TRANSFORMER PROTECTOR

The only proven solution against transformer explosions.

TP Description to be used for Customer Technical Specifications

TRANSFORMER PROTECTOR

Transformer, On Load Tap Changer, Oil Cable Boxes Explosion and Fire Prevention, from 0.1 MVA

SYSTEM CERTIFICATION ISO 9001:2008 SGS

Transformer Explosion and Fire Prevention

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The only proven solution against transformer explosions.

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Document revisions

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N°10	fTPd10e	06/04/07	DB	KT	PM	CTP configuration updated
N°11	AfTPd11e	26/06/07	DB	JW	PM	CTP configuration updated
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REFERENCED DOCUMENTS AVAILABLE ON REQUEST FROM TPC

No.	Reference	Publications
[1]	AtTPra12b01e	"Transformer Explosion Prevention", AIST 2009 Conference, Saint-Louis, USA, 2009
[2]	AtTPra02b01e	"Transformer Relief Valves efficiency calculations by comparison to the TRANSFORMER PROTECTOR during short-circuits"
[3]	AtTPra03b03e	"Transformer Explosion and Fire Incidents. Guideline for Damage Cost Evaluation. Transformer Protector Financial Benefit"
[4]	AtTPrdab	"Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations", NFPA 850, 2010 edition
[5]	AtTPrdac	"Recommended Practice for Fire Protection for Hydroelectric Generating Plants", NFPA 851, 2010 edition

No.	Reference	Additional Documents
[6]	AtTPrtfa	Attestation from CEPEL Laboratory
[7]	StTPgd	Brochure
[8]	StTPpa	Adaptation on New Transformers
[9]	StTPpb	Adaptation on Existing Transformers
[10]	StTPpc	On Site Erection, Commissioning and Testing
[11]	StTPpd	Operation Maintenance and Periodical Test
[12]	StTPdb	TP Description to be used for Customer Technical Specification

Disclaimer

TPC makes no express representation or warranty regarding the contents of this manual. We reserve the right to amend the manual or revise the product specifications described. The information contained in this manual is intended solely for the general use by our customers. Customers should be aware that the Transformer Protection field is subject to many patents. All of our customers should ensure their use of product does not infringe upon any patents.

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SUMMARY

The objective of this document is to help the electrical authorities, industries, consultants and engineering companies to include the TRANSFORMER PROTECTOR (TP) in their Technical Specifications. This technology is recommended in the 2010 edition of the NFPA codes.

Four kinds of Technical Specifications are proposed in paragraphs 1, 2, 3, 4: complete, simplified, single page and half page versions. In the proposed Technical Specifications, the wording «Transformer and On Load Tap Changer Explosion Prevention» replaces the term «TRANSFORMER PROTECTOR».

As tests and sizing computation are the TRANSFORMER PROTECTOR Cornerstone, gas generation during short-circuit, the resulting dynamic pressure peak, pressure gradient and depressurization calculations are highlighted.

1 COMPLETE TECHNICAL SPECIFICATION

1.1 TRANSFORMER EXPLOSION AND FIRE, ORIGINS, CAUSES AND CONSEQUENCES

Power transformers are among the most expensive equipment located in power plants and substations. They contain a large quantity of combustible substance, which can spray fire to nearby installations. Special attention should therefore be given to their protection.

Transformer explosion and fire generally result from a fault inside the transformer tank. This may be caused by overloads, short-circuits or failure of the associated equipment such as On Load Tap Changer or oil bushings.

For an electrical arc, a huge volume of explosive gas is created during the first millisecond, 2.3m³ - 81.2 ft³ for the first Mega Joule. This huge gas generation creates one dynamic pressure peak and the transformer tank is violently shaken by accelerations reaching 400g. This shockwave is travelling in the tank at a speed of the sound inside oil, 1,200 m/s - 3937ft/s. The first pressure peak of the resulting shockwave, initial amplitude up to 14 bars, activates the Depressurization Set of the Transformer and On Load Tap Changer Explosion Prevention before static pressure increases inside the tank and provokes tank explosion.

Transformers are exploding because they are not protected against fast static pressure increase. The Pressure Relief Valve (PRV) is ineffective during short-circuit as every destroyed transformer tank is equipped with one. The tank pressure gradient that follows short-circuit is much too fast for a PRV to operate, see references, page 3.

- The inertia of the PRV spring is 5 milliseconds;
- Very small evacuation at the beginning of the opening, 15% of the section up to 50% of the PRV opening height, which also leads to an additional operational delay of almost 5 milliseconds;
- U-turn for oil evacuation, which sharply and dramatically obstructs the flow evacuation.

