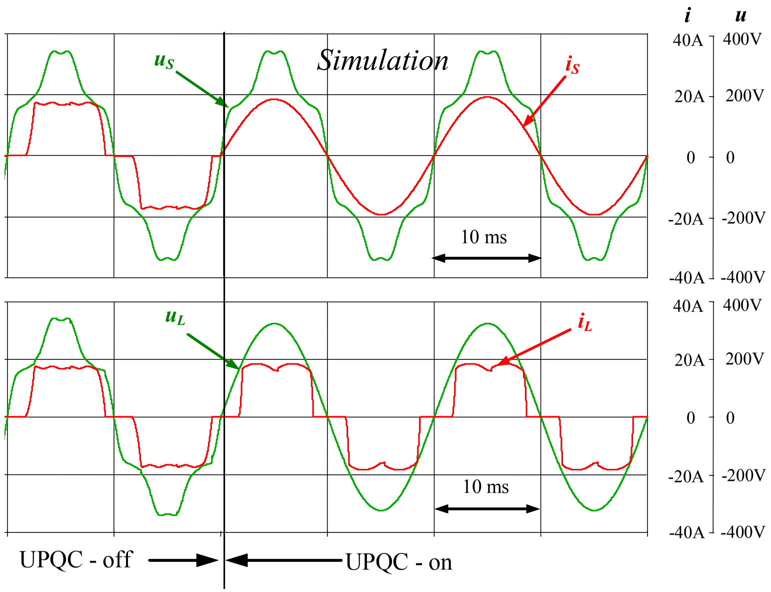
Compensating Type Custom Power Systems

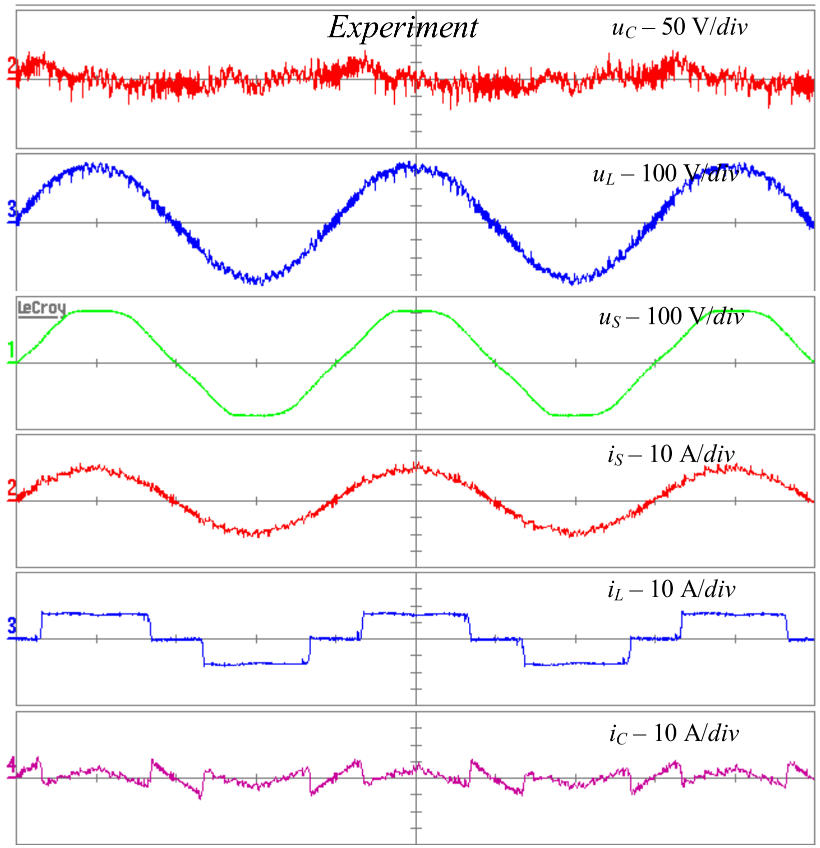
Unified Power Quality Conditioner - Scheme



Scheme of the investigated UPQC

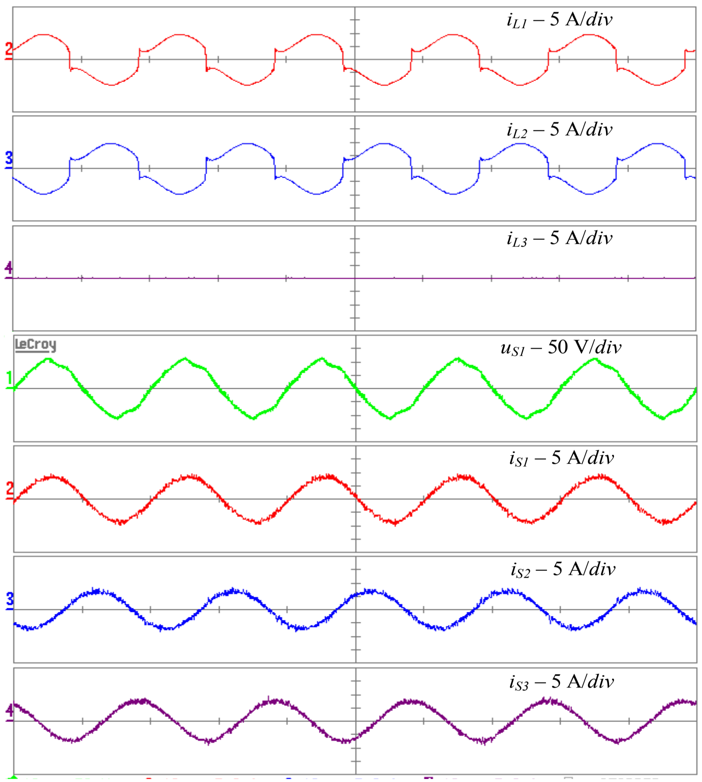
Results obtained during steady states - 1



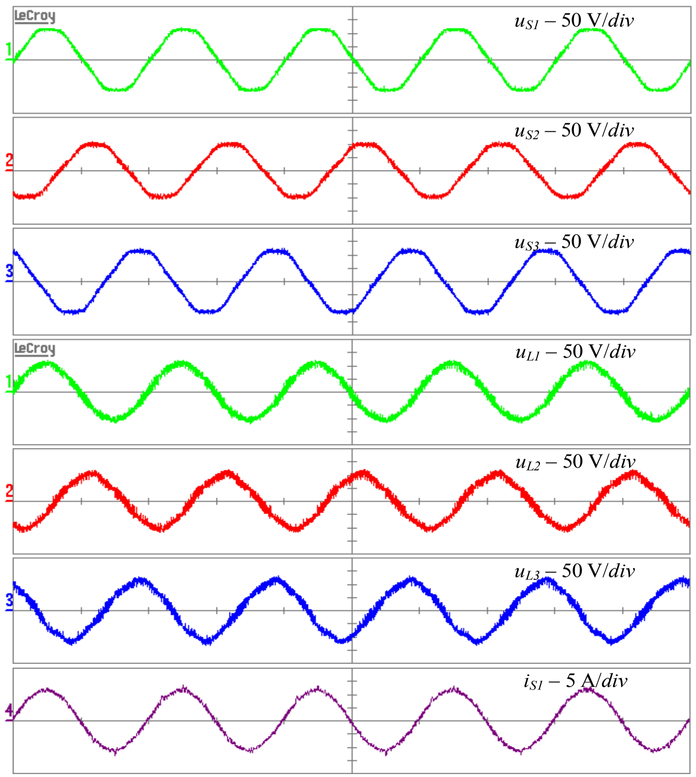


Simulation and experimental courses in case of the network voltage and load current harmonics compensation

