PREPARATION OF TRANSFORMER SPECIFICATIONS

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OBJECTIVES

- To prepare specifications for procuring reliable transformers at market prices.
- To prepare clear and concise specifications with no ambiguities.
- To guide users in determining the transformer parameters.
- To ensure that the transformer parameters meet system needs.
- To use existing standards to the full extent in the specifications.
- To familiarize users as to how specifications affect the design and the cost.
- To encourage the manufacturers to submit cost effective alternates with low losses, meeting all the system needs.
- To understand the dangers when the transformers are used different to what is stated in the specifications.
- To discuss the advantages and disadvantages of invited tendering verses open tendering.
- To know and understand the clarifications/confirmations to ask in the Tender Review and Design Review meetings.
- To avoid delays in delivery by following up with the manufacturer at critical intervals.
- To check the quality of the transformer by inspecting at correct production stages.
- To ensure that the factory tests meet system conditions and the standards.
- To identify the importance of transportation, installation and maintenance when evaluating tenders.
- To obtain the best benefits by knowing the characteristics and the costs of the materials and the components used in the transformers.
- To interact with transformer manufacturers for mutual benefits.
- To initiate new or evolving innovations in transformer design and manufacture for the reduction of cost without compromising the performance.

FUNCTIONS OF TECHNICAL SPECIFICATIONS

1. “From an User perspective: To formally and fairly communicate exactly what the Contractor has to deliver.” [1]
2. “From a Contractor perspective: To be able to accurately offer services and products which provide a satisfactory solution (technical and commercial) to user; while remaining a long-term profitable business.” [1]
3. “For both User and Contractor: To avoid relationship mishaps associated with costly variation work.” [1]
4. Enable the manufacturer’s design engineers to understand the characteristics of the user’s system and how the transformers are operated in service.
5. Create an opportunity for manufacturers to apply improved design and manufacturing methods beneficial to users. Also an opportunity to use advanced materials and accessories.
6. Many users are of the opinion that they are procuring the lowest cost transformers by ordering based on the lowest evaluated cost bid. Effective specifications will help procure transformers with the lowest life cycle cost.
7. Technical specifications provide the user a future record of design parameters to which a particular transformer was purchased. This information is essential for users when a specific transformer has to be moved to a different location with different system needs or when a mature system’s contingency plans change. New requirements evolve over time. Past specifications may not have considered modern criteria such as:

   (i) GIC (Geometrically Induced Currents) requirements.
   (ii) Free buckling requirements on inner coils.
   (iii) Advanced on-line monitoring devices.
   (iv) Vacuum type on-load tap changers.
   (v) SFRA requirements.
   (vi) Apparent charge (pC).
   (vii) Impact of secondary generation, especially on transformers with dual secondaries.

Thorough specifications are the first step in establishing long term reliability of transformers. Specifications should cover the present and future system requirements. Transformers are reliable and offer trouble free service if they are operated as stated in the specifications and maintained to minimize aging of the insulation. Specifications should encourage new developments that increase efficiency while reducing the life cycle cost. Constructive participation of users in tender review, design review, inspections and resolving conflicts will enhance the long term reliability of the transformers.

CEATI (Canadian Electrical Association Technical Institute) has published a report on ‘Review and summary of key standards and guides for station-class power transformers’ [18]. This is a good reference while preparing the specifications.

Input from maintenance engineers, operating engineers and the manufacturer’s design engineers is essential in preparing effective specifications.

TOPICS

1. Ratings.
2. Standards.
3. Single phase verses three phase.
4. Winding connections.
5. Vector group.
6. Insulation levels.
7. Terminals.
8. Accessories.
9. Types of cooling.
10. Sound levels.
11. Taps (range, locations etc.).
12. Types of taps.
13. Impedance.
14. Capitalization of losses.
15. Short-circuit withstand.
16. Special requirements (altitude, over excitation, GIC etc.).
17. Overloads.
18. Parallel operation.
19. Rating plate.
20. Alternatives.
21. Interesting clauses in the specifications.
22. Globalization.
23. Data sheets.
24. Tests.
25. Tender and design review meetings.
26. Transportation and limiting dimensions/weights.
27. Conclusions.

RATINGS

The transformer's MV.A rating is usually determined based on the system expected load growth, available generation and expected rate of return on the investment. The business plan is based on capital cost recovery, depreciation rate and the profit to be made each year. Transformer applications such as two winding, autotransformer, step-up or step-down etc. influence the transformer rating. Other factors such as expected power demand growth and load factor have a large influence in determining the transformer rating.

CSA-C88-M90 clause 4.1 defines the rating as follows. "the rated load in MV.A together with any other assigned characteristics, such as voltage, current, and frequency assigned by the manufacturer. It shall be regarded as a test rating that defines an output that can be taken from the apparatus under prescribed conditions of test, and within the limitations of this standard". Further, 'Basis of MV.A' is defined in section 7.2.

IEEE standard C57.12.80-2010 clause 3.355 states the rating as follows:- "The rating of a transformer consists of a volt-ampere output together with any other characteristics, such as voltage, current, frequency, power factor, and temperature rise, assigned to it by the manufacturer. It is regarded as a rating associated with an output that can be taken from the transformer conditions and limitations of established standards".

IEEE standard C57.12.00-2010 clause 5.4.1 describes the rating as follows. "The rated KV.A of a transformer shall be the output that can be delivered for the time specified at rated secondary voltage and rated frequency without exceeding the specified temperature-rise limitations under prescribed conditions of test, and within the limits of established standards".

IEC 60076-1, 2000 clause 4.1 states the rating as follows:- "The interpretation of rated power according to this sub-clause implies that it is a value of apparent power input to the transformer. This is different from the method used on US tradition (ANSI/IEEE C57.12.00), where 'rated KV.A' is 'the output that can be delivered at …rated secondary voltage…' According to that method, allowance for voltage drop has to be made in the design so that the necessary primary voltage can be applied to the transformer".

If transformers are purchased per IEEE standard, the electrical location of the taps (in HV, in LV, in series winding, in common winding etc.), application of the taps (for input voltage fluctuations or for output voltage regulation), and whether the transformers are operated as step-down or for step-up determine different MV.A ratings for the input and output circuits (HV and LV). Considering this, some users make the calculations themselves and specify the currents for each winding. This is preferred since if left to the manufacturers, each manufacturer could calculate the currents differently.

Many users have standardized the transformer MV.A ratings used in their systems. This is based on overall economy (resulting in fewer spare transformers) and the flexibility of moving the transformers to different stations in their system. Site location and transportation limitations can limit the MV.A rating of the transformer.

Input and output (HV and LV) voltage ratings are determined by the economics of power transmission based on the total MV.A to be transported, length of transmission lines etc.

STANDARDS

Many specifications list a number of transformer standards and make a statement in the specifications that the transformers must meet these standards. Some definitions and requirements of these standards, such as CSA-C88-M90, IEEE C57.12.00 and IEC 60076 are different. The following have different explanations in these standards:-

- Normal or usual service conditions.
- Rated power.
- Over voltage conditions.
- Overload capacity at low ambient temperature.
- Suggested impedances.
- Tests and test levels.
- Dimensions and insulation levels of bushings. Also, the external clearances.
- Oil temperature rise.
- Types of taps.
- Tap range.
- Tolerances on impedance, losses and magnetization current.

The specifications should state which clause in the specification should meet which standard. The specifications should also reference the latest version of the standard. When the specifications are not clear, most of the manufacturers bid the transformers with least first cost. Often these assumptions may not meet system needs. Some examples are: RCBN taps when system requirement is FCBN taps, in-feed from TV is not considered when there is in-feed from TV in the system etc.

Before quoting a clause from a standard in the specifications, the users must ensure the standards satisfy their needs. Some users specify that certain parameters should be per industry standard. There is no ambiguity if the specifications give the reference to this industry standard. Users should know that there are no universal “industry standards” and there are only standards such as CSA, IEEE and IEC.

Users should be aware of the latest revisions in the standards and also the current discussions in the committees that write the standards. A few of such topics in IEEE transformers committee are given below.

- Rating of stabilizing winding (buried tertiary).
- Correlation of winding temperature indicator (WTI) time constant to the type of cooling and the winding time constant.
- Partial discharge measurement in pico coulombs rather than micro volts.
- Sound level test based on sound intensity rather than sound pressure.

CSA-C88-M90 was published in 1990 and was reaffirmed in 2009 but was not updated. Normally IEEE and IEC standards are updated or revised at least once in ten years. In IEEE, the Transformers Committee Working Groups are assigned for continuous improvement of C57.12.00 and C57.12.90 standards. When specifying the transformers per CSA-C88-M90 users should make the necessary updates to their specifications.

Standards do not, by themselves, form specifications. The use of the standards correctly will enable procurement of economical transformers meeting system requirements.

SINGLE-PHASE VERSES THREE-PHASE

Dimensional and weight limitations at site, transportation restrictions, economics of spares and transformer reliability primarily determine whether the transformer required is single-phase or three-phase. A bank of three single-phase transformers cost about 1 ½ times the cost of a three-phase transformer having the same total MV.A.

Single-phase transformers may be specified for hydraulic stations because of transport restrictions and space limitations at site. At large nuclear stations, the risk assessment generally requires the use of single-phase GSU transformers. To replace a failed single-phase transformer takes much less time than a three-phase transformer, reducing down-time to the system and saving considerable cost. Very high voltage transformers (765KV, 1200KV etc.) are single-phase because it is not practical to achieve the required air clearances in a three phase-transformer. For overall economic reasons, most sub-stations up to 500KV use three-phase transformers.

When an old single-phase transformer fails, it is often replaced with a new single-phase transformer. For a functionally identical new transformer, losses, weight and dimensions are often much lower than those of the old transformer. This is due to improvements in materials, accurate design analysis with advanced mathematics, computers and better manufacturing methods. Users should consider these factors, and if it is economical and feasible (existing foundations, space limitation, etc.), then they should replace the old single-phase transformers with a new three-phase transformer rather than buying another single-phase transformer.

When the user desires an identical replacement transformer, all the parameters of the old transformer must be given to the bidders. If users do not have the data on the old transformers, a pre-tender meeting with the bidders could help.

The following will help in writing specifications for a single phase transformer to replace a failed unit in a three-phase bank.

1. Neutral bushing current rating is based on where the neutral connection is made (between the units or in the station bus).
2. Tertiary bushings current rating is based on where the delta connection is made (between the units or in the station bus).
3. Type of transformer core (three-limbs with coils on one limb, or two limbs with coils on both limbs, or four-limbs with coils on two-limbs) is preferred to be the same as the remaining two healthy units.
4. LTCs to have same run-through positions (this simplifies the control scheme).
5. Check with breaker supplier as to whether the capacitance to ground should be the same on all the units (limit on fault current interruption duty).
6. Check whether the two healthy units have subtractive or additive polarity. Prefer to order subtractive polarity per present standards. If required, specify proper insulation levels (fully insulated) to use for replacement.
7. Stabilizing winding (buried tertiary) must be designed for the faults on the tertiary (this is not required on three phase transformers).
8. To avoid undesired circulating current in the tertiary delta, the voltage for the tertiary must be same for all the units. If the tertiary voltage on the two healthy units is 33.1KV, then specify 33.1KV and not 33KV.

WINDING CONNECTIONS

Three phase transformers have windings connected in wye, delta or zig-zag inside the tank. These connections for single phase transformers are made outside the tanks. When a neutral is required then, it is economical to choose a wye or a zig-zag. If a neutral is required on a delta side, then a grounding transformer is needed.

Neutrals usually have a lower insulation level compared to the lines. Such windings can be economically designed with graded insulation. To reduce no-load loss and end clearances to the core; other factors permitting, such windings can be designed as center-fed windings. Compared to the taps in delta, taps at neutral result additional cost savings in the tap changers, tank size, oil quantity etc.

When both HV and LV are wye connected, a stabilizing winding (buried tertiary) may be needed for suppression of third harmonics and for neutral stabilization. The determining factors are based on the type of core (core type transformers with three-phase three limbed cores does not require a stabilizing winding, but some users specify a stabilizing winding), the system and the neutral connection in the system. This often leads to a choice to have one of the main windings delta connected. Protection costs should be considered in determining whether the HV or the LV should be delta connected.

