Solar Inverters

Application note

TRIO-20.0/27.6-TL-OUTD
PRO-33.0-TL-OUTD
TRIO-50.0/60.0-TL-OUTD

LV/MV transformers for large plants with string inverters

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Date	Rev.	Note
2015-11-17	1	First release.
2015-11-17	2	Revision of the number of inverter.
2016-11-17	3	Added TRIO-50.0-TL-OUTD
2016-11-26	4	New Chapter 2 & 3
2016-12-15	5	Added TRIO-60.0-TL-OUTD

Scope and application area

The document provides a detailed description of the inverter characteristics that are most relevant for the appropriate selection of the step-up transformer. Together with the technical specification of the transformers that can be used for the integration of large plants with TRIO string inverter series this document also provides indications about the max number of inverters that can be connected in parallel on the same LV winding of LV/MV step-up transformer.
This document refers to the inverter models listed in table 1.

Inverter Model	Max apparent power	Max active power
TRIO-20.0-TL-OUTD[1]	22250 VA	22000 W
TRIO-27.6-TL-OUTD[1]	30705 VA	30000 W
PRO-33.0-TL-OUTD[1]	33000 VA	33000 W
TRIO-50.0-TL-OUTD[1]	50000 VA	50000 W
TRIO-60.0-TL-OUTD[1]	60000 VA	60000 W

TABLE 1: list of inverters the document refers to.

1. Inverter Characteristics – AC terminal voltages with respect to ground

The TRIO (and PRO) inverter architecture deliver <u>LOW COMMON MODE NOISE</u>.

- Unlike conventional "pulsed inverters", TRIO power architecture does not generate high frequency switching voltage components between the output terminals and ground (no high frequency common-mode noise), as confirmed from the phase voltage to ground waveform plotted in fig.1 (see also scope plot)
- This prevents high frequency current circulation in the ground loop, thus allowing the possibility of connecting multiple inverters in parallel at the common AC output, as schematically illustrated in Fig. 2. The parallel connection can be referred to multiple inverters connected at the same secondary winding of the step-up transformer.
- Only inverters like TRIO with a pure low frequency spectrum of the output voltage with respect to ground can be considered "inherently" transformer-less, because can be effectively paralleled AT THE SAME AC output line.

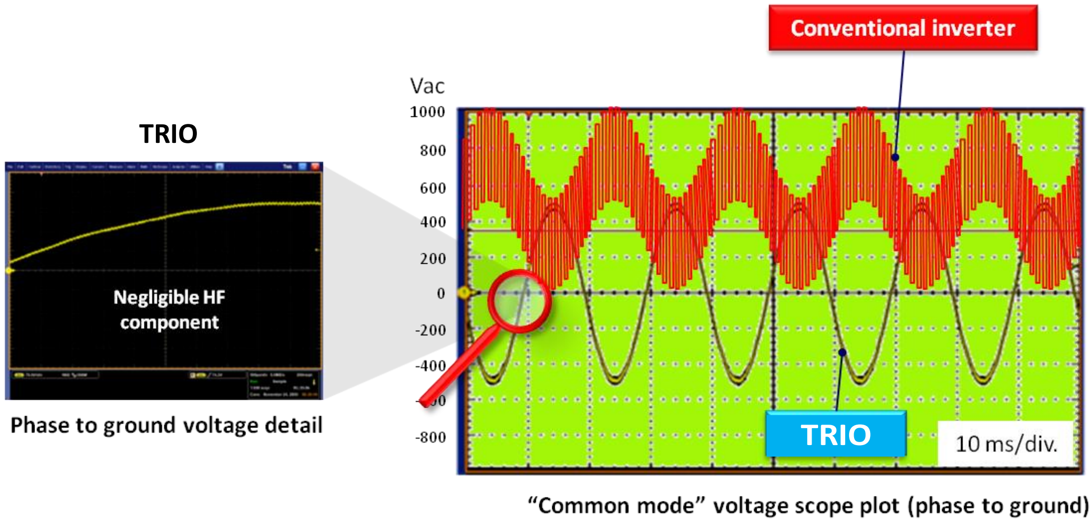


Fig.1: Comparison of the AC output voltage with respect to ground for a CONVENTIONAL INVERTER (RED) and for the TRIO inverter series (black/yellow)