1.2 EQUIPMENT DESCRIPTION

Examples of Transformer and On Load Tap Changer Explosion Prevention described in this specification are shown in figure 1, for the standard configuration, and in figures 2 to 8 for other arrangements.

The Transformer and On Load Tap Changer Explosion Prevention shall be made of several sets, each playing a different role:

- The Depressurization Set (DS) shall prevent a Transformer and On Load Tap Changer explosion when suffering a short circuit. Each DS shall relieve the dynamic pressure within milliseconds and a Decompression Chamber (DC) favors high-speed depressurization.
  The depressurization time is the critical parameter. Therefore, the DS diameter shall be calculated individually for each Transformer and On Load Tap Changer type.
- The Inert Gas Injection Set (IGIS) is required for personal safety to avoid the bazooka effect caused by the explosive gas in contact with air (oxygen) when the tank is opened after the incident. The IGIS creates a safe environment in the Transformer and the On Load Tap Changer after the depressurization process by injecting an inert gas flow, which also cools the tank.
- An Oil-Gas Separation Tank (OGST) shall collect the depressurized oil and explosive flammable gas to split oil from gases. It's recommended to locate the OGST in the transformer conservator where a slice shall then be devoted for the OGST as often done for the OLTC oil conservator. This configuration is shown Figures 1 and 4. The transformer conservator slice devoted to the OGST should have a volume of 0.5m³ - 17.6 ft³.
- The Explosive Gas Evacuation Pipe (EGEP) shall then channel the gas to a remote area.

It is possible to separate the OGST from the transformer as shown for other arrangements in Figures 2, 3, 5, 6, 7 and 8, but the installation costs are higher because:

- When the OGST function is integrated with the conservator there is no need for local installation;
- When independent from the transformer conservator, an additional tank and piping are necessary.

The Transformer and On Load Tap Changer Explosion Prevention Depressurization Set (DS) shall preferably be type Vertical (VDS) and located on the tank cover. These arrangements are shown Figures 1, 2 and 3.
If problems with high voltage clearances render it impossible to fit the VDS on the tank cover, then a Horizontal Depressurization Set (HDS) shall be located on the tank wall. These arrangements are shown Figures 4, 5, 6, and 7.
For smaller transformers, typically below 5 MVA such as bunker transformer, the TP can be installed as per the arrangement shown in Figure 8.

The transformer manufacturer shall integrate the OGST in the conservator; the transformer conservator slice devoted to the OGST should have a volume of $0.5m^3$ - 17.6 ft^3. If the transformer manufacturer has a problem to devote a slice of the conservator, the OGST can be remote but in this case the OGST bottom shall always be located 10cm - 4” above the top of the conservator. Several OGST arrangements are possible:

- SOGST, Sliced OGST, located in a slice of the conservator, Figures 1 and 4;
- EOGST, Elevated OGST, elevated above the transformer conservator, Figures 3 and 6;
- WOGST, Wall mounted OGST, attached to the transformer firewalls, Figures 2, 5, 7 and 8.

The efficiency and reliability of the Transformer and On Load Tap Changer Explosion Prevention shall be ensured by the DS, which shall be opened by the first dynamic pressure peak of the pressure wave before static pressure build-up.
No triggers and no electrical actuators shall be involved in the depressurization process because they add unacceptable operating delays.
Two types of injection of inert gas are possible, manual injection or automatic injection, depending on customer choice:

- The manual injection can be ordered from the control room or from close to the transformer in a safe area. However, alarms should remind operators of the necessity to inject inert gas before maintenance teams start working (bazooka effect).
- For the automatic injection, two signals shall be required simultaneously to start up the Explosive Gas Elimination:
  - The integrated Rupture Disk Burst Indicator confirming the dynamic pressure and the beginning of the depressurization process;
  - One of the electrical protection signals, confirming the electrical fault of the protected Transformer or On Load Tap Changer.

The inert gas flow shall prevent air (oxygen) to be in contact with the explosive gases and shall further cool down the Transformer and the On Load Tap Changer as inert gas injection should run for 45 minutes. As a result, no more explosive gasses are produced when inert gas injection is over. Then, maintenance teams can start working..

With reference to Figure 7, when required the transformer and on load tap changer explosion prevention shall also be designed to protect Oil Cable Boxes.

The oil fire extinguishing system “Inert gas Drain and Stir” shall back up the explosion and fire prevention for transformers with power range starting at 5MVA.
The fire extinction backup “Inert gas Drain and Stir” shall be activated by other signals than those used for the prevention method, except for the electrical protections:

- One from the Linear Heat Detector located on the transformer;
- One of the transformer electrical protections.

For smaller transformers below 5 MVA, the “Inert gas Drain and Stir” is not required.

