Miniature substations - what they are really capable of delivering

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16 October 2017

Overview

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- Important concepts and definitions
- Impact of the enclosure on the transformer rating
- Effects of solar radiation
- Experience with temperature rise type testing of miniature substations
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- Conclusion

Introduction

- As users of miniature substations, how many of you have ever heard of the term "class of enclosure"?
- Not all 500 kVA miniature substations are created equal
- SANS 1029 Edition 3 and IEC (SANS) 62271-202
- SANS 62271-202 provides:
  - key definitions and concepts
  - temperature-rise type test requirements
  - guidelines for determining the transformer load factor based on the class of enclosure
- Effects of solar radiation are ignored in SANS 62271-202

Important concepts and definitions (IEC 62271-202)

- **Prefabricated substation (e.g. miniature substation)**: assembly comprising an enclosure containing a transformer, HV and LV switchgear and their inter-connections.
- **Class of enclosure**: the difference in temperature rise between the transformer in the enclosure and the same transformer outside the enclosure. There are six rated classes of enclosure i.e. 5 K, 10 K, 15 K, 20 K, 25 K and 30 K.
- **Transformer load factor**: per unit value of constant current that can be taken from the transformer at constant rated voltage.
- **Rated power of the prefabricated substation:** the rated power of a miniature substation is determined by the rated power of the transformer.

Important definitions (IEC 60076-2)

- **Ambient air temperature**: temperature of the air surrounding the enclosure of the miniature substation.
  - **Yearly average temperature**: the calculated yearly average ambient air temperature at the installation site (i.e. ≤ 20^{o}C for oil transformers).
  - **Monthly average temperature**: the calculated monthly average ambient air temperature at the installation site (i.e. ≤30^{o}C for the hottest month for oil transformers).
  - **Maximum ambient air temperature**: the upper limit of the permissible ambient air temperature (i.e. ≤ 40^{o}C for oil transformers).
- Temperature rise limits are determined based on the above.

Important concepts and definitions

Location	Yearly average temperature [^{o}C]	Monthly average temperature (hottest month) [^{o}C]	Average of the daily maximum temperatures (hottest month) [^{o}C]	Highest recorded temperature [^{o}C]
SANS 60076-2 limits	**20**	**30**	**-**	**40**
Johannesburg	16	20	25	33
Cape Town	17	21	25	37
Durban	21	25	27	37
Port Elizabeth	18	22	24	38
Bloemfontein	16	23	30	38
East London	18	21	25	41
Kimberly	18	25	31	40
Polokwane	19	23	29	37
Skukuza (Kruger Park)	21	26	32	38
Nelspruit	19	23	28	40

Substation class of enclosure

- SANS 62271-202 requires that each component is tested to its relevant product standard.
- Once assembled in the complete miniature substation, the design and performance of the substation as a whole is verified by additional type tests described in SANS 62271-202. These tests include:
  - temperature rise tests on the complete substation
  - relevant tests on the HV and LV interconnections
  - mechanical and corrosion tests (e.g. IP Code)
  - internal arc tests