In certain cases when the LTC is electrically connected to the low voltage winding (considering that the voltage of this winding is not high), it can be considerably cheaper to use delta connection for the low voltage winding. A delta connected winding has a lower current by $\sqrt{3}$ and this could avoid the use of a series transformer to reduce the current in LTC. However, this has some disadvantages. If the insulation level of this winding is high, then the cost advantage could be lost. As well, very few three-phase LTCs for delta connections are available. Instead, three single-phase LTCs are to be used. In such a case, shifting the LTC on to the wye-connected HV needs to be explored. Based on how the transformer is operated, this could make the transformer a variable flux design.

By connecting the windings in wye/zig-zag rather in wye/delta, the need for a grounding transformer on the delta can be eliminated. Often in a wye/zig-zag transformer, it is economical to limit the single line to ground fault current to not exceed the three-phase fault current, by connecting a neutral grounding reactor of suitable reactance in the zig-zag neutral. Without the grounding reactor, single line to ground fault currents in a wye/zig-zag transformer will be high compared to that of wye/delta transformer with the same parameters (same MV.A and positive sequence impedance). A wye/zig-zag transformer costs about 6% more than a wye/delta transformer. In general, a wye/zig-zag transformer with a grounding reactor costs less compared to a wye/delta transformer with a grounding transformer. As it is difficult and costly to have taps on a zig-zag winding; the taps are normally on the wye winding. In a step-down transformer when the zig-zag winding is the output winding, users prefer to have taps on the zig-zag winding. This is because; taps on the input winding to compensate for regulation will make the transformer a variable flux unit. Disadvantages of the variable flux taps are discussed under “Types of Taps”.

Users should be aware that when there is no delta in the transformer (wye/wye or wye/zig-zag) the harmonics will flow in to the system. A method to prevent the harmonics flowing in to the system is discussed under Vector Group.

VECTOR GROUP

CSA-C88-M90 clause 4.1 states as follows: “Angular displacement (of a polyphase transformer)--the time angle, expressed in degrees, between the line-to-neutral voltage of the reference identified high-voltage terminal (H1) and the line-to-neutral voltage of the corresponding identified low-voltage terminal (X1). Note: The preferred connections for polyphase transformers are those which result in the smallest possible phase-angle displacement measured in a clockwise direction from the line-to-neutral voltage of the reference identified high-voltage terminal (H1). Thus, standard three-phase transformers have angular displacements of either zero or 30º Clock system (of phase displacement) --a method expressing the phase displacement between two windings by analogy to the hands of a clock.”

Many standards and text books show multiple vector group connections. The same angle shift between HV and LV can be achieved by various vector groups. One o’clock vector can be achieved by the Yd1, Dy1 or Yz1 groups. Twelve o’clock vector can be achieved by the Yy0, Dd0 or Dz0. Vector group has to be carefully selected because it has a bearing on transformer cost and on the system operation. This is because, each vector group has a different zero sequence impedance, resulting in different fault currents.

Only certain types of cores are recommended for the wye/wye connection. The book ‘Transformer Engineering’ by L.F. Blume states the following on wye/wye connection [2].

“Y-Y connected transformers, excepting three phase three legged core type units, are not capable of supplying an appreciable single-phase load from line to neutral, owing to the fact that the corresponding primary currents of such loads, flowing through the primaries of the unloaded phases, magnetize them. This statement is true for Y-Y connected single-phase units and shell-type three-phase units. Core-type units however, may, on account of the interlocking of the magnetic fluxes in the three legs, give tolerably good results under conditions of single-phase loads from line to neutral or unbalanced electrostatic charging currents. Y-Y connection with grounded neutral in single-phase and shell-type three-phase units is dangerous on account of the possibility of resonance in the third harmonic with the line capacitance. It should never be used”.

In a delta/delta connected transformer, a neutral for grounding is not available. When two LVs are required, some users are specifying wye/zig-zag/zig-zag. Users should consider specifying wye/delta/zig-zag (Hoeppner transformer). In these transformers a neutral is available. Since there is a delta, the third harmonics will stay in the transformer and do not flow in to the system.

When line voltage is high and the current is small, then connecting this winding in wye is economical compared to connecting in delta. This is because the phase voltage = (line voltage/$\sqrt{3}$). When the line voltage is small and the current is large, then to connect this winding in delta is economical. This is because phase current = (line current/$\sqrt{3}$). Users should consider system costs, system requirements and discuss with transformer manufacturers before stating in the specifications which side should be delta, which side should be wye, and the vector group.

INSULATION LEVELS

CSA-C88-M90 clause 4.1 defines Lightning Impulse Level as follows: "the prescribed peak value of the lightning-impulse withstands voltage (full wave). Note: The lightning-impulse level (LIL) has been commonly referred to as the 'BIL'."

Below are more definitions from CSA-C88-M90 clause 4.1.

Switching impulse level (SIL) - the prescribed peak value of the switching impulse withstands voltage (full wave).

Uniform insulation (of a transformer winding) - the insulation of a transformer winding when all its ends connected to terminals have the same power frequency withstand voltage.

Nonuniform insulation (of a transformer winding) - the insulation of a transformer winding when it has an end intended for direct or indirect connection to ground and is designed with a lower insulation level assigned to this ground or neutral winding end.

Insulation levels should be based on insulation coordination of the system. Standards give different insulation levels (BIL levels) for the same system voltage. One example is for 245KV; CSA-C88-M90 gives four different BIL levels 650KV, 750KV, 850KV and 950KV. For 230KV IEEE C57.12.00-2010 gives four different BIL levels 650KV, 750KV, 825KV and 900KV. Some consultants who write specifications for users often specify higher BIL levels than needed. These consultants say that by specifying higher BIL levels they are helping their clients to procure better transformers. Insulation levels (BIL levels) have a large impact on transformer cost and the losses. As such, it is recommended that the users to specify only the needed BIL levels, and not to over specify them.

Some users feel that more reliable transformers can be purchased by specifying higher BIL level for the bushings than the windings. Since the bushing is the first component to see the impulse, some users specify one or two higher BIL level for the bushings than what is actually needed. In such transformers, windings could fail before the bushings, because the BIL level of the bushings is higher than the windings. This is very costly because compared to the cost of the winding; the cost of the bushing is small. Also, to replace the windings is costly and time consuming compared to the bushings.

Many techniques (interleaved, counter shield turns etc.) to uniformly distribute the impulse voltage in the windings have been developed and all the transformer manufacturers are using them successfully. Also manufacturers have reliable computer programs to calculate the impulse voltage distribution in the windings. As such, there is no need to over specify the BIL levels for windings.

Since requests for quotes are 'free', some users ask for alternate quotes for transformers with different BIL levels. One example is for 500KV units where three alternate quotes were requested. The first one was 1425KV BIL for windings and 1425KV BIL for bushings. The second alternate was 1425KV BIL for windings and 1800KV BIL for bushings. The third alternate was 1800KV for windings and 1800KV for bushings.

INSULATION LEVELS (continued)

Often not enough time is given to prepare the tenders. The designer of the transformer manufacturer has to make two separate designs with different BIL levels for windings and three separate outline drawings to cover all the alternates. In such cases, if not enough time is given there is a possibility that the tenders may not be exactly what is needed by the user. Preparation of tenders is a significant cost to the manufacturers. Even for house repairs (plumbing, heating, air conditioning repairs, etc.) the contractors often charge to give estimates. If the users were to pay at least for the alternatives to cover a part of the cost incurred by the manufacturers, then users will get economical tenders meeting their system requirements. As in house repair work, customers need not pay this cost to the successful bidder.

Lightning arrestors design has improved to give better protection; so, many standards no longer require chopped wave tests during impulse tests. Front of wave testing requirements have also been eliminated by almost all of the standards. Users should discuss this with their insulation coordination engineers and protection engineers before specifying a chopped wave test or a front of wave test and they should be specified only if needed by the system. Some users specify a RW-FW-CW-FW impulse test sequence because in their experience this sequence enables easier failure detection.

Some users compare physical clearance distances between windings, between windings and ground to evaluate different bids. Some users use these clearances for initial comparison of the bids; and in the final evaluation, the stresses in oil and in solid insulation are compared. Comparison of the total distances is not an effective practice since this does not correctly determine the voltage stresses in oil and in solid insulation. The more appropriate practice is specifying separately the stress limits in oil and in solid insulation for power frequency, switching surge and impulse voltages. Some specifications have stated these limits. There are many ways to design the insulation system to control these stresses.

Some specifications specify more tests, higher test levels and stricter tolerances than those stated in the standards. Lower costs can be attained by not deviating from the standards unless it is specifically needed by the system.

Some users specify the BIL of the HV neutral to be the same as the line terminal even though the neutral will be solidly grounded in operation. This will significantly increase cost. The cost will be further increased if there an LTC in the HV neutral.

Certain types of circuit breakers (SF6 and vacuum interrupters) or when switching certain types of loads (solid state loads), can produce a much steeper voltage wave than what is specified in the standards. Transformers can fail (failures had occurred due to part winding resonance, high voltage stresses in the winding etc.) if the windings are not designed for these voltage waves. If the breaker is going to produce a different wave shape than what is specified in the standards then the wave shape to which the transformer should be designed and tested must be clearly stated in the specifications.

Based on system needs, if the user wants the impulse test connections to be different from those stated in the standards then it must be stipulated in their specifications. One example is when HV line is impulse tested on an autotransformer, whether the LV line must be solidly grounded or grounded through impedance.

TERMINALS

Following definitions are from CSA-C88-M90 clause 4.1:

Terminal--conducting element intended for connecting a winding to external conductor.
Line terminal--a terminal for connection to a phase conductor of a system.
Neutral terminal--(a) for polyphase transformers and polyphase banks of single-phase transformers, terminal (s) connected to the neutral point of a star-connected or zigzag-connected winding and (b) for single-phase transformers, the terminal intended for connection to a neutral point of a system.

Following definition is from C57.12.80-2010 clause 3.449:
Terminal--(A) A conducting element of equipment or a circuit intended for connection to an external conductor. (B) A device attached to a conductor to facilitate connection with another conductor.

In the specifications users should specify all the electrical characteristics and physical details of the terminals. A few are listed below.

1. Type of bushings (condenser type, bulk oil type etc.).
2. Insulation level of line and neutral bushings.
3. Overvoltage.
4. Overloads.
5. Type of terminal (oil-to-air, oil-to-oil, oil-to-SF6 etc.).
6. Oil preservation system (conservator, nitrogen pressurized etc.).
7. List of CTs and characteristics to determine ground shield length of the bushings.
8. Cover-mounted or horizontally-mounted on the side wall.
9. Location (C57.12.10-2010 clause 5.1 indicates the segments).
10. Terminal arrangement and markings (Ref: C57.12.10-2010 clause 5.2 Figure 3).
11. Standards to which to comply (CSA/EEMAC or IEEE/ANSI or IEC)
12. Neutral bushing current rating (same or half of line current).
13. Special details (Bus-duct or any other special requirements).
14. Connection (bottom-connected or draw-lead/rod).
15. Requirement of Doble connectors and bus connectors.
16. Creepage length.
17. Requirement of cap tap and/or potential tap.
18. Porcelain or composite bushings.
19. Bushings terminals heights from the transformer base, spacing etc.
20. Minimum external clearances (line to line and line to neutral) if non-standard.
21. Interchangeability with existing spares or with bushings of another standard.
22. Order of bushings arrangement (H1, H2, H3 or H3, H2, H1 etc.) if non-standard.
23. Paper resin core (PRC) or paper oil core (POC).
24. Swap-out capability without draining main tank oil.

Bushings built to IEEE/ANSI standards are less expensive and have a shorter lead-time than bushings built to CSA/EEMAC standards. As such, many users in Canada are specifying the bushings built to IEEE/ANSI standards. If a bushing built to CSA/EEMAC standards has to be replaced with a bushing built to IEEE/ANSI standards, it can be done by using the adapters which can be purchased from bushing manufacturers.