1.3 SIZING

1.3.1 PRESSURE RISE CALCULATIONS

To avoid transformer and on load tap changer explosion and therefore fire, the supplier shall have analyzed and calculated the oil breaking mechanism under thermal effect, which generates the tank dynamic and static pressure. This should be done for all short-circuit locations inside the transformer and on load tap changer tank and compared to the DS position for the maximum volume of explosive gas generation, when an electrical arc transfers all the energy of the short-circuit to oil.

Gas volume generation versus time, the pressure peak amplitude, the dynamic pressure parameters, the pressure gradient and the static pressure increase, shall be calculated with the multi-physic model to quantify the oil-gas mixture to be exhausted from the transformer and on load tap changer tank to avoid explosion.

1.3.2 DEPRESSURIZATION CALCULATIONS

The depressurization parameters shall be calculated by taking into account the pressure gradients and the gas volume production, versus time. Therefore, the multi-physic model shall include the following:

- Rupture Disks opening function versus time and pressure gradient;
- Oil-gas mixture speed versus time during the depressurization process, taking into account all energy losses;
- Explosive and flammable gas generation during depressurization, versus time;
- Oil-gas mixture volume to be evacuated to avoid transformer explosion and fire, versus time;
- Transformer tank pressure drop, versus time.

1.4 TESTS

The supplier shall prove that the Transformer Explosion and On Load Tap Changer Prevention operates with the first dynamic pressure peak before static pressure increases to the level of transformer tank explosion. Therefore, an Official Test Certificate from a recognized and independent high voltage laboratory shall be provided.

The Test Certificate shall show that a campaign of at least 30 successful live tests have been done with electrical arcs inside the oil of a closed transformer tank.

1.5 RECOMMENDATIONS

The Transformer and On Load Tap Changer Explosion Prevention is recommended for all Power Plants and Substations on the National Fire Protection Association Recommended Practices 2010 editions of:

- NFPA 850 (Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations). See “AtTPrdab - NFPA 850”.
- NFPA 851 (Recommended Practice for Fire Protection for Hydroelectric Generating Plants). See “AtTPrdac - NFPA 851”.

1.6 TRANSFORMER LOCATION

Wherever the transformer is located, the explosive and flammable gases shall be separated from oil, in order to be evacuated in a remote area, Figures 1 to 8.

2 SIMPLIFIED TECHNICAL SPECIFICATION

2.1 EQUIPMENT DESCRIPTION

Examples of Transformer and On Load Tap Changer Explosion Prevention described in this specification are shown in figure 1, for the standard configuration, and in figures 2 to 8 for other arrangements.

The Transformer and On Load Tap Changer Explosion Prevention shall be made of several sets, each playing a different role:

- The Depressurization Set (DS) shall prevent a Transformer and On Load Tap Changer explosion when suffering a short circuit. Each DS shall relieve the dynamic pressure within milliseconds and a Decompression Chamber (DC) favors high-speed depressurization.
  The depressurization time is the critical parameter. Therefore, the DS diameter shall be calculated individually for each Transformer and On Load Tap Changer type.
- The Inert Gas Injection Set (IGIS) is required for personal safety to avoid the bazooka effect caused by the explosive gas in contact with air (oxygen) when the tank is opened after the incident. The IGIS creates a safe environment in the Transformer and the On Load Tap Changer after the depressurization process by injecting an inert gas flow, which also cools the tank.
- An Oil-gas Separation Tank (OGST) shall collect the depressurized oil and explosive flammable gas to split oil from gases. It's recommended to locate the OGST in the transformer conservator where a slice shall then be devoted for the OGST as often done for the OLTC oil conservator. This configuration is shown Figures 1 and 4. The transformer conservator slice devoted to the OGST should have a volume of $0.5m^3$ - 17.6 ft^3.
- The Explosive Gas Evacuation Pipe (EGEP) shall then channel the gas to a remote area.

It is possible to separate the OGST from the transformer as shown for other arrangements in Figures 2, 3, 5, 6, 7 and 8, but the installation costs are higher because:

- When the OGST function is integrated with the conservator there is no need for local installation;
- When independent from the transformer conservator, an additional tank and piping are necessary.