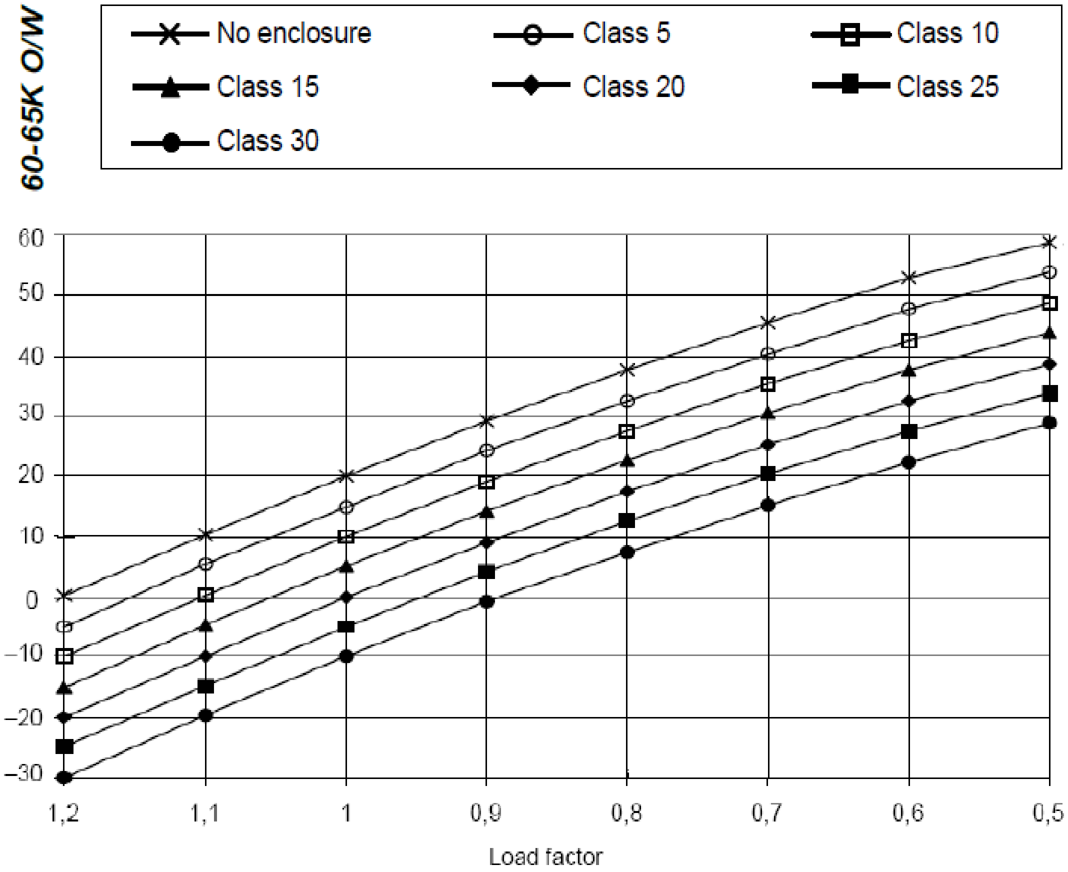
Substation class of enclosure

- The losses generated by the internal components result in an internal ambient temperature that is higher than the external ambient.
- A transformer loaded with rated normal current inside an enclosure has a temperature rise which is higher than when tested on its own in free-air conditions
  - the temperature limits given in SANS 60076-2 can be exceeded.
- the “class of enclosure” is based on this fact and effectively makes provision for the conditional de-rating of the transformer once installed inside the miniature substation.