TERMINALS (continued)

Bushing manufacturers in Canada are also reluctant to supply bushings built to CSA/EEMAC standards. Users should consider this before specifying the standard for the bushings. Users should also consider IEC bushings, because often prices of IEC bushings are lower than CSA/EEMAC and IEEE/ANSI bushings.

If users want any tests other than the standard routine tests on the bushings then these must be specified in the specifications. This is because the transformer manufacturers are usually not equipped to do tests on the bushings themselves. These tests must be done by bushing manufacturers who would also supply the test certificates.

When oil-to-oil or oil-to-SF6 bushings are specified, the transformer manufacturer will install a chamber with additional oil-to-air bushings to conduct factory tests on the transformer. In such cases, it is recommended that the user finalize the test set-up and the tests at the design review stage.

To clean the oil surface of the porcelain, special precautions and special materials are required. User should obtain these details from the transformer manufacturer. Some users specify that gaskets must be suitable for high temperature (ex. Viton gaskets). Suitability of these gaskets at cold temperatures should also be specified since some gasket materials perform well at high temperatures but poorly at cold temperatures.

A few other points to consider are the current ratings of the bushings in a bus duct, oil expansion volume adequate for the entire operating temperature range including overloads, a need for external corona shields etc. The internal corona shield should be dedicated to the intended bushing model and the transformer. Internal corona shields should not be changed or used on another model bushing or in another transformer without the approval from the transformer manufacturer.

Specify when the bushings are located inside isolated-phase bus ducts, or surrounded by the transformer’s sound enclosure along with all the required details for correct selection and mounting of the bushings. Some of the details to include are the height of the bushing terminal from the transformer base, spacing, flanges etc. If the minimum air clearances of bushings needed are more that those stated in the standards, then these must be given in the specifications. In many instances, these air clearances depend on the model of the bushing terminal connectors. If a particular bushing catalogue number is needed then it should be specified in the specifications.

Clause 3.5 of CSA-C88-M90 specifies Low-Ambient Temperature Load Capability. It is suggested that users verify this capability in the Tender Review Meeting. Users should also ensure that the turrets of the terminals are properly designed to enable any gases evolving from transformer oil and insulation to find their way to the gas accumulation relay.

While working as a maintenance engineer with a user, the author has experienced more problems on terminals than on the windings. Therefore, extra care is recommended in specifying the details for the terminals and during the approval review of the drawings.

ACCESSORIES

C57.12.80-2010 clause 3.4 defines accessories as follows, “devices that perform a secondary or minor duty as an adjunct or refinement of the primary or major duty of a unit of equipment”.

A comprehensive list of accessories is given below:

- Oil preservation system (conservator, nitrogen pressurized etc.)
- Breather (normal silica gel, maintenance free silica gel, cryogenic principle etc.)
- Moving facilities (lifting, jacking, rolling, sliding etc.)
- Gas accumulation relay
- Oil level indicator
- Oil temperature indicator
- Winding temperature indicator (WTI)
- Fiber optics temperature sensors
- Fans
- Pumps
- Valves (drain sampling, filter, radiator etc.)
- Grounding (core, tank, electrostatic shields, magnetic shunts etc,)
- Surge arresters and counters
- Sudden pressure relay
- Deluge
- On-line monitoring systems
- Pressure relief device
- Explosion-resistant tank
- Fall arrest systems

Due to time constraints, accessories are not described in detail. If user is familiar with the construction of the accessories, how they operate and how they function then it will be very useful in the maintenance of the transformers. The following will help in preparation of the transformer specifications.

- Is an air bag required in the conservator? If required, then must it be of any particular make? Specifying the temperature limits. Is a particular make of nitrogen pressurized system required and if so, what should the pressure limits be?
- Is a specific make of breather required? Should it be maintenance free?
- Does the time constant of the WTI match with the time constant of the windings? This is very important on Oil Directed) OD cooled transformers.
- If a specific type or make of accessory is needed then this should be specified.
- If revenue metering CTs are needed, specify their accuracies and need for certification.
- If any provisions (on-line monitoring systems, arrestor brackets etc.) are required, specify the particulars like sizes, types of valves, mounting brackets details etc..

By discussing all the particulars of the accessories in the tender review meeting, most conflicts can be avoided. This may also help in deciding on which bidder to place the order.

TYPES OF COOLING

For oil-natural cooling systems (ONAN, ONAN/ONAF etc.) CAN/CSA-C88-M90 and IEEE C57.12.00-2010 specifies 65ºC for average winding and for top oil rises above the ambient. But still many users are specifying 55ºC or 55/65º rise. Some users feel that by specifying 55ºC or 55/65ºC rise they are getting better quality and higher rated transformers at lesser price than those of 65ºC rise. By specifying only 65ºC per the standards, confusion and mistakes in referring the parameters (impedance, load loss capitalization, sound level etc.) to the wrong MV.A base can be avoided.

A few commonly used cooling designations are given below:
ONAN – Oil natural, air natural.
ONAF – Oil natural, air forced.
OFAF – Oil forced and not directed into the windings, air forced.
ODAF – Oil forced and directed into the windings, air forced.
ODWF – Oil forced and directed into the windings, water forced.

Per CSA-C88-M90 when a transformer is designated as ONAN/ONAF/ONAF and the top rating is 1 p.u., then the middle rating is 0.8 p.u. and the base rating is 0.6 p.u.

Some of the points to be considered in selecting the cooling type are listed below:

--For remote locations, if the transformer dimensions and weight allow then ONAN cooling alone can be considered. This is because changing a defective fan or a defective pump costs too much time and money. The cost of cooling with fans and/or pumps verses the cost of ONAN cooling should be considered.
--Where snowfall accumulations are small, permit the use of bottom mounted fans. This is because, bottom mounted fans are more efficient than side mounted fans.
--If a particular make/type of fans or pumps are needed then specify them.
--In the design review check the mounting details of the fans to eliminate excessive vibrations that could cause premature failure of the fans in service.
--When pumps are used and the oil is not directed in to the windings, check that the temperature rises of the windings are calculated by considering proper oil velocity in the windings (velocity based on thermal head only).
--When pumps are used and the oil is directed in to the winding, check the oil velocities in different areas (between radial ducts, between axial ducts etc.) of the winding to avoid static build-up and damage of the insulation.
--For water cooled units specify leak detector type coolers.
--For a triple rated transformer (especially with pumps) consider a temperature rise test on the middle rating on the first transformer in the order.

For the normal well-type WTI the time constant is about 45 minutes. For windings, the time constant is about 4 to 10 minutes. For OD cooled transformers, a WTI with equal or lower time constant than the windings should be chosen. The IEEE Task Force on WTI has done extensive work on this topic and the author recommends referring to their work. This information is available at www.transformerscommittee.org

For water cooled transformers chemical analysis of the water should be provided in the specifications. Supply voltage available at the station must be included in the specifications for the correct selection of fans, pumps, LTC motor and other accessories.

SOUND LEVELS

Many users are specifying lower sound levels than the values in standards due to stricter environmental laws. Before specifying the sound level, users should consider the location of the transformer within the system and the future settlement of residential dwellings near the transformer station.

Sound level has a large effect on the transformer cost. Use of laser etched steel (ZDKH etc.) and step-lap core construction are yielding lower sound levels than the normal cold rolled grain oriented steel (CRGO), and mitred core construction without step-lap construction. Most of the manufacturers operate the core at low flux density to obtain low sound level. Some manufacturers have developed special core binding methods to reduce the sound level. In the tender review meeting the user should check these special methods and how the transformers of similar design have tested and are operating in service.

Users should pay attention to CAN/CSA-C88-M90 clause 13.2 when taps are operated as variable flux taps: “On transformers with on-load and deenergized tapping switches, or both, not in the winding being regulated, the induction and sound level will vary with tap position. Unless otherwise specified by the purchaser, the sound-level limit shall apply at principal rated tap positions, except as noted in clause 13.3.”

Many transformer specifications state the sound level requirement at rated tap. Clause 13.3 of CAN/CSA-C88-M90 will help users to decide on which tap the sound level guarantee should be. “If a bridging reactor is used and the bridging position is a normal operating position but not the principal rated voltage position, then the sound-level test shall be made on that adjacent tap position calculated to give the highest sound level.” IEEE standards do not discuss the sound level at the bridging position.

Some users specify the sound level at full load. As it is not possible to do this test in the factory, user and the manufacturer should mutually agree to the method to calculate the sound level at load. The following clauses in IEEE standards may be of help.

Clause 8.2.3 of C57.12.00-2010: “The transformer shall be connected for, and energized at, rated voltage, frequency, and at no-load. Noise-contributing elements of the transformer, such as pumps and fans, shall be operated as appropriate for the rating being tested. When it is impractical or undesirable to include the appropriate cooling equipment, the self-cooled sound level may be corrected for cooling noise contribution, if suitable corrections are available and it is mutually agreeable to those concerned.” It is suggested also refer to clause 13.3.4 of C57.12.90-2010.

Clause 13.1.1 of C57.12.90-2010 states: “Audible sound from transformers originates principally in the transformer core and transmits through the dielectric fluid and/or structural supports to the outer shell and/or other solid surface, where it radiates as airborne sound. In some situations, the windings may be a noise source under rated load conditions, but this noise is not included in this standard.”

When a future sound level reduction enclosure is required, the specifications should clearly state the work to be performed by the manufacturers such as (flanges height from the transformer base, details of the flanges, pressure relief mounting details etc.).

TAPS (range, locations etc.)

The function of the voltage taps is to keep the output voltage constant. LTC and DETC stand for Load Tap Changer and De-energized Tap Changer, respectively.

Definitions below are from IEC 60076-1.
Voltage Taps
In a transformer having a tapped winding, a specific connection of that winding, representing a definite effective number of turns in the tapped winding and, consequently, a definite turns ratio between this winding and any other winding with fixed number of turns.

Tap range
The variation range of the tapping factor, expressed as a percentage, compared with the value '100'.
Note: - If this factor ranges from 100+a to 100-b, the tapping range is said to be: +a%, -b% or ±a% if a = b.

Definition below is from IEEE C57.12.80-2010.
Tap (clause 3.441)
A connection brought out of a winding at some point between its extremities, to permit changing the voltage, current, or ratio.

Most aspects of taps are covered in detail in the following tutorials. The tutorials will help users in determining the tap range, location etc. The tutorials can be accessed at www.transformerscommittee.org or in Google.

"TAPS" October 26, 2004 IEEE Transformers Committee Meetings in Las Vegas, Nevada, USA by V. Sankar.

"TAPS IN AUTOTRANSFORMERS" October 25, 2010 IEEE Transformers Committee Meetings in Toronto, Canada by Dr. Tomasz Kalicki and V. Sankar.

The following clauses are from C57.12.10-2010.
Clause 4.5.1 High-voltage winding taps for de-energized operation:
If specified, de-energized tap changer (DETC), the following four high-voltage rated kilovoltampere taps shall be provided. 2.5% and 5% above rated voltage and 2.5% and 5% below rated voltage. When a load tap changer (LTC) is furnished per 4.5.2, the high-voltage DETC may not be required.

Clause 4.5.2 Taps for LTC transformers:
When an LTC transformer is specified, LTC equipment shall be furnished in the low-voltage winding to provide approximately ±10% automatic regulation of the low-voltage winding voltage in approximately 0.625% steps, with 16 steps above and 16 steps below rated low-voltage.

Many utilities in Canada and in USA have rewritten their specifications eliminating DETC taps wherever possible. The biggest difficulty with DETC taps is that the transformer

TAPS (range, location etc. continued)

must be de-energized to change the taps. Many users never change the DETC tap position over the life time of the transformer. Some users operate the DETC tap changer once a year to break the oxide film formed on the contacts. Now some manufacturers guarantee that the DETC tap changer can be operated once in five years or more to break the oxide film. Users must check the coating on the contacts to ensure that no oxide film will be formed in five years. A few utilities state in their specifications that DETC tap changer is not accepted, only a link board inside the transformer is acceptable. The specifications should clearly specify all the requirements. The advantage of DETC tap changer is that the cost is very much lower compared to a Load Tap Changer (LTC).

