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Voltage Stability improvement using FACTS devices: SVC and STATCOM

S. Schneider (Siemens AG), B. Strong (SNS Delta Power)

Content of the Presentation

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Structure of the Power System

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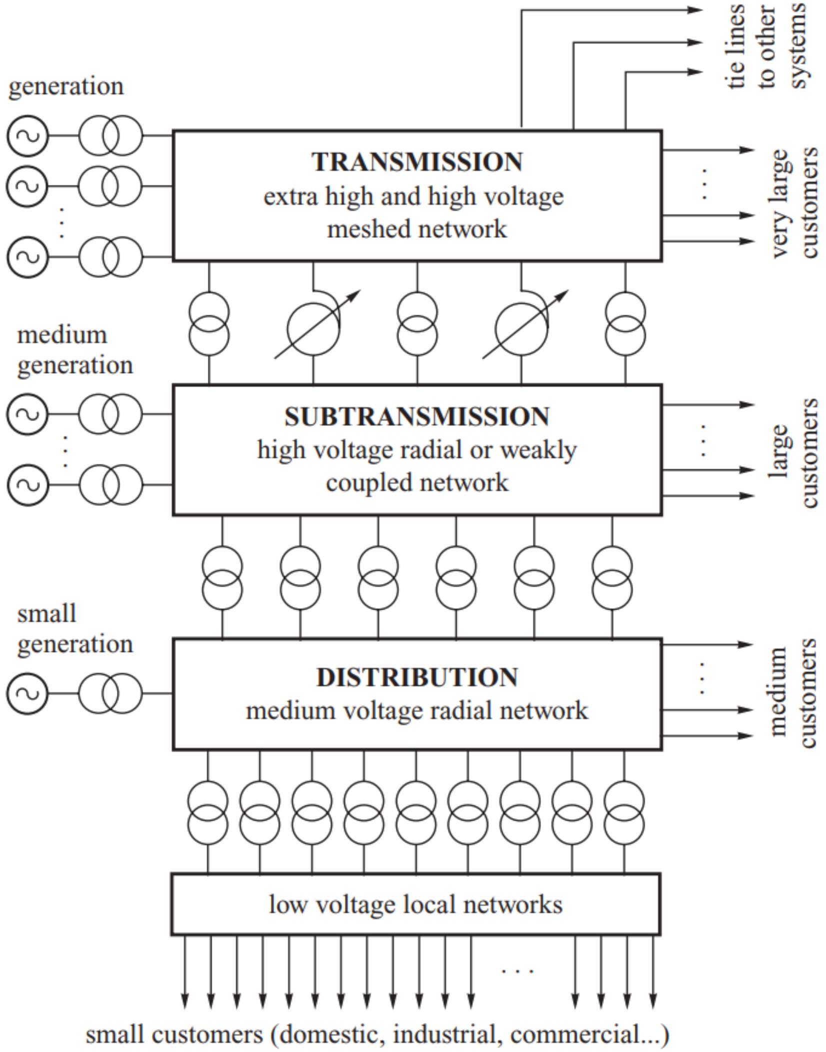
1. Power network is a very complex structure, which contains generation units, transmission lines, transformers and various types of loads

2. The structure of of the European's Power System is going thorugh significant changes due to expansion of the Renewable Energy Systems (RES)

3. One of the major responisbilites of the Power System Operator is to maintain voltage quality within tolerable levels



Machowski J; Białek J.W.; Bumby J.R; Power System Dynamics

Principles of the Shunt Compensation

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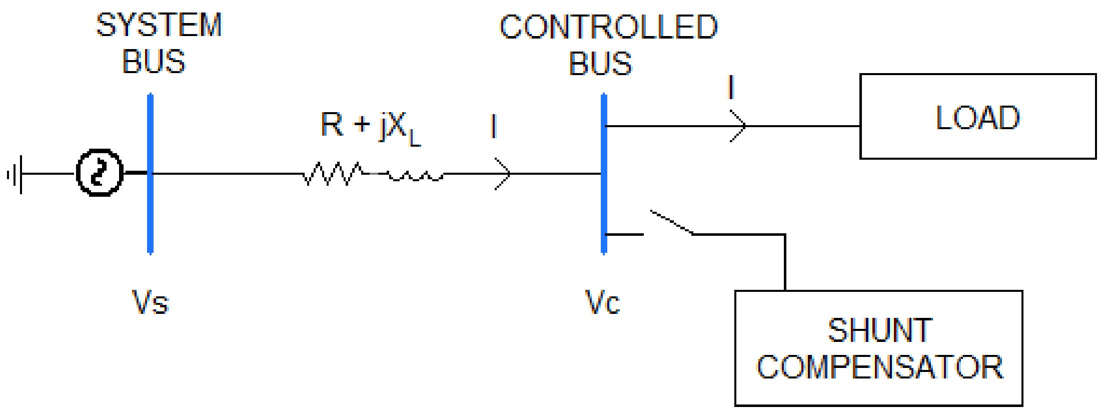
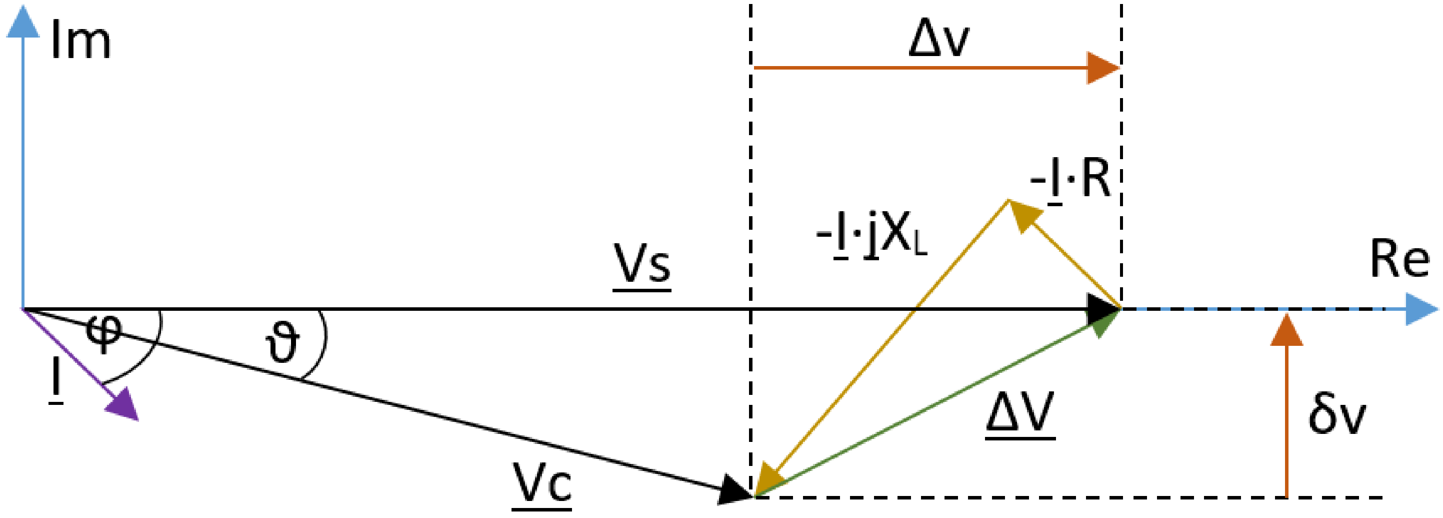


$$\underline{S}_{S\rightarrow C} = \underline{V}_C \cdot \underline{I}^* = P_C + \underline{j}Q_C = \frac{V_C V_S \cos\vartheta}{X_L} + \frac{\underline{j}(V_C V_S \sin\vartheta - V_C{}^2)}{X_L}$$

$$P_{S\rightarrow C} = \frac{V_C V_S \cos\vartheta}{X_L}$$

$$Q_{S\rightarrow C} = \frac{V_C V_S \sin\vartheta - V_C{}^2}{X_L}$$



Voltage Stability

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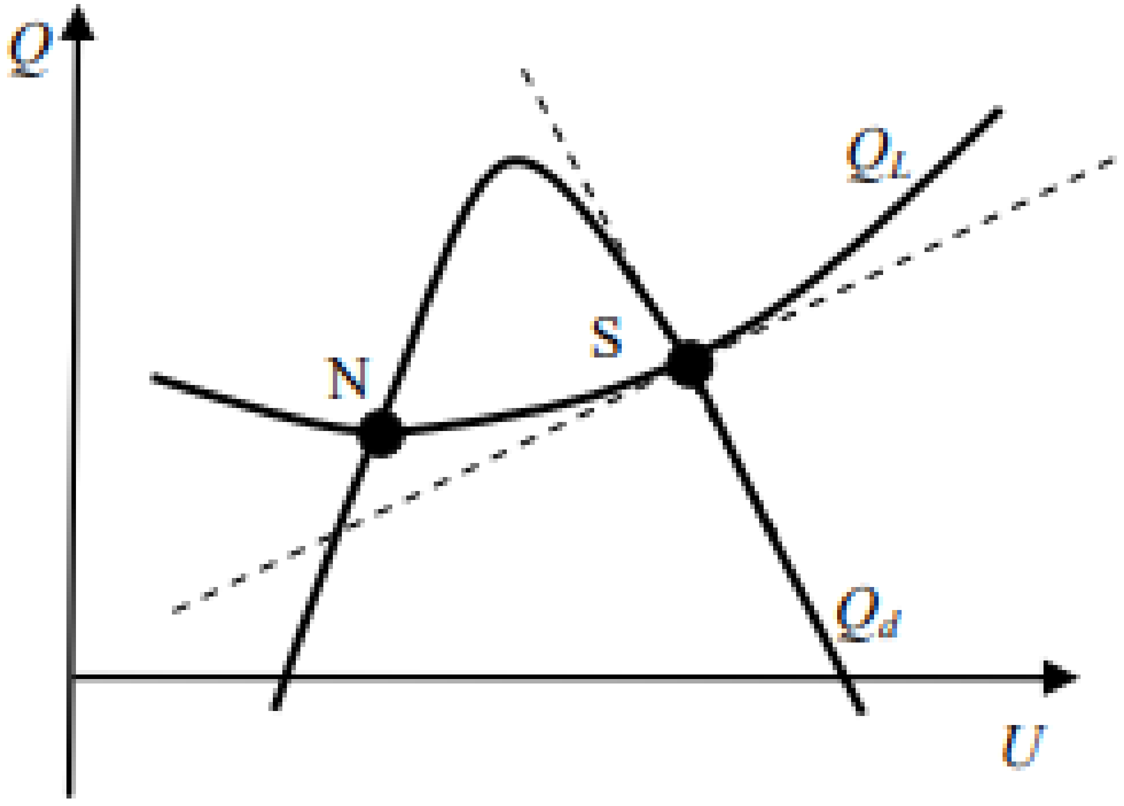
Definition (Venikov, Wendy):

„Capability of the system to supply the load with reactive power for a given real power demand"

$$Q_{S\to C} = \sqrt{\left(\frac{V_S V_C}{X_L}\right)^2 - P^2} - \frac{{V_C}^2}{X_L}$$



Machowski J; Białek J.W.; Bumby J.R; Power System Dynamics

Voltage Stability

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1 Long term voltage stability (minutes - hours):

What can influence?:
- Load changes in Power System
- Outages in Power System
- Re-dispatch operations

Possible solution:
- Mechanically-Switched Capacitors (MSCs),
- Mechanically-Switched Reactors (MSRs)
- Readjustemt of a tap-changer

Voltage Stability

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2 Transient voltage stability (ms - s):

What can influence?:

- Short-circuits
- Sudden Load rejections

Possible solution:

- AVR of the generators
- Synchronous Condenser (response time ~1s)
- SVC (response time ~50ms)
- STATCOM (response time ~30ms)

