EAF SMARTRafo Solution

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Agenda

- Introduction
- Life cycle cost model
- SMART Transformer
- Numerical study
- Conclusions
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Since 1916:
A Century in Energy Applications

1916
- Tamini starts its activities in Milan, producing small oil immersed transformers

1961
- Production is moved to the new Melegnano premises

1988
- Acquisition of Novara-based Verbano Trasformatori S.r.l.

1991
- The Company acquires former OEL facilities in Legnano

1995
- Acquisition of Veneta Trasformatori Distribuzione S.r.l. (now V.T.D. Trasformatori S.r.l.), based in Valdagno (Vicenza province)

2000
- The Group establish a commercial entity for the North American market, Tamini Transformers USA

2006-2010
- In 2006 the Group started a €20m investment plan to revamp the Legnano plant

2014
- The Group has been acquired by Terna Group

2015
- The Group finalized the business combination with TES Transformer Electro Service S.r.l., based in Ospitaletto (Brescia province)

Since 1916:
A Century in Energy Applications
Electric Arc Furnace (EAF)

- **PAST** - Main improvements in energy performance:
  - Reduction of Power Off time
  - Reduction of Tap-to-Tap time
  - Chemical energy use
  - Foamy slag production
  - Electronic adjustment of the electrodes
  - Increasing of arc voltage and use of reactors to stabilize

- Energy still represents a significant share of the total costs

- **TODAY** - New improvements in the EAF process are difficult to obtain
  - Needs of improving other components of the system: i.e. EAF Transformer
EAF Transformer

- EAF transformer are exposed to more critical conditions than any distribution transformer
  - Very high secondary currents and low secondary voltage
  - Heavy current fluctuations and unbalanced conditions
  - Switching transients
  - Harmonics
  - Short circuits
  - Mechanical stresses
  - Frequent overloading conditions
  - Vibrations
  - Pollution & Dust
Literature Review

- Transformer is a consolidated technology but is still subject to research on control/monitoring systems and working conditions.
- Optimisation of EAF Transformer is a recent topic with increasing interest by the research community.
- LCC model for transformers are widely available in literature but none of them is focused on EAF Transformers.

Papers appeared in Scientific Journals

EAF SMARTrafo Solution

Keywords search performed with: Scopus
Goal

- Development of a Life Cycle Cost (LCC) model considering relevant aspects for EAF context
  - Impact of operating conditions
  - Maintenance activities
- In order to select the best design solution for a specific load cycle
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LCC model

EAF Transformer price

Operating costs
- Energy losses costs
- Cooling system costs

Maintenance costs

\[ LCC = EAF \text{ Transformer price} + \sum_{i=1}^{n} \frac{Ownership \text{ cost} + Maintenance \text{ cost}}{(1 + \rho)^i} \]
LCC model

EAF Transformer price

Operating costs
- Energy losses costs
- Cooling system costs

Maintenance costs

- Transformer → capital intensive equipment
- Price results of
  - design specifications
  - additional equipment
LCC model

EAF Transformer price

Operating costs
- Energy losses costs
- Cooling system costs

Maintenance costs

Energy losses [kW h/cycle] = \( P_0 + P_k \sum_{j=1}^{m} x_j^2 \)

- No-load losses
- Load losses
- LV terminations losses
- On service vs laboratory conditions

TAILOR MADE CONFIGURATION
- Cooling system control
  - Without \( \rightarrow \) Oversized cooling power
  - With \( \rightarrow \) Modular utilization
  - …
Example 1: The Low Voltage terminations

- Low Voltage bus bars/pipes
  - losses evaluation with FEM Model for two different layout options

<table>
<thead>
<tr>
<th>Losses</th>
<th>In the cover</th>
<th>1 kW</th>
<th>4.5 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>In LV bus bars</td>
<td>54 kW</td>
<td></td>
<td>74 kW</td>
</tr>
</tbody>
</table>

+43%
The bus bars arrangement can drastically increase the losses and oblige to select expensive solution.
Example 2: The Cooling System Effect

