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Design and operation consideration for selection of transformers for solar photovoltaic plant applications

A2-PS1- Question 1.2: What design and operation considerations should be included to optimize the selection of transformers for photovoltaic applications?

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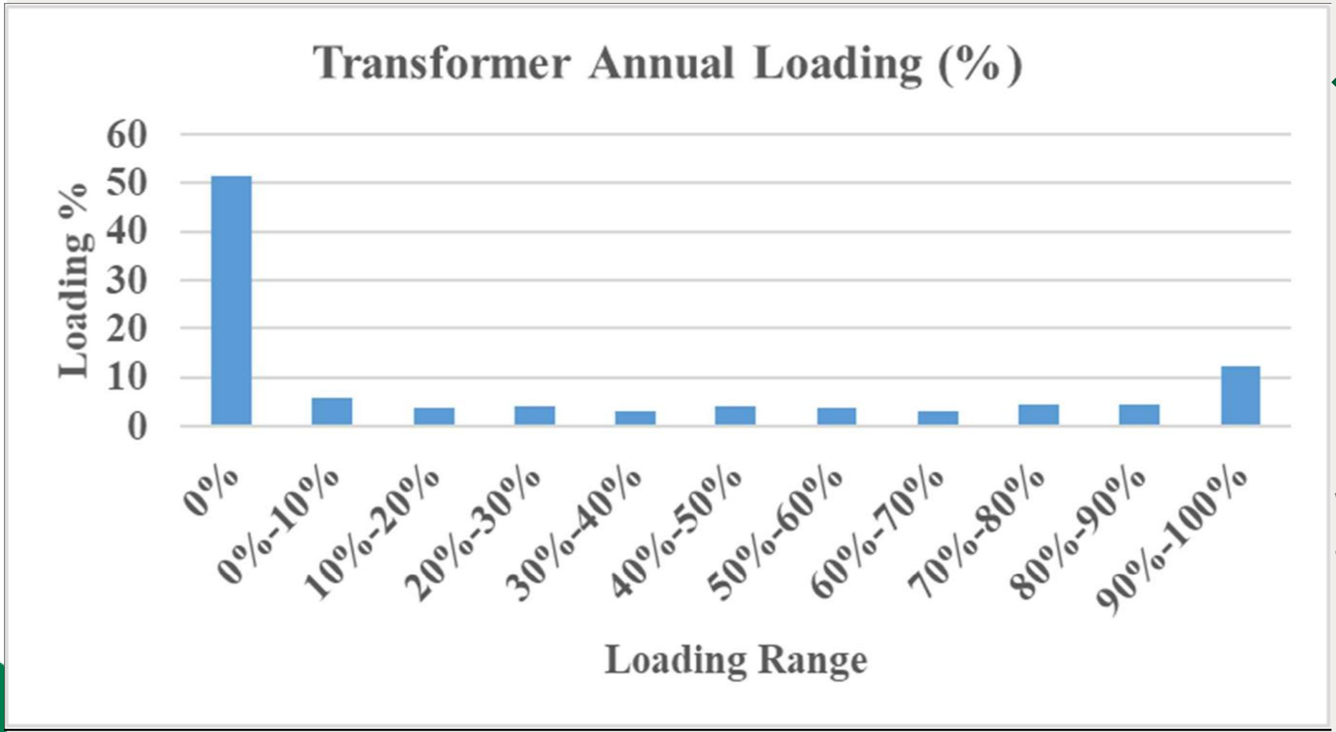
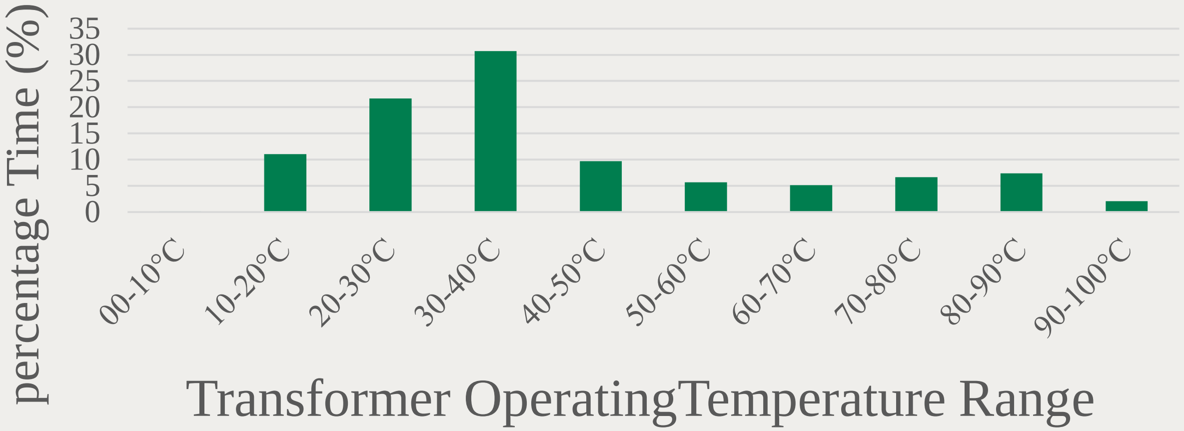