Shunt Compensation Devices

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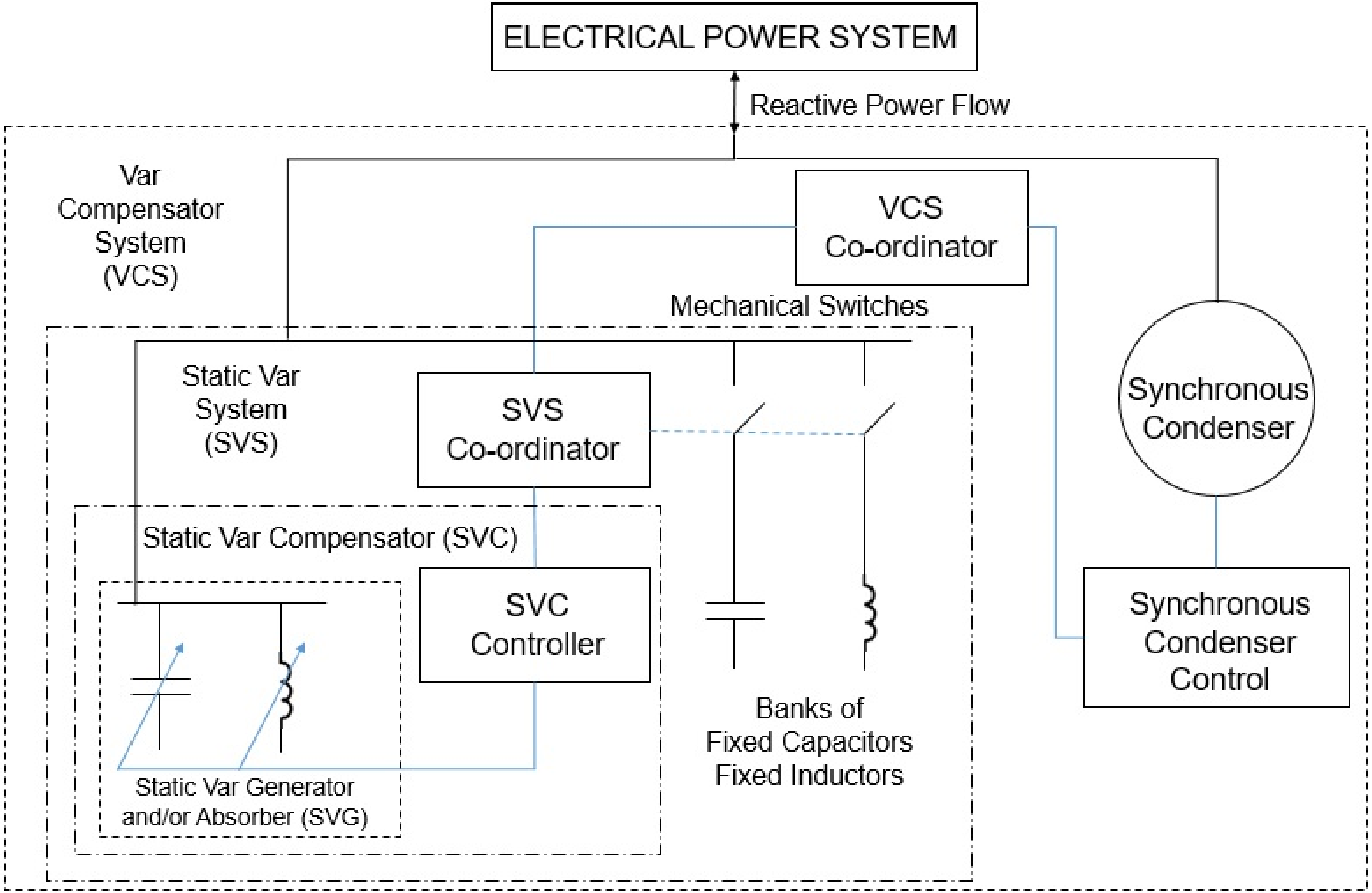
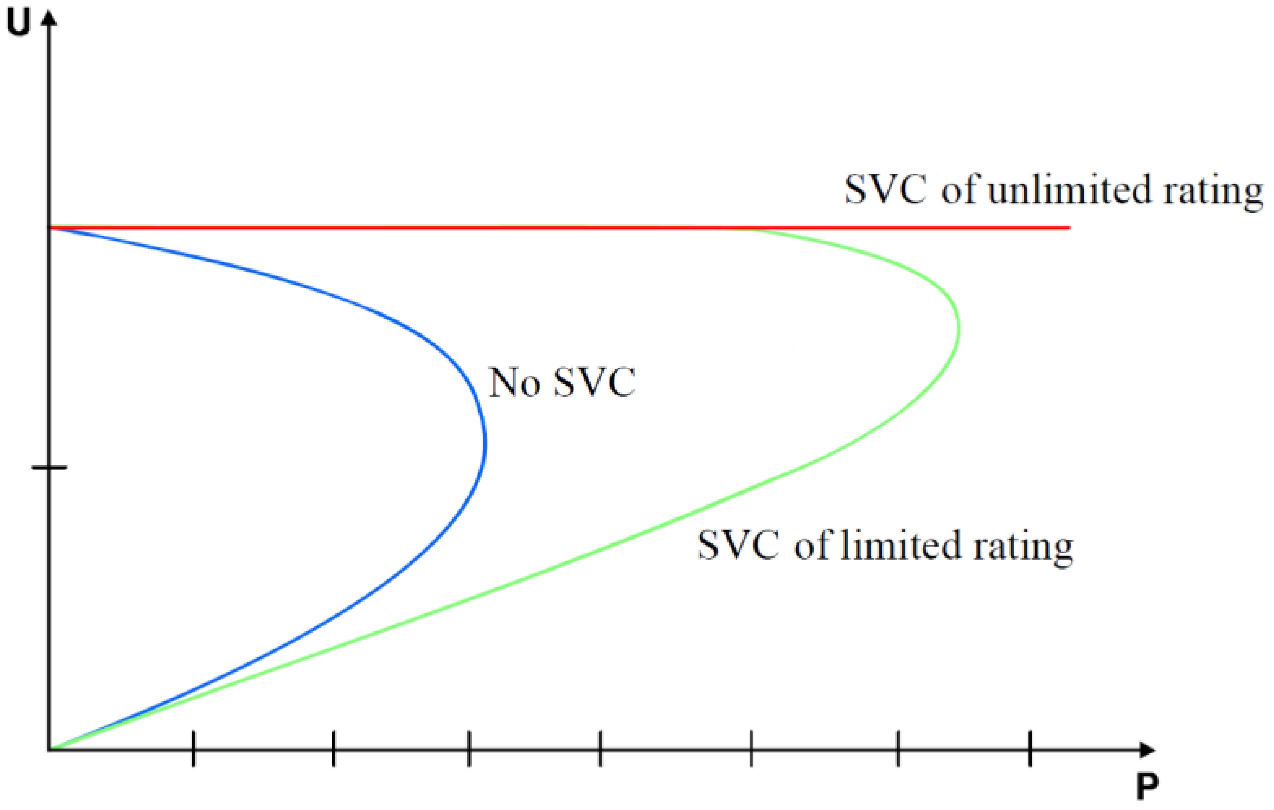


Influence of the SVC on the voltage stability

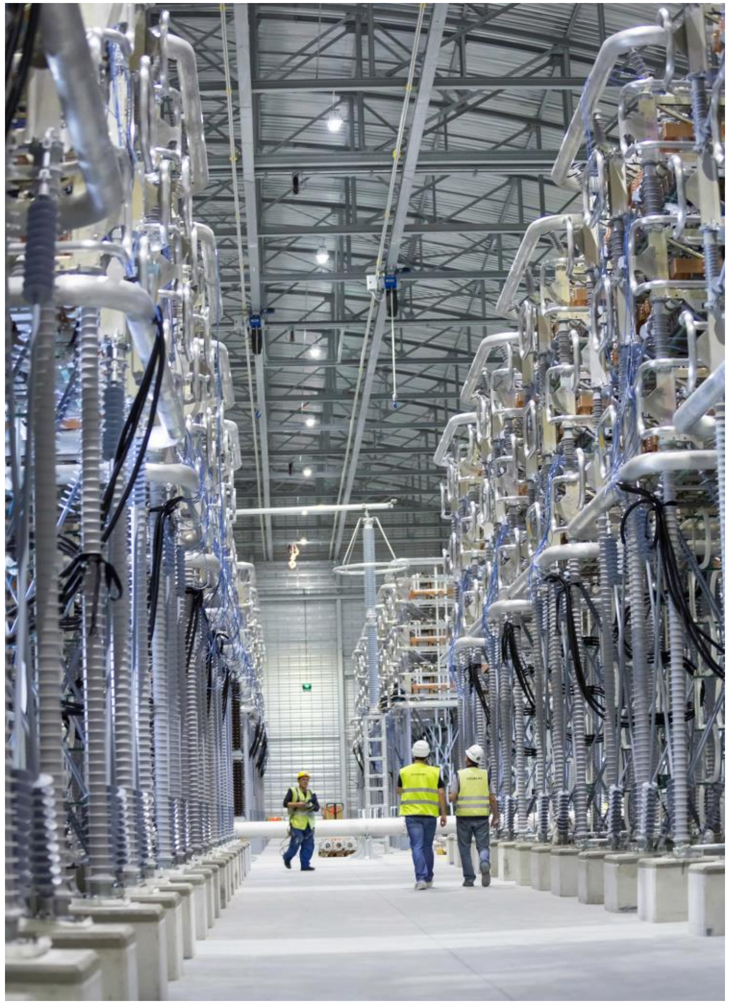
1. Incease of stability margins especially in transient stability imporvement
2. Increasing transmission capability
3. Reducing the transient overvoltages



Flexible AC Transmission System

IEEE definition of FACTS is following:

“a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability”.



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SVC classic® (Siemens SVC) and SVC PLUS® (Siemens STATCOM)

SVC classic®, SVC PLUS® - Content

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Siemens SVC – SVC classic®

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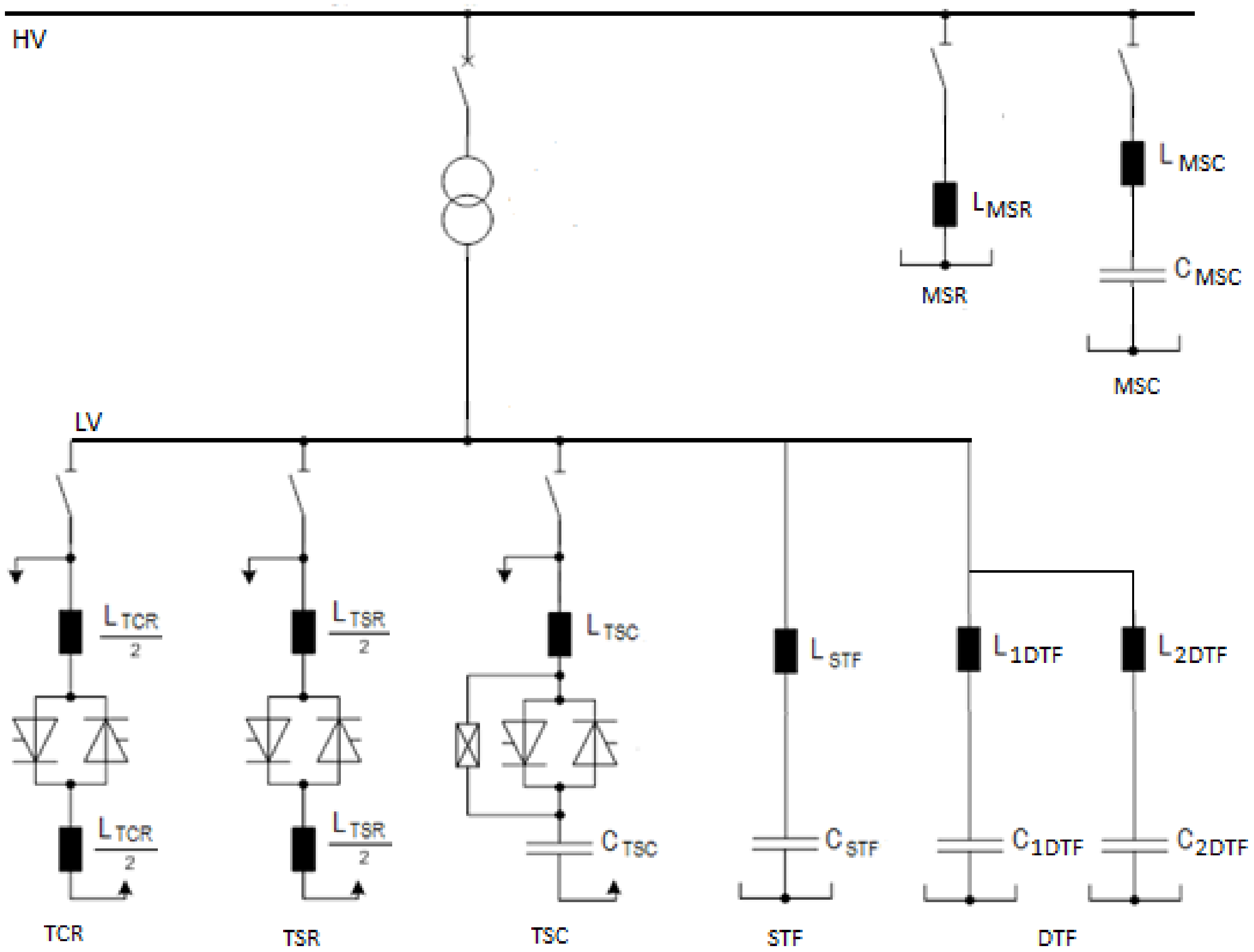