The Transformer and On Load Tap Changer Explosion Prevention Depressurization Set (DS) shall preferably be type Vertical (VDS) and located on the tank cover. These arrangements are shown Figures 1, 2 and 3.
If problems with high voltage clearances render it impossible to fit the VDS on the tank cover, then a Horizontal Depressurization Set (HDS) shall be located on the tank wall. These arrangements are shown Figures 4, 5, 6, and 7.
For smaller transformers, typically below 5 MVA such as bunker transformer, the TP can be installed as per the arrangement shown in Figure 8.
The transformer manufacturer shall integrate the OGST in the conservator; the transformer conservator slice devoted to the OGST should have a volume of $0.5m^3$ - 17.6 ft^3. If the transformer manufacturer has a problem to devote a slice of the conservator, the OGST can be remote but in this case the OGST bottom shall always be located 10cm – 4” above the top of the conservator. Several OGST arrangements are possible:

- SOGST, Sliced OGST, located in a slice of the conservator, Figures 1 and 4;
- EOGST, Elevated OGST, elevated above the transformer conservator, Figures 3 and 6;
- WOGST, Wall mounted OGST, attached to the transformer firewalls, Figures 2, 5, 7 and 8.

Two types of injection of inert gas are possible, manual injection or automatic injection, depending on customer choice:

The inert gas flow shall prevent air (oxygen) to be in contact with the explosive gases and shall further cool down the Transformer and the On Load Tap Changer as inert gas injection should run for 45 minutes. As a result, no more explosive gasses are produced when inert gas injection is over. Then, maintenance teams can start working.

With reference to Figure 7, when required the transformer and on load tap changer explosion prevention shall also be designed to protect Oil Cable Boxes.

The oil fire extinguishing system "Inert gas Drain and Stir" shall back up the explosion and fire prevention for transformer power greater than 5MVA.

2.2 SIZING

2.2.1 PRESSURE RISE CALCULATIONS

To avoid transformer and on load tap changer explosion and therefore fire, the supplier shall have analyzed and calculated the oil breaking mechanism under thermal effect, which generates the tank dynamic and static pressure.
This should be done for all short-circuit locations inside the transformer and on load tap changer tank and compared to the DS position for the maximum volume of explosive gas generation, when an electrical arc transfers all the energy of the short-circuit to the oil.

Gas volume generation versus time, the pressure peak amplitude, the dynamic pressure parameters, the pressure gradient and the static pressure increase, shall be calculated with the multi-physic model to quantify the oil-gas mixture to be exhausted from the transformer and on load tap changer tank to avoid explosion.

2.2.2 DEPRESSURIZATION CALCULATIONS

The depressurization parameters shall be calculated by taking into account the pressure gradients and the gas volume production, versus time. Therefore, the multi-physic model shall include the following:

- Rupture Disks opening function versus time and pressure gradient;
- Oil-gas mixture speed versus time during the depressurization process, taking into account all energy losses;
- Explosive and flammable gas generation during depressurization, versus time;
- Oil-gas mixture volume to be evacuated to avoid transformer explosion and fire, versus time;
- Transformer tank pressure drop, versus time.

2.3 TESTS

The supplier shall prove that the Transformer Explosion and On Load Tap Changer Prevention operates with the first dynamic pressure peak, before static pressure increases to the level of transformer tank explosion. Therefore, an Official Test Certificate from an independent high voltage laboratory should be provided.

The Test Certificate must show that a campaign of at least 30 successful live tests have been done with electrical arcs inside the oil of a closed transformer tank.

2.4 RECOMMENDATIONS

The Transformer and On Load Tap Changer Explosion Prevention is recommended for all Power Plants and Substations on the National Fire Protection Association Recommended Practices 2010 editions of:

- NFPA 850 (Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations). See "AtTPrdab - NFPA 850".
- NFPA 851 (Recommended Practice for Fire Protection for Hydroelectric Generating Plants). See "AtTPrdac - NFPA 851".

2.5 TRANSFORMER LOCATION

Wherever the transformer is located, the explosive and flammable gases shall be separated from oil, in order to be evacuated in a remote area, Figures 1 to 8.

3 ONE PAGE TECHNICAL SPECIFICATION

3.1 EQUIPMENT DESCRIPTION

Examples of Transformer and On Load Tap Changer Explosion Prevention described in this specification are shown in figure 1, for the standard configuration, and in figures 2 to 8 for other arrangements. The Transformer and On Load Tap Changer Explosion Prevention shall be made of several sets:

- The Depressurization Set (DS) shall prevent a Transformer and On Load Tap Changer explosion when suffering a short circuit. Each DS shall relieve the dynamic pressure within milliseconds and a Decompression Chamber (DC) favors high-speed depressurization.
- The Inert Gas Injection Set (IGIS) is required for personal safety to avoid the bazooka effect caused by the explosive gas in contact with air (oxygen) when the tank is opened after the incident.
- An Oil-gas Separation Tank (OGST) shall collect the depressurized oil and explosive flammable gas to split oil from gases. Is recommended to locate the OGST in the transformer conservator where a slice shall then be devoted for the OGST as often done for the OLTC oil conservator. This configuration is shown Figures 1 and 4. The transformer conservator slice devoted to the OGST should have a volume of $0.5m^3$ - 17.6 ft^3.
- The Explosive Gas Evacuation Pipe (EGEP) shall then channel the gas to a remote area.