Results obtained during steady states - 2



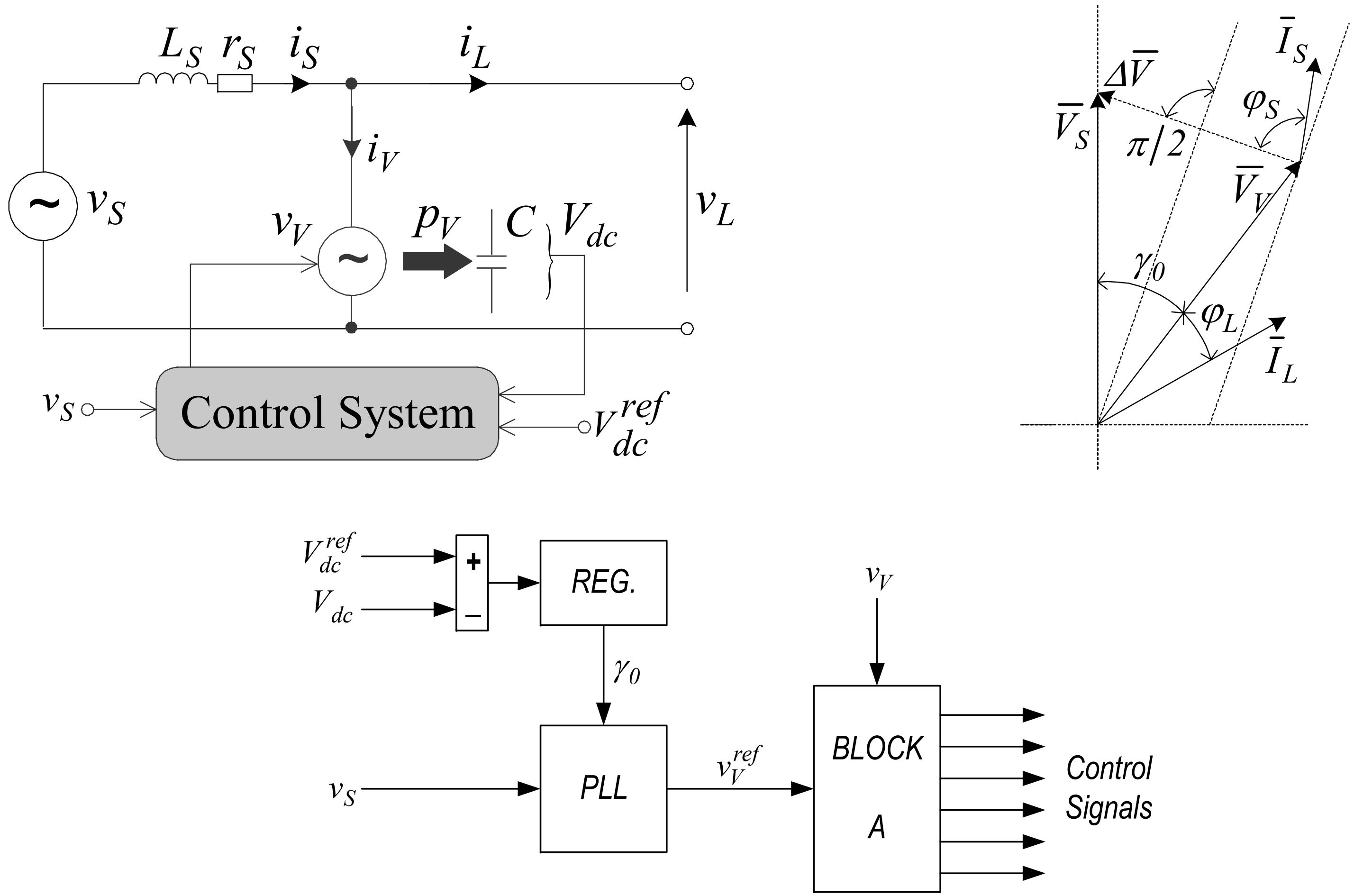
Symmetrical supply and non-linear and non-symmetrical load



Non-symmetrical supply and symmetrical resistive load

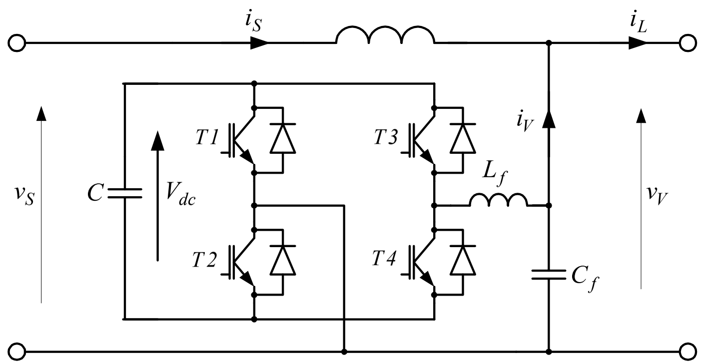
Voltage Source Custom Power Systems

Voltage Active Power Filter – Basics

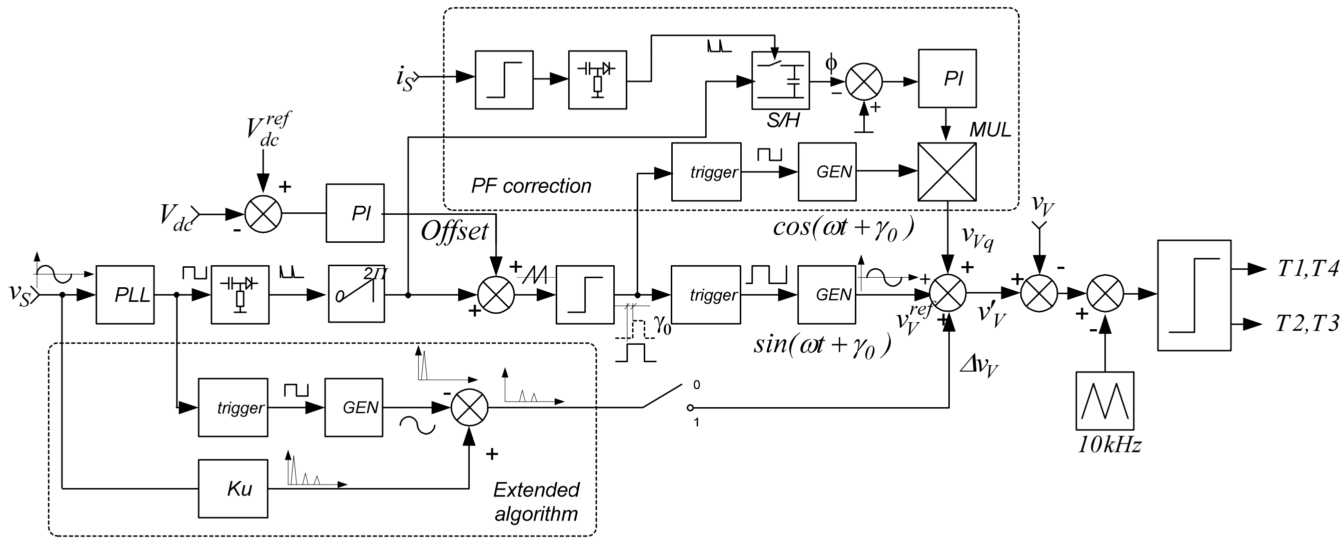


Voltage Active Power Filter: one line scheme, vector diagram and simplified control algorithm