Possible components of the SVC classic®

- Thyristor-Controlled Reactor (TCR)
- Thyristor-Switched Capacitor (TSC)
- Filters (single- or double-tuned)
- Thyristor-Switched Reactor (TSR)

Thyristor-Controlled Reactor

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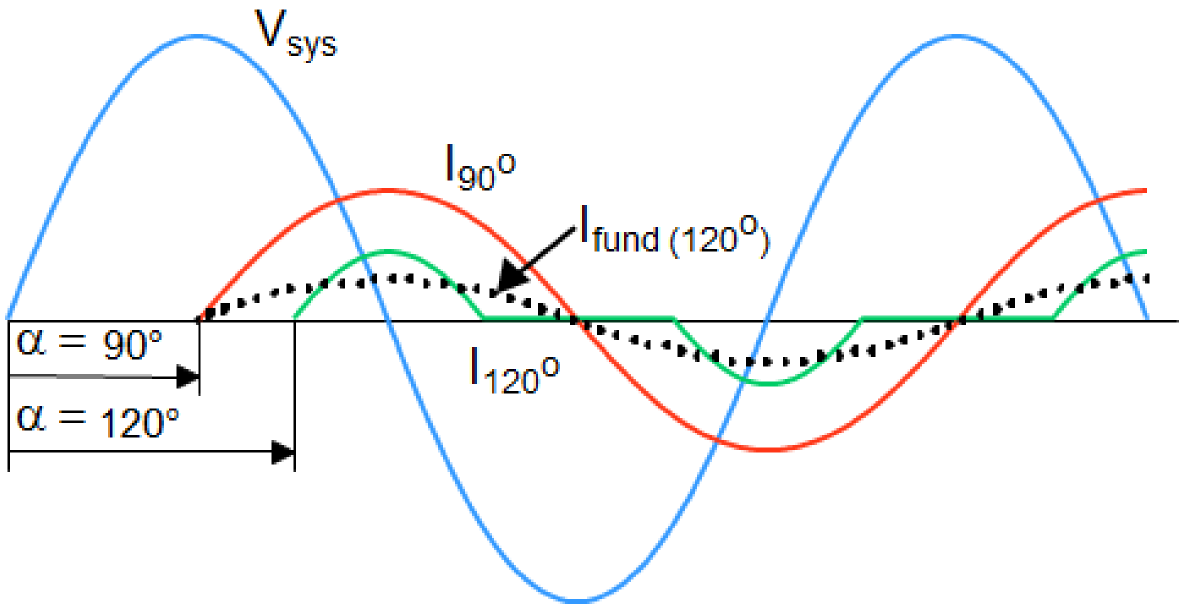
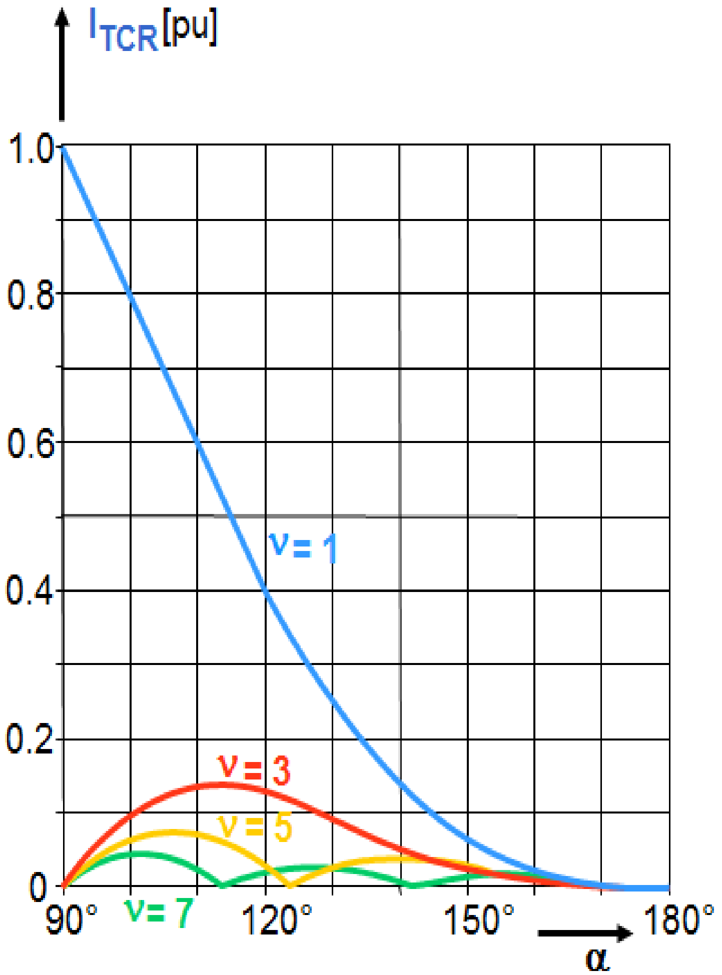
$$B(\alpha) = \frac{2(\pi - \alpha) + \sin 2\alpha}{\pi \cdot X_L}$$

α – firing angle in radians

X_L – reactance of the TCR in Ω





TCS + Filters, TSC

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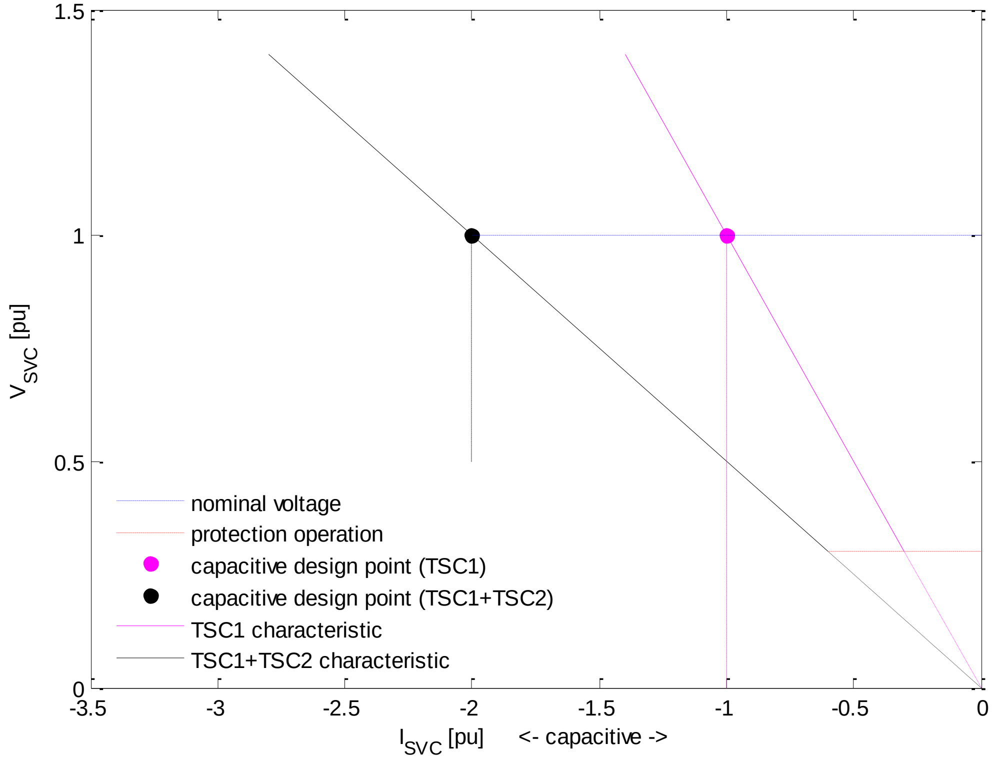
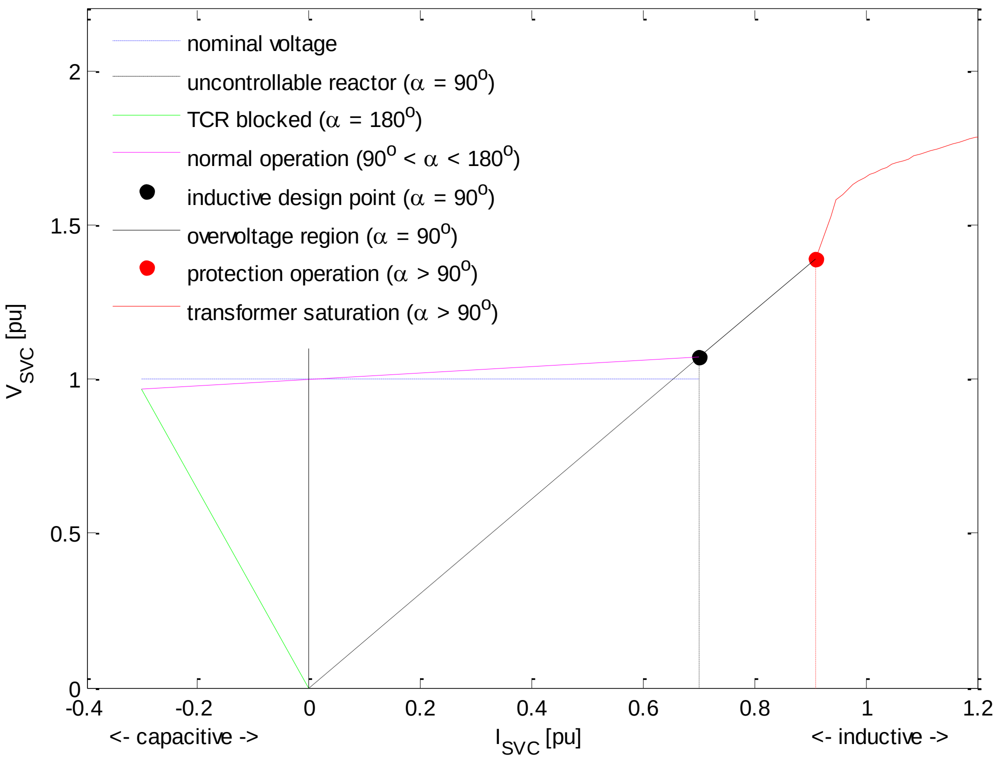
$$i_C(t) = C\frac{dv_C(t)}{dt}$$