It is possible to separate the OGST from the transformer as shown for other arrangements in Figures 2, 3, 5, 6, 7 and 8. In this case, the bottom of the OGST must always be located 10cm – 4" above the top of the conservator.

With reference to Figure 7, when required the transformer and On Load Tap Changer Explosion Prevention shall also be designed to protect the Oil Cable Boxes.

3.2 SIZING

To avoid transformer and on load tap changer explosion and therefore fire, the supplier shall have analyzed and calculated the oil breaking mechanism under thermal effect, which generates the tank dynamic and static pressure.

Gas volume generation versus time, the pressure peak amplitude, the dynamic pressure parameters, the pressure gradient and the static pressure increase, shall be calculated with the multi-physic model to quantify the oil-gas mixture to be exhausted from the transformer and on load tap changer tank to avoid explosion.

The multi-physic model should also calculate during the depressurization process, versus time: Rupture Disks opening function, oil-gas mixture speed and transformer tank pressure drop.

3.3 TESTS AND RECOMMENDATIONS

The supplier shall prove that the Transformer Explosion Prevention operates with the first dynamic pressure peak before static pressure increases to the level of transformer tank explosion. Therefore, an Official Test Certificate from an independent laboratory should be provided. The Test Certificate must show that a campaign of at least 30 successful live tests have been done with electrical arcs inside the oil of a closed transformer tank.

The Transformer and On Load Tap Changer Explosion Prevention is recommended for all Power Plants and Substations on the National Fire Protection Association Recommended Practices 2010 editions of NFPA 850 (AtTPrdab) and NFPA 851 (AtTPrdac).