Voltage Active Power Filter – Basics



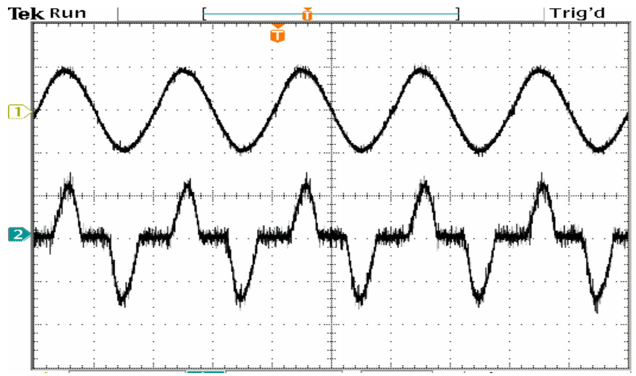
1 – phase VAPF

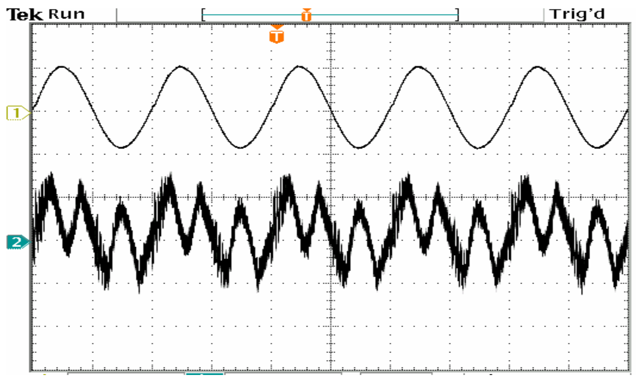


Control algorithm

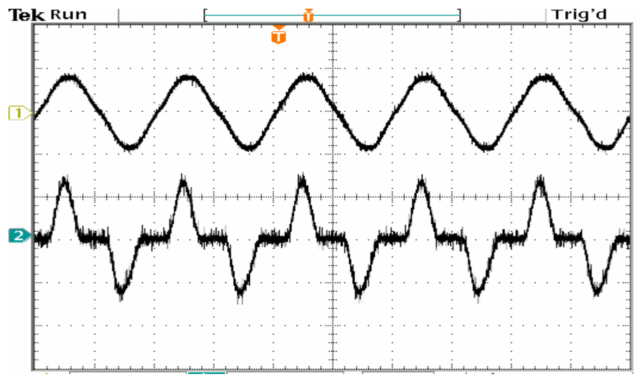
VAPF – Experimental Results

Extended Control Algorithm



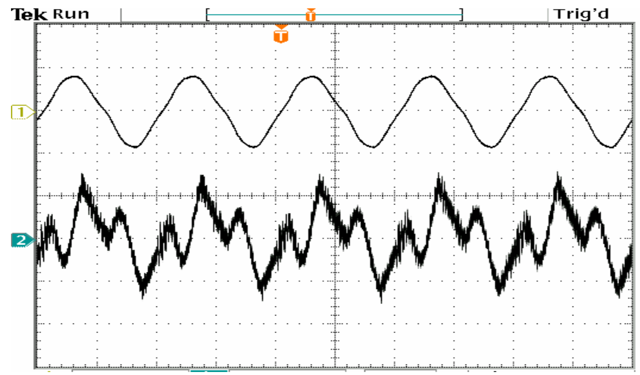


Basic Control Algorithm



$i_S \Rightarrow 10A/div$

$i_L \Rightarrow 10A/div$



$i_S \Rightarrow 10A/div$

$i_V \Rightarrow 2A/div$

VAPF – Experimental Results

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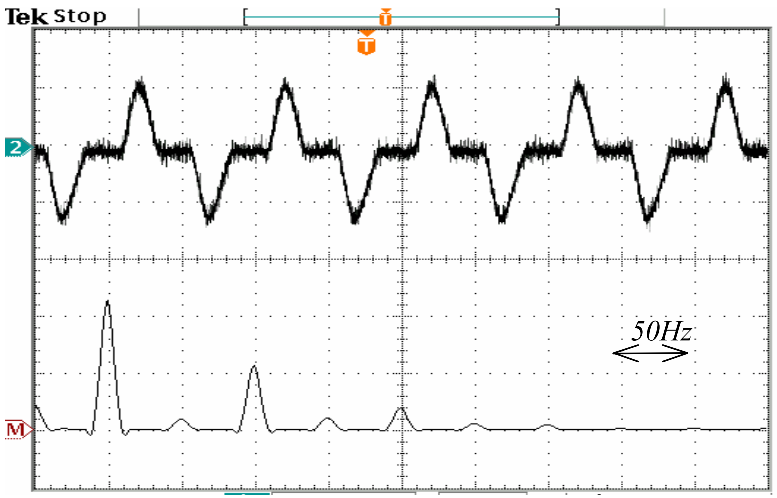
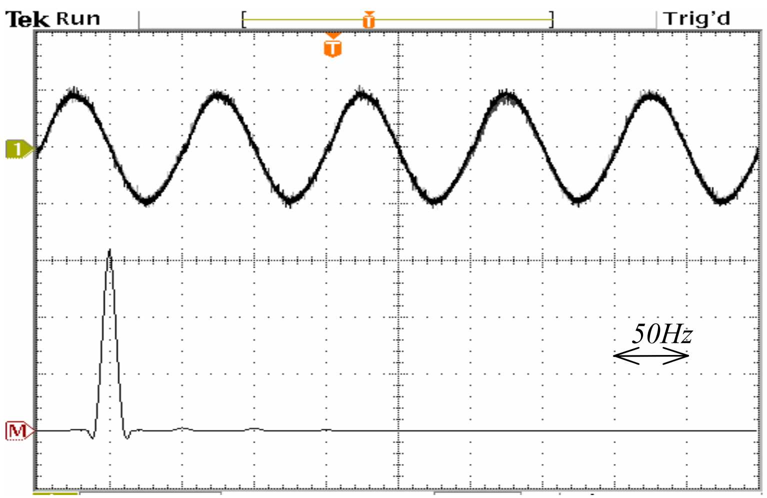


