Study Committee A2

Title of Study Committee Power Transformers & Reactors

Paper ID_10433

TITLE

Design and Operation Consideration for Selection of Transformers for Solar Photovoltaic Plant Applications

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Motivation

- Solar energy is one of the prominent renewable energy sources for electricity, and the scale of the solar plant is constantly growing to meet the growing energy demand.
- There has been marked in reduction of levelized cost of energy (LCOE) due to development of Large Utility scale PV power plant.
- Inverter Transformers are one of the most critical components in solar PV plants and are deployed in large numbers.
- Power output from PV Solar plant is inherently intermittent depending on available solar irradiance. Accordingly, load on solar inverter transformers also varies. Most of the time they operate at part load only.
- Judicious selection of design parameters not only reduces the initial cost of transformer, they also help in optimizing the life cycle cost.
- Solar projects have very stringent project timelines. With the low tariff being discovered for upcoming projects, measures to reduce the project cost and aux power consumption are the new focus areas.
- This paper presents Solar PV plant architecture details, annual solar generation profile and loading cycles of solar inverter transformers, estimation and comparative analysis of these transformer losses, service life and cost savings opportunities for presently used and proposed design along with operational practices. Selection of suitable short-circuit impedance of solar inverter transformers for application with different rated inverter based on techno-economical consideration. Software simulation, mathematical computation, and techno-economical analysis are presented in details.

Method/Approach

- Solar PV plant architecture details, annual solar generation profile and loading cycles of solar inverter transformers, estimation and comparative analysis of these transformer losses, service life and cost savings opportunities for presently used and proposed design along with operational practices, Software simulation, mathematical computation, and techno-economical analysis.

Objects of investigation

- Judicious selection of design parameters not only reduces the initial cost of solar inverter transformer, they also help in optimizing the life cycle cost.
- Solar projects have very stringent project timelines. With the low tariff being discovered for upcoming projects, measures to reduce the project cost and aux power consumption are the new focus areas.

Experimental setup & test results

- Solar PV plant architecture details, annual solar generation profile and loading cycles of solar inverter transformers, estimation and comparative analysis of these transformer losses, Software simulation, mathematical computation.

Discussion

- Detailed dicussions are in subsequent slides.

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.

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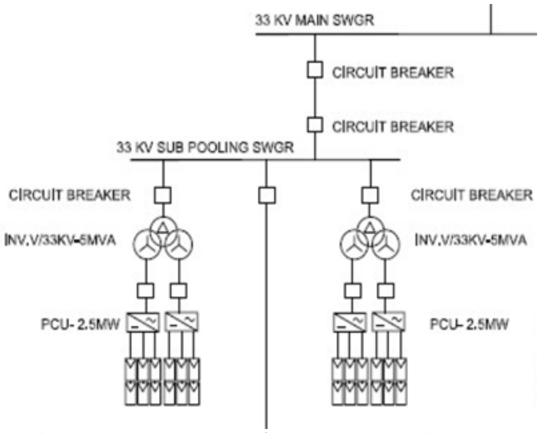
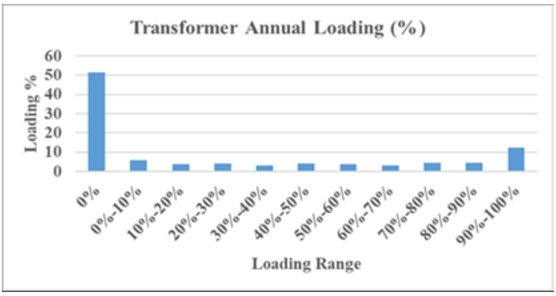
continued

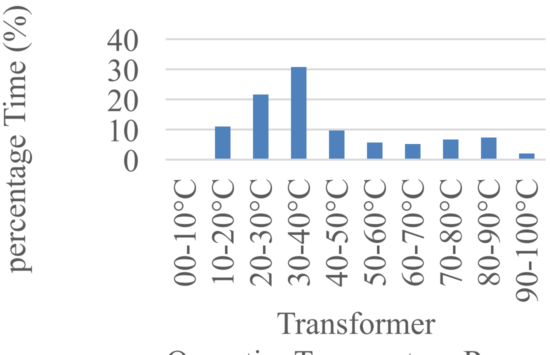
TYPICAL SOLAR PV PLANT ARCHITECTURE



Solar Inverter Transformer typical annual loading pattern



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



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.

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

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**

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**

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

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**

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

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

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.

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

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**

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

- Solar inverter transformers can be switched-off during night hours to save 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, 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 higher temp. rise.