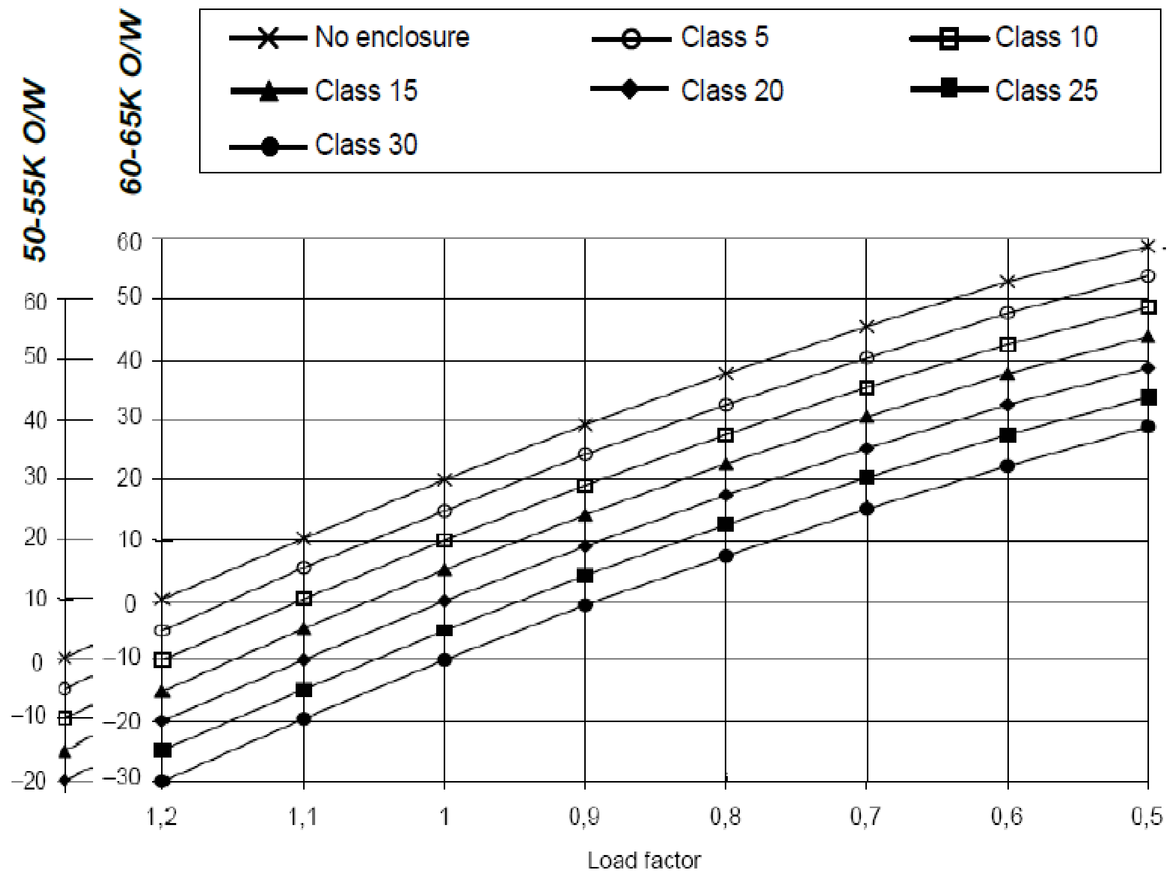
Substation class of enclosure

- The class of enclosure is required to be confirmed by type testing in accordance with SANS 62271-202.
- As natural ventilation is the only means of cooling in miniature substations, effective enclosure ventilation is therefore critical.
- The designer is often challenged by the user’s desire to specify a high IP Code (e.g. to limit dust and water ingress) as this reduces the natural ventilation and thus temperature rise performance of the substation.
- The manufacturer or user can calculate the transformer load factor using Annex DD of SANS 62271-202.

Substation class of enclosure



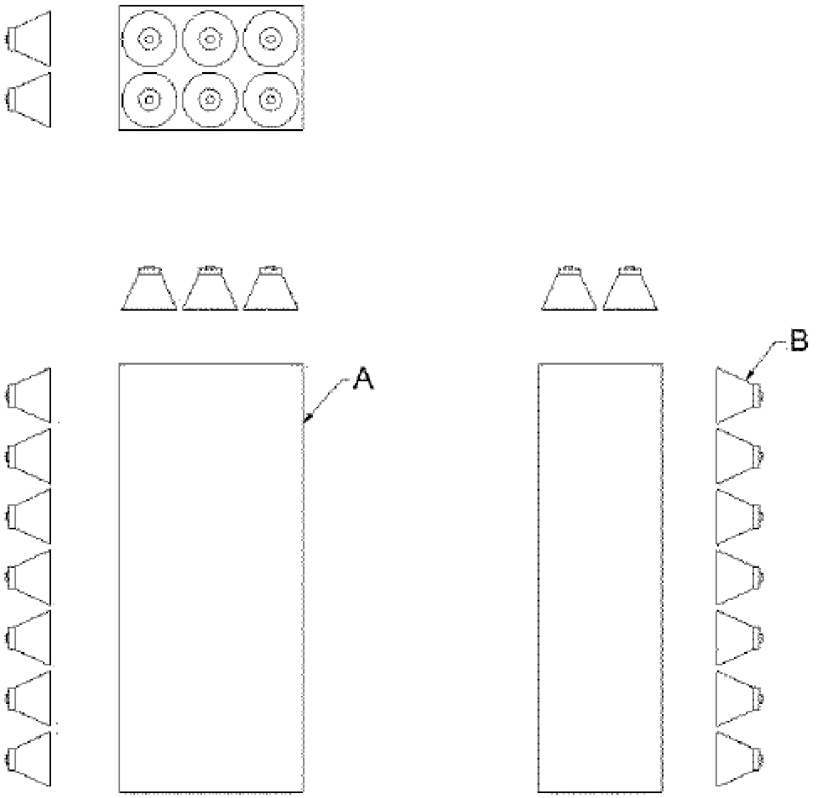
Substation class of enclosure



Effects of solar radiation

- The temperature rise type tests for the miniature substation currently do not take into account the effects of solar radiation.
- A revised temperature rise type test for LV power switchgear ASSEMBLIES used in PV applications has recently been proposed in IEC 61439-2 – which takes into account solar radiation on the enclosure
- As a minimum, this type test should be included for miniature substations used in PV applications.