[1] *Every possible versions.*

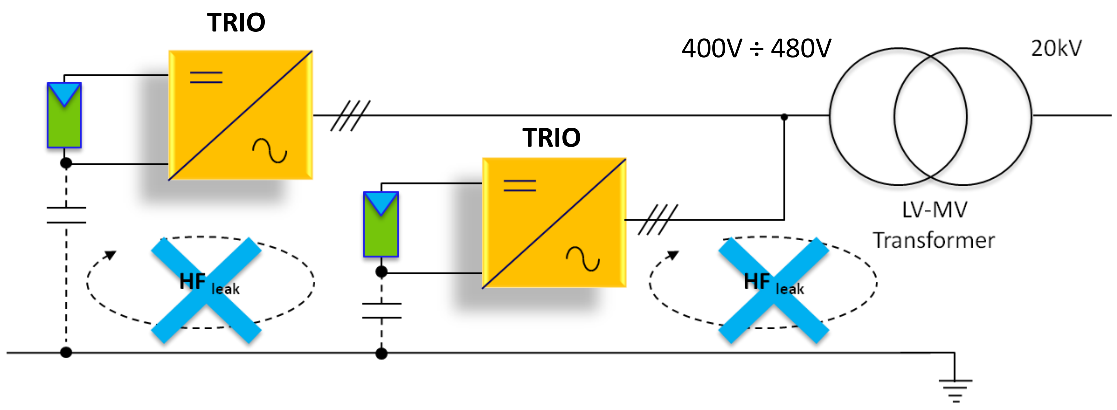


Fig.2: TRIO Inverter. Connection of multiple units in parallel at the common AC output is possible, thanks to the inherently low (negligible) leakage current.

2. LV/MV step-up transformer – Technical specification

The main advantage of the inherently low-frequency spectrum of the voltage measured between the output terminals and ground is that standard power transformers can be used for energy feeding of any PV power plant designed with TRIO inverters.
In detail, the following apply:

- **Standard line frequency power transformers**
  STANDARD line frequency power transformers can be specified for the use in combination with TRIO inverters. In particular there's NO NEED to use special transformers designed for operation with pulsed inverters.

- **Standard isolation (transformer and LV distribution components)**
  The isolation voltage of the LV windings with respect to the chassis as well as the isolation of all LV-side distribution components (LV switchgear, cables, etc…with respect to ground) are the same as those experienced during operation of a standard LV distribution system. There's no need to over-specify the insulation requirements of transformer, cables and switches. Assuming for the TRIO a rated line-to-line AC voltage of 400Vrms (480Vrms), the rms value of the voltages between each output phase terminal and ground is limited to 400Vac (480Vac), less than 50% of the value developed by conventional inverters based on pulsed-mode operation, despite the latter are running with remarkably lower line-to-line voltages of 300-360Vrms!

- **Single LV-winding**
  In case multiple inverters shall be connected to the same transformer, all inverters can be connected to the same SINGLE low-voltage winding. Unlike conventional pulsed-mode inverters, TRIO inverter technology does not require separate galvanically isolated low-voltage windings. A standard 2-winding transformer can be used (1 MV primary winding and 1 LV secondary winding).
  The use of multiple winding transformers may be optionally considered only when a large inverter capacity shall be combined on the same transformer. In this case in order to limit the maximum AC current on the LV side (and the cost/complexity of the LV panel) it may be necessary to separate the overall amount of inverters into 2 sections, each connected to a separate LV winding.

- **No High dU/dt. Grid-friendly noiseless operation and reduced transformer stress.**
  Line-to-line AS WELL as line-to-ground voltages are characterized by a low frequency spectrum and do not include any high speed voltage transient or high dU/dt. The transformer shall not withstand any high speed repetitive voltage transient with respect to ground, that may reach values as high as 1000 V/µs with conventional pulsed-mode inverters. Transformer stress is minimized as well as low-noise operation ensured without the need to integrate a grounded shield winding between primary and secondary winding.

- **Vcc(%) – transformer impedance voltage.**
  The impedance voltage of the transformer shall be nominally specified at 6%, with a tolerance of ±10% (Vcc spec. limit= 5,4% ÷ 6,6%). Other transformer impedances are possible, but shall be agreed upon with the ABB Solar technical support engineering, taking into account the overall plant capacity and grid short circuit impedance at the Point of Common Coupling on the MV side.

- **LV transformer configuration.**
  An accessible neutral point is required on the low voltage side of the transformer for the operation of the inverter. However, many transformer configurations are possible, as described in the following sections, taking into account the specific plant requirements, the local electrical grid codes as well as transformer sourcing or cost constraints (i.e. a wye configuration is most widely adopted for the configuration of LV winding of power distribution transformers).

