Study Committee A2

Power Transformers and reactors

Paper 10771

Design of a 24-pulses 250 Mvar Thyristor Controlled Transformer

Enrico ROTOLO[(1)], Francesco PALONE[(1)], **Luca BUONO**[(1)], Lorenzo PAPI[(1)], Simone SACCO[(1)], Roberto SPEZIE[(1)], Luca LOMBINI[(2)], Dario ROGORA[(2)]

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Motivation

- New challenges in terms of reactive power compensation due to a continuously accelerating of the decarbonization process;
- Space availability in existing substations and long authorization times for **S**ynchronous **C**ondensers (SCs) and STATCOMs forced Terna to examine different solutions for reactive power compensation.
- **Asymmetric capability** as many Extra High Voltage (EHV) lines of the National Transmission Network are generally operated **below the Surge Impedance Loading**.

Method/Approach

- Define a **new static compensation system** for Italian Power Transmission system with a higher reactive power density and lower cost and footprint if compared to standard commercial solutions such as STATCOM and SCs.

Objects of investigation

- **Space availability** in existing substations and **long authorization times** for SCs and STATCOMs forced Terna to examine different solutions for reactive power compensation, to reduce the footprint and the delivery times.
- One of the main drivers for this project is the need for an **asymmetric capability**: in fact, as many Extra High Voltage (EHV) lines of the National Transmission Network are generally operated **below the Surge Impedance Loading**, a significant reactive power surplus is expected.
- Aiming at a rated power of **250 Mvar**, for eliminating the need for filters, Terna and Tamini defined a 24 – pulses **T**hyristor **C**ontrolled **T**ransformer (TCT).
- The paper aims to describe the working principle of 24-pulse TCT and the expected performances in terms of characteristic harmonics, upon ideal and real operation.

Experimental setup & test results

- TCT is a variant of the Thyristor Controlled Reactor (TCR); instead of using a separate step-down transformer and linear reactors, the transformer is designed with a very high leakage reactance.

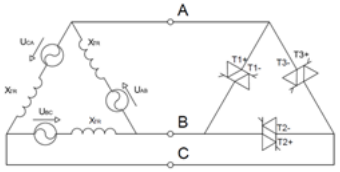

Figure 1 - – Equivalent circuit of a 6-pulses TCT with secondary delta winding transformers.

Discussion

- Time domain simulations, performed using a detailed model in ATP-EMTP, evidence a **good agreement with the simplified theoretical** treatment presented in the paper.
- The most of reactive power regulation can be performed between firing angle between **120° and 150°**.
- High current harmonic distortion can be almost completely mitigated by using a more complex winding arrangement for the magnetic unit (24 pulses TCT).

Conclusion

- TCTs represent an efficient solution for reactive power / voltage regulation, combining **reduced costs** and **footprint** with excellent **dynamic performances** and high expected reliability if compared to synchronous condensers and STATCOMs.
- Results evidence that the characteristic harmonics can be almost completely cancelled by increasing the number of pulses of the magnetic unit:
    - upon ideal (balanced) operation the total demand distortion is lower than **0.5% using the 24 pulses configuration**;
    - the total demand distortion is slightly increased to **0.67%, when considering the maximum expected voltage asymmetry** (2% for the Italian 400 kV network);

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Main characteristics

- Power transformer design is related to its rated power. Terna adopted single-phase units in two tanks per phase for the 250 Mvar rating and in one tank per phase for the 180 Mvar rating.
- **Four 6-pulses** TCT, each supplied by a dedicated winding, with a phase shift of -22.5°, -7.5°, 7.5°, 22.5°;
- **Single-phase design** for the TCT project, due to the transport constraints on the ageing Italian road/railway infrastructures;
- Each unit will be equipped with **five winding**: one EHV and four Medium Voltage (MV) windings.
- To attain the required phase shift, **extended delta connection** is adopted on MV windings

EHV winding		MV winding	
U_r [kV]	S_r [MVA]	U_r [kV]	S_r [MVA]
400/√3	83.3	11/√3	20.8
230/√3	60	11/√3	15

Table 1 - Main characteristics of single-phase power transformer.

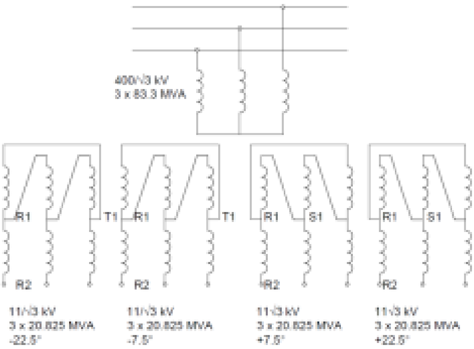

Figure 2 - Winding arrangements of the 24-pulses TCT single phase power transformer 400 kV/√3 / 11 kV/√3.