Users are advised to make a strong effort not to specify the DETC taps. Many users feel that when old transformers have the DETC tap changers, the new replacement transformers should also have the DETC taps. In most cases, specifications for the new replacement transformers can be written without the DETC tap changer while still obtaining the needed performance.

The example below shows that the LTC tap range should be based on ultimate system requirements and not ±10% as suggested in the IEEE standard C57.12.10-2010.

(1) Per clause 4.1.6.1 of C57.12.00-2010 the load power factor is 80%.
(2) Consider a three stage cooled (ONAN/ONAF/ONAF) transformer with LTC and HV BIL of 750KV.
(3) Per Table 3 of C57.12.10-2010 impedance is 10.5% at ONAN rating.
(4) Considering %R=0, regulation at maximum MV.A = 11.48%.
(5) Therefore ±10% tap range is not enough to keep the output voltage constant.
(6) When %R is considered the regulation will be higher than 11.48%.
(7) During overload the regulation will increase further.
(8) If the power factor of the load is lower than 80%, then this must be specified in the specifications. This is because regulation at lower power factor will be higher.
(9) Regulation on tap extremes must be checked by the user. Often, impedance on one extreme tap could be much higher than the impedance on the rated tap.

Some specifications provide all loading conditions (MV.A, power factor, maximum impedance limit on any tap, etc.) and ask the transformer manufacturer to determine the tap range to keep the output voltage constant. This is preferable over the user specifying the tap range, because if the user specifies the tap range, then meeting the needed regulation is the responsibility of the user. If the user wishes to specify the tap range per standards, then the user should check whether the tap range meets the needed regulation.

The following will help in deciding the location of the taps.

(a) To maintain the output voltage constant for input voltage fluctuations, it is preferable to have the taps on the input winding.

TAPS (range, location etc. continued)

(b) To compensate for the regulation (load and power factor of the load are the governing factors), it is preferable to have the taps on the output winding.
(c) Normally, it is economical to have the taps on a wye winding rather on a delta winding. This is because not many tap changers are available for delta connection and tap leads have to be insulated to ground at the line insulation level. In general, the neutral insulation level of a wye winding is much lower than the line insulation level. This makes taps in a wye winding more economical.
(d) If the taps are on the LV, constant flux taps and a series transformer is required; then consider locating the taps in the HV even if the taps become variable flux taps, because this will eliminate the need for a series transformer. The final location of the taps can be determined based on relative costs and losses.
(e) Based on operation of the transformers, it is recommended that users discuss with transformer manufacturers the design problems, manufacturing problems and costs associated with having the taps in the LV or in the HV winding.
(f) When the user has no time to investigate all aspects of the taps, then it is suggested to give all the operating conditions in the specifications and ask that the bids include the calculations to prove that the quoted transformers meet the system requirements.
(g) Voltage across the tap range, step voltage and number of steps are important because, these parameters determine the selection of the tap changer. To give an example, on an LTC of a particular model when tap steps are reduced from 33 to 23, permitted step voltage goes up by 66% and when tap steps are reduced from 33 to 29, permitted voltage across the tap range goes up by 45%.
(h) Step KV.A is another parameter that determines LTC model. A reduction in the step KV.A, by increasing the number of steps, results in a more economical LTC.
(i) Based on tap range, if tap turns are not enough for a cost effective transformer design; then increasing the tap range could help for a cost effective design.
(j) For autotransformer specifications consider the following:
(1) Avoid specifying taps in the LV line. Usually, this will be costly compared to having the taps in the series winding or in the common winding. However, be aware that this may result in a variable flux design.
(2) If possible do not specify DETC taps. DETC taps in an autotransformer are much more complicated as compared to DETC taps in a two-winding transformer.
(3) Do not specify both DETC and LTC taps. To reduce the cost and increase the reliability, consider increasing the LTC tap range and eliminating the DETC taps.
(4) Do not specify DTEC taps on the tertiary. This will increase the cost significantly and will not keep tertiary voltage constant in service. If needed, specify a compensating transformer.
(k) Specifications should give the impedance limits on the extreme tap positions; because this determines the physical location of the taps, which in turn has considerable bearing on the autotransformer cost.

The following will help in deciding the tap range:

(1) When the system conditions require +5% to -15% taps do not specify ±15% taps; specify only +5% to -15% taps. Some users are of the opinion that the tap range on the positive side and on the negative side must be the same, this is incorrect.

TAPS (range, location etc. continued)

(2) Specifying the taps as ±10% in ±16 steps is not recommended. With such a specification, manufacturers will often quote reversing taps for the fear that a quote with other types of taps (linear or coarse/fine) will be rejected as they are not per the specification. In many cases, a quote with linear or coarse/fine taps can yield lower life cycle cost as compared to a quote with reversing taps.
(3) For example, in a 125MVA transformer, load loss on minimum tap with coarse/fine taps was about 25% lower than with reversing taps. The tendered cost for both the transformer designs was the same.
(4) Instead of specifying 230KV±10% taps in ±16 steps, consider specifying the taps as 'taps are required for voltage variation from 207KV to 253KV in 32 steps'. With such specifications, the manufacturers can offer bids either with coarse/fine taps or with reversing taps.

Other considerations on the taps are given below.

(a) Reliability and cost of allowing connecting non-linear elements (MOVs) across the taps verses other design practices without non-linear elements (MOVs).
(b) A number of specifications indicate a preference for a specific LTC manufacturer. It is suggested leaving this choice to the transformer manufacturers. If needed ask for extra warranty on the tap changers of other makes.
(c) Compared to tie-in resistors with tie-in capacitors, the arc generated during changeover switch operation is more intense. But with the tie-in capacitors the losses in tie-in elements is almost zero. Consider these in finalizing the bids.
(d) As the capitalization cost of fixed losses is often very high, allow the manufacturer the option to quote with a potential switch or with tie-in resistors.
(e) Do not specify that only tank-mounted tap changers are acceptable. In some cases tank-mounted tap changers are more costly than in-tank tap changers.
(f) Some specifications state that the selector contacts should not be in the main-tank's oil. This results in a costly option with no useful benefit. Very few tank mounted tap changers are available and the selection is limited by insulation level, step voltage, current etc.
(g) Specifications should specify whether the taps are RCBN (Reduced Capacity Below Normal) or FCBN (Full Capacity Below Normal).
(h) When the reversing taps (either for DETC or for LTC) are electrically in the HV circuit and physically below the HV windings, the tapping winding will experience free buckling force. Whereas when the linear taps (includes coarse/fine taps) are electrically in the HV circuit and physically below the HV windings, the tapping winding will not experience free buckling force.
(i) Recommend not to specify that the LTC winding should be a separate winding, because linear taps (including coarse/fine taps) can be effectively situated in the body of the main winding. Often this will be a more economical design as compared to a design with the LTC as a separate winding. Recommend allowing the manufacturer to decide the location of taps based on performance and cost.
(j) When a bid requires an LTC with current splitting, obtain LTC manufacturer's confirmation on the application. This is because in certain applications balancing transformers could be required. Also, check with the transformer manufacturer that the windings are designed for current splitting application.

TYPES OF TAPS

IEC 60076-1 clause 5.2 states as below.

“The short notation of tapping range and tapping steps indicates the variation range of the ratio of the transformer. But the assigned values of tapping quantities are not fully defined by this alone. Additional information is necessary. This can be given either in tabular form with tapping power, tapping voltage and tapping current for each tapping, or as text, indicating ‘category of voltage variation’ and possible limitations of the range within which the tappings are full-power tappings”.

Very few users give the above needed information in the specifications to design the transformer. Fundamental aspects are where the taps are located (in HV or in LV), how the transformer is operated (step-down or step-up) and how the taps are used (for fluctuations in input voltage or to compensate for regulation with a varying load and the power factor). Most of the specifications state the tap range only. These specifications can result in transformers that don’t meet operational requirements.

CAN/CSA-C88-M90 clause 24 covers some details on types of taps; but does not cover all the details of the taps to be stated in the specifications. Users should be aware of this before specifying the taps per CAN/CSA-C88-M90.

CSA and IEEE standards do not classify taps clearly. Taps can be classified as below.

1. Constant flux taps (IEC category is CFVV – Constant Flux Voltage Variation).
   Voltage in any untapped winding is constant from tapping to tapping. i.e. volts per turn remain constant throughout the tap range. The magnetic flux in the core is the same for all the tapping positions. Specifications should include the following:
   (a) the category of voltage variation (constant flux taps).
   (b) which winding has the taps, the tap range and the number of tap steps.
   (c) whether the taps are RCBN (Reduced Capacity Below Normal) or FCBN (Full Capacity Below Normal).

2. Variable flux taps (IEC category VFVV – Variable Flux Voltage Variation).
   Voltage in the tapped winding is constant from tapping to tapping i.e. volts per turn changes from tap to tap. Specifications should include the following:
   (a) the category of voltage variation (variable flux taps).
   (b) which winding has the taps, the tap range and number of tap steps.
   (c) whether the taps are RCBN or FCBN.
   (d) whether the taps are to have equal turns (voltage of the tap step is based on the volts per turn on that tap) or whether they are to have approximately equal voltages. When the LTC is of linear type, the manufacturer can adjust the turns per tap to obtain approximately equal volts per step. When the LTC is of

TYPE OF TAPS (continued)

reversing type or of coarse/fine type, it is not possible to obtain approximately equal voltage tap steps.

(e) It should be agreed between the user and the manufacturer on which tap the no-load loss is guaranteed.

3. Mixed regulation (IEC category Cb.V.V – Combined Voltage Variation). A portion of the taps act as constant flux taps and the remaining portion of the taps act as variable flux taps.
   (a) the category of voltage variation (Cb.V.V).
   (b) which winding has the taps, the tap range, and number of tap steps.
   (c) which tapping is the 'maximum voltage tapping' with the corresponding tapping voltages.
   (d) which tapping is the 'maximum current tapping' with the corresponding tapping currents.
   (e) IEC 60076-4 gives a Table showing Tappings, Voltages and Currents. Such a Table should be included in the specifications.
   (f) It should be agreed between the user and the manufacturer for which tap the no-load losses is guaranteed.

The table below summarizes the effects of the LTC location and operation on the core flux for two winding transformers.

Taps Location	Operation	Constant Voltage	Varying Voltage	Core Flux
HV	step-down	HV	LV	variable
		LV	HV	constant
	step-up	HV	LV	variable
		LV	HV	constant
LV	step-down	HV	LV	constant
		LV	HV	variable
	step-up	HV	LV	constant
		LV	HV	variable

For a similar Table for autotransformers refer the tutorial "Taps in Autotransformers" by Dr. Tomasz Kalicki and V. Sankar on IEEE web page www.transformerscommittee.org

In all systems the input voltage, the load, and the power factor will be constantly changing. So, almost all transformers are being operated as mixed regulation taps (Cb.V.V.). Operating engineers must clearly understand the changes in the transformer parameters based on how the transformers are operated. Impedance, fault current and sound level varies or remains constant from tap to tap based on whether the taps are operated as VFVV taps or CFVV taps.

TYPES OF TAPS (continued)

If the user has preferences or special requirements on the following then they must be stated in the specifications with all the required details to design the transformer.

1. Resistor type LTC.
2. Reactor type LTC.
3. Tank mounted LTC.
4. In-tank LTC.
5. Vacuum type LTC.
6. LTC is Reversing type or Linear type or Coarse/Fine type.
7. Preventive autos (LTC reactor).
8. Series Transformers.
9. Compensating Transformers.
10. Non-linear devices.
11. Tie-in resistors or potential switch.
12. Extra current rating on LTC (1.5 p.u., 2 p.u. etc.).
13. Particular make of the LTC.
14. Capability of the LTC to meet Low-Ambient Temperature Load Capability.

For reliability, users should check the type and design of the tapping winding, leads bring-out or lead exits etc. When eccentric winding arrangement is used to bring-out the leads, it should be checked that the coils are radially supported with no slackness.