$i_L \Rightarrow 10A/div$

$2A/div$

$THD(i_L) = 45\%$

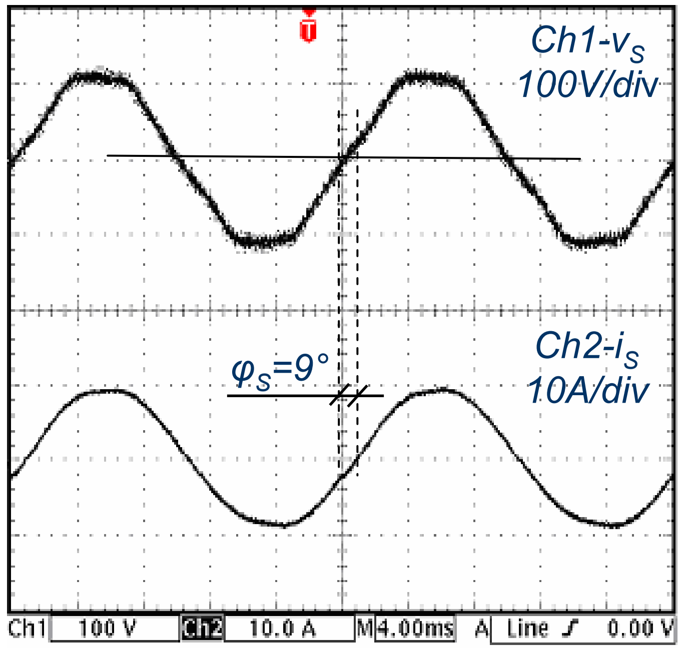


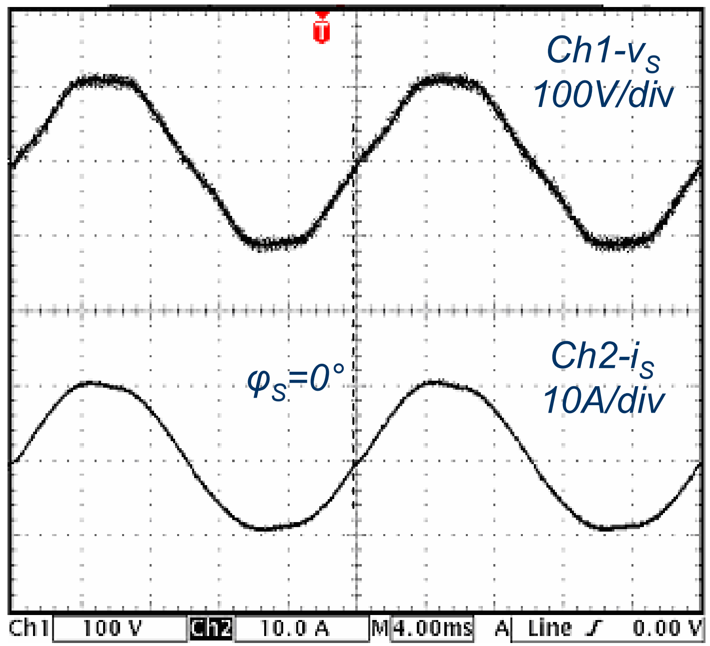
$i_S \Rightarrow 10A/div$

$2A/div$

$THD(i_S) = 3.5\%$

VAPF – Experimental Results

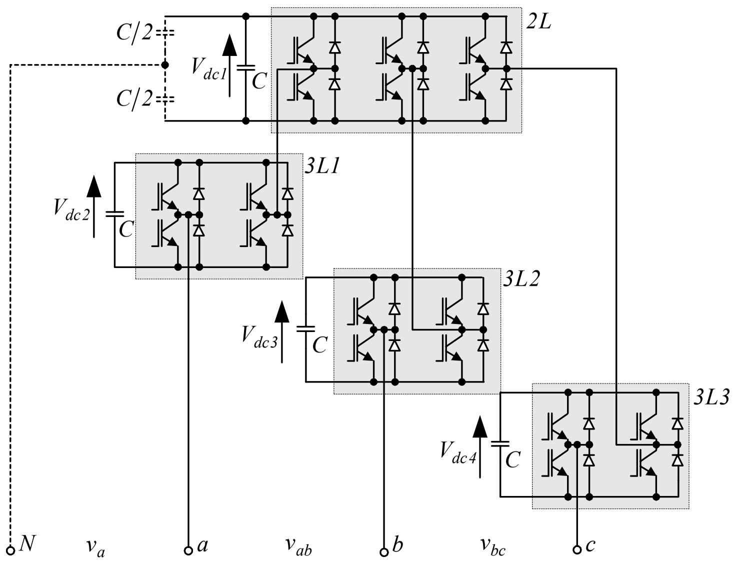


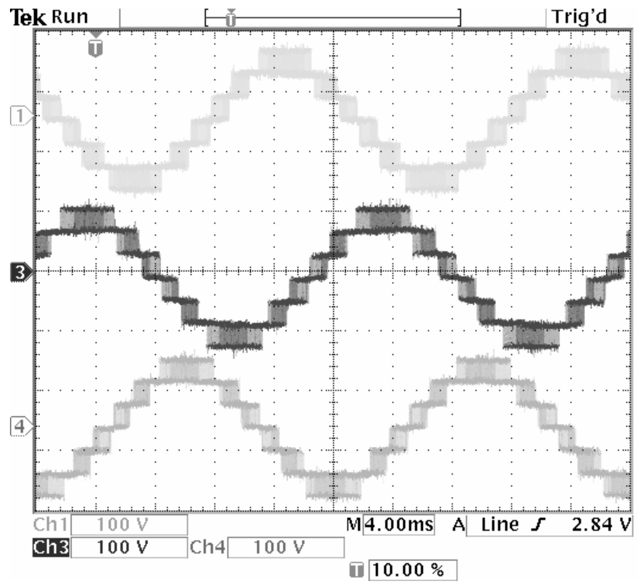


VAPF – input power factor correction

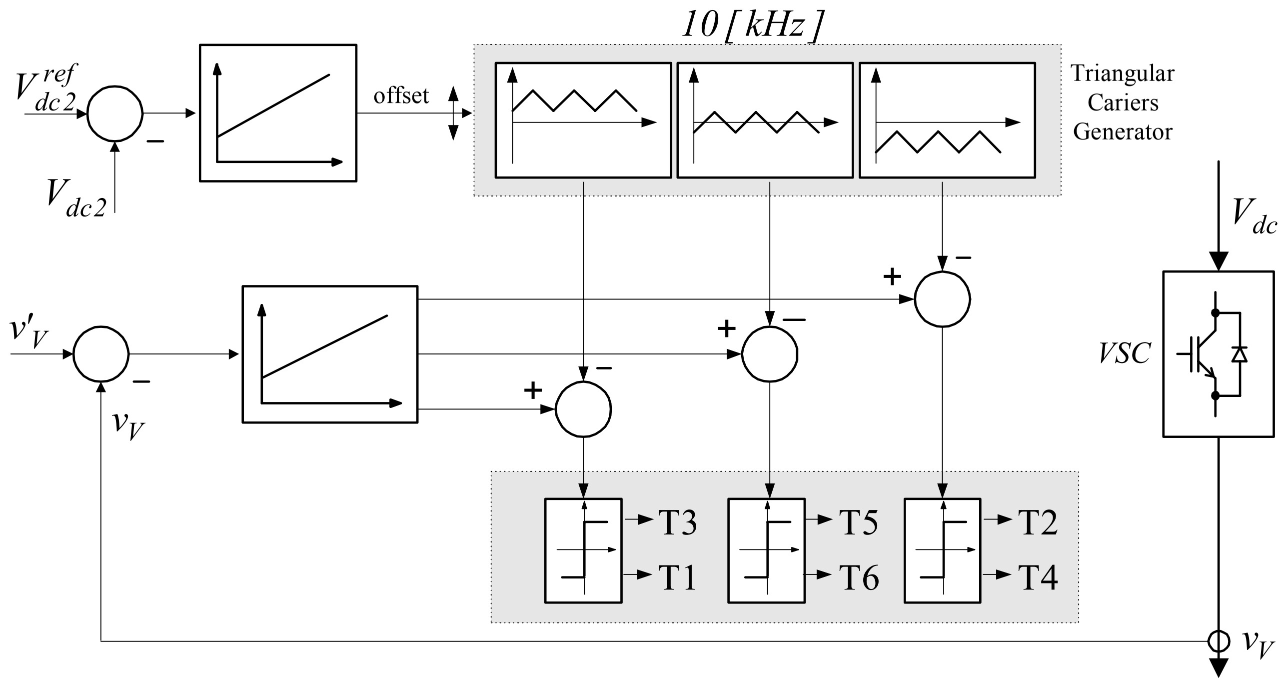
Voltage Source Custom Power Systems