Effects of solar radiation

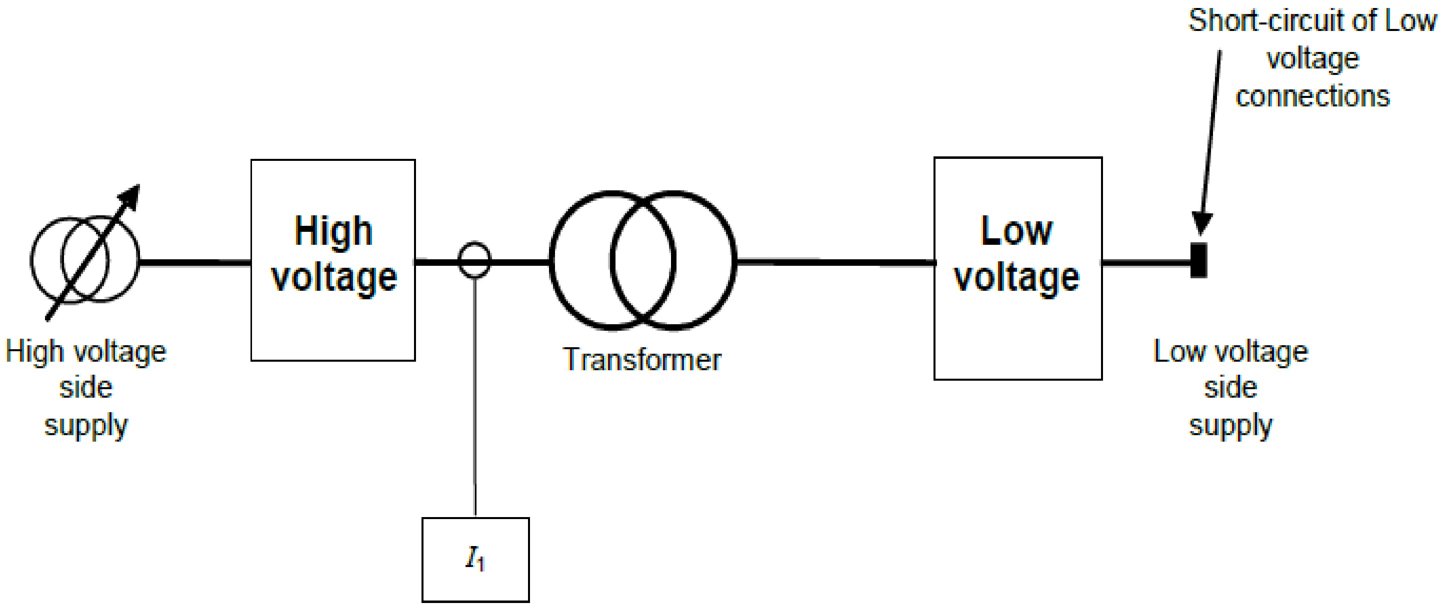


Key
A ASSEMBLY under test
B Array of radiant heat lamps

- Top = 0,76 kW/m^2
- Front or back = 0,54 kW/m^2
- Side = 0,54 kW/m^2

Experience with temperature rise type testing

- Typical temperature rise type test method where one power supply is used



Experience with temperature rise type testing

- The 1st stage of the test requires sufficient current to be supplied to generate the total rated losses of the transformer:
  - the transformer top oil temperature-rise is measured

- The 2nd stage, the current is reduced so as to produce the rated secondary current of the transformer for two hours:
  - the transformer winding and LV ASSEMBLY temperature rise values are measured

Experience with temperature rise type testing

- 1000 kVA miniature substation temperature rise test

Experience with temperature rise type testing

- SABS type test report extract for the 1st stage of a 1000 kVA miniature substation temperature rise test

Thermo couple No.		Temperature-rise measurement position	Actual Rise K		Max Rise Allowed K
AI1		Top oil temperature-rise of the transformer	50.5		60
AI2	AI3	On the top of the radiator of the transformer	44.5	44.5	-
AI4	AI5	On the bottom of the radiator of the transformer	31.9	34.3	-
**		Top oil temperature-rise with transformer outside the enclosure	46.83		60
-		**Difference between top-oil temperature-rise with the 1000 kVA transformer outside the enclosure and when inside the enclosure**	**3.67**		**+5**

Experience with temperature rise type testing

- SABS type test report extract for the 2nd stage of a 1000 kVA miniature substation temperature rise test

Thermo couple No.		Temperature-rise measurement position	Actual Rise K		Max Rise Allowed K
AI1		Top oil temperature-rise of the transformer	50.16		-
AI2	AI3	On the top of the radiator of the transformer	43.9	43.8	-
AI4	AI5	On the bottom of the radiator of the transformer	30.7	33.3	-
➢		Low voltage winding temperature – rise of the transformer	44.32		65
➢		High voltage winding temperature – rise of the transformer	44.09		65
1		TRFR connection red phase	57.2		105
2		TRFR connection yellow phase	61		105
3		TRFR connection blue phase	58.8		105
4		Main MCCB upper connection yellow phase	66.8		80
5		Main MCCB lower connection yellow phase	59.3		80

