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Possible Benefits for Shunt Capacitor Bank Applications

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1- Introduction

2- Technical aspects

3- Benefits for the circuit breaker

4- Benefits for the Capacitor units

5- Benefits for the system (power quality issues)

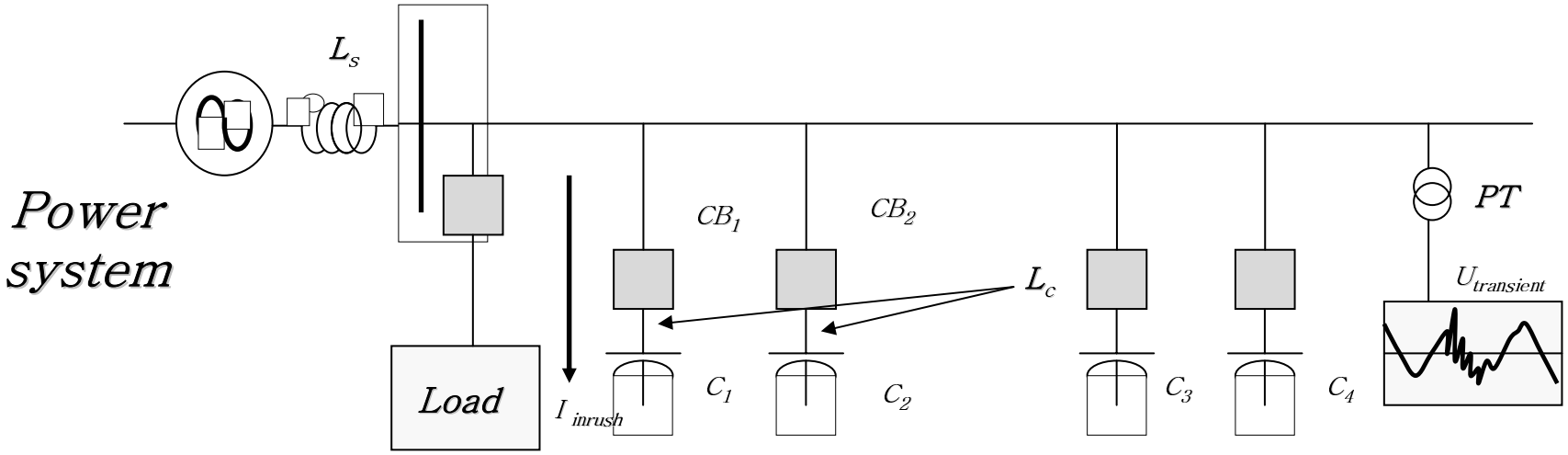
6- Benefits for other equipment

7- Basic conditions for successful implementation

1- Introduction

- Shunt Capacitor Banks (SCB) are used to produce the reactive power needed to compensate loads, reduce losses and to ensure the voltage stability of power system
- They are usually switched very frequently (300 to 700 times/year)
- Important transient currents and overvoltages are produced when they are switched
- Conventional solutions : Pre-Insertion Resistors (PIR)
- Alternative solution : Controlled Switching Systems (CSS)

2- Technical aspect: Example of a back-to-back configuration



$$i_{inrush} = \frac{\sqrt{2}}{\sqrt{3}} \times U_{l-l} \times \sqrt{\frac{C_{eq}}{L_{eq}}}$$