Multilevel VAPF – Experimental Results



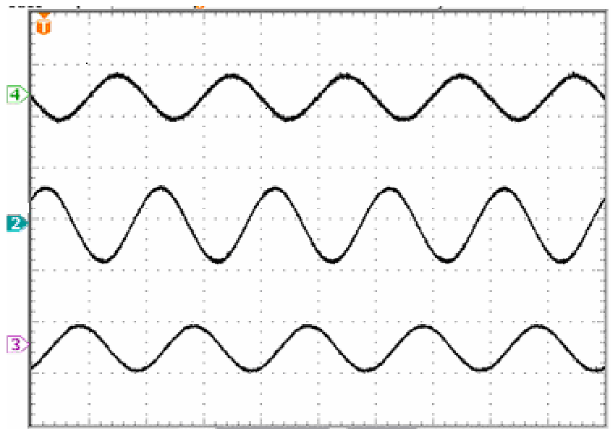


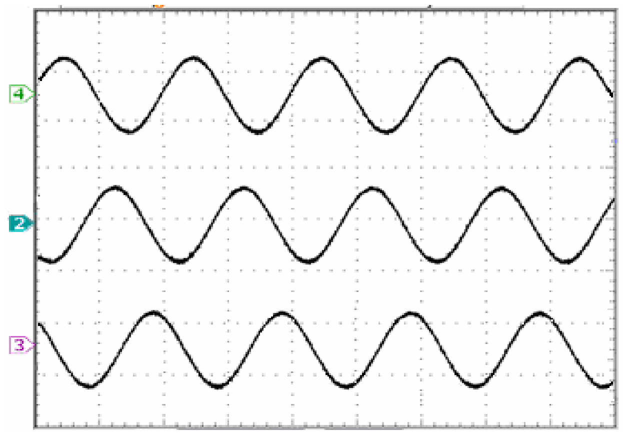
Cascaded multilevel converter and phase-to-phase output voltages



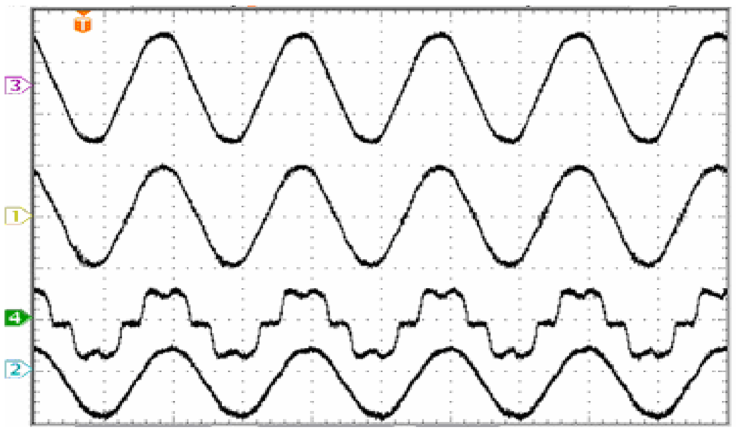
Algorithm for balancing *DC* voltages

Multilevel VAPF – Experimental Results





Current waveforms (*Δt=10 ms/div,10A/div*) for linear unbalanced load: left – load side; right – network side