Some other considerations on the taps are given below.

1. When the current in the tap winding is high, the use of a series transformer is a common method to reduce the current in the LTC. In these cases, reversing taps will reduce the series transformer KV.A to almost half of that which would be required with linear taps (includes coarse/fine taps). In such cases, reversing taps could be more economical as compared to linear taps or coarse/fine taps.

2. Tap changer rating should be adequate for low-Ambient Temperature Load Capability.

3. In general no thermal measurements will be done on the tapping winding itself. So, users should check at the Design Review how the calculated average gradient and hot-spot gradient of the tapping winding compare to the main windings. Users should make sure that if the average gradient or hot-spot gradient of the tap winding is higher than the main windings then these are used for the cooling calculations.

4. Many failures have occurred when the supports of the tap leads are inadequate to support their weight. Failures have also occurred when the clearances (distances) from the tap leads of one phase to the tap leads of another phase and/or the clearances (distances) from the tap leads to the ground were inadequate.

IMPEDANCE

The following definitions in C57-12.80-2010 are related to impedance.

3.172 Impedance Drop: The phasor sum of the resistance voltage drop and the reactive voltage drop.
Note: - For transformers, the resistance drop, the reactance drop, and the impedance drop are, respectively, the sums of the primary and secondary drops reduced to the same terms. They are determined from the load-loss measurements and are usually expressed in per unit or in percent.
3.359 Reactive drop: The component of the impedance voltage drop in quadrature with the current.
3.376 Resistance drop: The component of the impedance voltage drop in phase with the current.

During preparation of the specifications the following information on the impedance will be of help.

1. In a considerable number of specifications while the percent impedance is always stated, the MV.A base at which the impedance applies is not stated.
2. In some specifications impedance in ohms is stated but whether the ohms are referred to HV side or LV side is not stated.
3. It is not possible to make generalizations about impedance magnitude versus cost. Statement like a lower (or a higher) impedance results in reduced costs are not necessarily true. This depends on many factors like transformer MV.A, two-winding transformer or an autotransformer, impedance value, capitalization cost of the losses, short-circuit forces etc.
4. When the impedance is low the short-circuit currents will be high. When the impedance is high; regulation, eddy losses in windings and stray losses in the tank, end frames etc. will be high.
5. Before adopting the impedance values suggested in the standards (Table 3B of CAN/CSA-C88-M90 or Table 3 on C57.1210-2010), users should check the breaker capacity, short-circuit current limitations at the station and the regulation requirement.
6. Some specifications do not provide an impedance value and state that impedance should be per industry standard. Users should realize that there is no industry standard for transformer parameters. If different bidders assume different impedance values then the bids cannot be evaluated equitably since the transformer cost will vary with the impedance value.
7. In almost all the specifications impedance at rated tap only is stated. If the impedance on an extreme tap is low then the short-circuit current could exceed the system limitation. It is suggested that impedances on the tap extremes also be specified.
8. The physical location of the tap winding, whether the taps are CFVV or VFVV and the tap range determine the impedance values on extreme taps.
9. It will be beneficial to users if they discuss the impedance requirements with manufacturers at the time of preparation of the specifications.
10. Impedance is inversely proportional to the square of the volts/turn. Users should be aware of the change in impedance when CFVV taps are used as VFVV taps.
11. CIGRE July 1973 paper [15] is a very good reference on how the autotransformer impedance changes based on electrical connection of the taps, on physical location of the tap winding, the tap range and the ratio of HV/LV voltages.

CAPITALIZATION OF LOSSES

“IEEE Loss Evaluation Guide for Power Transformers and Reactors” C57.120-1991 is a very good reference that should be reviewed while preparing the specifications. The following is from this Guide:-

‘The purpose of this Guide is to provide a method of establishing the dollar value of the electric power needed to supply the losses of a transformer or reactor. Users can use this loss evaluation to determine the relative economic benefit of a high-first-cost, low losses unit verses one with lower first-cost and higher losses. Manufacturers can use the evaluation to optimize the design and provide the most economical unit to bid and manufacture. The evaluated cost of losses also enables a user to compare the offering of two or more manufacturers to aid in making the best purchase choice among competing transformers and reactors. Loss evaluation also provides information to a user for establishing the optimum time to retire or replace existing units with modern low-loss transformers or reactors’.

Users will get the lowest lifetime cost by providing the following loss evaluation values in the specifications.

1. No-load loss in $/KW.
2. Load loss in $/KW at a specified MV.A (Base MV.A or maximum MV.A).
3. Auxiliary loss in $/KW (losses of pumps, fans etc.).

IEEE Guide C57.120-1991gives the detailed description and a worked out example of evaluation of the bids. The Guide describes Demand Portion (cost of installing system capacity in dollars per Kilowatt) and Energy Portion (Present Value of the energy that will be used by one Kilowatt of loss during the book-life of the transformer, converted to dollars per Kilowatt).

The following will be helpful to users in preparing the specifications.

1. In many specifications $/KW for load loss is stated but the MV.A reference is not stated. In a bid for a 72/96/120MV.A transformer, the author made a quote design taking the load loss evaluation at the base MV.A (72MV.A). Though the first cost of the transformer was $100,000 cheaper than the other bidders, the order was lost because the user evaluated the bids with the load loss evaluation at top rating (120MV.A). The evaluated cost was $125,000 more than the nearest competitor.

2. Some specifications state that the losses are not evaluated. This may be due to restrictions on capital spending. In such cases the users will lose out on the life cycle cost. Due to the customer requirements of free buckling criteria, sound level etc, often it is not possible to reduce the first cost even when losses are not evaluated.

3. Some users buy spare transformers with no loss evaluation. Based on how long the spare unit will operate in the system, the user could lose or make money.

4. Some specifications give a KWH rate and a few other details but not $/KW. From the data in the specifications there is no guarantee that all the bidders will come-up with the

CAPITALIZATION OF LOSSES (continued)

same no-load and load loss evaluations. In the best interest of the users, the specifications should give loss capitalization values in $/KW.

5. For 65ºC rise transformers, CSA and IEEE standards state the reference temperature for no-load loss at 20ºC and for load loss at 85ºC. Some specifications specify the reference temperature for both no-load and load losses at 85º. No-load loss is usually measured at room temperature i.e. around 20ºC. The temperature correction factor for no-load loss is not that accurate. If the user wants the no-load loss at 85ºC then suggest including the temperature correction factor in the specifications. Users do not benefit by referencing both the no-load and load losses at 85ºC or at 75ºC. The specifications should follow the standards unless there is a special reason that the user can profit by deviating from the standards.

6. Almost all specifications state that if the tested losses are above the guaranteed values then the penalty is applicable (In many specifications this penalty is much higher than the capitalization values of losses) and if the tested losses are lower than the guaranteed values then no compensation will be given. This is not fair as it is one-sided contract. Also, in the long run users will loose out with such clauses.

7. During the design stage or during the manufacturing stage, the manufacturer could come-up with an idea to reduce the losses. Often to implement such an idea needs extra materials or extra labor or both. Unless this extra cost is shared by the user, the manufacturer has no incentive to come up with ideas that will save money for the user or to implement them. A manufacturer came up with a solution on regulators to reduce load loss on half of the taps up to 60% after the bid was closed. The user did not cash-in with the reason that the solution is after the bid was closed.

8. Users spend a lot of money on conservation, such as rebate incentives to replace old appliances with new appliances that consume less power etc. Reduction of losses is conservation; users should work with manufacturers to develop green transformers (innovative ideas to reduce the losses). A utility engineer came up with a new idea of core configuration to reduce the no-load loss. But this was not allowed to be pursued as it was believed that the equipment development is manufacturers' arena and not that of utilities. Management of users should change this belief.

9. Some users have not changed loss evaluation values in their specifications for a long time. Cost of power generation and transmission are increasing every year. To obtain the benefits users should up-date the loss capitalization values each time the bids are invited. Often with the bulk orders for five years or so, the users will be the losers as they miss out in taking advantage of new ideas, better evaluated designs based on relative costs of materials etc.

10. Some specifications specify the no-load and the load losses for the tendered transformers and say that no benefit will be given to bids with lower losses. Providing loss evaluation values is a better method because the bidders can adjust the materials and losses to offer transformers with the lowest evaluated cost.

SHORT-CIRCUIT WITHSTAND

CSA-C88-M90 and C57.12.00-2010 provide many details on short-circuit characteristics. A few are given below.

1. Transformers shall be designed and manufactured to withstand, without injury, the mechanical and thermal stresses by external faults.

2. Short-circuit withstand capability can be adversely affected by the cumulative effects of repeated short circuits which cause mechanical and thermal overstressing.

3. C57.12.90-2010 defines a procedure by which the mechanical capability of a transformer to withstand short-circuit stress may be demonstrated. The prescribed tests are not designed to verify thermal performance. Conformance to short-circuit thermal requirement shall be calculated per C57.12.00-2010.

4. Short-circuit duration is 2 seconds unless otherwise specified by the user.

5. Windings shall be designed to withstand the electromagnetic forces corresponding to the first cycle asymmetrical peak current. Calculation of asymmetrical peak current is per C57.12.00-2010.

6. Terminal conditions and system impedances under which the transformer has been designed for short circuit should be contained in the Instruction Manual.

The following should be specified in transformer specifications.

1. Ultimate future characteristics of the system.
2. Sub-transient reactance of rotating machinery connected to the transformer.
3. System and transformer grounding conditions.
4. Impedances of directly connected apparatus that may limit short-circuit current magnitudes.
5. Pre-fault operating voltage at unfaulted terminal(s).
6. Station auxiliary transformers or main generator step-up transformers directly connected to a generator that may be subjected to prolonged duration terminal faults as a result of the inability to remove the voltage source quickly.
7. Method of connections e.g. isolated phase bus etc.
8. The characteristics of each system short-circuit apparent power level and the ratio between the zero sequence impedance and the positive-sequence impedance.

The following will help in procuring reliable and economical transformers.

1. In many specifications it is stated that fault current calculations should be based on infinite bus on all terminals. Alternatively, some specify system impedances per a specific standard (CSA-C88-M90, C57.12.00 etc.). Since system impedance values stated in the standards are low, it is advisable for the user to specify the system impedances at the transformer station. System impedances will help to reduce the short-circuit currents (especially on transformers with low impedances).

SHORT-CIRCUIT WITHSTAND (continued)

When interchangeability with other stations is needed, it is recommended specifying the system impedance which is lowest of all the stations, rather than infinite bus.

2. A short-circuit test is not common, because it is very expensive. For users to have confidence that the transformers will withstand all types of faults, the users have to depend on manufacturer's design calculations (equivalent circuits to calculate fault currents, off-set values, amp-turn balance etc.) and manufacturing practices (clamping structure, drying process, sizing of the coils, exposure time during the tanking of core & coils etc.). In most cases by the time the transformer experiences a fault with full asymmetry and maximum pre-fault voltage, the warranty would have expired. So, it is very important for the user to know the philosophies each manufacturer adopts in calculating the short circuit currents, forces and stresses in the windings and the withstand strengths of the windings.

3. For three-circuit transformers, in many specifications whether the in-feed is from one system or from two systems is not stated. Per C57.12.00-2010 for three-circuit transformers the in-feed is by more than two sets of unfaulted terminals rated greater than 35% of the terminal KV.A of the highest capacity winding. For the three-circuit transformers, if user requirement is different from C57.12.00-2010 then specifications should specify whether the in-feed is from one system or from two systems.

4. In many specifications for the autotransformers, it is specified that the tertiary has to be brought-out to supply station loads (usually a few KV.A). When the tertiary is brought-out then it has to be designed to withstand a three-phase fault on its own terminals. This will increase the tertiary winding size considerably or a Current Limiting Reactor will have to be used. In many cases it will be economical to the users to supply the station loads from another source such as SSVT (Station Service Voltage Transformer).

5. Almost all specifications state that inner windings should withstand free buckling. When the LTC is electrically in the HV winding or in the series winding and the LTC winding is physically located inside of the HV winding or of the series winding, it may experience free buckling force, depending on the type of taps. If the taps are of linear or coarse/fine type, then the tap winding will not experience any free buckling. If the taps are of reversing type, then the tap winding will experience free buckling.