STATCOM / Voltage-Source Converter (VSC)

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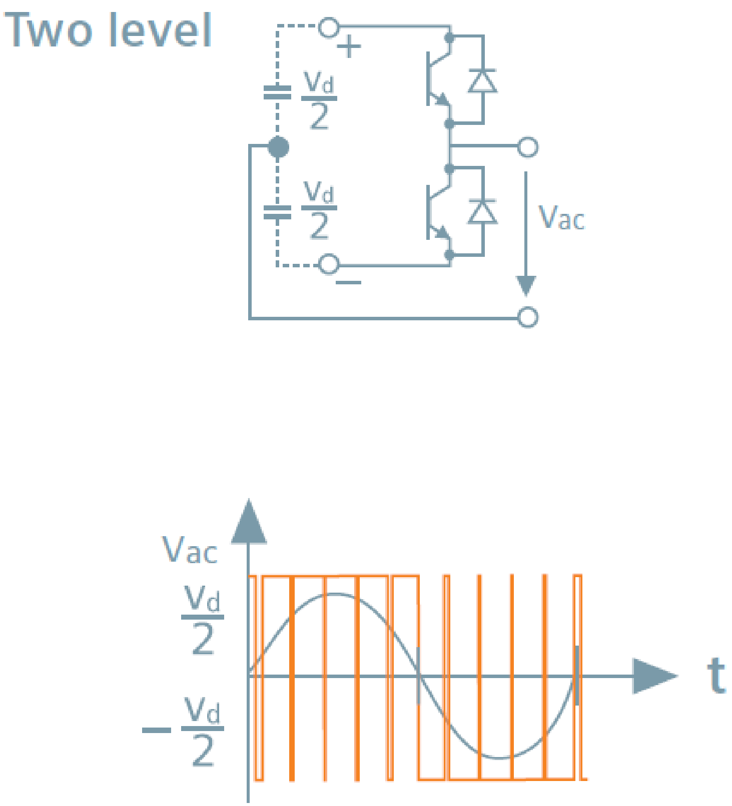

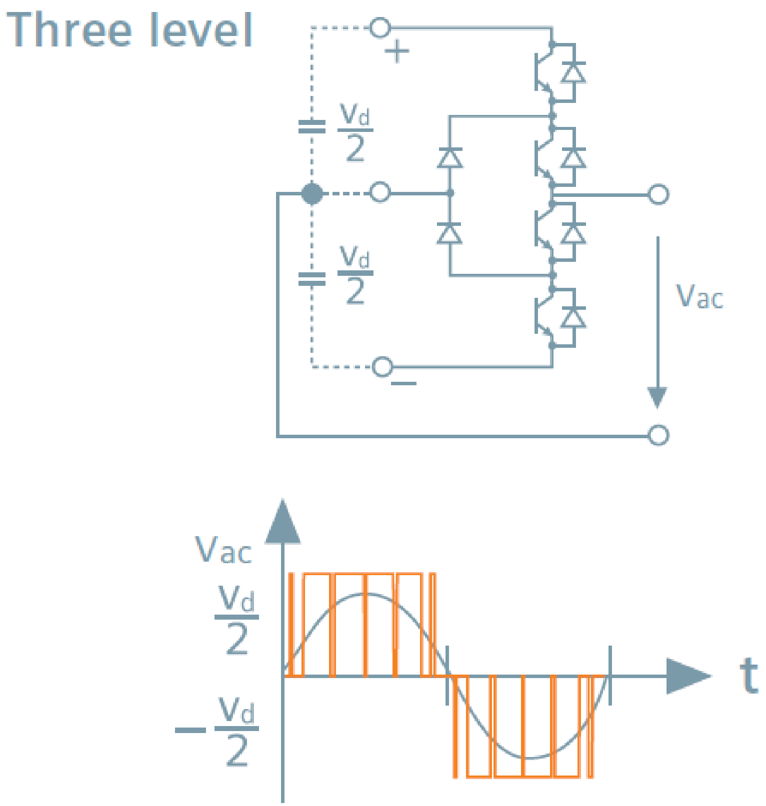

The total charge of the DC capacitors of the VSC plays the role of a DC voltage source, which is converted into controlled AC voltages (V_{VSC}), which can be synchronized with the power system voltages (V_N), by the voltage-sourced converter (VSC).

First VSCs on the market had respectively: two and three levels.

Modular Multilevel Converter (MMC)

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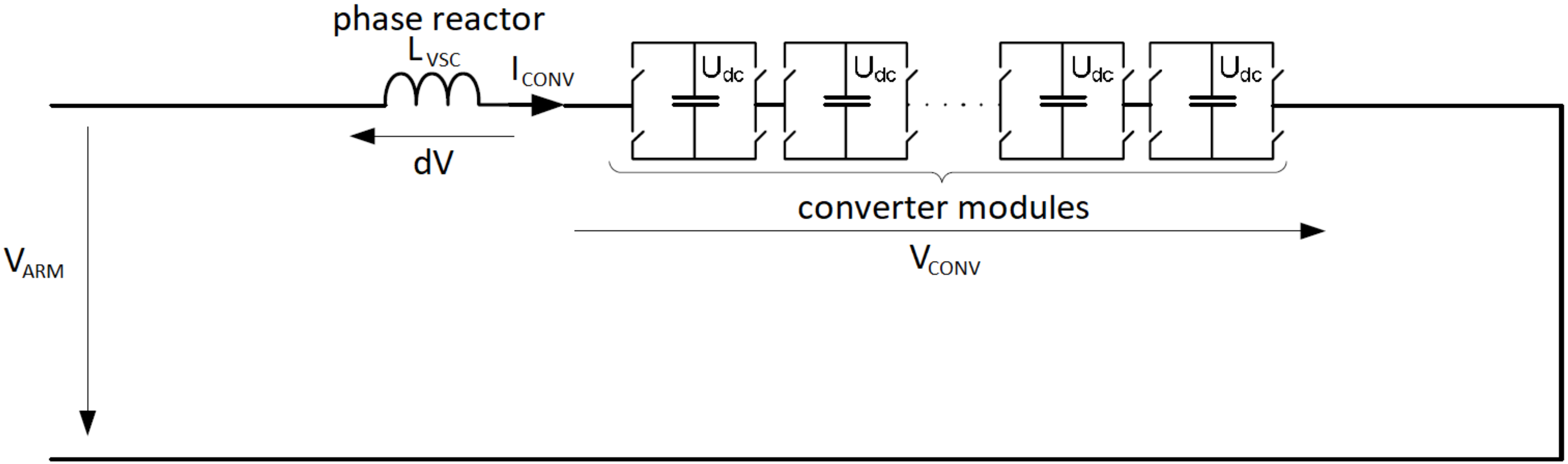
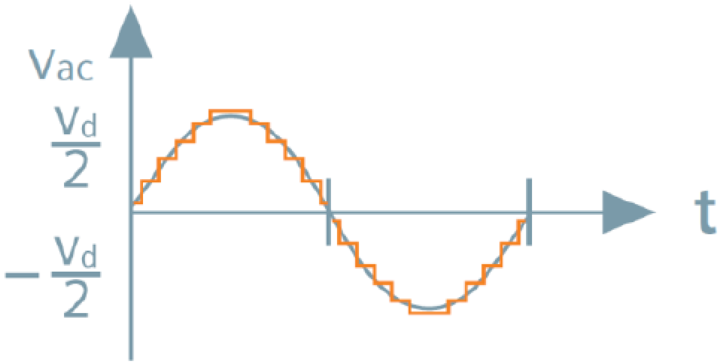
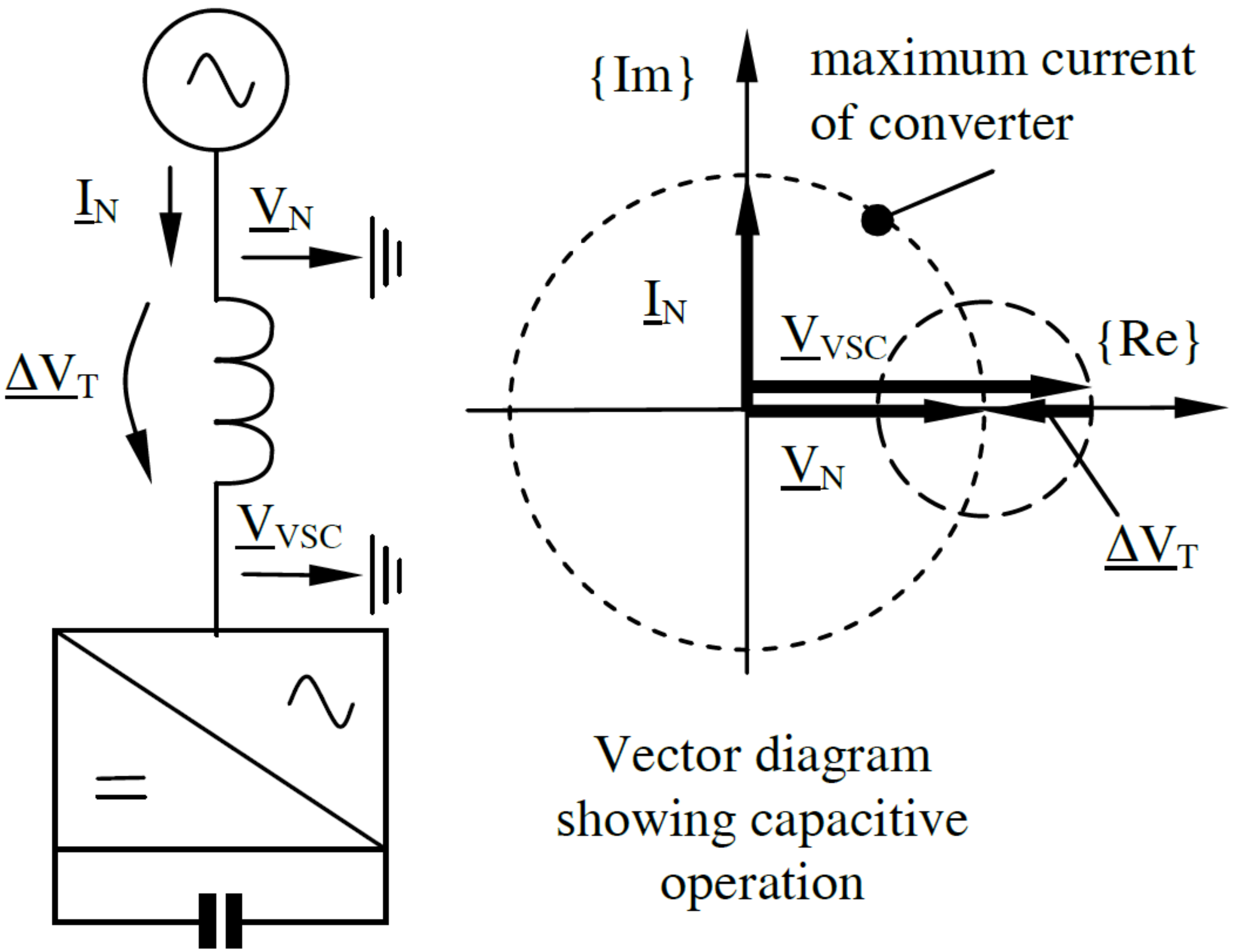


SVC PLUS® is a Siemens STATCOM which uses voltage-sourced converter technology based on modular multilevel converter (MMC) design. The MMC provides a nearly sinusoidal voltage waveform. Therefore, SVC PLUS® does not inject any significant harmonics and can work without any filters.



Operation Principle of the STATCOM



Vector diagram showing capacitive operation

The control of the reactive power flow is realized by the varying voltage's magnitude. If $V_{VSC} > V_N$, the voltage drop across the reactance, ΔV_T, becomes negative so that the current, I_N, leads the V_{VSC} voltage by 90 degrees. Then, the STATCOM operates as a capacitor and supplies reactive power. In the opposite situation: $V_{VSC} < V_N$, the current lags the V_{VSC} voltage by 90 degrees so that the STATCOM acts like an inductor and absorbs reactive power.