$$f_{inrush} = \frac{1}{2\pi\sqrt{L_{eq} \times C_{eq}}}$$

$C_{eq} =$ Equivalent line to ground capacitance

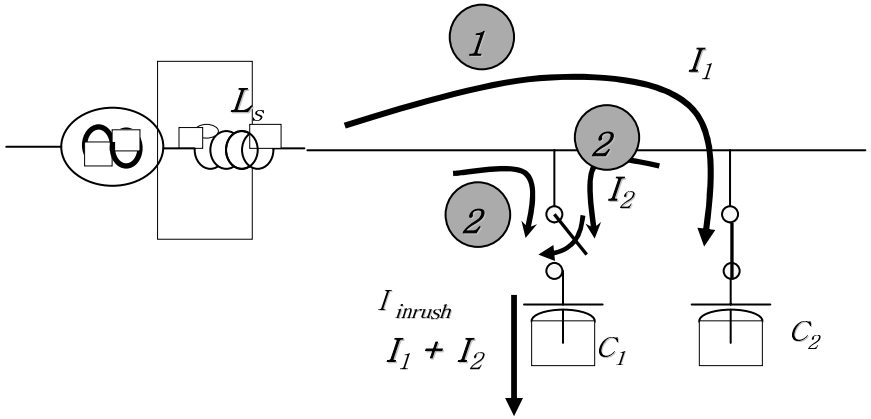
$L_{eq} = L_s + L_c$ Equivalent inductance between the source and the capacitor bank

$U_{transient}$: *1,5 to 1,7 p.u. typically*

2- Technical aspect: Example of a back-to-back configuration

1. *In a back-to-back configuration, the first capacitor bank to be energized will result in the worst transient overvoltages disturbances (up to 2,0 p.u.) but will show a smaller inrush current.*

2. *The last capacitor bank to be energized will result in the highest transient current (few tens of kA) and will create transient overvoltages of lower amplitude.*



3- Benefits on Circuit breakers

- *Less Electrical wear*
- *Enhanced restrike-free performances*
- *Reduced Mean Time Between Maintenance (MTBM)*
- *Reduced major failure probability*

3- Benefits on Circuit breakers

➡ ***Example for Evaluation of Electrical wear for 25 years of service (refer to document IEC 17A/629/DTR issued by WG 29 of SC 17)***

	Uncontrolled switching	Controlled switching	Electrical endurance requirements (IEC 17A/629/DTR) Note1
Equivalent Electrical wear for 25 years of service *	107 T60	3,4 T60	21 T60
Assumptions made	Average pre-arcing time = 4 ms Average inrush current = 5 kA Nb of operations = 700/year	Average pre-arcing time = 2 ms Average inrush current = 2 kA Nb of operations = 700/year	

**** Based on equivalence law considered in document IEC 17A/629/DTR***

For interruption of current lower or equal to 35% of rated short circuit current: $N_I = N_{35} (I_{35}/I)^3$

For interruption of current higher than 35% of rated short circuit current: $N_I = N_{35} (I35/I)^{1.7}$

Where : N_{35} = number of current interruption at 35% of rated short circuit current , N_I = number of current interruption at current I

I_{35} = 35% of rated short circuit current

Note1 : IEC 17A/629/DTR is a technical report under issued by WG 29 of IEC. This report evaluates the electrical wear stresses of the line CB

3- Benefits on Circuit breakers

➡ *Enhanced restrike-free performances*

Restrike probabilities of the CB according to IEC 62271-100

- *C2 : very low probabilitiy :* ➡ *168 capacitive current interruptions*
- *C1 : low probability:* ➡ *48 capacitive current interruptions*