Expected footprint

- Considering the high value of rated reactive power of converter stations, 24-pulses TCT solution guarantees lower footprint if compared to Terna STATCOM projects:
  - ±125 Mvar Terna STATCOMs require **2 containers for control and auxiliary systems** (2.5 m x 12 m) and **3 containers for valves housing** (3.3 m x 13.7 m);
  - A 250 Mvar 24-pulses TCT would require only **2 standard ISO containers** (2.5 m x 12 m): each container contains **both the control and auxiliary systems** and thyristor valves for two 6-pulses converters.

TCT WORKING PRINCIPLE

- **First operation mode** (full continuous conduction) for firing angles **π/2 ≤ α < 2π/3**: **three thyristor** valves are in conduction state at the same time.
- **Second operation mode** (reactive power modulation over two phases) for firing angles **2π/3 ≤ α < 5π/6**: **two thyristor** valves are in conduction state at the same time)
- **Third operation mode** (minimum reactive power, one phase) for firing angles 5π/6 ≤ α < π: **one thyristor** valve is in conduction state.

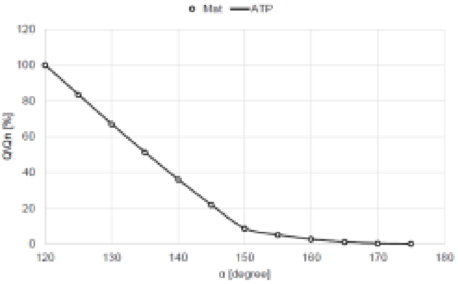

Figure 3 - Reactive power in per unit of rated power of an ideal TCT as a function of the firing angle.

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Model validation using Alternative Transients Program (ATP)

- The validation of the mathematical treatment has been performed using the software ATP –EMTP. At first losses have been neglected as well as the thyristor deionization time and holding current (ideal valve).

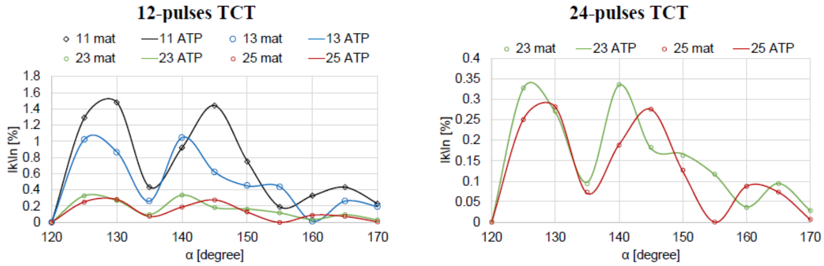

Figure 4 - Comparison of harmonic current content of a 12 and 24-pulses TCT for a firing angle α equal to 140° evaluated according to the mathematical treatment and ATP-EMTP simulations..

TCT upon real operating condition

A sensitivity analysis has been caried out considering several scenarios:

- No-harmonic background content and symmetrical voltage supply (see Figure 4);
- No-harmonic background content and 2% asymmetric of voltage supply (see Figure 5).

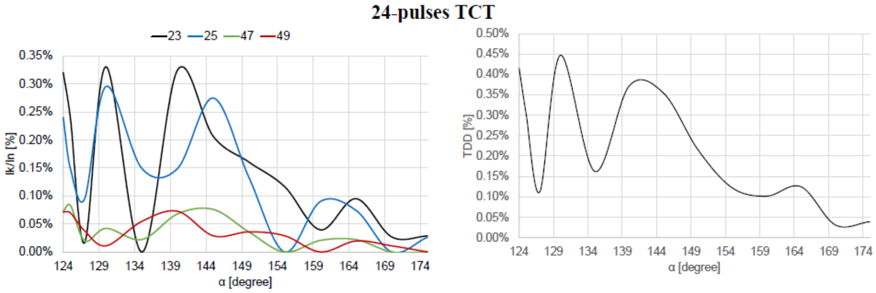

Figure 5 - Harmonic content and Total Demand Distortion of a 24-pulses real TCT in per unit of the rated current without harmonic background content..

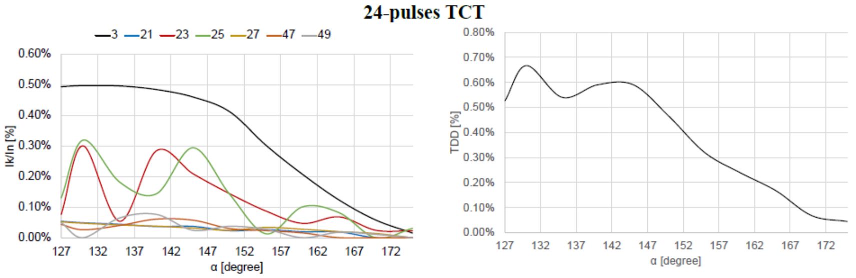

Figure 6 - Harmonic content and Total Demand Distortion of a 24-pulses real TCT in per unit of the rated current without harmonic background content and with a 2% asymmetric of voltage supply.