Control of the SVC PLUS®

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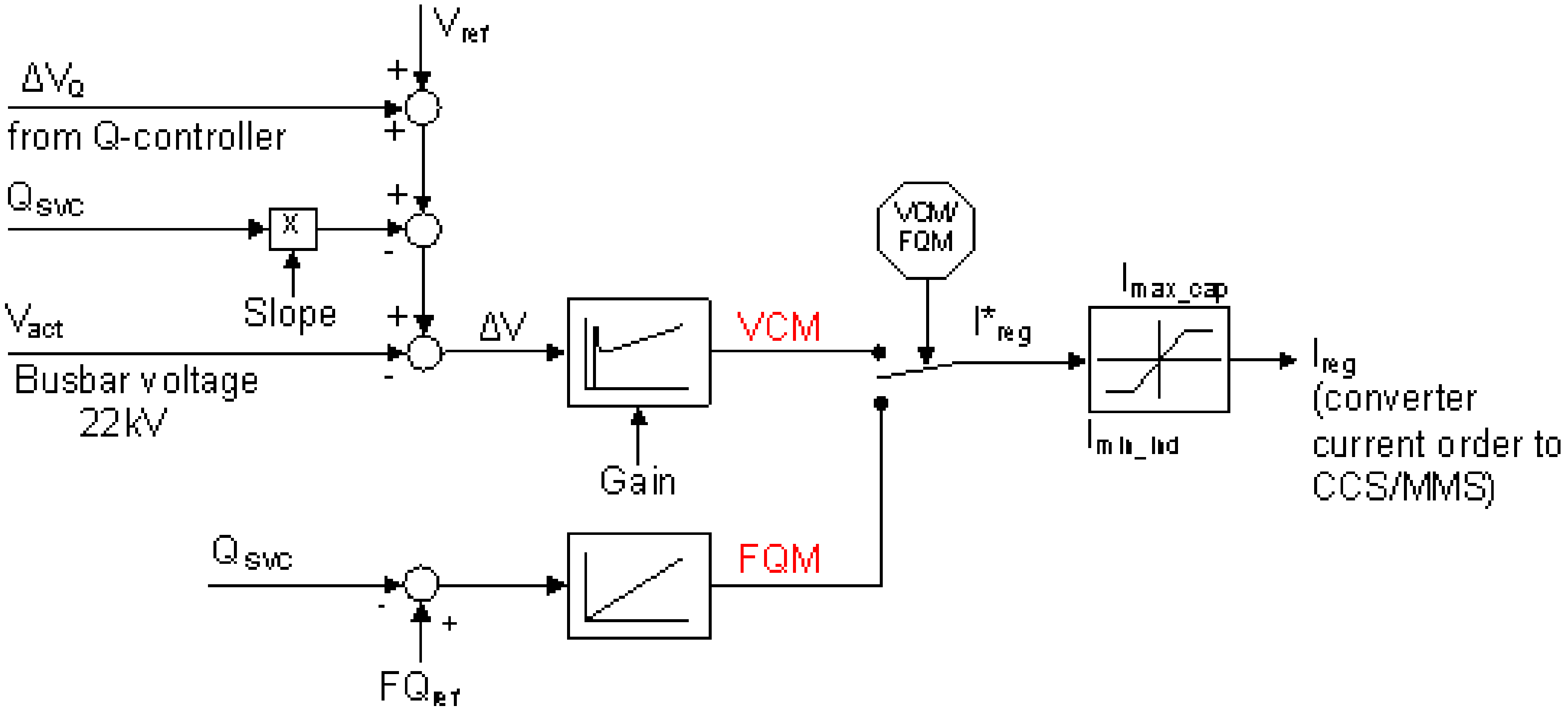
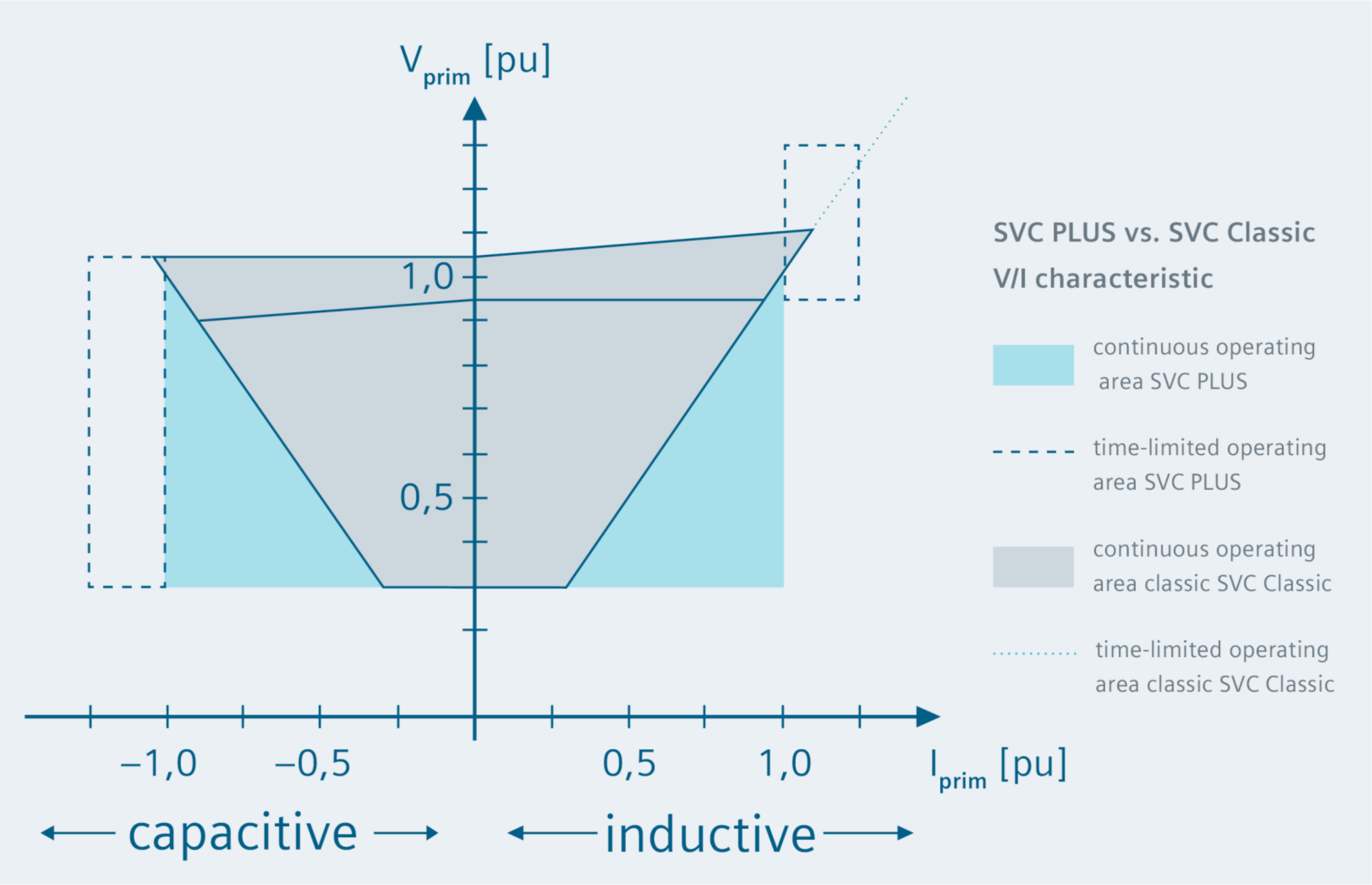
1. Voltage Control Mode, where the SVC PLUS® injects current in order to obtain desired voltage level – this control mode was used in this study.

2. Reactive Power Control Mode, where the SVC PLUS® keeps constant output reactive power.



V / I Characteristic: STATCOM vs SVC



During the operation, the converter of the device keeps required charge level of the individual capacitor. At all times capacitors have almost constant voltage so the range of operation is nearly independent of the system voltage. This is a great advantage in comparison to SVC technology and means that the STATCOM is more efficient during under-voltages.

Losses: STATCOM vs SVC

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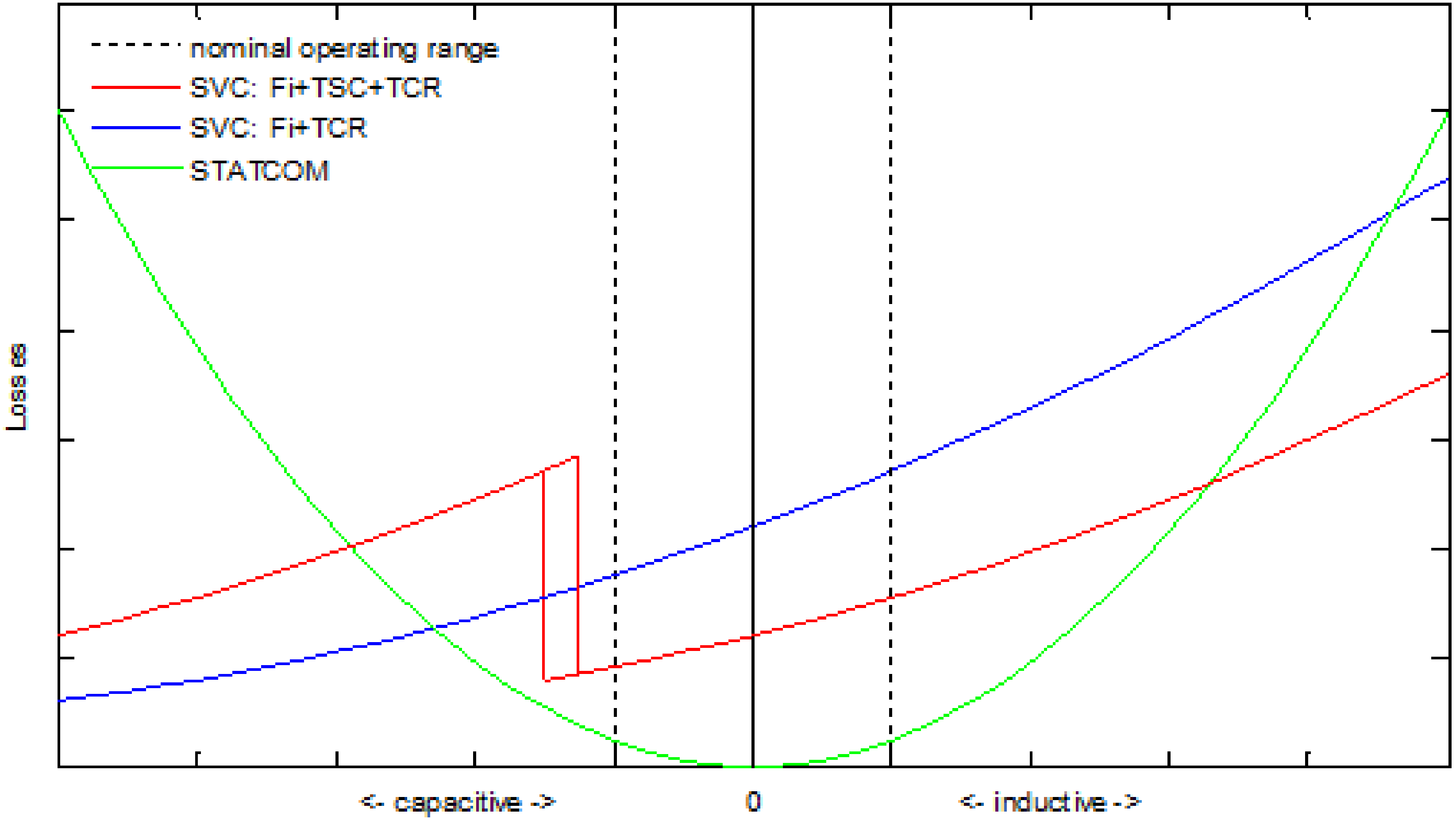

The MMC technology allows the usage of low switching frequencies, which reduces losses of the STATCOM.