- **Transformer vector groups.**
  In general all transformer vector groups with a wye on the secondary side are acceptable for the use in combination with TRIO inverters, while in particular the Primary/Delta-Secondary/Wye arrangements with vector group Dyn11, Dyn5 or Dyn1 are those that most commonly have been specified for our applications.
  Fig.3 illustrates an example of the most popular transformer used in MV/LV distribution stations, the Dyn11 transformer. This solution can be used as well for step-up applications in PV plants based on TRIO inverters.
  Consideration shall be made to the reverse power flow operation of step-up transformers (power flow from LV side to HV side) with respect to the standard operation of distribution transformers, where power always flows from the primary HV side to the secondary LV side. In particular this shall be taken into account while setting up the transformer nominal turns ratio to match the nominal voltage values of the grid. In addition and in order to align the voltage level to the actual values at the medium voltage Point of Interconnection of the specific plant, ABB Solar recommends to use transformers equipped with ±2x2,5% Off-Load Tap Changers on the MV side windings, as described on Table 2.

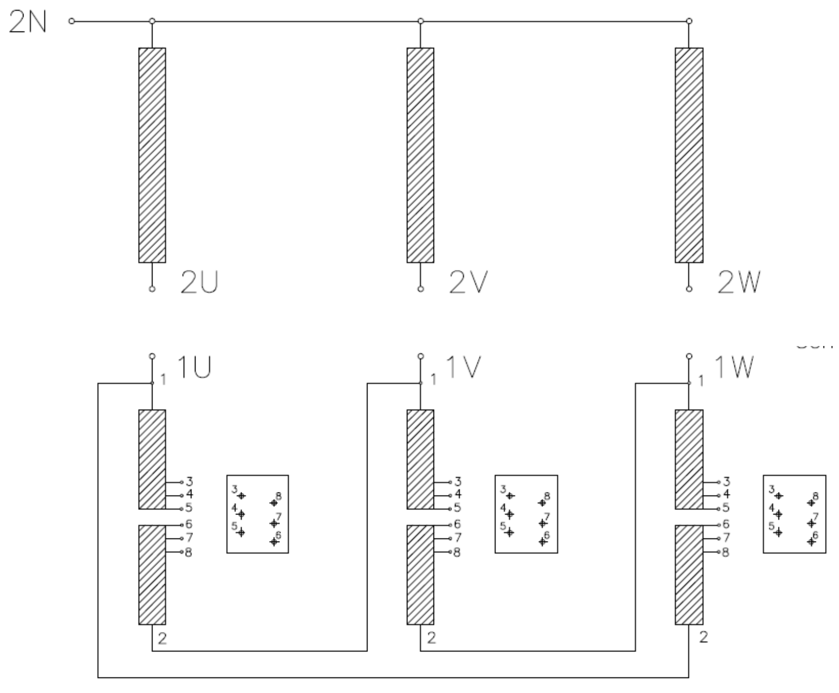


Fig.3: LV/MV transformer arrangement with Dyn11 vector group

High Voltage					Low Voltage		
CONNECTIONS	**U/Un [%]**	**Volt**	**Ampere**	**Off-Load Tap Changer connection**	**CONNECTIONS**	**Volt**	**Ampere**
1U – 1V – 1W	105,0	21000	43.99	6 - 5	2U – 2V – 2W	400	2309
	102,5	20500	45.06	5 - 7			
	100,0	20000	46.19	7 - 4			
	97,5	19500	47.37	4 - 8			
	95	19000	48.62	8 - 3			

TABLE 2: 1600kVA transformer connection and Off-Load Tap Changer arrangement

- **Transformer temperature rating.**
  The transformer shall be specified and designed for continuous operation at full rated apparent power with an ambient temperature of 45degC and cosφ=0,90 (lead or lag). An average winding temperature rise not exceeding 60degC is required.

3. The max number of inverters that can be paralleled

The max number of inverters that can be paralleled on the same LV winding of the LV/MV step-up transformer is defined by the interaction between three main factors:

- Inverter control.
- Current harmonics produced by the inverters.
- Network characteristics at the PV plant point of common coupling.

The interaction between the above listed factors could bring to an unstable operation of the inverters which may result in repetitive disconnections thus affecting the overall system availability.