➡ ➢ *CB can not be categorized <restrike-free>*

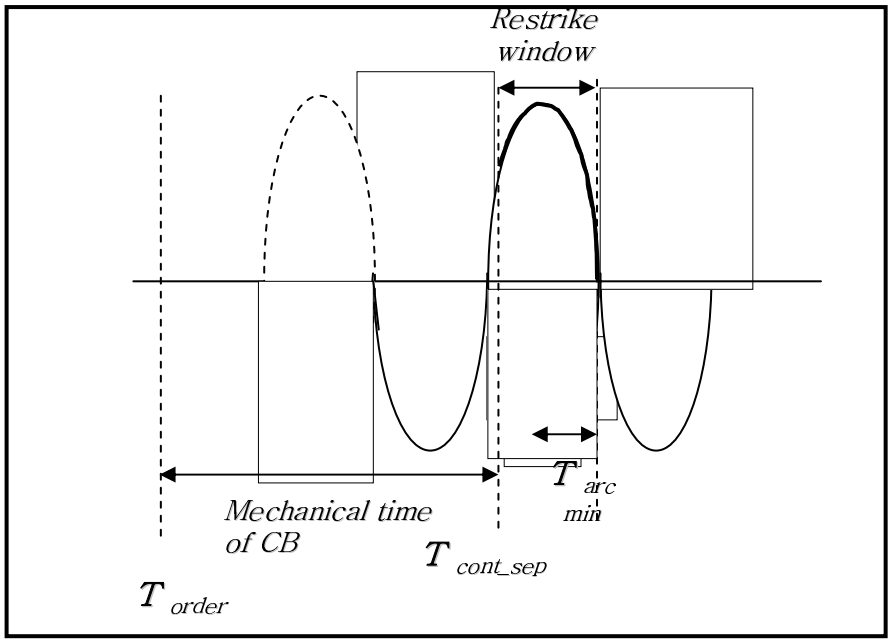
➢ *Due to the great numbers of operations, it is not impossible that the CB will restrike during its lifetime*

➢ *Restrike on modern SF6 CB could cause permanent damages to nozzles and arc contacts, thus reduce breaking capabilities of CB and increasing the risk of major failure.*

3 - Benefits on Circuit breakers

➡ *How does CSS improves the restrike-free performances ?*

➡ *By fixing the contact separation out of the restrike window determined during type tests*