$v_S \Rightarrow 100V/div$

$v_V \Rightarrow 100V/div$

$i_L \Rightarrow 10A/div$

$i_S \Rightarrow 10A/div$

$P_L = 1.2kW$

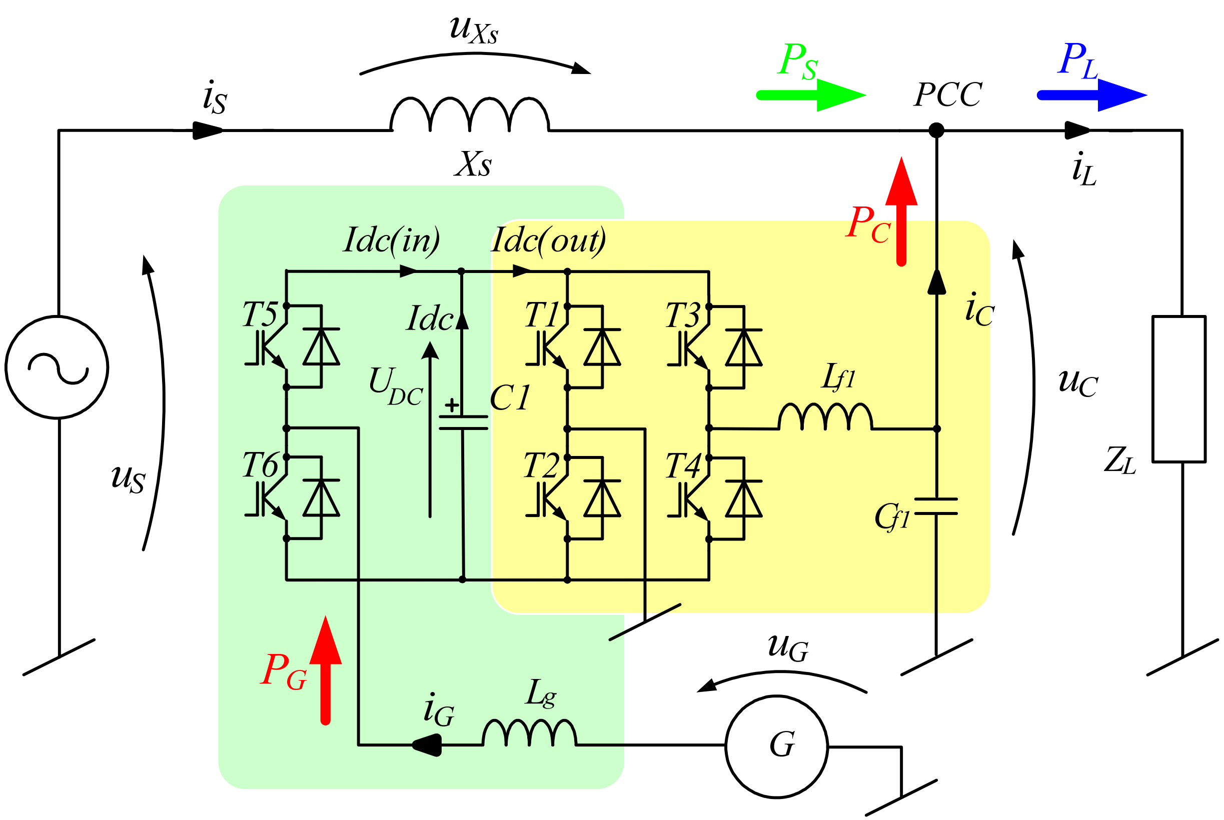
$THD(i_S) = 2.6\%$

Waveforms (*Δt=10 ms/div*) for non-linear balanced load

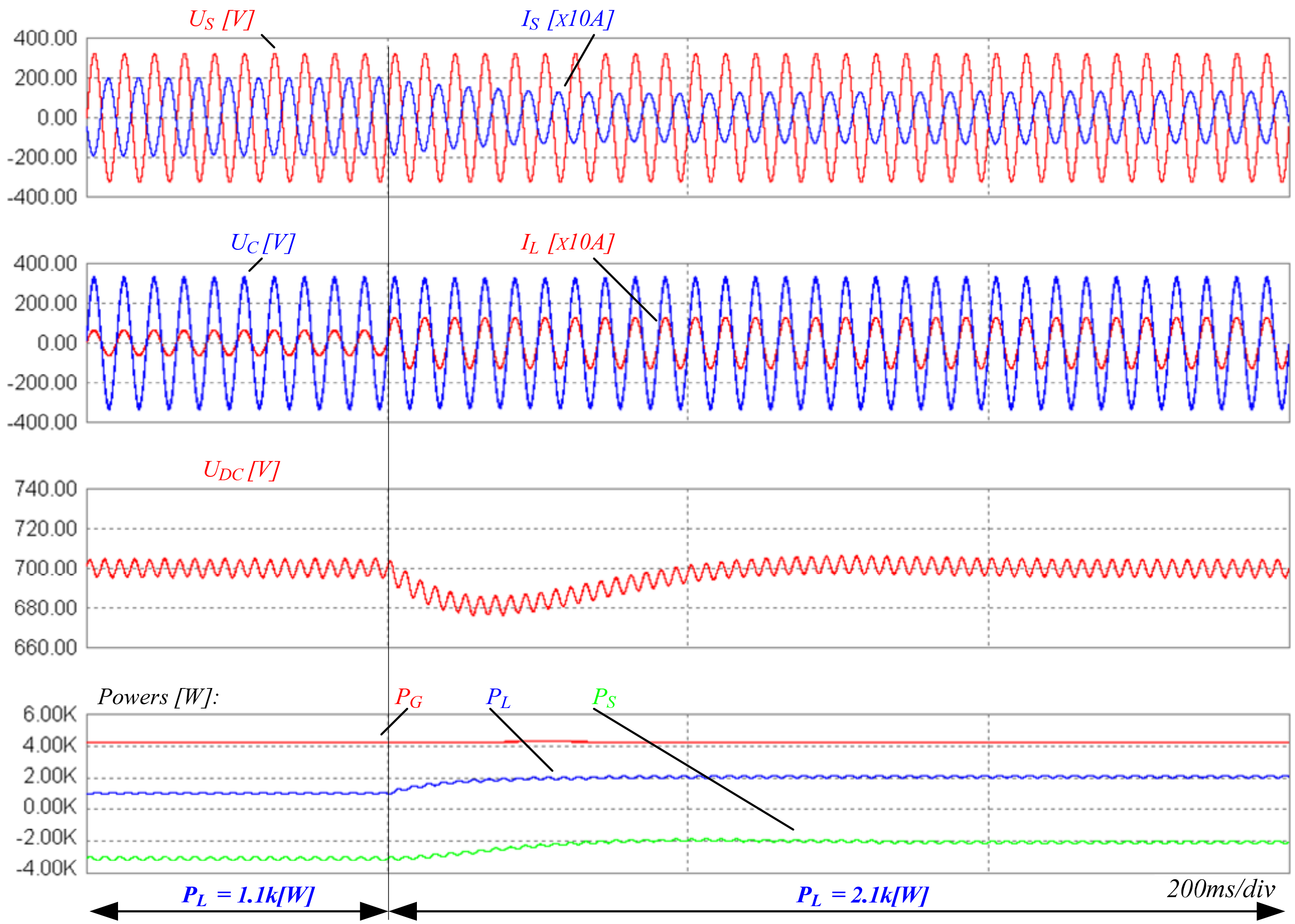
Voltage Source Custom Power Systems

Symmetrical VAPF – DG Interconnection

$$P_G = P_C \Rightarrow P_L = P_S + P_C$$



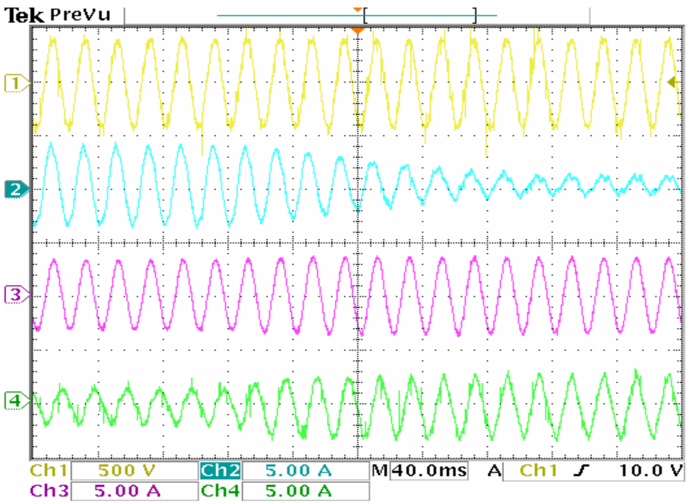
Symmetrical VAPF – DG Interconnection



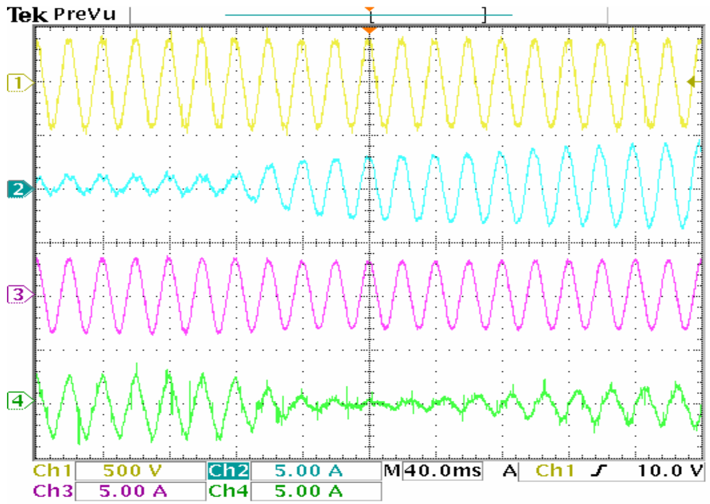
P_L power changes (generator DC; $P_G > P_L$)