Transformer

\[ P_{\text{trafo}} \quad \rightarrow \quad P_{\text{out}} \quad \rightarrow \quad P_{\text{cooling}} \quad \rightarrow \quad P_{\text{cooling}}'' \quad \rightarrow \quad P_{\text{loss}} \]

Load [MVA]

Pcooling [kW]

00:00 04:48 09:36 14:24 19:12 00:00

No cooling control vs With cooling

00:00 04:48 09:36 14:24 19:12 00:00

EAF SMARTrafo Solution
LCC model

EAF Transformer price

Operating costs
• Energy losses costs
• Cooling system costs

Maintenance costs
• Maintenance activities
  (i.e. inspections and actions performed)
• Out-of-service
  (i.e. steel production lost due to downtime)
• Reliability penalty
  (i.e. replacement of the transformer due to failure)
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Why a SMART Transformer?

- Use condition (EAF) affects the design customization of the EAF Trafo
SMART Transformer Approach

GOAL

LIFECYCLE

TOOLS & DEVICES

ENERGY EFFICIENCY

RELIABILITY

DESIGN TOOLS

MONITORING & CONTROL SYSTEM

DESIGN

USE

EAF SMARTTrafo Solution
Design and Use

**Main aspects:**
- Secondary Voltage range
- Number of taps
- Short circuit impedance
- Losses

**Design and Use**

- **DESIGN**
  - Design principles
  - Tailor-made solutions (On-service operating conditions)
  - Materials selection
  - Components & Accessories

- **USE**
  - Temperature control
  - Working time management
  - Load Management
  - Conditions monitoring and control

**Main aspects:**
- Secondary Voltage range
- Number of taps
- Short circuit impedance
- Losses

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EAF SMARTrafo Solution

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How to design a SMART Transformer

Secondary voltage range
- The designed internal power is related to the secondary voltage range:
  \[ P_d = \frac{P_n}{2} \left( \frac{V_{\text{max}}}{V_{\text{min}}} \right) + \frac{V_{\text{max}}}{V_{\text{p}}^{\frac{1}{2}}} \]
- An unused range of voltage increase the designed power
- A wide range of voltage taps leads to expensive and improper design solutions

Number of taps
- An incorrect number of taps leads to:
  - Long time period for the transition through the secondary voltage range
  - Expensive tap changer solution or transformer schema solution

Short circuit impedance
- The variability of the short circuit impedance highly influences the design and the efficiency of the transformer

Losses
- The target losses should be carefully evaluated in terms of global efficiency, not only in terms of price reduction criteria
- Total losses should encompasses all the transformer and related elements losses
  - cooling system
  - low voltage terminations
  - auxiliary accessories
  - 

EAF SMARTTrafo Solution
Monitoring & Control system

REAL-TIME MEASUREMENT
Immediate information on component/system parameters

SENSOR

DATALOGGER

DATA RECORDING
Time series analysis

FEEDBACK & CONTROL

CONTROL ACTIONS
- Cooling system control
- Deteriorated condition prevention
- Early failure detection

Monitoring & Tracking

Web based Advanced Monitoring and Feedback System

Feedback & Control

EAF SMARTrafo Solution
Parameters Effects

**ENERGY EFFICIENCY**
- Oil temperature
- Hotspot temperatures
- Tap Position
- Energy and water consumption

**PARAMETER**
- Oil temperature
- Hotspot temperatures
- Tap Position
- Energy and water consumption

**INDICATOR**
- Temperature
- Load current
- Power, water

**TOOL & DEVICE**
- Temperature sensor (Pt100)
- Thermal model
- Thermal imaging
- Accelerometer
- Voltage metering
- Buchholz
- DGA
- Pressure sensor/valve
- Level indicators

**RELIABILITY**
- Mechanical deformation
- Insulation degradation
- Gas-in-oil
- Moisture
- Oil Pressure
- Oil Level

- Vibro-acoustic spectrum
- Voltage
- Nature/quantity of gas (and moisture)
- Pressure
- Level

**EAF SMARTrafo Solution**
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Numerical example

DATA
- Load Cycle: 45 min at 160 MVA, 15 min at 0 MVA
- 250 days a year x 20 years
- Transformer A: 140 MVA (+ 15% overload)
- Transformer B: 160 MVA
- OFWF cooling system: 2 x 75%
- Annual discount rate, \( r \): 5%
- Electricity cost: 0.15 €/kWh
- Contribution margin: 100 €/ton
- Maintenance activities
  - 100 h per year of out-of-service
  - 50 k/year