3 - Benefits on Circuit breakers

→ *Increased Mean Time Between Maintenance (MTBM) -*

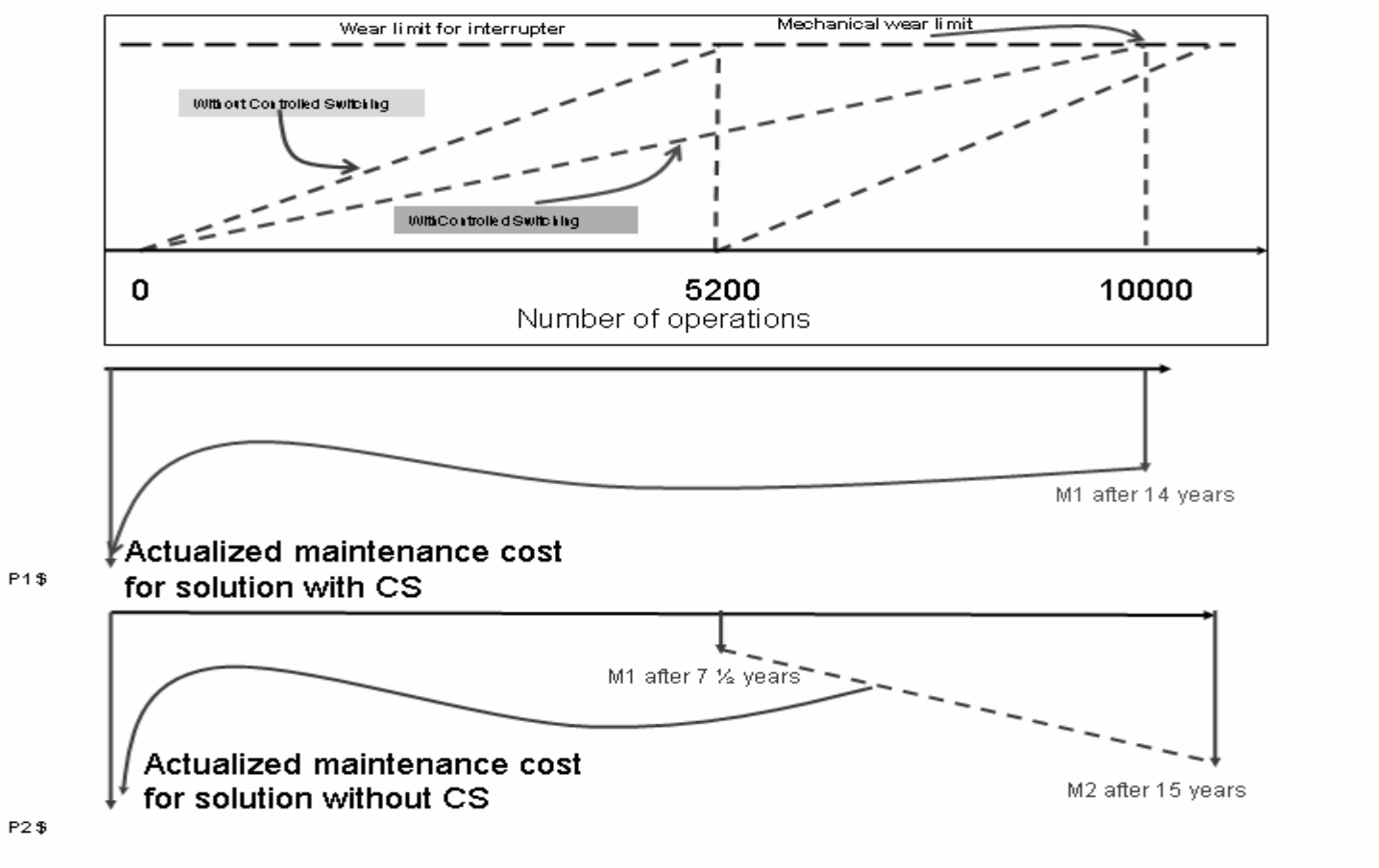
Electrical wear vs mechanical wear

- *CB intended for SCB switching need generally a lot of maintenance*

→ *work due to the high number of operations*

- *Today's CB are provided with 10 000 mechanical operations (M2 class of IEC), therefore, electrical wear becomes the first reason for having a major maintenance operation*