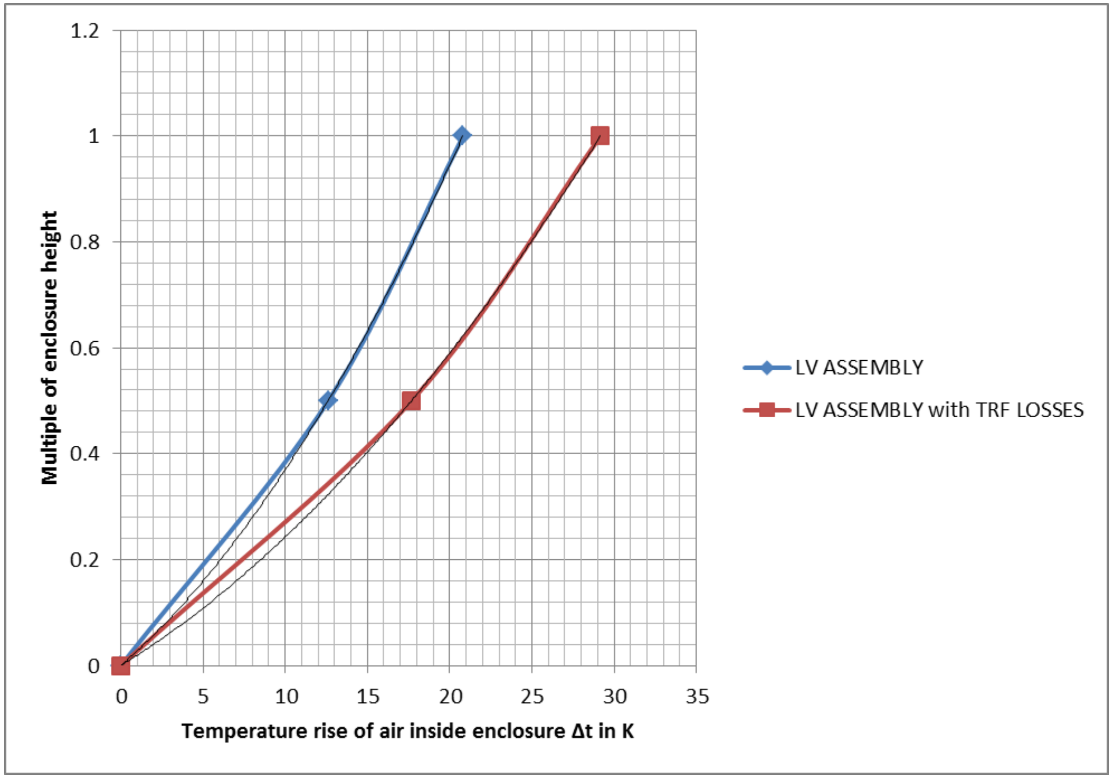
Experience with temperature rise type testing

- SABS type test report extract for the 2nd stage of a 1000 kVA miniature substation temperature rise test (cont.)

6	LV main busbar red phase	51.3	105
7	LV main busbar yellow phase	51.9	105
8	LV main busbar blue phase	48.6	105
10	LV compartment top internal ambient	28.7	-
11	LV compartment mid-point internal ambient	17.7	-
12	Star point	50.7	105
14	Accessible enclosure metal surface-front	9.6	30
16	Accessible enclosure metal surface-LV end	10.1	30
17	Main MCCB operating handle	24.5	25

Experience with temperature rise type testing

- Internal LV compartment ambient temperature rise of a 1000 kVA miniature substation



Historical performance of miniature substations

- So what has changed in the application of miniature substations to make the thermal performance of transformers increasingly relevant?
  - residential vs industrial applications (i.e. cyclic load profile vs continuous)
  - specification of transformer sizes to match the prospective load
  - solar (PV) applications

Conclusions

- Most users and manufacturers remain unaware of the "class of enclosure" concept and its impact on the rating of the transformer (and LV ASSEMBLY) housed in the enclosure.
- Temperature-rise type testing in accordance with SANS 62271-202 in general is not done and most users expect that their miniature substation transformers are able to deliver the power indicated on the transformer nameplate.
- As a minimum, temperature rise testing should be done for the largest kVA rating offered.

Conclusions

- Enclosure colours to be considered for solar radiation
- Orientation of miniature substation to minimise exposure of surfaces to solar radiation
- Being mindful of the internal ambient temperature gradient from the bottom to the top of the enclosure, it is recommended that LV equipment, and in particular sensitive electronic equipment, be positioned as low down as possible.
- Additional routine test proposed for the measurement of the main circuit resistance of the LV ASSEMBLY and inter-connections

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