Standard Configuration for Transformers from 5 MVA to 1000 MVA

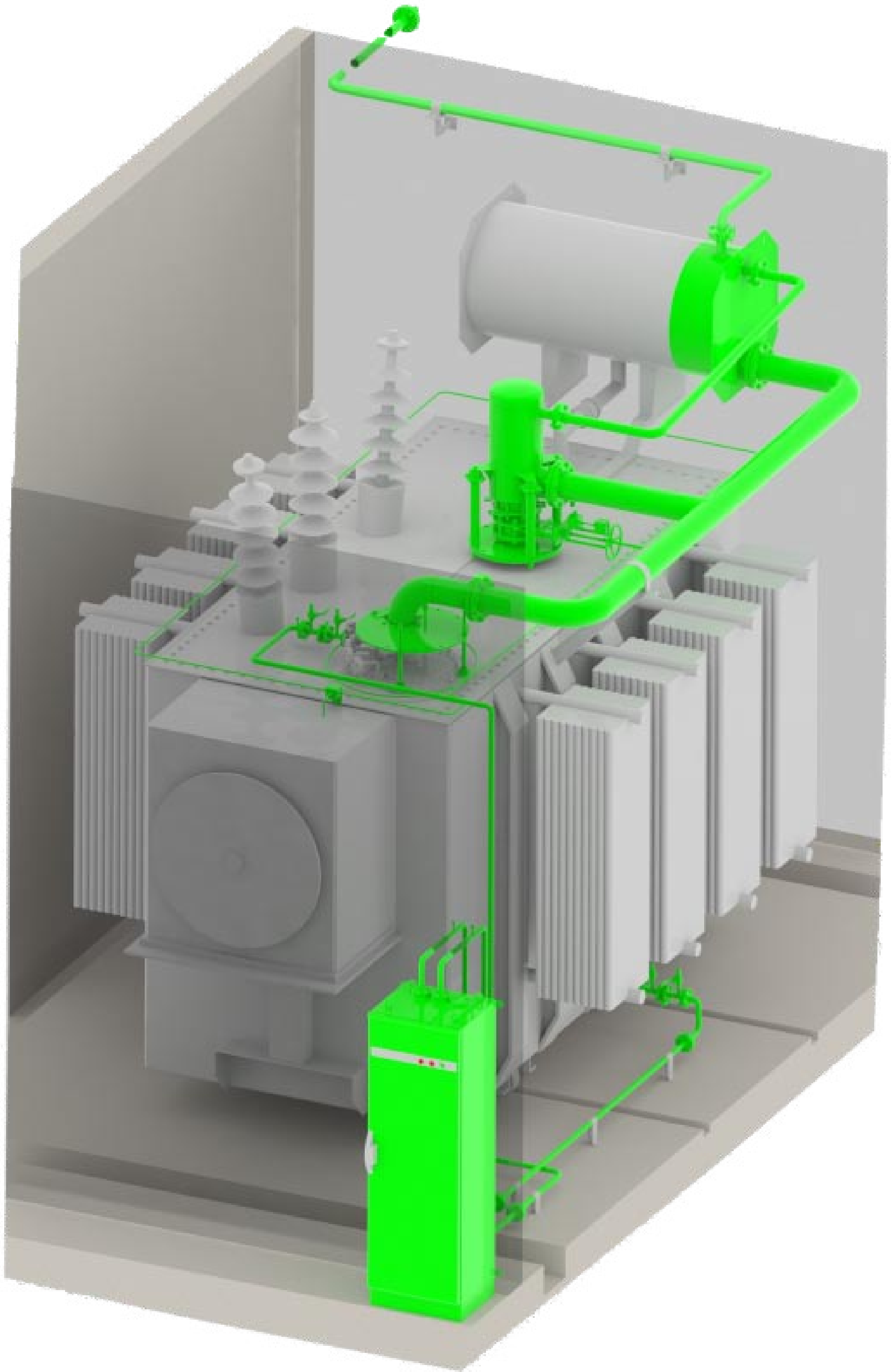

Figure 1: *TRANSFORMER PROTECTOR, type TPA with VDS and SOGST*

Other Configurations for Transformers from 5 MVA to 1000 MVA

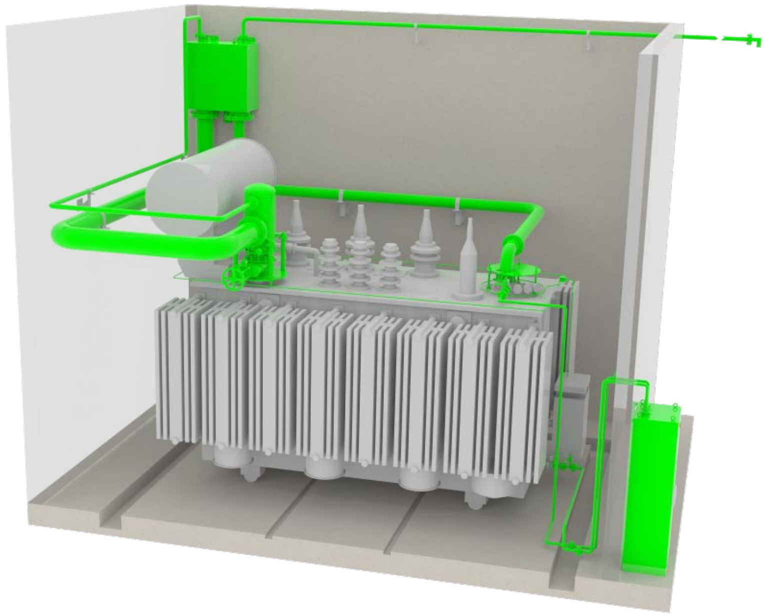

Figure 2: *TRANSFORMER PROTECTOR, type TPA with VDS and WOGST*

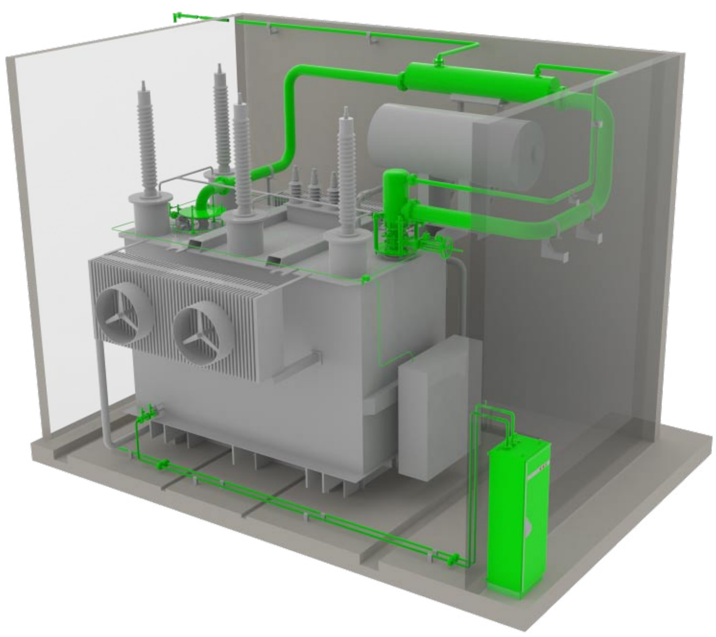

