Asset risk management
Measuring transformer reliability
The purpose of procuring a power transformer is the **efficient and highly reliable** operation in order to **ensure power transmission** for production.

Any failure or unplanned **down time** endangers your production and cause significant financial damages.
Impacts of power failure endanger various factors which are important for a successful operation

Reliability of electrical equipment
Focus: US Refinery Shutdowns 2009 - 2012

Overall refinery shutdowns in US 2009-2012 in %

Causes for power disruptions in US Refineries 2009-2012 in %:

- Electrical Equipment: 56%
- Rotary Equipment: 323
- Mechanical: 12%
- Unspecified Equipment: 7%
- Refinery processing units: 25%
- Other: 19%
- Maintenance: 23%
- Electrical disruptions: 19%
- Mechanical: 12%

Refinery shutdowns happen on a daily basis. Power Disruption due to malfunction of electrical equipment is one of the major root causes.

There are many marketing arguments from each transformer manufacturer...

...so which relevant KPIs exist to identify a risk during operation?

... basically we need to know the Failure Index (FRe) or Meantime Between Failure (MBTF) of the specific factory...
External Failure Rates of Siemens Transformers show better than excellent performance in all factories worldwide

EM TR In-Service Failure Statistic 2005 - 2014 for Power Transformers based on ANSI C 57.117 and [1]

<table>
<thead>
<tr>
<th>Plant</th>
<th>N</th>
<th>SY</th>
<th>nF</th>
<th>FRe [%]</th>
<th>MTBF [yrs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>13017</td>
<td>61980</td>
<td>96</td>
<td>0.15</td>
<td>646</td>
</tr>
<tr>
<td>Plant 2</td>
<td>2033</td>
<td>9681</td>
<td>7</td>
<td>0.07</td>
<td>1383</td>
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<td>Plant 3</td>
<td>1001</td>
<td>5031</td>
<td>12</td>
<td>0.24</td>
<td>419</td>
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<tr>
<td>Plant 4</td>
<td>814</td>
<td>4211</td>
<td>8</td>
<td>0.19</td>
<td>526</td>
</tr>
<tr>
<td>Plant 5*</td>
<td>677</td>
<td>3803</td>
<td>8</td>
<td>0.21</td>
<td>475</td>
</tr>
<tr>
<td>Plant 6</td>
<td>150</td>
<td>401</td>
<td>1</td>
<td>0.25</td>
<td>401</td>
</tr>
<tr>
<td>Plant 7</td>
<td>939</td>
<td>4646</td>
<td>4</td>
<td>0.09</td>
<td>1161</td>
</tr>
<tr>
<td>Plant 8</td>
<td>1420</td>
<td>6921</td>
<td>9</td>
<td>0.13</td>
<td>769</td>
</tr>
<tr>
<td>Plant 9</td>
<td>655</td>
<td>3013</td>
<td>5</td>
<td>0.17</td>
<td>603</td>
</tr>
<tr>
<td>Plant 10</td>
<td>605</td>
<td>3009</td>
<td>5</td>
<td>0.17</td>
<td>602</td>
</tr>
<tr>
<td>Plant 11**</td>
<td>964</td>
<td>5909</td>
<td>2</td>
<td>0.15</td>
<td>657</td>
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<tr>
<td>Plant 12</td>
<td>589</td>
<td>1332</td>
<td>7</td>
<td>0.15</td>
<td>666</td>
</tr>
<tr>
<td>Plant 13</td>
<td>1716</td>
<td>7347</td>
<td>19</td>
<td>0.10</td>
<td>1050</td>
</tr>
</tbody>
</table>

* Plant 5 2007 - 2013
** Plant 11 2009 - 2013

FRe ≤ 0.5 % : excellent
0.5 < FRe ≤ 1.0 % : good
1.0 < FRe ≤ 1.5 % : satisfactory
1.5 < FRe ≤ 2.0 % : acceptable
FRe > 2.0 % : not acceptable

FRe as reported by China Electric Power
Siemens shows best-in-class performance

Informations from China: 220 kV Power Transformer Service Failure Index 2001/2002*