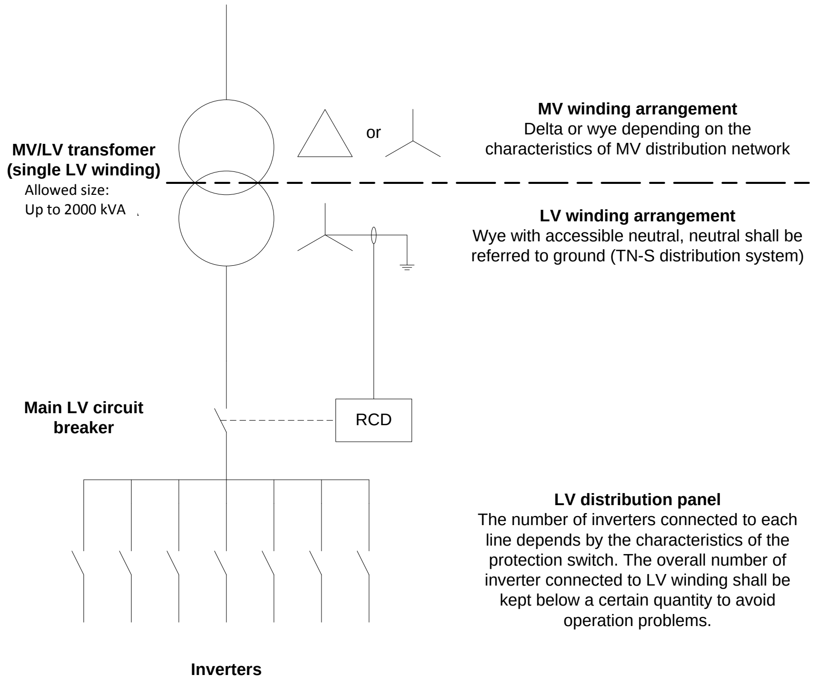
To avoid such unstable operation it is important to limit below a certain quantity the number of inverters connected to the same LV winding of the LV/MV step-up transformer, following the criteria described below.

For large plants this means to define a specific architecture. In the followings, two main architectures are proposed, respectively based on single LV winding transformers (up to 2000kVA) and double LV winding transformers (up to 3150kVA).

It is important to highlight that the network impedance at the PoCC plays a key role, for this reason the options described below can be considered valid once the short circuit power is at least 7,5 times higher than the plant installed power:

$$S_{sc,PoCC} \geq 7.5 \cdot S_{plant}$$

4. Single LV winding transformers



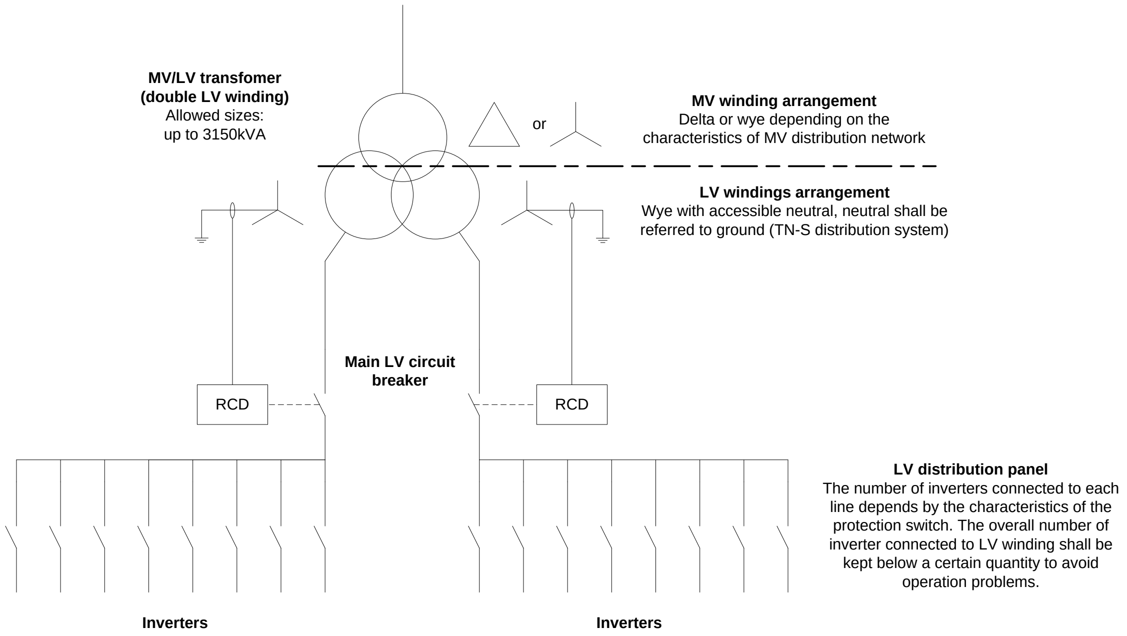
In the above diagram the RCD is connected to the main LV breaker. However alternative schemes can be considered, for example the installation of a separate RCD on each single line. It is recommended in any case to include an RCD to protect the AC lines against leakage and indirect contacts.