Figure 3: *TRANSFORMER PROTECTOR, type TPA with VDS and EOGST*

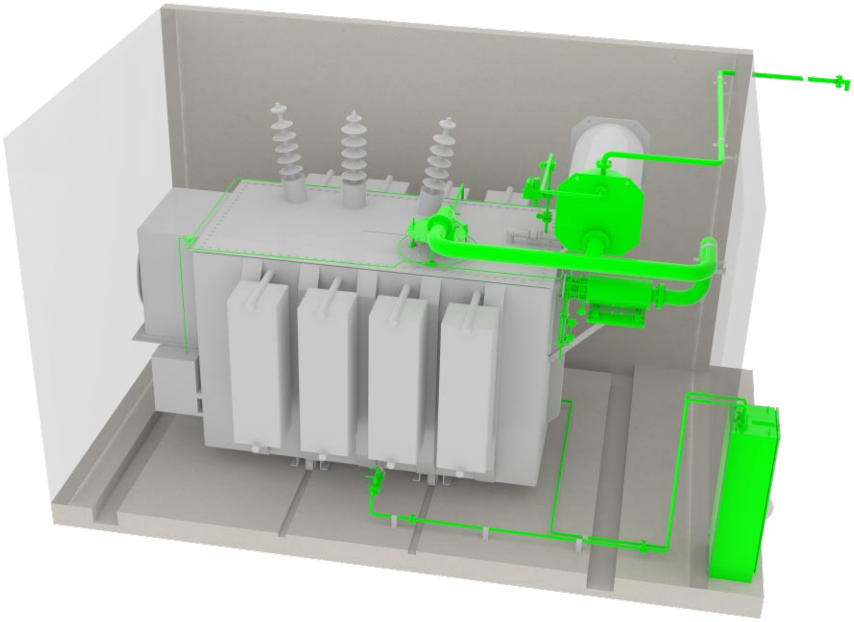

Figure 4: *TRANSFORMER PROTECTOR, type TPA with HDS and SOGST*

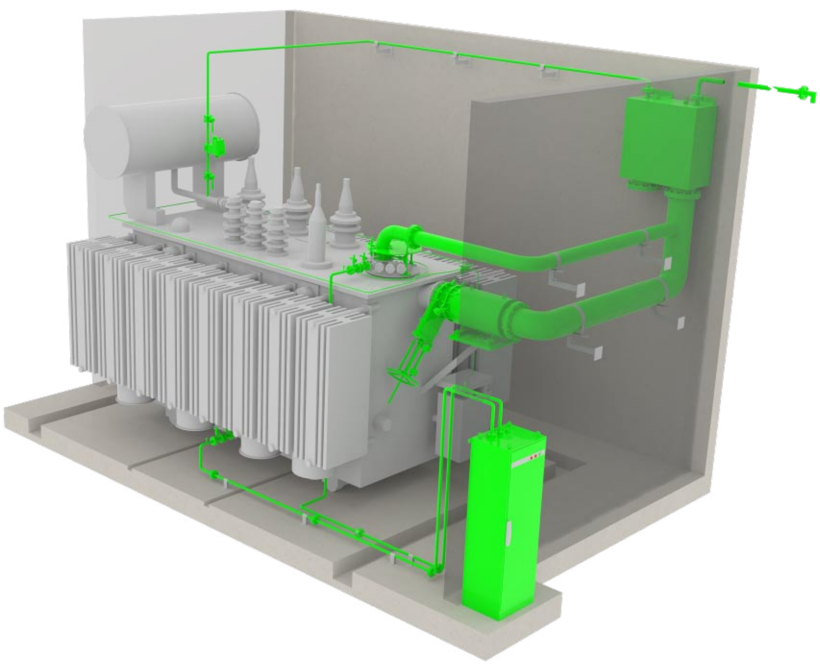

Figure 5: *TRANSFORMER PROTECTOR, type TPA with HDS and WOGST*

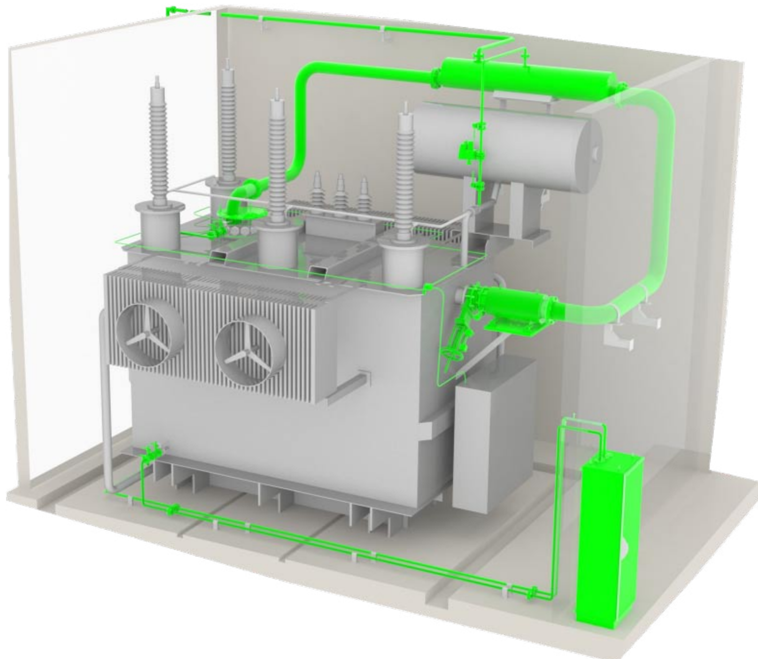

Figure 6: *TRANSFORMER PROTECTOR, type TPA with HDS and EOGST*