Voltage Source Custom Power Systems

Interline VAPF – Experimental Results



increased P_G

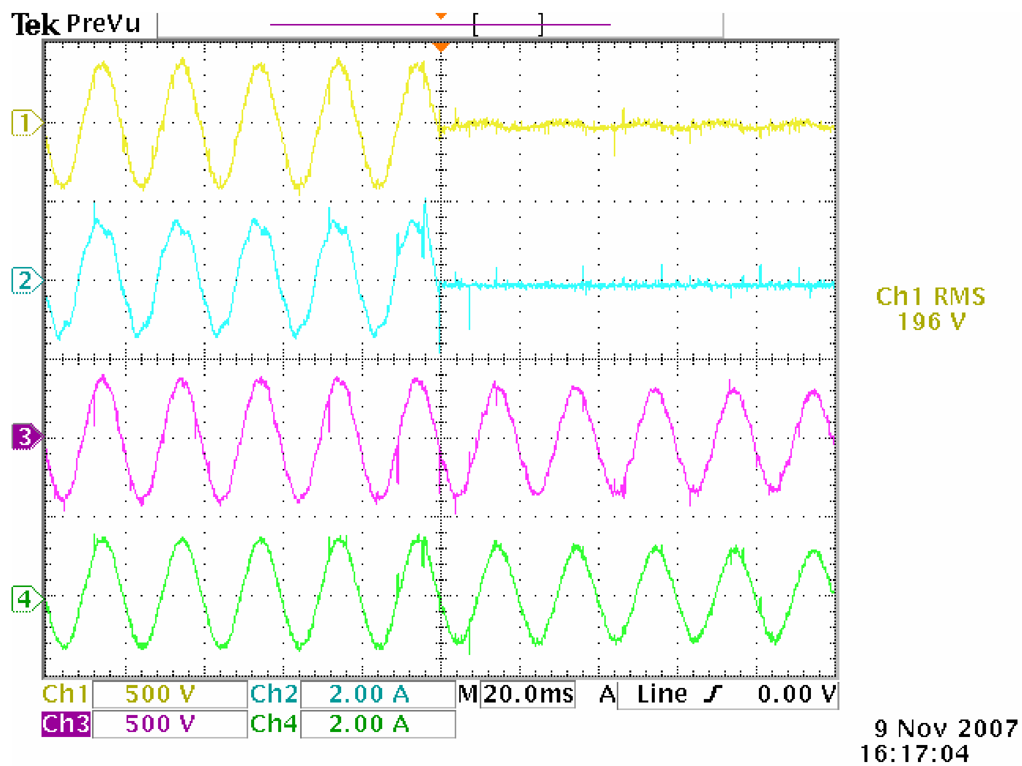


decreased P_G

Changes of the generated power P_G;
where: Ch1 – U_{S1}, Ch2 – I_{S1}, Ch3 – I_{L1}, Ch4 – I_G)

Voltage Source Custom Power Systems

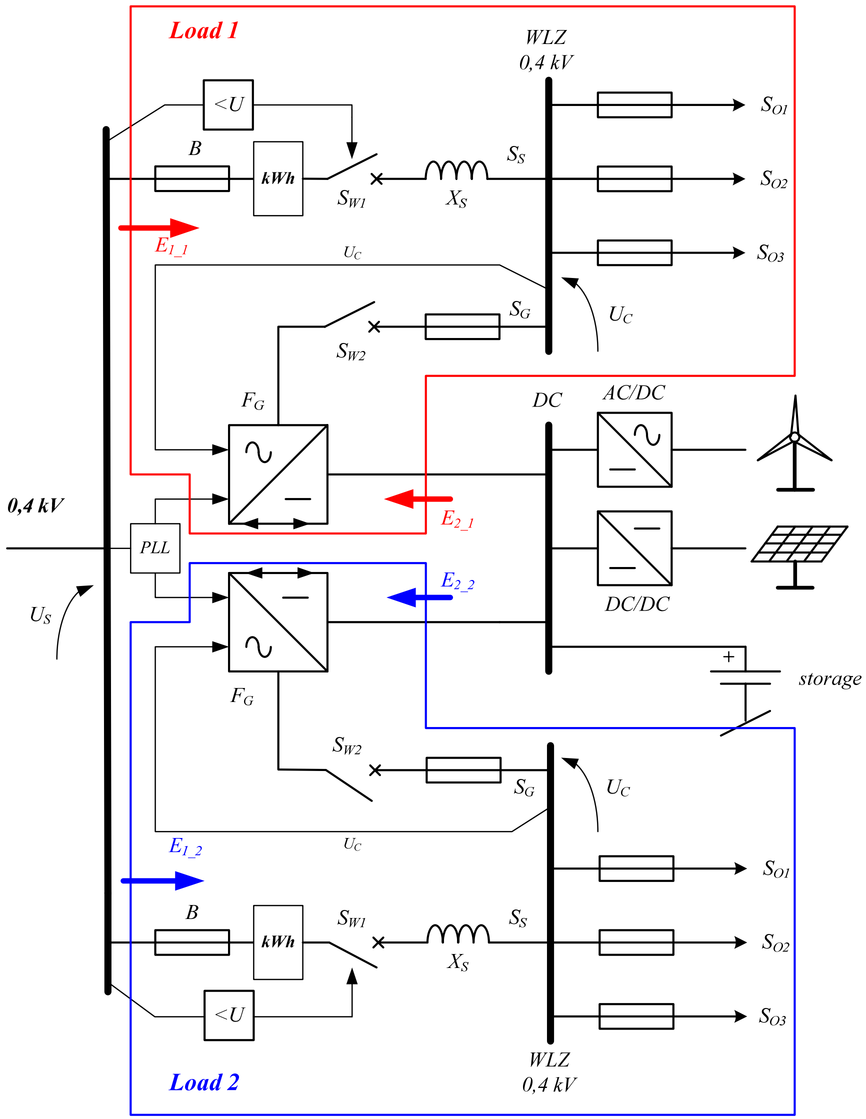
Interline VAPF – Experimental Results



Source voltage dip (DC distributed generation); where: Ch1 – U_{S1}, Ch2 – I_{S1}, Ch3 – U_{C1}, Ch4 – I_{L1})