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An example of the study:

Compensation of the Voltage Fluctuations in the Distribution Network of London Underground using the SVC PLUS®

Presented on IET ACDC 2019 (07.02.2019) in Coventry, UK

Voltage Fluctuation Study – Content

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Introduction

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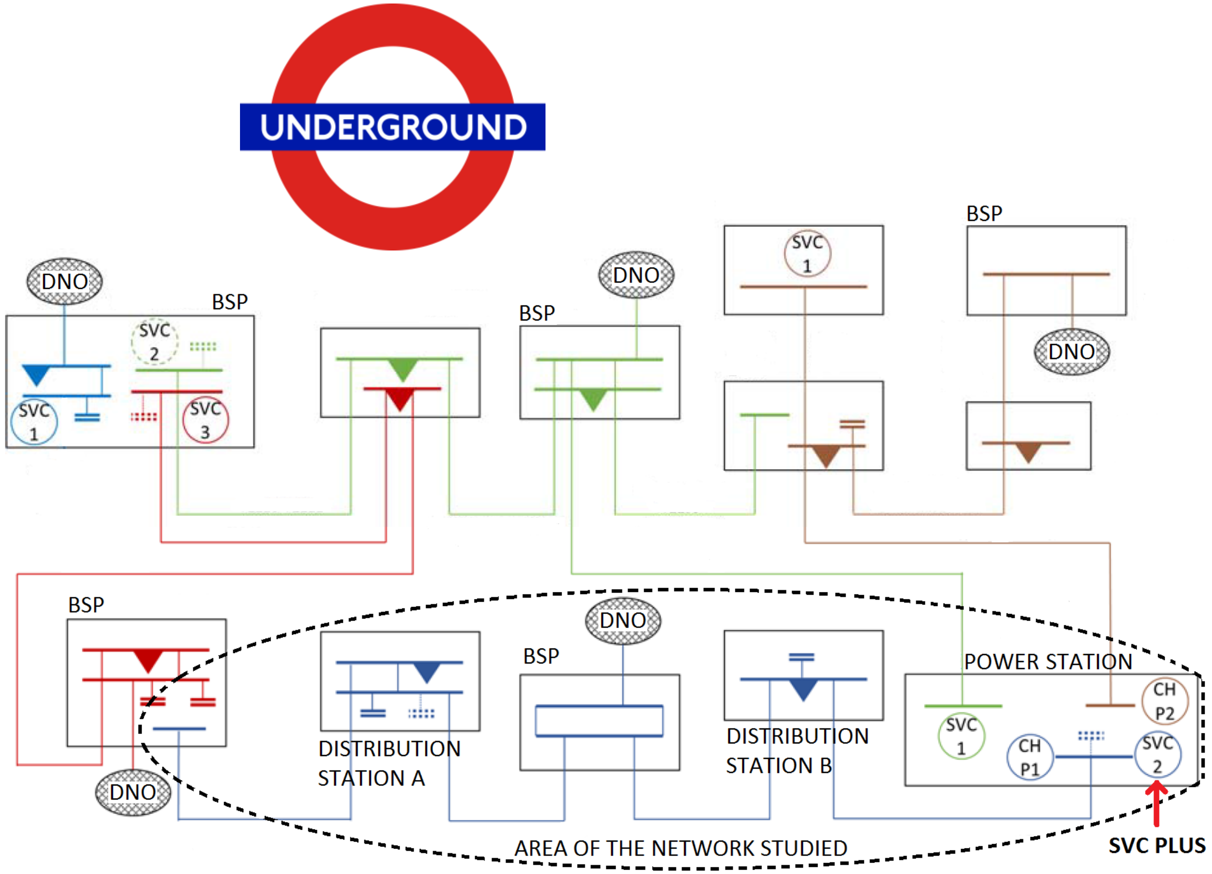
1. Voltage fluctuations are a very common phenomenon in industrial and railway traction networks, where power consumption changes quickly and unpredictably.

2. Voltage Fluctuation Study was a part of the project, whose main objective was an installation of the ±37MVAr Siemens STATCOM (SVC PLUS®) in LU's 22kV network.

3. The SVC PLUS® was installed in order to improve the voltage quality in the LU's 22kV network to provide the possibility to increase the number and frequency of trains in future.



Model of the 22kV Network of London Underground

Defined Scenarios

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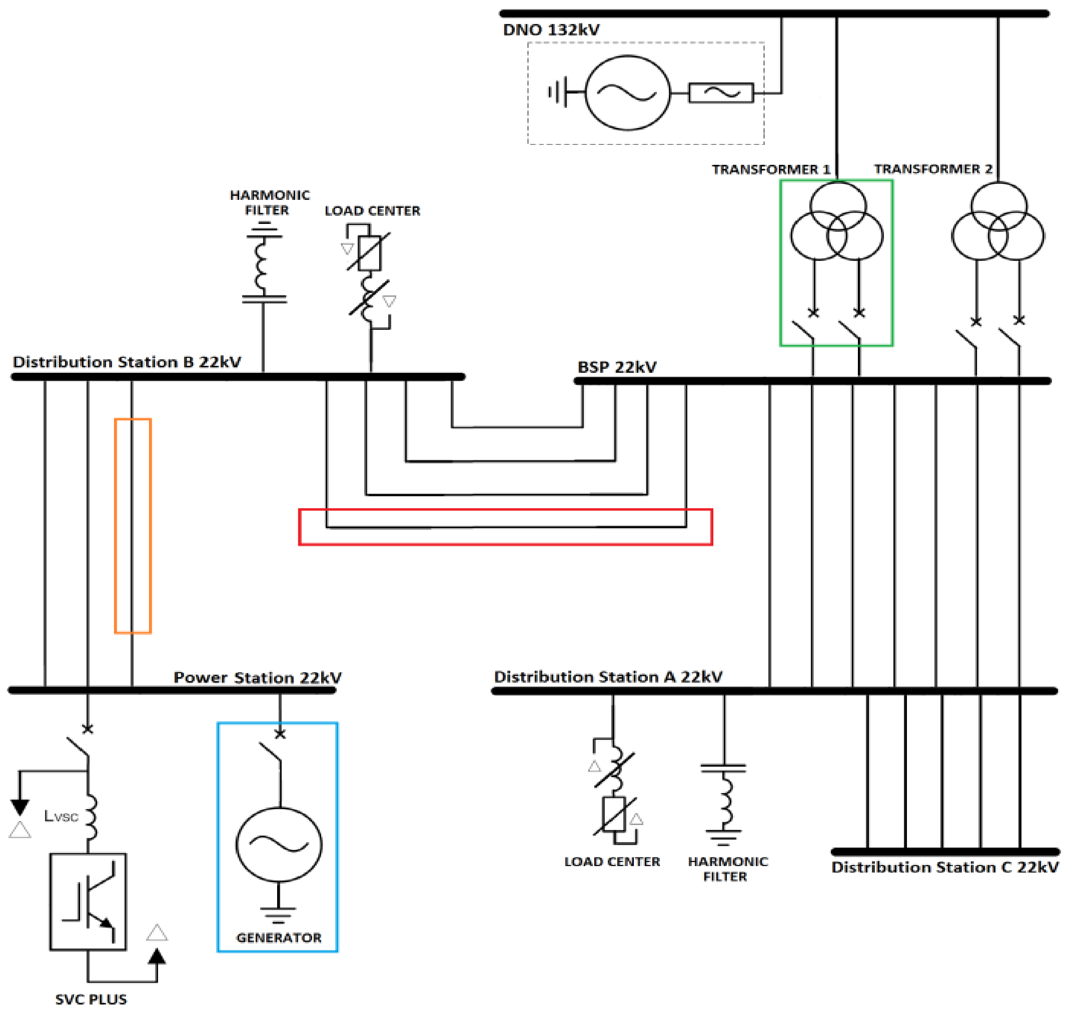
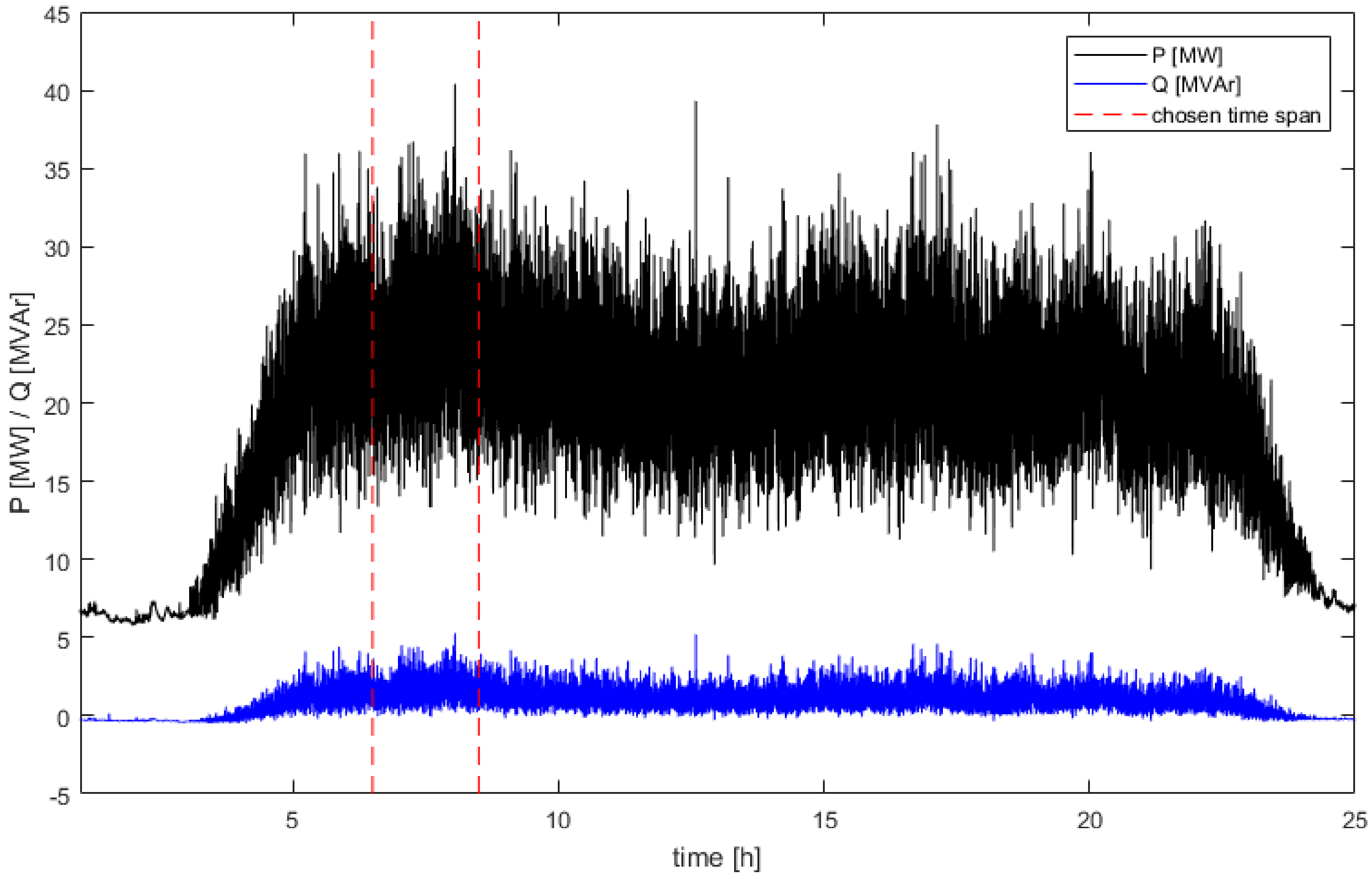
No.	Description
S1	No outage
S2	Out of service: one of the DNO BSP transformers (green)
S3	Out of service: one of the cable lines between LU Power Station and LU 22kV Distribution Substation B (orange)
S4	Out of service: one of the cable lines between DNO BSP Substation and LU 22kV Distribution Substation B (red)
S5	Switch-in one generator unit at LU Power Station (blue)
S6	Projected worst-case profiles at full BSP load



Train Loads
Daily Load Curves



Daily load curves were measured using FLUKE measuring unit during the normal operation of trains.