6. Many text books give information on equivalent circuits and how to calculate the short-circuit currents and the forces. IEC60076-8 "Power transformers - Application guide" also gives information on equivalent circuits to calculate the short-circuit currents. Manufacturers have developed their own methods to calculate short-circuit forces based on the tests they have conducted on the materials. IEC60076-5 'Ability to withstand short-circuit' gives guidelines on allowable forces and stresses. As there are differences in the above, it is recommended that the specifications to state the basis for the short-circuit calculations and withstand values.

7. Most users are satisfied when the manufacturers use computer programs to calculate the short-circuit forces. Users should check the formulae in these programs.

SHORT-CIRCUIT WITHSTAND (continued)

The following are applicable to core-form transformers (for shell-form transformers suggest referring to applicable literature).

The following forces are normally calculated:
1. Radially-inward forces on inner coils.
2. Radially-outward forces on outer coils.
3. Axial compression forces on all coils.
4. Total end thrust (axial compression) of the entire coils assembly.
5. Free buckling forces on inner coils.
6. Short-circuit forces on leads.

From the above forces, the following stresses are normally calculated:
1. Mean hoop tensile stress on outer windings.
2. Mean compressive stress on inner windings.
3. Radial bending stress on inner windings
4. Axial bending stress on all coils.
5. Compressive stress on radial spacers (duct sticks).
6. Compressive stress on axial spacers (keyed spacers) and on the paper insulation of the winding conductors.
7. Compressive stress on clamping ring (pressure ring).
8. Tensile stress on clamping structure.
9. Compressive stresses for tilting.
10. Free buckling stresses on inner windings.
11. Short-circuit stresses on lead structures.

It is a good idea for users to check the following.

1. Whether the CTC is epoxy bonded (when bonding is used in stress calculations).
2. Yield strength of the winding conductor.
3. Grade and strength of the pressboard.
4. Construction and withstand strength of the edge strip on helical coils (for press-board, the withstand strength varies considerably depending on whether the forces are on the surface or on the thickness).
5. Grade and strength of material used for clamping rings. If openings are made in the clamping ring for leads bring-out, this should be considered in withstand strength.
6. Distances from the leads to the ground and between phases (especially when the short-circuit currents values are high).
7. Support of the coils to the core.
8. Withstand strength of the tank (especially for explosion-resistant tank).
9. Devices to relieve the tank pressure during short circuit (to relieve the pressure fast to avoid the bursting of the tank).
10. Design of current limiting reactors in the tertiary.
12. Design and value of neutral grounding reactor/resistor.
13. Design of clamping structure (external tie rods, flitch plates, internal tie rods etc.) and its adequacy to withstand short circuit forces and also for lifting the core & coils assembly.
14. On transformers with DETC and LTC taps, calculations of the forces on all DETC tap positions, combined with LTC rated tap position and both LTC extreme tap positions.

SPECIAL REQUIREMENTS

Along with the regular transformer parameters (MV.A, voltages, insulation levels, impedance, loss evaluation values, taps details etc.) the specifications should include details of many other special requirements.

1. Ambient temperatures, if different from the standards (CSA-C88-M90, C57.12.00-2010 etc.).

2. Specifications that quote IEEE standards from the southern United States can obtain economical transformers by specifying that an increase in MV.A rating at cold temperatures (up to -30ºC per C57.91-1995) is not required. This is because the ambient temperatures in southern states will never reach such negative temperatures.

3. CSA and IEEE standards generically specify the continuous over-voltage requirement as 110% at no-load and as 105% under load. Some specifications state 130% continuous over-voltage (not clear at no-load or under load). Users should understand that this over-voltage requirement will increase the transformer cost considerably. Some users specify such high over-voltage requirement thinking that they can obtain better quality transformers. Some users specify high over-voltage requirement with the opinion that when the LTC is on the input side and if the LTC control circuits malfunction then the LTC motor could runaway to the minimum tap position. Proven control circuits are available to avoid such malfunctions at a much lower cost. Specifying the over voltage requirement for the transformers directly connected to the generators is very important, because during the load rejection, the transformers will see much higher over-voltage than specified in CSA-C88-M90 or C57.12.00-2010.

4. CSA-C88-M90 specifies a pre-fault voltage of 1.1 p.u. Unless there is a system need, users should not over-specify this requirement.

5. Most on-load tap-changers operate down to -25ºC ambient temperature with high-viscosity oils like Voltesso 35. With low-viscosity oils like Petro Canada Luminal, LTC operation below -25ºC is permissible without heaters. Type of oil, ambient temperature, and low temperature cut-out setting are to be correctly coordinated.

6. Some specifications call for tap-changers with higher current rating than the maximum nameplate rating (1.5 p.u., 2 p.u. etc.). Understand that this higher current rating is to have a safety margin. IEEE standard for Load Tap Changers C57.131 contains clauses (clause 6.1.1 Maximum rated through current and clause 6.2.1.1 Service duty test at rated step voltage) that provide adequate safety margins. In some situations the manufacturers could be forced to use a series transformer to meet the higher current requirement (1.5 p.u., 2 p.u. etc.). This will increase the overall cost and the losses.

7. If the transformers are to be operated at altitudes higher than 1000m above the sea level, then specify the altitude. Manufacturers need this information to apply correction factors for air clearances and for cooling calculations. This information is also required in selection of the bushings with creepage length suitable to the altitude.

8. If the transformers are to operate in polluted environments, then specify the creepage lengths needed on the bushings. Other requirements like special skirt extensions on LV

SPECIAL REQUIREMENTS (continued)

bushings, extra air clearances, special painting requirements, galvanized radiators etc. should also be stated in the specifications.

9. Most specifications give transport limitations of the height and the weight. If no profile limitations (certain width at certain height) are given, then the user could have surprises at a later date in moving the transformer to a different location. It is a good idea for user to know the shipping limitations for transport by rail or by truck or by sea; this will be helpful if the transformer has to be sent to a manufacturer different to the original manufacturer for repairs.

10. Specifying dimensional and weight limitations, spill containment volume limitation etc. is suggested when a direct-replacement transformer is required.

11. Lately many specifications are calling Geomagnetically Induced Current (GIC) requirements. GIC requirements in most specifications are not possible to achieve. Users should consult with GIC specialists on what to include in the specifications. Users should also consider installing blocking devices. IEEE web page www.transformerscommittee.org has a very good tutorial on GIC given in the spring of 2012 in Nashville, Tennessee.

12. Specifications should clearly state the oil preservation system needed; free breathing conservator, conservator with air bag, nitrogen pressurized system etc. Some specifications say gas insulated system. To avoid ambiguity suggest specifying nitrogen pressurized system instead of gas insulated system. For nitrogen pressurized transformers specifications should clarify as to whether the tank stiffeners can be used for the nitrogen expansion space. Some specifications state nitrogen pressurized system even for transformers with high insulation levels. For reliable operation many users and manufacturers limit nitrogen pressurized system up to 750KV BIL. For transformers with high insulation levels (say above 750KV BIL) suggest specifying the conservator unless only nitrogen pressurized system is required for other reasons.

13. When the users have special requirements such as bottom mounted fans are not allowed, pump bearings to have monitoring systems, on-line monitoring devices, optic sensors, neutral grounding devices, bushing potential devices etc. then they should be stated in the specifications with all needed particulars.

14. When transformers with special oils like FR3 are required then the specifications should state whether this oil is required in accessories like tap-changers, bushings etc.

15. In an autotransformer with variable flux taps, the tertiary voltage will be changing from tap to tap. This is not desirable when the tertiary is supplying station loads or for VAr control. If the user wishes to maintain the tertiary voltage fairly constant throughout the tap range, then the specifications should ask that the autotransformer include a compensating transformer.

16. If moving the fully assembled transformer (with oil filled) within the substation is required, then this must be stated in the specifications.

OVERLOADS

C57.12.80-2010 clause 3.302 defines overload as below:
Overload (general): Output of current, power or torque, by a device, in excess of the rated output of the device on a specified rating basis.

Users should be aware of the risks given in C57.91-1995 when specifying the overloads (Loading beyond nameplate rating). Some of the risks are listed below.

--Evolution of free gas from insulation of windings, leads and adjacent to the metallic parts.
--Loss of transformer life.
--Reduced mechanical strength of insulation.
--Permanent deformation of materials.
--Leaking gaskets.
--Tap-changer thermal runaway condition.
--Risk of damage to internal parts like CTs, TV current limiting reactors, tap changer reactors, etc.
--Excessive pressure build-up in bushings due to expansion of oil in the bushings.
--Operation of pressure relief device due to pressure build-up in the tank.
--Increase in regulation (voltage drop).

The following will be helpful in specifying the overloads.

1. Many specifications state that the overloads are per C57.91. C57.91 is a guide and not a standard. C57.91 does not specify overload profiles. C57.91 categorizes overloads as Planned overloads, Long-time overloads and Short-time overloads. For each type of these overloads it suggests limits on hotspot temperature and oil temperature. Users must detail the overload profile in the specifications.

2. Some specifications provide overload magnitude and duration such as; 1.75 p.u. for ½ hour, 1.6 p.u. for 2 hours, 1.15 p.u. for 8 hours etc. These specifications do not say whether these overloads occur one after the other or at different times. Also, the specifications do not say how many times in a year these overloads occur. DTEC and LTC manufacturers need this information in sizing the tap changer.

3. Almost all the specifications have the following sentence based on clause 9.2.2 of C57.91 irrespective of whether the overload profile and all the relevant data is included in the specifications: ‘Ancillary equipment should not restrict loading to levels below those permitted by the insulated conductor and other metallic part hot spots’. When overload information is not stated in the specifications, having this clause in the specifications is irrelevant.

4. The specifications must include complete information per clause 9.7 of C57.91.
(a) Load.
    (1) Two step load cycle approach.
        Prior steady-state load, percent of maximum nameplate rating.
        Maximum load, percent of maximum nameplate.
        Duration.

OVARLOADS (continued)

(2) Load cycle over a 24 hour period.

(b) Ambient temperature, ºC

(1) Constant per load cycle approach.

(2) Variable over the load cycle for load cycle approach.

(c) Type of loading, planned or emergency, long-time or short-time.

(d) Limiting oil temperature.

(e) Limiting hottest-spot temperature.

(f) Statement that ancillary components shall not limit the loading capability.

In almost all the specifications with RCBN taps it is not stated how RCBN taps are to be considered for overloads.

<u>Loading capability at low temperatures</u>

1. Clause 3.5 of CSA-C88-M90 states that the transformers (except GSU units) shall be capable of an increase in loading for each degree that the daily average ambient temperature is lower than that of 25ºC down to a minimum average ambient temperature of 0ºC.

2. Clause 6.4 of C57.91 states increase in loading for each degree Celsius that the daily average ambient temperature is lower that of 30ºC for air cooled units and 25ºC for water cooled units down to a minimum average ambient temperature of -30ºC.

--Self cooled (ONAN) and water-cooled units shall have an increase of 1% for each degree Celsius.

--Forced air/forced liquid cooled units shall have an increase of 0.75% for each degree Celsius.

It is advisable that the users should include in the specifications that written confirmation from DETC, LTC and bushing manufacturers that they meet the above low temperature capability requirement. On-load tap changer rating is mainly dependent on switching KV.A and bushing rating at low temperatures is different to that of the transformer.

Some specifications for autotransformers are not clear whether the overload requirement applies to the tertiary or not. Some specifications are not clear whether the overloads are applicable for step-down condition, step-up condition, arithmetic loading of tertiary load and output load, vectorial loading of tertiary load and output load or simultaneous loading of tertiary load and output load, etc. On high voltage autotransformers many users connect reactors to the tertiary. These specifications should be clear whether the reactors are connected or disconnected during the overloads. During overloads, some specifications also limit top oil temperature and hottest-spot temperature the same as that of normal load 105ºC and 120ºC respectively. Users should realize that they are just buying a larger MV.A rated transformer.