Solar Inverter Transformer typical annual loading pattern

Solar inverter transformers operates in cyclic loading pattern in a 24 hour cycle. Also, their loading varies according to seasons & weather conditions. Loadings on solar inverter transformers are almost nil during night hours.

Typical solar inverter transformer operating temperature range and duration (one year hourly data)



Sr. no.	Parameters	Values
1	No-load Loss (NL) (KW)	8.85
2	Load loss (LL) (KW)	115
3	Switch-off duration per day (Hours)	12
4	Energy save per day (KWh) (4=1X3)	106.2
5	Per unit energy charge (INR/KWh)	3.45
6	Monetory saving per day (INR) (6=4X5)	366.4
7	Capital gain per year (INR) (6X365)	**133732**

Transformers are subjected to mainly two type of losses, namely-

1. Core loss- depends on voltage, independent of load current.
2. Copper loss- depends on load current.

Typical 12.5 MVA 33/4X0.630 KV, 5 winding Inverter Transformer annual capital gain by switching off during night hours

Transformer magnetizing current contains predominantly 2nd order harmonics content. Provision of a 2nd order harmonic filter at the input side of transformers will reduce the charging current during switching-on operation.

Typical 12.5 MVA 33/4X0.630 KV, 5 winding Inverter Transformer capital gain by the selection of suitable flux density

Sr. no.	Parameters	Values
1	CRGO core weight (KG)	7468
2	Present flux density (Tesla)	1.73
3	Proposed flux density (Tesla)	1.79
4	Increase in flux density (%) (4=(3-2)/2X100)	3.5
5	Decrease in core area (%) (5=4)	3.5
6	Reduction in core weight (KG) (6=1X5/100)	261.4
7	Price of core (INR/KG)	325
8	Savings in Capital investment (INR) (8=6X7)	**84955**

Sr. no.	Parameters	Values
1	Copper conductor weight (KG)	4240
2	Present current density (A/mm2)	3.0
3	Proposed current density (A/mm2)	3.8
4	Increase in current density (%) (4=(3-2)/2X100)	26.7
5	Decrease in conductor area (%) (5=4)	26.7
6	Reduction in conductor weight (KG) (6=1X5/100)	1132
7	Price of copper conductor (INR/KG)	950
8	Savings in Capital investment (INR) (8=6X7)	**1075400**

Typical 12.5 MVA 33/4X0.630 KV, 5 winding Inverter Transformer capital gain by the selection of suitable current density

Reduction in core & conductor area could now further reduce volume of paper insulations, press boards, frames, barriers, spacers, cellulose weight, tank dimensions & its accessories, oil volume, cost of transportation, equipment handling, civil foundation, layout space requirement etc.