Voltage Source Custom Power Systems

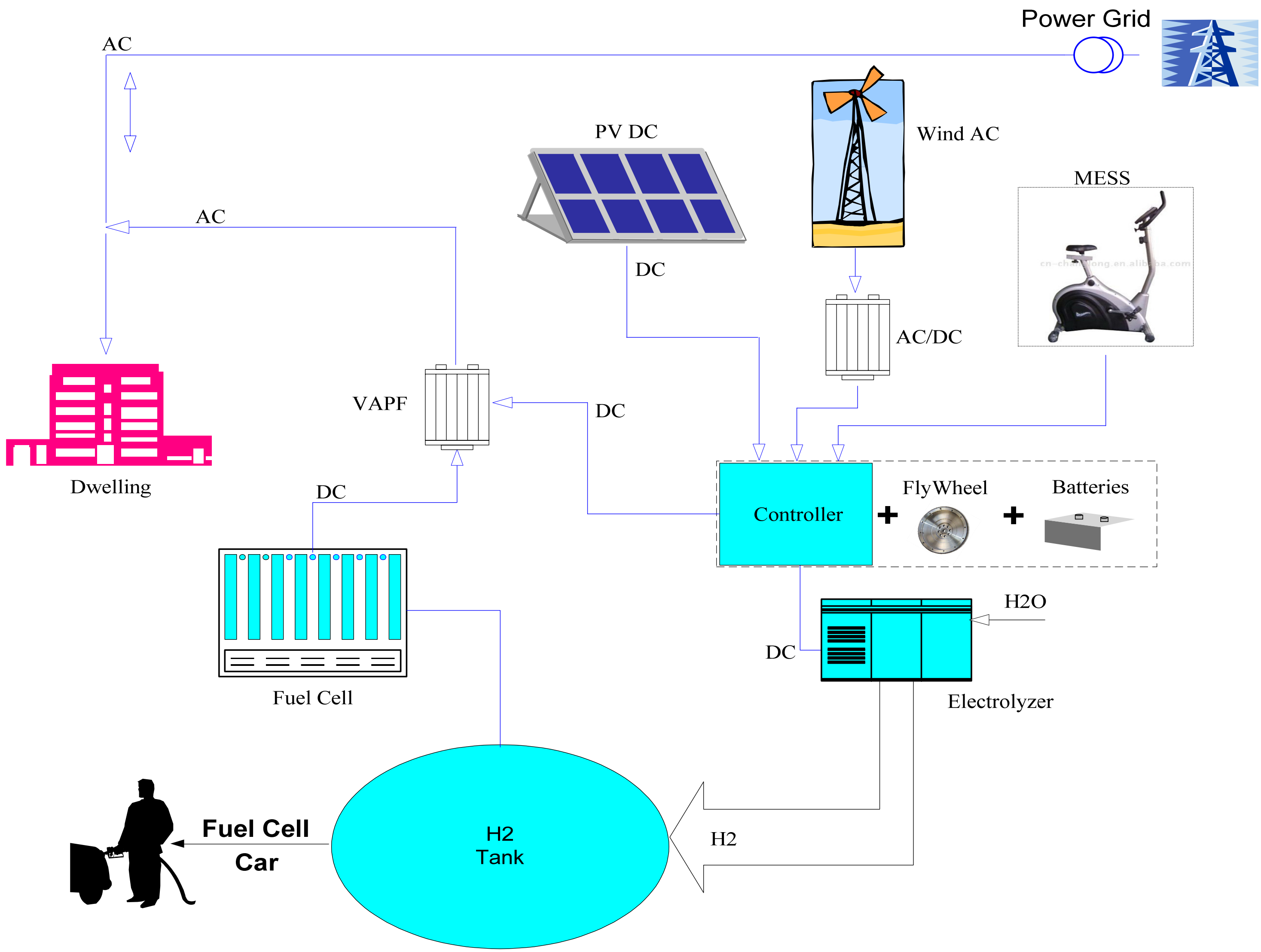
Interline VAPF



IVAPF possible applications

Voltage Source Custom Power Systems

Interline VAPF - application



Smart Electrical Energy Network

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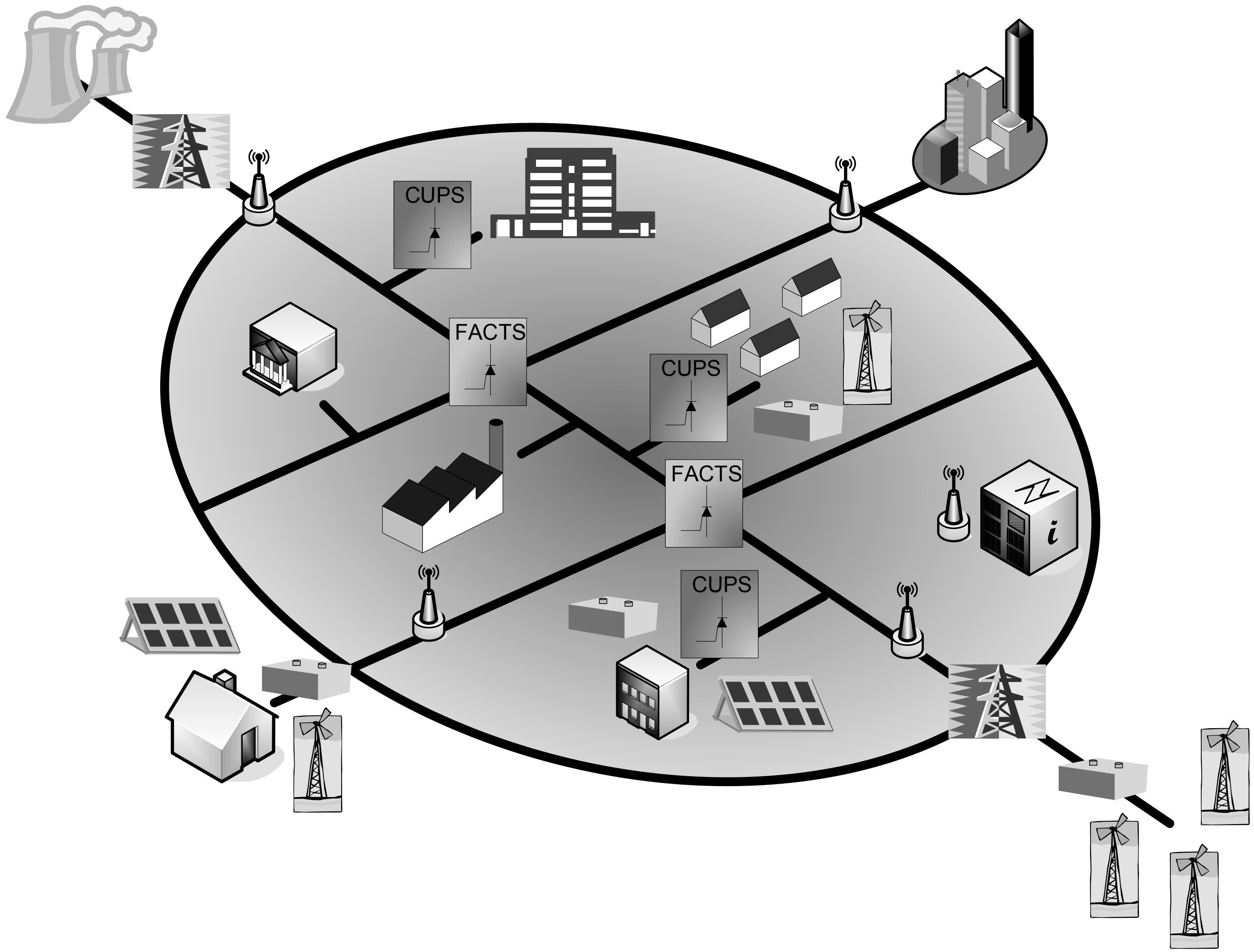

Smart grid would create system that:

- Will **reduce peak loads**;
- Will **delete capital costs** of new T&D infrastructure as well as generating plants;
- Will **lower T&D line losses** together with operation and maintenance costs;
- Will **improve voltage profiles** and stability;
- Through extensive monitoring, quick communications, and feedback control of operations, will have much **more information about system rising problems** before they affect service;

Conclusions

Conclusions

Specified problems related to power grids were presented.

To overcome selected problems FACTS, on transmission, and CUPS on distributed level as well as Distributed Generation together with Energy Storage Systems could be applied.

Smart grids will be strong, more flexible, reliable, self-healing, fully controllable and will be a platform to make possible the coexistence of smart-self-controlling grids with great numbers of DGs and large-scale centralized power plants.

Grzegorz BENYSEK

THANK YOU FOR YOUR ATTENTION