Many specifications state one ambient temperature for summer overloads and one ambient temperature for winter overloads. The ambient temperature is much less during the evening and the night compared to that during the afternoon. Only a few specifications state the hourly ambient temperature in 24 hour period. Recommend

OVERLOADS (continued)

specifying hourly ambient temperature; because transformers to this specification will cost less than the transformers with the same temperature for 24 hour period.

To obtain a lower operational cost some specifications state that additional fans/pumps are to be provided for use during overloads. Inclusion of this sentence in the specifications is recommended because often the pumps are provided to meet the overloads.

C57.91-1995 does not recommend any value for loss of life. If the user wishes to restrict the loss of life per overload cycle then it should be stated in the specifications.

Specifications should define whether the overload is Planned loading beyond nameplate rating or Long-time emergency loading or Short-time emergency loading and give limiting values for insulated conductor hottest-spot temperature, other metallic hot-spot temperature (in contact and not in contact with insulation) and top-oil temperature if they are different from the values in Table 8 of C57.91-1995

If the user wishes to perform the overload test then it must be stated in the specifications. Sometimes manufacturers test equipment can be a limitation to perform the overload test. It is recommended that the user and the manufacturer agree on how to perform the overload test in the Design Review meeting. Gas-in-oil levels during overload test will be higher than those during the heat-run test. In the Design Review meeting user and the manufacturer should agree on acceptable gas-in-oil levels during the overload test.

In the Design Review meeting it should be checked that magnetic shields are not saturated during the overloads. Also the need for splitting the last core step or other methods of avoiding generation of undesirable hot spots in the core during the overloads is to be checked.

Some specifications state the normal loads and overloads for step-up and step-down operations. Based on electrical location of the LTC (in HV winding, in series winding, in LV winding, in common winding, etc.), the tap position, voltages on each winding and the regulation; currents in HV and LV vary for step-up and step-down operations. This is because of the following: when the LTC is in HV, during step-down operation the LTC is in input winding and during the step-up operation, the LTC is in output winding. This is extremely important in autotransformers with loads on tertiary, because the current in common winding vary very much based on the above conditions.

PARALLEL OPERATION

Paralleled transformers are those connected in such a manner that they share a source and a load.

Many text books and standards give the details on parallel operation. Many papers have been published on this subject. A few references are given below.

1. IEEE standard C57.153 – Transformer Paralleling Guide.
2. CSA-C88-M90.
3. IEEE standard C57.12.10-2010.
4. Tutorial "Transformer Paralleling" by Jim Graham, Tom Jauch and Jin Sim presented in IEEE Transformers Committee Meetings in April 2009. This paper can be accessed at www.transformerscommittee.org

If parallel operation with the existing transformers is required then this should be stated in the specifications and the following information on the existing transformers should be given to the bidders.

(a) rated MVA.
(b) exact turns ratio of windings at rated voltage.
(c) exact turns ratio corresponding to the taps, if any, on the high-voltage winding.
(d) exact turns ratio corresponding to the taps, if any, on the low-voltage winding.
(e) impedance and its MV.A base on the principal tap and on the tap extremes.
(f) diagram of connection and phasor relationship between windings.
(g) compatibility of controls to maintain the correct tap positions on all transformers while minimizing circulating current.
(h) type of paralleling method preferred.

Some general paralleling operational basics stated in C57.12.10-2010 are given below.

1. Transformers of the same MV.A rating and equal impedance share the load equally.

2. Transformers of different ratings share loads based on their ratings as long as the percent impedances at their respective maximum MV.As are equivalent.

3. If transformers with percent impedances at their respective base MV.As are equivalent but with different cooling ratings are paralleled, the total capacity of the transformers connected in parallel could be limited to less than the sum of their capacities.
Example: When a 60/80MV.A, ONAN/ONAF transformer with 8% impedance at its base rating (8% at 60MV.A) is paralleled with a 60/80/100MV.A, ONAN/ONAF/ONAF transformer with 8% impedance at its base rating (8% at 60MVA) the total capacity will be less than 180MVA.

PARALLEL OPERATION (continued)

Some paralleling methods are given below.

1. Master/follower.
2. Power factor.
3. Negative reactance.
4. Circulating current.
5. Circulating reactive current.

While preparing the specifications the users should also consider the following.

1. Many specifications state that paralleling operation with the existing units is required and give the impedance of the existing units at the rated tap only. This information is not enough. The specifications should give the complete data for paralleling (impedances at extreme tap positions etc.).

2. Some specifications state that paralleling information will be given to successful bidders only. Users should realize that without complete paralleling information in the specifications, bid submission is almost impossible.

3. Some specifications state that information on the existing units is proprietary information and will not be given to the bidders. This information is required for bid preparation and is not proprietary.

4. In specifications with 65ºC rise transformers to parallel operate with the existing 55ºC/65ºC rise transformers or a three stage cooled (or rated) transformer to parallel operate with the existing two stage cooled (or rated) transformers, impedance based on maximum MV.A rating only should be given and not based on the base MV.A rating.

5. Specifications should state whether the tertiary of the tendered unit to be parallel operated with the tertiary on the existing unit or not.

6. If lesser tolerances (especially on impedances) than those specified in CSA-C88-M90 or C57.12.00-2010 are needed by the user then the needed tolerances should be given in the specifications.

7. Users should realize that parallel operation is the users' responsibility and the transformers will be designed per the specifications only.

RATING PLATE

The rating plate is the most important and readily accessible record of the transformer to the user. C57.12.10-2010 calls it a Nameplate. Often after a few years in service the information on the rating plate fades away and it is difficult to read. Per CSA-C88-M90 the data should be inscribed by etching, engraving, stamping or other equally durable method. Per C57. 12.00-2010 a durable metal nameplate shall be affixed to each transformer by the manufacturer. Unless otherwise specified, it shall be made of corrosion-resistant material. Size of the rating plate and size of the letter etc. are also important for easy reading.

Minimum data to be included on the rating plate is given in the standards. Information given by other standards and not given in CSA-C88-M90 is listed below.

1. In accordance with the requirements of C57.131 load tap changer (LTC) transformer shall also contain a tap changer nameplate, permanently attached to the LTC compartment.
2. Phasor diagram for polyphase transformers including hour clock designation (Dyn11, Dyn1 etc.).
3. Step-up operation suitability.
4. Size of the letters and numerical (C57.12.00-2010 specifies 4mm minimum).
5. Tertiary MV.A rating (when the transformer has a tertiary).
6. Provision of future forced-cooling equipment (where applicable).
7. Suitability for reversal of power flow.
8. Voltage transformers, potential devices, current transformers, winding temperature devices when used shall be shown.
9. Nonlinear devices, capacitors, resistors etc. installed on the winding assembly or on any tap changer shall be indicated on the nameplate.
10. All internal leads and terminals not permanently connected shall be identified with numbers or letters in a manner that permits convenient reference to prevent confusion with terminal and polarity markings.
11. Contains no detectable level of PCB (less than 2 ppm) at the time of manufacture.
12. Standard number including the year of the standard to which the transformer in manufactured.
13. Impedances on extreme tap positions.
14. Vacuum withstand capability of conservator and all oil circulating parts.
15. In addition to the main rating plate, plates with identification and characteristics of auxiliary equipment (bushings, tap changers, special cooling equipment etc.).

Users should consider including the following under what is to be included on the rating plate.

1. Diagram showing the location of emergency man-holes.
2. Diagram showing the location of major valves (drain, filter etc.).
3. Where applicable to show the following.

(a) Tie-in resistors including their rating and the manufacturer’s name.
(b) Type, make and serial number of LTC reactors.
(c) Current limiting reactors including their impedance values and the manufacturer’s name.

RATING PLATE (continued)

4. Diagram showing the type and location of fall arrest system.
5. On nitrogen pressurized transformers minimum and maximum pressure settings of the regulator.
6. User specification number to which the transformer is manufactured.
7. Location of static cylinders when used (on the core, under LTC winding etc.).
8. A statement that the voltages and currents marked are based on no-load and are not during the load.
9. Zero sequence impedance.
10. Serial number, make and complete type designation of LTC and DETC tap changers.
11. Make, serial number, voltage ratio and rating of series transformer and/or compensating transformer when used.
12. Construction designation – core type or shell type.
13. Core details – single, two, three, four, five or seven legged.
14. Provision for future sound enclosure including the type of enclosure.
15. Maximum current in common winding on autotransformers with loaded tertiary and during the step-up operation.
16. Sound levels at all ratings (sound pressure or intensity).
17. Type of oil (Voltesso 35, Luminal etc.)
18. PCB content in oil (less than 2ppm) at the time of first filling.

ALTERNATIVES

Encouragement by users is the key for the birth of innovative ideas. If the users had said in the specifications that step-lapped cores, shielded windings etc. are not acceptable, these technologies would not have evolved. A few decades back some specifications used to state that the core must be built with the top yoke.

It is unfortunate that some specifications state that “No alternative will be considered”. Some specifications have stated that “no prototype features will be accepted”. Some specifications have stated “Bidders are encouraged to quote alternatives to the specifications detailing the benefits and meeting all the requirements of the user, provided the main bid is per the specifications”.

Some users have purchased these alternatives with lower losses on all the tap positions below the normal tap (linear taps instead of reversing taps), with better voltage control, lower short-circuit forces etc. Some users have not purchased these beneficial alternatives because they are not exactly identical to the transformers they had procured in the past. For the health of this industry the users should give incentives and work with the manufacturers for improvements in design and manufacturing.

Many users are of the opinion that transformer development works (reduction of losses, improved reliability etc.) is the sole responsibility of the manufacturers. Many engineers working for users have very good ideas and these should be nourished. The best developments occur when users and manufacturers work as a team rather keeping their distance as the buyers and the suppliers.

Users should consider the alternative without the main bid when the alternative meets the system requirements stated in the specifications. Often there is no time to design and cost the main bid and the alternative. Preparation of two bids (one for the main bid and the other for the alternative) is costly and time consuming for the manufacturers.

Some of the hurdles the technical department (or specifications writing Group) of the user faces to consider the alternatives without the main bid are: convincing the purchasing department, convincing the maintenance department, technical evaluation of alternatives etc. Some of the users have conquered these hurdles. Understand from these users that it is not difficult and hope that all the other users will also conquer the hurdles.

Some specifications ask for too many alternatives. This is because the user does not need to pay money for any number of alternatives. The author has seen specifications asking for 25 alternatives with different impedances, different insulation levels, different MV.As etc. This is not fair. The users should consider the difficulties of the manufacturers.

ALTERNATIVES (continued)

To reduce the number of alternatives, users should interact with the manufacturers while writing the specifications to determine the exact parameters of the transformers. Almost all the specifications have a clause stating that the purchaser has a right to reject all the bids without giving any reason. Some users even after asking for quotes with alternatives will not place an order. Users should realize that preparation of the bids require considerable technical resources to the manufacturers. Preparation of the bids also adds considerable cost to the manufacturers. As an example, the cost for preparation of a bid for the phase-shifting transformers was about $100,000 dollars for each bidder. When all the bids are too expensive for the budget allocated to the project, then it is understandable that user not placing the order. In such a situation the user should inform the reason for not ordering to all the bidders.

In an enquiry the user requirement was 3% impedance at a given MV.A. An alternate with 6% impedance at the same MV.A is also asked. Understand that the user thought that it is not possible to design a transformer with 3% impedance at that MV.A. If the user had discussed with the manufacturers prior to issuing the specifications, the manufacturers would have saved time and money in preparing a main bid and an alternative.

In another enquiry the main bid with HV wye / LV delta and the alternative with HV delta / LV wye were asked. The taps are on LV for LV variation. When LV is wye, the current in LV is high and a series transformer has to be used. When LV is delta the series transformer is not needed. This made LV wye option very expensive as series transformer cost and losses are to be included. Users should do some home-work while writing the specifications and ask for the alternatives that are beneficial.