- *Major overhaul is generally needed after 1500-2000 operations on most of CB installed in the field*
- *CSS could help to increase the MTBM*
- *Not enough field experience with CSS on SCB to measure the direct effects of CSS on the MTBM (depends on CB designs, electrical stresses, etc.)*

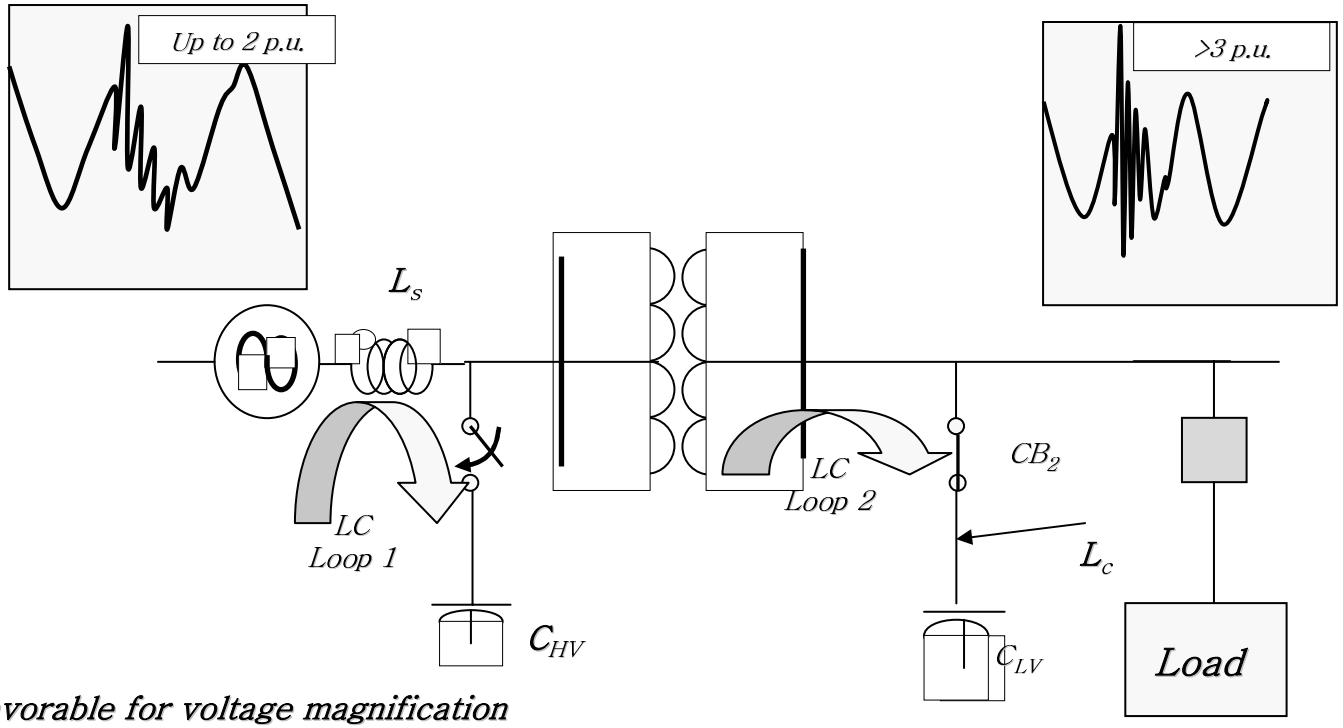
Example of maintenace schedule (electrical wear vs mechanical wear)