Typical selection of Solar Inverter Transformer sizing

ONAN rating of transformer could be selected matching the estimated power flow during the lean solar generation period. During peak loading , these transformers can be operated in ONAF mode to meet the peak demand by enhancing its power delivery capability by dissipating the additional losses, keeping its active parts unchanged.

Sr. no.	Parameters	Values
1	Avg. lean periods load demand (MVA)	12.5
2	Avg. lean periods (Hours)	9
3	Peak demand (MVA)	21
4	Peak demand periods (Hours)	3
5	Selected transformer size (ONAN) (MVA)	**12.5**
6	Operation in ONAF mode (MVA)	21

Sr. no.	Parameters	Values	
1	Transformer (MVA)	2.5	12.5
2	HV/LV (KV)	33/2X0.350	33/4X0.650
3	Per LV current (A)	2062	2864
4	Per LV Impedance (%)	5.25	8.75
5	Short circuit fault current contribution by transformer in LV (KA) (5=3/4/10)	39.28	**32.73**
6	Short circuit fault level margin available at LV bus (of 50 KA for 1 sec sized) (KA) (6=(50)-5)	10.72	**17.3**

Comparison of typical dynamic & thermal withstand capability requirement during short circuit of solar Inverter Transformers of rating 2.5 MVA & 12.5 MVA

Now a days, solar plants are coming up of higher ratings of inverters in the range of 2.5 MW-7.5 MW. This can allow designer to consider solar transformers with higher impedance values due to significant increase in transformers ratings. Higher impedance of transformers will reduce fault current during short circuits which will reduce the thermal and dynamic withstand capability requirement (radial & axial mechanical clampings of transformers windings) in transformer design & manufacturing during any short circuit fault. As a result, transformers life could be enhanced significantly. It could also provide significant higher short circuit fault level margin at inverter power bus end.

Application of synthetic ester oil

This oil generally has very good oxidation stability, higher flash point in the range of 300 deg C and bio degradability makes it very much environment friendly. Higher flash point makes it almost self fire retardant in nature which could eliminate requirement of additional external fire fighting arrangements. Moreover, its higher flash point could allow to design transformers with slight higher temperature rise of oil & winding with slight higher side of core & copper losses.

Conclusion

Inverter Transformers being most critical components in solar PV plants, following considerations may be adopted during design which may help to reduce the initial cost as well as in optimizing the life cycle cost and energy generation cost.

- Solar inverter transformers can be switched-off during night hours to save the unnecessary continuous no load losses with provision of 2nd order harmonic filter at the input side and shielding over the windings of transformers.
- Transformers with slightly higher flux density and no load loss may be adopted in design which will help to reduce quantity of costly core (CRGO) material.
- Such transformers could also be designed with marginally higher load loss and higher current density, since they will be operating only in day hours that too with variable loading pattern and significant time of part loading which may help in reduction of costly copper area/quantity which will further reduce requirements of costly insulating materials, overall tank dimensions, oil volume, total transportation weight, lesser transportation cost, equipment handling cost, civil foundation requirement cost, space requirement in layout etc.
- ONAN rating of transformer could be selected matching the estimated power flow during the lean solar generation period with provision of ONAF mode to meet the peak demand by enhancing its power delivery capability by dissipating the additional losses, keeping its active parts unchanged.
- Higher ratings of inverters can allow designer to consider solar transformers with higher impedance values due to significant increase in transformers ratings which will reduce fault current during short circuits which will reduce the thermal and dynamic withstand capability requirement which may enhance life of transformers significantly.
- Use of synthetic ester oil which has good oxidation stability, higher flash point, bio degradability (environment friendly) making it almost self fire retardant in nature which could eliminate requirement of external fire fighting arrangements at remote location transformers installations, making them as almost maintenance free and may allow to design transformers with slight higher temperature rise of oil & winding with slight higher side of core & copper losses making the overall design, manufacturing of transformers very much cost effective.