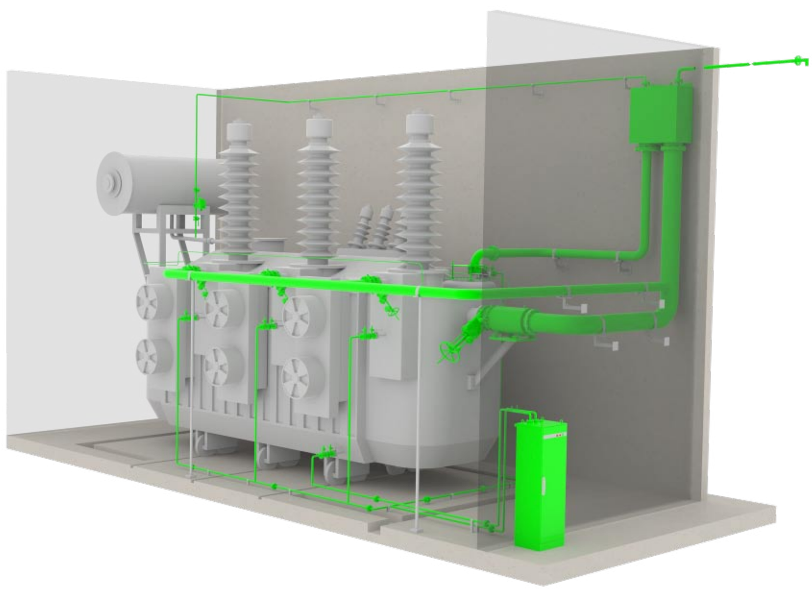

Figure 7: *TRANSFORMER PROTECTOR, type TPA3B with HDS and WOGST*

Example of TP Configuration for Transformers Below 5 MVA

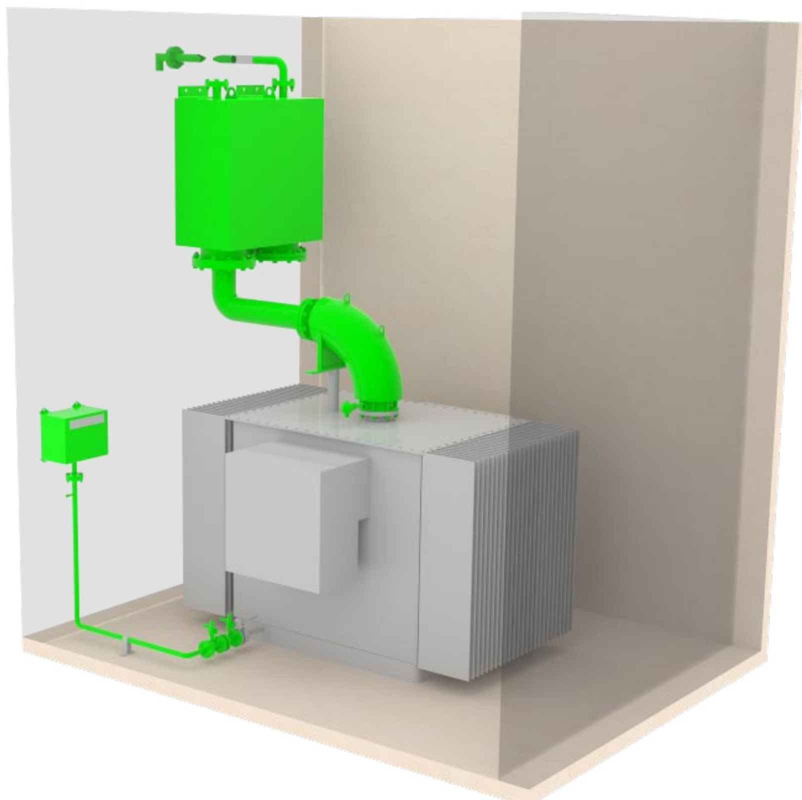

Figure 8: *TRANSFORMER PROTECTOR, type small TP with WOGST*

TRANSFORMER PROTECTOR

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