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Failure Index (FRe) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens Transformer Co., Jinan</td>
<td>0,16 %</td>
</tr>
<tr>
<td>Toshiba</td>
<td>0,30 %</td>
</tr>
<tr>
<td>Chang Zhou</td>
<td>0,38 %</td>
</tr>
<tr>
<td>ELIN</td>
<td>0,47 %</td>
</tr>
<tr>
<td>ABB, He Fei</td>
<td>0,48 %</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>0,56 %</td>
</tr>
<tr>
<td>ABB (abroad)</td>
<td>0,58 %</td>
</tr>
<tr>
<td>He Fei</td>
<td>0,60 %</td>
</tr>
<tr>
<td>Xi An</td>
<td>0,67 %</td>
</tr>
<tr>
<td>Shen Yang</td>
<td>0,93 %</td>
</tr>
<tr>
<td>Saporozhye</td>
<td>0,95 %</td>
</tr>
<tr>
<td>Bao Ding</td>
<td>1,16 %</td>
</tr>
<tr>
<td>Hitachi</td>
<td>2,99 %</td>
</tr>
</tbody>
</table>

ANSI / IEEE C57.117-1986:

<table>
<thead>
<tr>
<th>FRe (%)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0,5</td>
<td>excellent</td>
</tr>
<tr>
<td>0,5 &lt; FRe ≤ 1,0</td>
<td>good</td>
</tr>
<tr>
<td>1,0 &lt; FRe ≤ 1,5</td>
<td>satisfactory</td>
</tr>
<tr>
<td>1,5 &lt; FRe ≤ 2,0</td>
<td>acceptable</td>
</tr>
<tr>
<td>FRe &gt; 2,0</td>
<td>not acceptable</td>
</tr>
</tbody>
</table>

FRe [%] = (nF / SY) * 100

FRe: External Failure Rate
N: Number of units in service within evaluation period (floating 10 years)
SY: Number of service years accumulated with [N] units in service
nF: Number of failures with forced outage of a population within the evaluation period

*Source: China Electric Network (Utility Handbook)
Most of the suppliers have “good” (<1.0%) or “excellent” (<0.5%) failure indexes according to ANSI / IEEE C57.117-1986.

...so where is the difference?

... we need to look into the resulting Reliability ...each small difference has a huge impact...
Excellent Siemens FRRe Index results in best-in-class reliability values and lowest operational risks

**Reliability [%] based on ANSI C57. 117 (1986)**

**ANSI / IEEE C57.117-1986:**

\[ R = e^{-\lambda t} \]

- **R:** Reliability
- **t:** time in years
- **\( \lambda \):** failure rate in failures per transformer-years of service \((\lambda = nF/SY)\)
- **e:** 2.718

**Remaining Risk:**

\[ (100\% - R) \times (C_{LP} + C_{LR} + C_{R}) \]

* calculated on basis of failure rates taken from ANSI / IEEE C57.117-1986
Understood. The Failure Index has an exponential impact on reliability on my transformer. ...but how can I calculate the impact on my operation?

... we need to evaluate a realistic cost scenario in case the transformer fails in operation and causes an unplanned outage!
Impacting factors during unplanned downtimes
(Example: Refinery with own Cogen Power Plant)

- **Lost Oil Production**: Up to 300,000 barrels/day
- **Penalties for Slowed Deliveries**: Up to 350,000 USD/day
- **Workforce Downtime**: Up to 4,000 employees

Average daily damage in production of 300,000bbl/day (profit, staff, penalties, ...):
> 2.1 MM USD/dy

- **Lost Power Generation**: up to 29,000 MWh/day
- **Lost Steam Production**: up to 35,000 tons/day
- **Wasted Fuel**: up to 295,000 McF gas per day

Average daily damage in production of 1,200MW plant (fuel, power & steam sales, ...):
> 1.8 MM USD/dy
Linking transformer performance to economics (Example: 72 hour unplanned outage of a 300,000bll refinery with own 1,220 MW CoGen Plant)

### Cost estimation of a 72-hour refinery downtime:

#### Power Plant

- **Power Production (Co-Generation):**
  - Plant capacity: 1,220 MW
  - Electricity retail price: 0.32RM/kWh USD/MWh
  - Profit margin: 8 USD/MWh
  - **Sub Total:** USD 702,720