Type of transformer	**Single LV winding**	**Single LV winding**	**Single LV winding**	**Single LV winding**
Nominal power	1000 kVA	1250 kVA	1600 kVA	2000 kVA
Frequency	50Hz / 60Hz	50Hz / 60Hz	50Hz / 60Hz	50Hz / 60Hz
Primary (MV) winding				
Nominal voltage	According to MV network characteristics			
Winding configuration	delta or wye[2]	delta or wye[2]	delta or wye[2]	delta or wye[3]
Tap changer	±2 x 2,5%	±2 x 2,5%	±2 x 2,5%	±2 x 2,5%
Secondary (LV) winding				
Nominal voltage	400 V ÷ 480 V	400 V ÷ 480 V	400 V ÷ 480 V	400 V ÷ 480 V
Winding configuration	wye with accessible neutral			
LV side distribution system	TN-S (grounded neutral)			
Vcc%	6%	6%	6%	6%
Vector group (examples)	Dyn11 or Yyn0	Dyn11 or Yyn0	Dyn11 or Yyn0	Dyn11 or Yyn0
Number of inverters				
Max number of TRIO-20.0-TL	44	54	N.A.[4]	N.A.
Max number of TRIO-27.6-TL	32	40	52	N.A.
Max number of PRO-33.0-TL	30	37	48	N.A
Max number of TRIO-50.0-TL	20	25	32	40
Max number of TRIO-60.0-TL	17	21	27	33

TABLE 3: solutions with single LV winding.

[2] *According to MV distribution network characteristics.*
[3] *According to MV distribution network characteristics.*
[4] *Max number of inverters that can be paralleled is fixed to 54.*

5. Double LV winding transformers



In case of double LV windings transformer is recommended to limit the load unbalance it is recommended to equally split the inverters over the two windings.
In the above diagram the RCD is represent as connected to the main LV breaker. However alternative schemes can be considered, for example the installation of a separate RCD on each single line. It is recommended in any case to include an RCD to protect the AC lines against leakage and indirect contacts.

Type of transformer	Double LV winding	Double LV winding	Double LV winding
Nominal power	2000kVA	2500kVA	3150kVA
Frequency	50Hz / 60Hz	50Hz / 60Hz	50Hz / 60Hz
Primary (MV) winding			
Nominal voltage	According to MV network characteristics		
Winding configuration	delta or wye[5]	delta or wye[4]	delta or wye[4]
Tap changer	±2 x 2,5%	±2 x 2,5%	±2 x 2,5%
Secondary (LV) winding no.1			
Nominal voltage	400 V ÷ 480 V	400 V ÷ 480 V	400 V ÷ 480 V
Nominal power	1000kVA	1250kVA	1575kVA
Winding configuration	wye with accessible neutral		
LV side distribution system	TN-S (grounded neutral)		
Secondary (LV) winding no.2			
Nominal voltage	400 V ÷ 480 V	400 V ÷ 480 V	400 V ÷ 480 V
Nominal power	1000kVA	1250kVA	1575kVA
Winding configuration	wye with accessible neutral		
LV side distribution system	TN-S (grounded neutral)		
Vcc% (MV winding to each LV winding)	6%	6%	6%
Vcc% between LV windings	>10%	>10%	>10%
LV windings arrangement	Stacked - double tier construction without intermediate yoke		
Vector group (examples)	Dyn11-yn11 or Yyn0-yn0	Dyn11-yn11 or Yyn0-yn0	Dyn11-yn11 or Yyn0-yn0
Number of inverters			
Max number of TRIO-20.0-TL inverters	44 each LV winding	54 each LV winding	N.A.[6]
Max number of TRIO-27.6-TL inverters	32 each LV winding	40 each LV winding	51 each LV winding
Max number of PRO-33.0-TL inverters	30 each LV winding	37 each LV winding	47 each LV winding
Max number of TRIO-50.0-TL inverters	20 each LV winding	25 each LV winding	32 each LV winding
Max number of TRIO-50.0-TL inverters	17 each LV winding	21 each LV winding	26 each LV winding

TABLE 4: solutions with double LV windings.

[5] *According to MV distribution network characteristics.*
[6] *Max number of inverters that can be paralleled is fixed to 54.*

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