4 - Benefits on Capacitor banks

- *Capacitor units are designed considering that the CB is restrike-free, which is not necessarily the case*
- *Reduced stresses imposed by transient overvoltages and currents*
- *Reduce risk of cascade failure (especially for old technology)*
- *Could reduce the manufacturing costs because higher electrical gradient may be used – Furnas example, 45% cost reduction*

5- Benefits on Power system :Voltage magnification effects



Conditions favorable for voltage magnification

- $C_{HV} >> C_{LV}$
- $f_{HV} \sim f_{LV}$
- *weak load*

Références:

1- Magnification of transient voltages in multi-level shunt capacitor compensated circuits. D. Dunsmore and al., IEEE proceeding PES-T&D conference Dallas, pp. 898-907, sept 1991

2- Impact of Utility switched capacitors on customers – Magnification at low vo9ltage capacitors, M. F. McGranaghan and al. IEEE proceedings PES-T&D conference Dallas, pp. 908-914

5- Benefits on Power system :Voltage magnification effects

- *Can result in important line-to-line overvoltages at remote substations (dammageable for line-to-line insulation, ex. transformers, ..)*
- *Deterioration of the power quality at low voltage (Adjustable Speed Drive)*

Voltage magnification effects

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6 – Benefits on other equipment

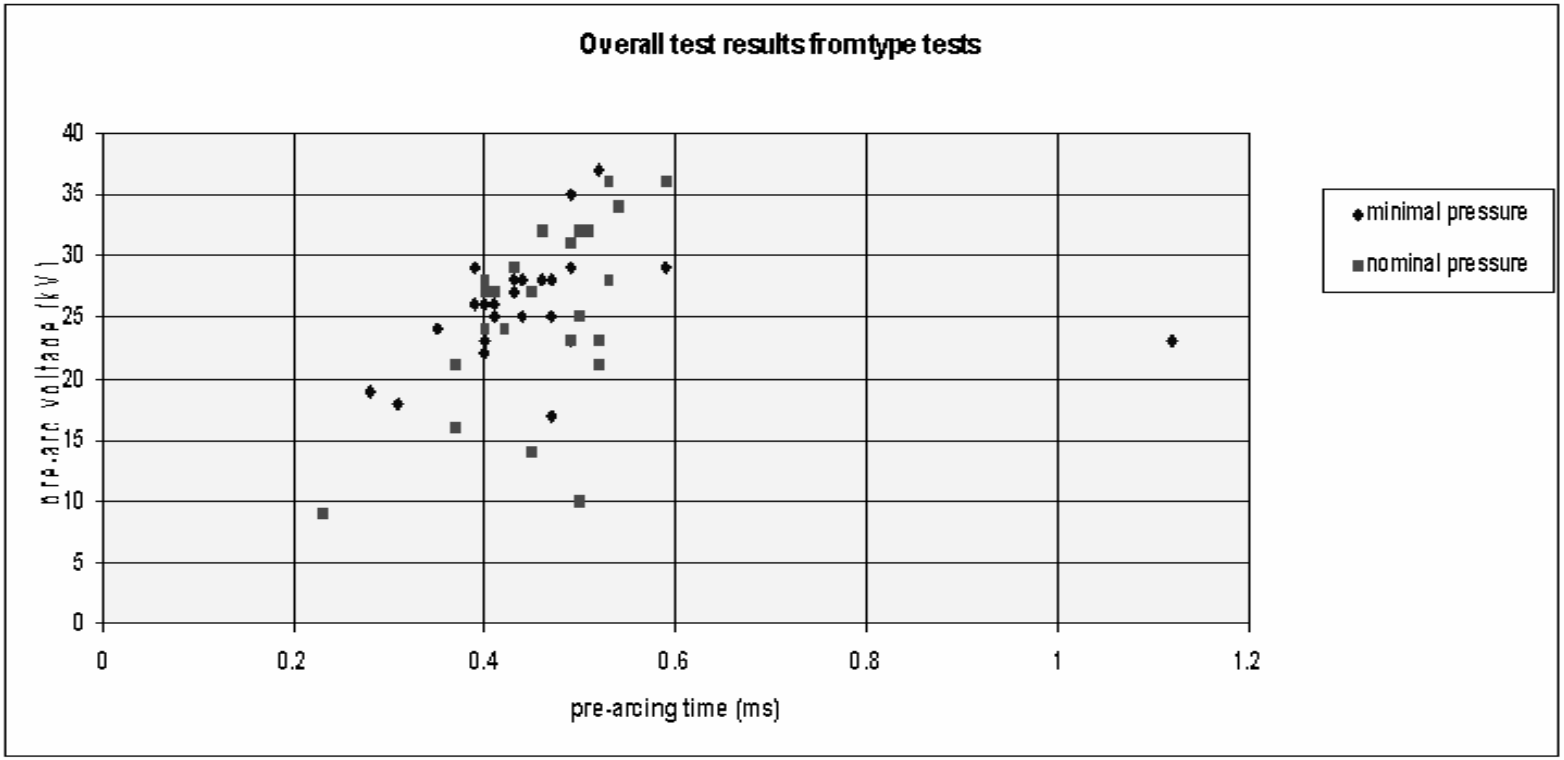
- *Transient overvoltages and currents can cause dammages to other equipment in the S/S (PT, CT, damping reactor, other equipment using paper/oil insulation)*

7 - Basic conditions for successful implementation of CSS

- *Suitability of the CB*
  - *Rate of Decrease of Dielectric Strength (RDDS) at least equal to the maximum voltage sine wave slope*
  - *consistent operating time of the CB (typically ± 1 ms)*
- *Controller performances*
  - *ability to compensate for influencing factors on operating times (ambiant temperature, drive energy, control voltage, idle time)*
  - *ability to inform the operators by the means of alarms in case of malfunction (wrong target time, etc..)*

7 - Basic conditions for successful implementation of CSS (next)

- *Demonstration of overall performances by performing laboratory or field tests.* *Example of a 145 kV CB*



Clarifications on the RDDS

- *RDDS is obtained by performing a special test duty in which the prestrike voltage is measured in reference with the mechanical contact touch*