- **Fuel Costs:**
  - Fuel Type: Natural Gas
  - Fuel Requirement: 5.79 btu/MWh
  - Fuel Cost: 11.35 USD/MMbtu
  - **Sub Total:** USD 5,773,225

- **Steam Production (if applicable):**
  - Steam production capacity: 1,480 ton/hour
  - Steam Retail Price: 25.00 USD/ton
  - Profit Margin for Steam Production: 5.00 USD/ton
  - **Sub Total:** USD 532,800

**TOTAL:** USD 7,008,745

#### Refinery

- **Oil Production:**
  - Oil production: 300,000 bbl. / day
  - Oil retail price: 55 USD/bbl.
  - Cash margin: 5 USD/bbl.
  - **Sub Total:** USD 4,500,000

- **Personnel Costs:**
  - Employees: 4,000 FTE
  - Average monthly income: 2,000 USD/FTE
  - **Sub Total:** USD 774,194

- **Penalties:**
  - USD/day: 340,000
  - **Sub Total:** USD 1,020,000

**TOTAL:** USD 6,294,194

#### Remedy

- Assets repair / replacement: 10,000 USD
- Civil works: 5,000 USD
- Recommissioning: 20,000 USD
- Other: -
  - **TOTAL:** USD 35,000

**GRAND TOTAL** USD 13,337,938

The supplier with the lowest FRe (highest reliability) delivers more than 1.5 MM USD additional value over a 30 years service period ... per transformer!
Okay. Now I know my risk of operation. But how is the **support just in case** my equipment fails during operation?

... we should ensure that there is a **dedicated service organization available** to support and capable to react on short note.
We are providing the full scope OEM service in order to ensure a fast solution in case of disturbances during operation...

- 24/7 Hotline
- 11 Remote Experts (available in headquarter 24/7)
- >140 Field Service (up to 24 hours mobilization)
- Mobile HV Testing (thereof 1 complete set in Asia)
- 4x OEM Service Shops in the Asia Region
- Remote Monitoring & OEM Diagnostics
- Oil Analysis at fully equipped laboratory

✓ We are available 24 hours, 7 days per week
✓ Our Field Experts are near you and can be on their way within up to 24 hours
✓ Our Remote Experts are on stand-by for support
✓ The next service shop is in your region and ready to react
CPS Energy temporarily halts production at new 750MW Spruce 2 power plant / US, because of broken GSU from Hyundai

CPS has taken its newly constructed coal plant offline until technicians can repair or replace a transformer at the $1 billion plant.

This is the main transformer that provides the power to nearby substations through high-voltage power lines. Testing in late summer indicated a potential problem with the Hyundai-manufactured component. In recent weeks, Hyundai technicians have been working on site to inspect the equipment while officials with the South Korean conglomerate works with CPS Energy to address the problem at the plant. The component is still under warranty. CPS Energy officials have not set a timeline as to when the power plant will be back online.

Construction on the 750-megawatt plant was completed in May 2010.


Estimated Damages:
Equipment: GSU-size 940MVA / 345kV

PP losses: 6,300,000 EUR per week
(estimated based on 0,05€/kWh)

HHI penalty: max. 400,000,- EUR
(for the transformer scope)
News, we do not want to hear…

Husky Shuts Down Lima Refinery

Production has been halted at the Lima Refinery, and it could be mid-August before it's running at full capacity.

The refinery is shut down while workers attempt to repair damage caused by a Thursday fire that destroyed a transformer in an electrical substation. Late last week, the plant was operating at 25 percent of its 165,000-barrel-per-day capacity but shut down completely over the weekend, according to Husky Energy Inc. spokesman Graham White.

Workers have replaced the damaged transformer, but some wiring and ancillary equipment need to be ordered. Even if the parts come in by the company's target date of Saturday, it will still take weeks to get the refinery up to full production.

White refused to comment on what the lost capacity would mean in lost profits for Husky or its possible affect on the national market.

Estimated Damages:

2,100,000 bll.
refined petroleum products
(based on 165,000 bll./day)

21,000,000 USD profit
(based on 10USD/bll. cash margin in 2007)

Siemens is your partner of choice for a reliable and profitable operation of transformer equipment.

“We are happy to provide our quality key figures for each factory worldwide... ...because we trust and measure our quality without compromises!”
Safe and reliable operation to ensure your success.

Thank you!
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