From the recordings the day with the highest load fluctuations was chosen.

The two-hour time span between 6:30 a.m. and 8:30 a.m. was chosen for the load implementation.

The same time-span was chosen for two aggregate train loads.

Train Loads

Projected Worst-Case Profiles at Full BSP Load (Scenario 6)

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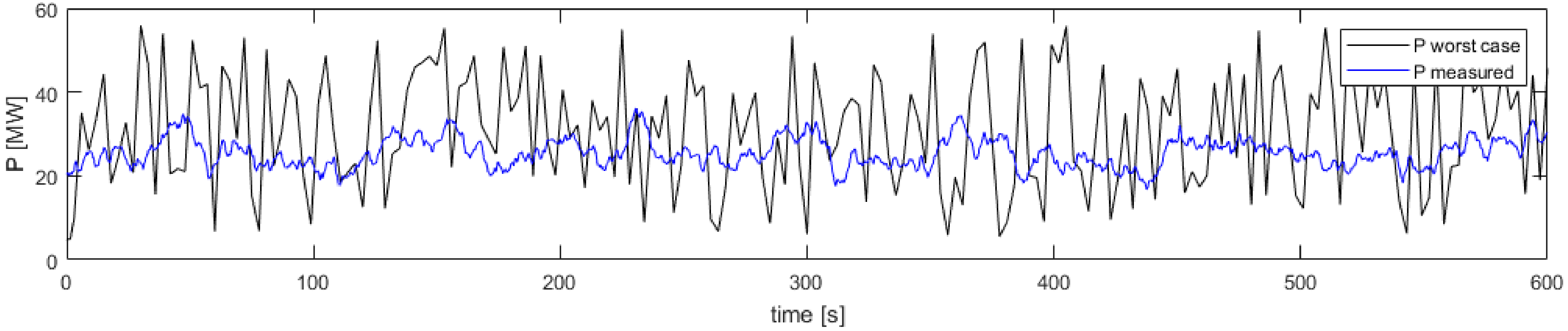

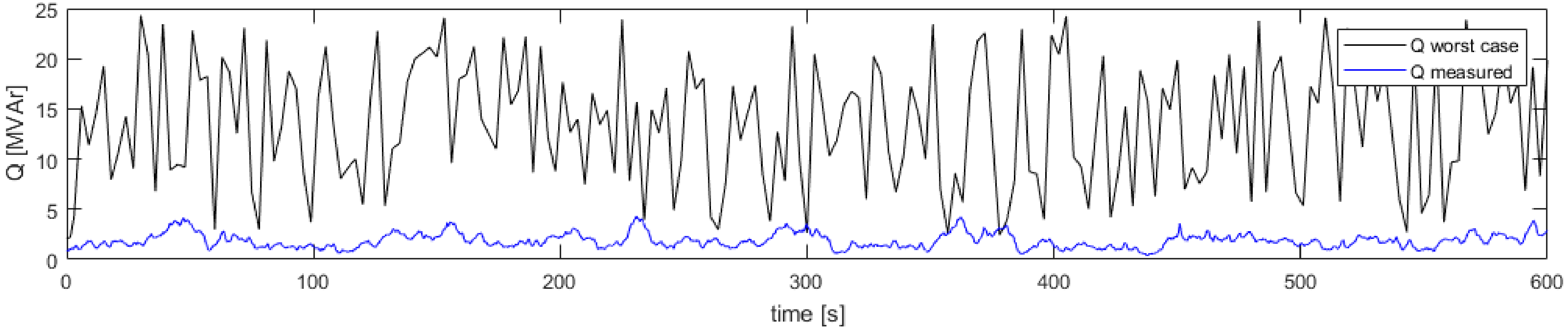

Voltage Fluctuations
Indicators and Limits

1 To asses voltage fluctuations following indicators were used:

- Flicker Severity (Pst)
- Maximum rapid voltage changes (d_{max})
- 95th percentile of the maximum rapid voltage changes (d_{max95})

2 The planning level of Flicker Severity equals to 0.9 for 22kV network and 0.7 for 132kV network.

3 The maximum rapid voltage changes should be below 3% in 22kV network and below 1% in 132kV network (same limit applies to 95th percentile of the maximum rapid voltage changes).

4 The model of the LU‘s network was created in DigSILENT PowerFactory, which is an RMS simulation software and which allows to efficiently simulate long time spans (i.e. 10min for flicker evaluation).

Voltage Fluctuation Results

22kV Side

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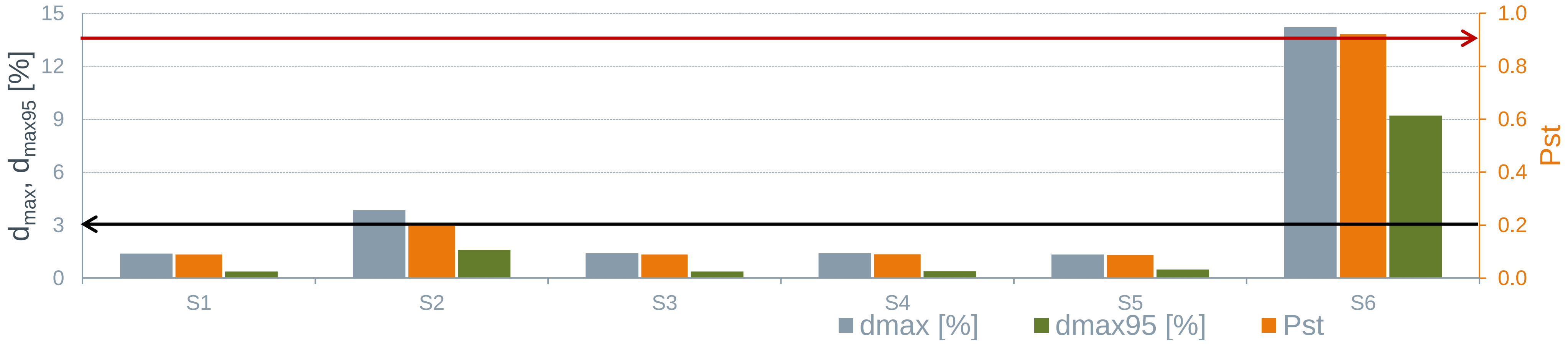
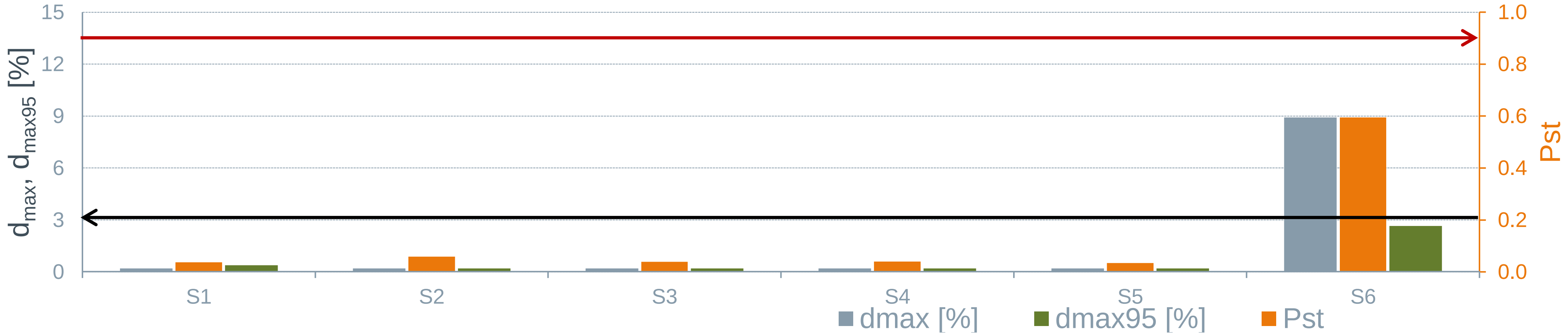
Without SVC PLUS®



With SVC PLUS®



Voltage Fluctuation Results

132kV Side

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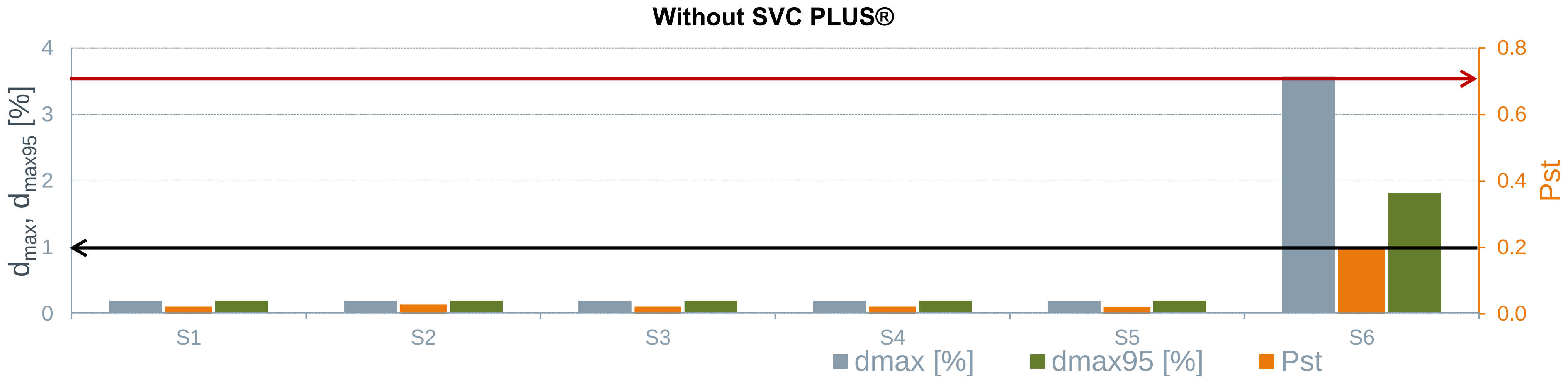

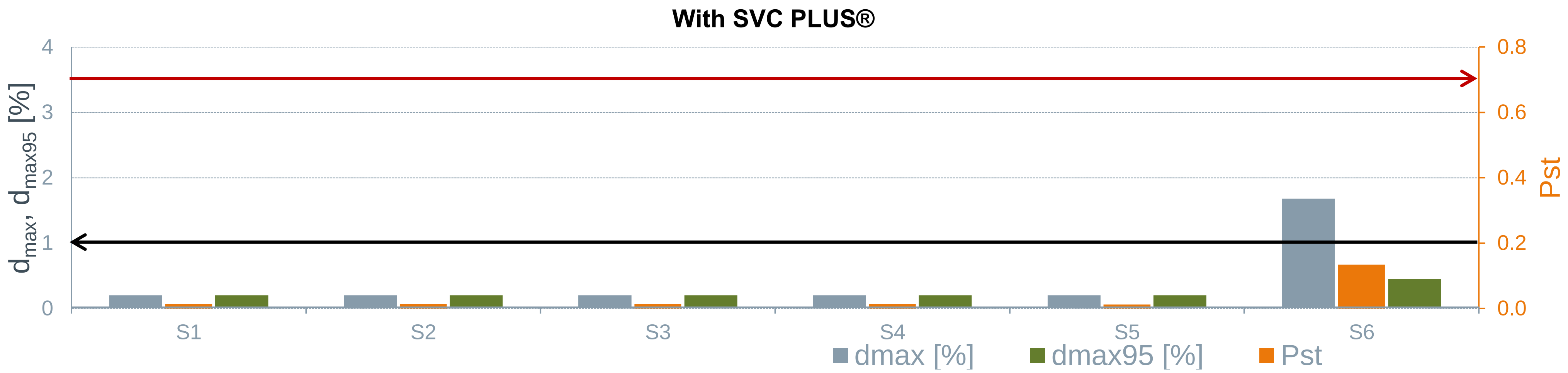

Voltage Profile Comparison

Projected Worst-Case Profiles at Full BSP Load (Scenario 6)