<table>
<thead>
<tr>
<th></th>
<th>Transformer A</th>
<th>Transformer B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power [MVA]</td>
<td>140</td>
<td>160</td>
</tr>
<tr>
<td>Purchasing price [k€]</td>
<td>1200</td>
<td>1500</td>
</tr>
<tr>
<td>No-load losses [kW]</td>
<td>62</td>
<td>60</td>
</tr>
<tr>
<td>Load losses [kW]</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Cooling system cost [k€]</td>
<td>29.54</td>
<td>21.02</td>
</tr>
</tbody>
</table>

![Failure Probability vs Lifetime](image_url)
Tailor made solution effects

<table>
<thead>
<tr>
<th>Power</th>
<th>Existing Transformer at rated power</th>
<th>New Transformer at reduced power</th>
<th>Existing Transformer in overload</th>
<th>New Transformer at rated power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer A</td>
<td>140 MVA</td>
<td>140 MVA</td>
<td>160 MVA</td>
<td>160 MVA</td>
</tr>
<tr>
<td>Transformer B</td>
<td>140 MVA</td>
<td>160 MVA</td>
<td>1050 kW</td>
<td>800 kW</td>
</tr>
</tbody>
</table>

New TES vs existing transformer for a cycle with 45 min at 160 MVA and off for 15 min: \(-188 \text{ [kWh/cycle]}\)

<table>
<thead>
<tr>
<th>Transformer A</th>
<th>Transformer B</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 MVA</td>
<td>160 MVA</td>
</tr>
<tr>
<td>Life cycle cost</td>
<td>15,541</td>
</tr>
<tr>
<td>Transformer price</td>
<td>1200</td>
</tr>
<tr>
<td>Losses cost</td>
<td>13,296</td>
</tr>
<tr>
<td>Cooling system cost</td>
<td>368.12</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>677.15</td>
</tr>
</tbody>
</table>

LCC reduction of 17.12%
Example: Cooling control effects

<table>
<thead>
<tr>
<th></th>
<th>Transformer A</th>
<th>Transformer B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>140 MVA</td>
<td>160 MVA</td>
</tr>
<tr>
<td>Life cycle cost</td>
<td>[k€] 15,490</td>
<td>12,778</td>
</tr>
<tr>
<td>Transformer price</td>
<td>[k€] 1230</td>
<td>1530</td>
</tr>
<tr>
<td>Losses cost</td>
<td>[k€] 13,296</td>
<td>10,364</td>
</tr>
<tr>
<td>Cooling system cost</td>
<td>[k€] 286.67</td>
<td>204.24</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>[k€] 677.15</td>
<td>679.76</td>
</tr>
</tbody>
</table>

Transformer A + cooling control
- 17.51%

Transformer B + cooling control
+24%

- Transformer price
- Losses cost
- Cooling system cost
- Maintenance cost

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Conclusions

- The improvements performed in the last decades on the EAF do not reach the limit in terms of process efficiency
  - holistic approach considering all relevant components of the process
  - greater part of the melting energy passes through electric transformer
- LCC model on transformer already exist but none of them are specific for the EAF transformer
  - EAF transformers are exposed to specific and more critical conditions than power and distribution transformers, thus it is necessary to consider real operations conditions
- The present work proposed a new holistic LCC model to determine total ownership cost of EAF transformers
  - evaluation of a technological solution that best suits the system requirements to minimize electrical losses, incorporating the proper design of all components (i.e. on-load-tap changer, LV terminals, etc.);
  - integration specific costs associated with the operation and components configuration effect, using a feedback regulation systems incorporated in the process control system (i.e. regulations of pumps for the cooling system);
  - implementation of an advanced monitoring and control system for the transformer and its main components to improve its lifecycle and optimise planned maintenance;
- A couple of numerical example showed the impact of the real conditions and operation on alternative solutions.
Conclusions
THANKS FOR YOUR KIND ATTENTION
Contacts Information

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