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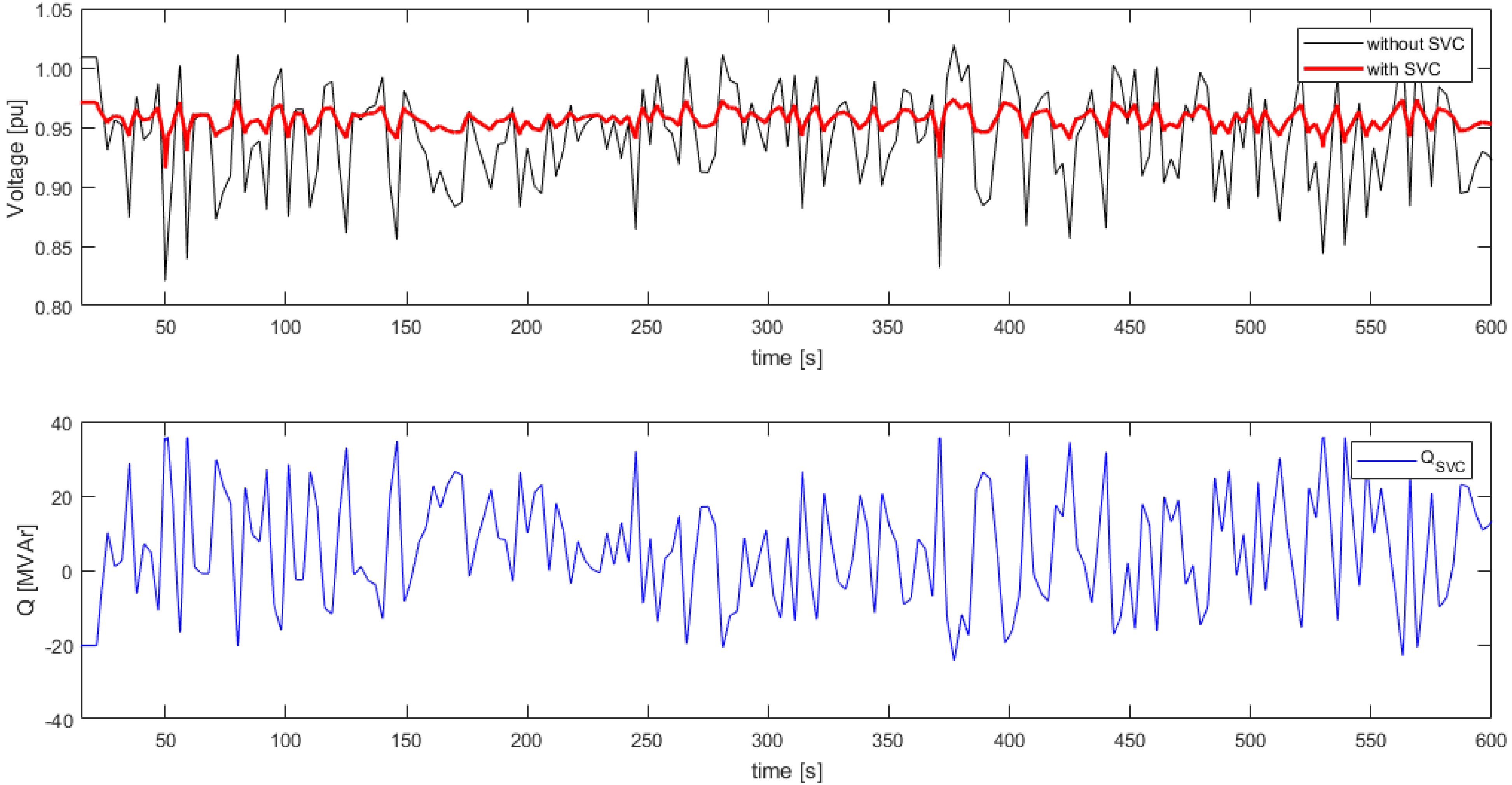

Conclusions

1. The voltage quality of the studied part of LU‘s network is mainly affected by 2 aggregated train loads.

2. The SVC PLUS® is an efficient solution for improvement of the voltage quality.

3. The LU‘s network with the SVC PLUS® meets all IEC standard criteria regarding the voltage fluctuations in all analyzed scenarios and gives sufficient margin for any train load peaks during the year.

4. The SVC PLUS® gives the network operator possibility to increase the amount and/or size of the fluctuating loads without easily compromising the power quality in the network.

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From the Model to the Real Implementation

Siemens Converter Factory

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VSC of the SVC PLUS®

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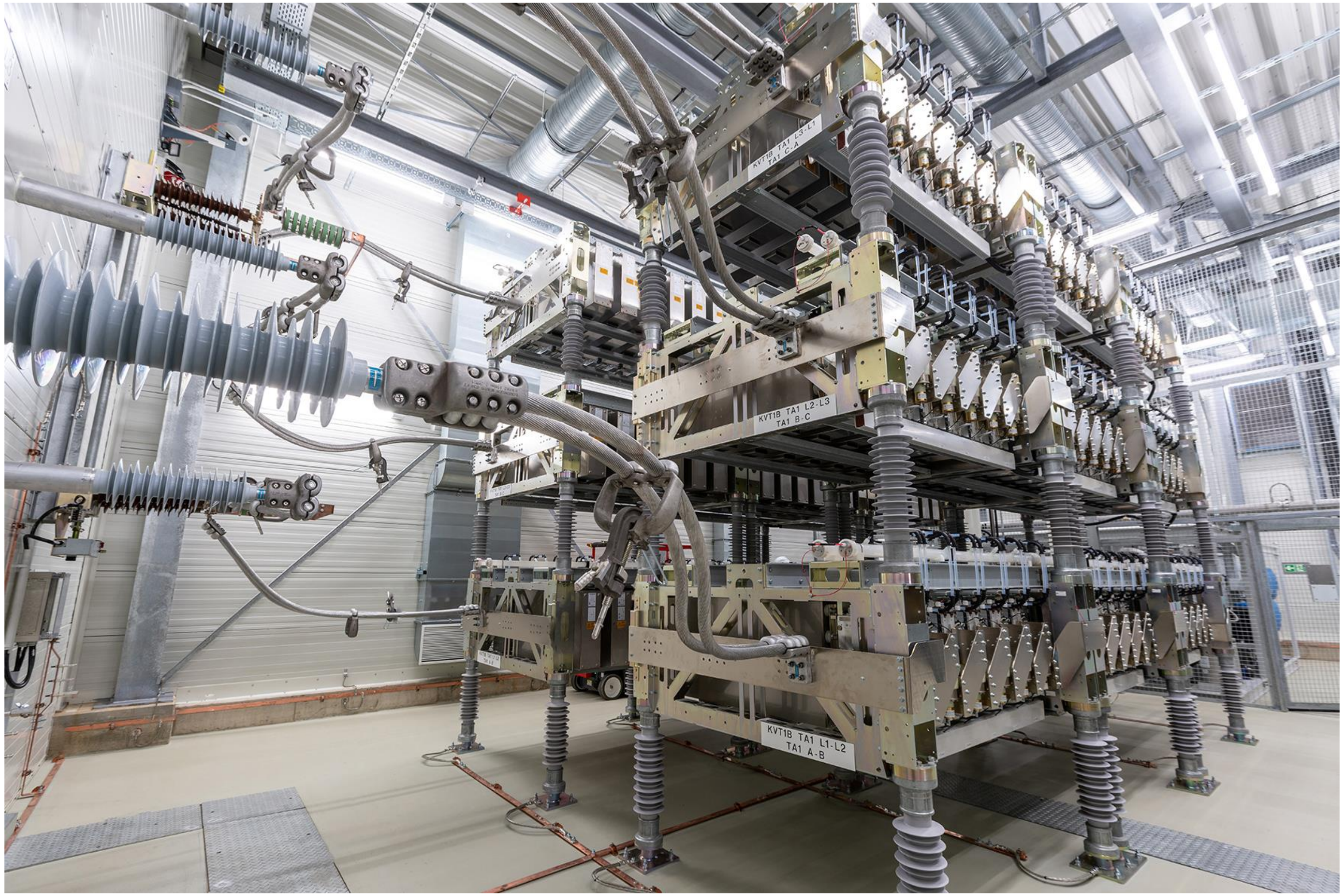

Complete Installation

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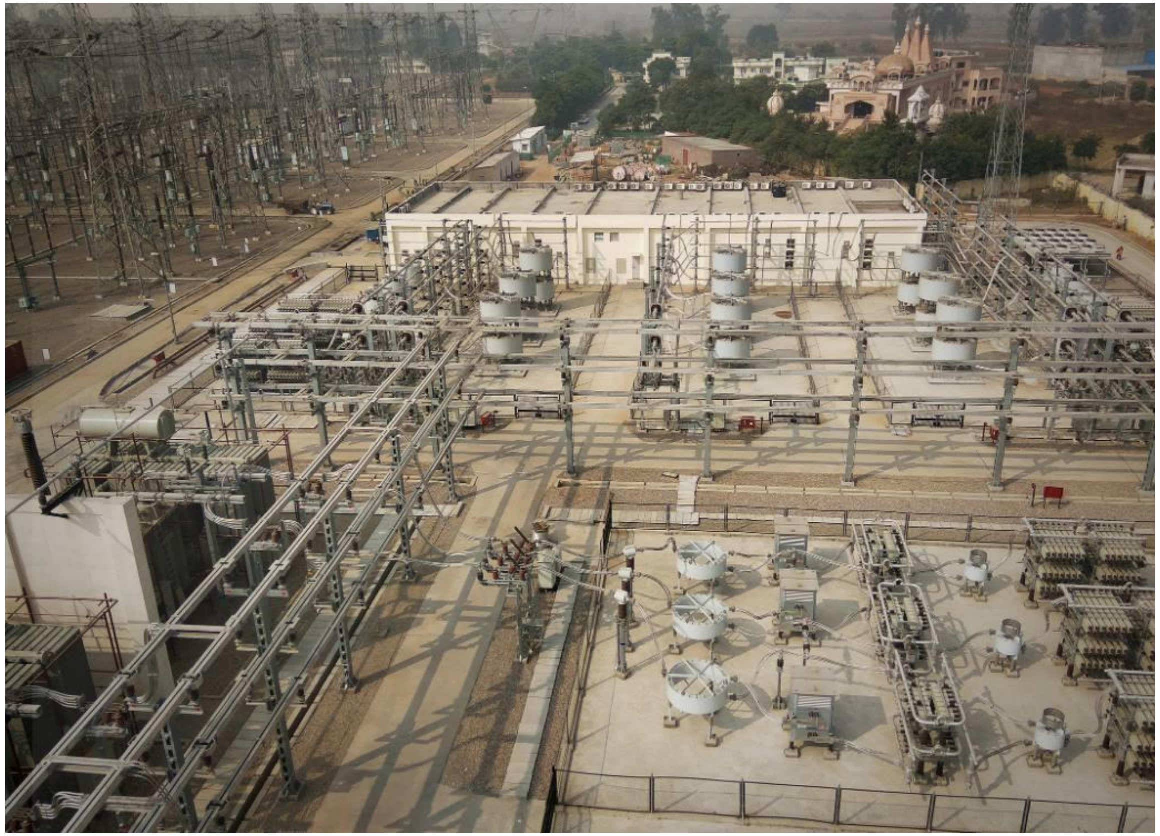

Thank you for your attention!

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