Some users ask for bids on 10 to 20 different transformers (all the ratings in their system) but place the order only on a few ratings. This avoids users going for bids when a need arises for a different rating transformer, thus saving them money. Also understand that this is for bulk orders to cover 5-years requirements. Suggest that at least once a year, users and manufacturers should discuss each other’s difficulties.

If the users are not sure about getting 100% of the budgeted funds and may have to reduce the capital cost, then the specifications can ask for a bid with loss evaluation and an alternative with no loss evaluation.

INTERESTING CLAUSES

It is suggested not to use the following clauses in the specifications as either they are ambiguous or will add considerable cost, with almost no benefit to the user.

1. If any technical information is missing from the specifications then it should be per industry standard (What is the industry standard? Where it is defined?).

2. The windings of each transformer shall be made of such materials and assembled in a manner best suited for the particular application (What is meant by best suited and how to measure it?).

3. Best materials should be used (Are windings to be of silver instead of copper?).

4. Adequate barriers shall be provided between the core and the low voltage winding, between the low voltage winding and the medium voltage winding and the medium voltage winding and the high voltage winding (Adequate for what? How to determine what is adequate?).

5. In-tank type LTC is acceptable but the selector contacts must not be in transformer main oil (This is very costly. Not having the diverters in transformer main oil is logical.).

6. Taps can be either on the HV or on the LV as long as they are ±10% in ±16 steps, (It is necessary that the specification state whether the taps are used to compensate for output voltage regulation or for input voltage fluctuations. The use of taps and their location have considerable bearing on transformer cost).

7. The bid must be as per the specifications; no exceptions, no deviations and no alternatives will be accepted.

8. Buried tertiary MV.A and voltage are per manufacturer's standard (There is no manufacturer's standard and how is the manufacturer supposed to know the amount of imbalance between phases in the user's system).

9. Transformers must be designed to withstand the short-circuits as described in C57.12.00-2010 with a system X0/X1 ratio of 2, but with infinite bus (If it is infinite bus, the system's X0/X1 ratio doesn't enter into the fault current calculations).

10. The life of the transformer supplied to this specification must be 40 years minimum (How will the manufacturer know if the transformer is adequately maintained, what loads and overloads are put on etc?).

11. Tank should have adequate stiffeners (What is adequate?).

12. Only bids from manufacturers with a skilled work force will be considered (What is meant by a skilled work force and how are the skills measured?).

13. Core should be built with high grade laminations (What is high grade?).

INTERESTING CLAUSES (continued)

14. Oil should be of good quality (Where is good defined?).

15. Overload in summer months is 1.6 p.u. of maximum rating (e.g.1.6x100= 160MV.A) for 10 hours continuous each day with a top oil temperature limit of 105ºC and a hottest spot temperature limit of 120ºC (These limits are for the continuous load per CSA-C88-M90 and C57.12.00-2010. Why not just specify that the continuous maximum transformer rating is 160MV.A).

16. For reliability reasons the transformers must be tested at 25% higher test voltages than the levels specified in C57.12.00-2010 (This increases the cost considerably, with no adequate benefit).

17. Impulse withstand and short-circuit forces withstand strength calculations must be by computer programs only (Is the computer program enough without verifying the formulae in the program?).

18. Autotransformer must be designed for step-down and step-up conditions, and for vector, arithmetic and simultaneous loads of the TV and the main output winding (All these conditions will increase the cost. Specify only the true operating conditions).

19. Transformers must be designed with the whole tap range as constant flux taps and also as variable flux taps. (This increases the cost of the transformer considerably. Consider specifying mixed regulation taps. IEC 60076-1 gives an example of this. Some users are specifying mixed regulation taps per IEC 60076-1. The author has designed transformers with mixed regulation taps nearly 40 years ago).

20. All components including the tap changers shall provide utmost reliability (Do not state that is not measurable. Specify a test).

21. During the service there should be no abnormal deterioration of insulation (It would be meaningful if normal and abnormal are defined).

22. The transformers shall conform in all respects to high standards of engineering, design and workmanship (Where are the high standards defined?).

23. Equipment meeting with the requirements of other authoritative international standards which ensure equal or better performance than the standards mentioned above shall also be considered (It will be interesting to know if the user was the bidder, what the user wound have done when such clauses are in the specifications).

24. The impedance voltage at principal tap and rated MV.A shall be stated in the order (No impedance value is stated in the specifications issued to get the bids. User should realize that to prepare a bid the impedance is required.).

25. Non-magnetic materials used shall be of established quality (Where this established quality is and who established it?).

GLOBALIZATION

Nowadays, users and manufacturers are frequently located in different countries and often on different continents. Different languages could become barriers in communications between the engineers on both sides. Repair cost and time to repair are important in selecting the bidder for the new transformers. Due to the above concerns, the reliability of transformers is gaining more awareness[16].

Computers and modern communication facilities have helped global business, but have also bought problems. Mostly the invitation to the bids is posted on web sites and states that 'the manufacturers are directed to post the clarifications to the specifications on the web site only; communication directly with the users by phone or by e-mail is not permitted'. When a bidder posts a question on the web site it will be known to all the other bidders. Also when the user posts the answer on the web site it will be known to all the bidders. In this process the bidder who raised the clarification does not benefit. Many bidders are feeling that they will have an edge by not posting the clarifications on the web site and by quoting the least cost transformer with the exceptions/comments stated in the bid. Due to this the interaction between users and the manufactures is lost and the ultimate looser is the user. This amplifies the importance of preparing the specifications to reflect all the system requirements including how the transformers are operated.

To save jobs, some countries have adopted the policy of purchasing the transformers made in their own country or giving a price preference for the bidders in their country. Many other countries are considering following in the same direction. Due to the stiff competition, almost all of the manufacturers are working with smaller safety margins between stresses and the strengths than those of a few decades back. Often we hear that the life of newer transformers is much shorter than the older transformers.

Specifications are the first and the most important tool the users have in procuring reliable transformers at economical prices. Before globalization, local manufacturers were supplying transformers to the local users. Due to many years of acquaintance between the local users and the local manufacturers, the manufacturers fully understood the user requirements. Now the specifications must reflect all of the system needs. As many bidders in the global market are not fluent in English, the specifications should be in simple English, with globally known terminology, clear to understand and with no ambiguities. Some users in locations where the main business language is not English, issue the specifications in their local language. To obtain cost effective bids, it is suggested that these users issue the specifications in English also.

A considerable number of users have not changed their specifications for many years. Even when the users are aware that slight modifications to the specifications give considerable benefits, they are reluctant to change. This trend should change for the benefit of all. When a clause in a standard restricts the economic benefits, then the user should make a suitable change to the clause in the standard before quoting the clause in the standard in the specification.

GLOBALIZATION (continued)

Manufacturers in the countries who adopt IEC standards have many years of experience in designing transformers with linear taps and coarse/fine taps. Users in these countries have good experience in operating these transformers. Conversely, users that adopt IEEE standards mostly call for the transformers with the reversing taps. By modifying the specifications such that the bids can be of any type of taps will bring great economic benefits to the users. The tap changer for coarse/fine and for reversing taps is the same, except for a connection. Because of this, tap changer manufacturers do not call the mechanism in these tap changers revering switch or coarse/fine switch. In both these types of tap changers, they call it changeover switch. Present vacuum type tap changers no longer require a minimum leakage inductance between the coarse and the fine tap windings.

Another example is based on the work done by IEC. Users and the manufacturers in many countries have established that internal non-linear devices (MOV devices) are reliable. Based on some unfortunate incidences, some specifications restrict the use of these devices. The author has experience with these devices as a user and as a designer. It is recommended removing such restrictions to obtain more reliable transformers and also to get the economic benefits. Regular updating of the specifications based on the work done in other countries will bring cost savings and more reliable transformers.

In the present globalization market, along with all the system requirements it is advisable that the specifications include user maintenance practices and the safety requirements. Specifications should also cover the problems related to the transport. Along with the transport restrictions to the specified station, restrictions to move the transformer in future from one station to another station within the utility network should also be included. Stresses experienced by a transformer during the sea transportation are quite different from those experienced during the rail or the road transportation. During the initial years after the transformer is placed in service, only a few problems are seen because the materials are new and the loads are light. Problems related to the leakage flux do not occur at light loads. Specifications should state that all details such as stresses during transportation, route of the shipment etc. should be supplied along with the transformer. This information will be handy if the user has to return the transformer to the original manufacturer’s plant for repairs after the warranty period or to ship to another manufacturer’s plant.

Although there are some fundamental differences, suggest that the Transformer Committees of IEC and IEEE are to be merged. When there is one global organization then global standards can be produced. With such global standards, the global users and the global manufacturers will have better interactions and all will benefit.

DATA SHEETS

Data sheets for the bids should ask for the information needed in evaluating the bids. Many users ask for the information as if the final design will be done by the bidders at the tender stage itself. In some bids there were 15 to 20 pages of the data sheets to be filled-in. In preparing these bids filling-in the data sheets takes more time than doing the actual design.

Some bids are brief and the data sheets ask only the following details in line with the standards.

1. No-load loss at 20ºC.
2. Load loss at 85ºC at a specified MV.A and on the rated tap.
3. Losses of cooling equipment.
4. Make and type of DETC and LTC tap changers.
5. Make and type of bushings.
6. Impedances at rated and extreme tap positions.
7. Core or shell type and number of legs.

Some data sheets ask for information not relevant to the evaluation of the bids. A few are given below.

1. Efficiency and regulation at ¼, ½, ¾ and 1 p.u. MV.A at unity power factor and at 0.8 power factor.
2. Number of strands in CTC conductors.
3. Calculated gradients of windings and the oil rise.
4. Impulse, applied and induced test levels.
5. Time from initiation to completion of one tap of the LTC.
6. Voltages of all DETC taps.
7. LTC is in which winding? (To be asked when the choice of winding is left to the bidder and not when the specification specifies LTC is in which winding).
8. Both no-load and load losses at 20ºC and also both the losses at 85º.
9. Load loss at base MV.A and at maximum MV.A.

Data sheets should not ask for information the user has in the specification. Also, the information asked in the data sheets must be understandable. There are incidences where the data sheets ask the information on which the users themselves are not clear.

Data Sheets in some specifications are in electronics form only and these specifications state that Data Sheets must be submitted in electronics form only. Often these Data Sheets have dropdown menu and very little space to fill-in the data. These Data Sheets will not allow the bidders to fill the information correctly and fully. Users should take extra care in preparation of Electronic Data Sheets.

After initial evaluation of the bids, if required, more information could be asked from one or two finalists before the Tender Review Meeting.

Data sheets cannot substitute the Tender Review Meeting. Purpose of the data sheets is for initial evaluation of the bids. Tender Review Meeting is strongly recommended.

TESTS

Often specifications list the tests for the fully assembled and oil filled transformers. Separate tests on parts used in high voltage stress areas are very important. There have been major failures on transformers when insulated bolts used for lead clamp structure and shafts used in DETC tap-changer were not corona free. There have also been failures due to the defective bonding material (glue) used in keyed-spacers etc. It is advisable that the users check the purchasing specifications of all such critical components/materials and to get copies of test certificates from suppliers of these materials. It is also advisable that the users obtain copies of test certificates of key components like tap changers, bushings etc.

A considerable number of specifications repeat the description of the tests in the standards. It is preferable to say the tests per the particular standard should be done. Only the tests not in the standard and if the user wishes to perform these tests then they should be stated in the specifications. A few such tests are listed below.

1. Per CSA-C88-M90 partial discharge measurements and limits are in μV. Suggest specifying the measurements and limits in pC per C57.12.90-2010.
2(a) Per CSA-C88-M90 switching surge test is a routine test for transformers 362KV and above. For voltages below 362KV if required, the switching surge test should be called.
(b) Per C57.12.00-2010 switching surge test is a routine test for transformers 345KV and above.
3. CSA-C88-M90 calls for one hour excitation run at 110% rated voltage after completion of the dielectric tests; C57.12.00-2010 does not call this test.
4. C57.12.00-2010 specifies the following tests and CSA-C88-M90 does not.
(a) Dielectric test for low voltage control wiring associated auxiliary control equipment, and current transformer secondary circuits.
(b) On transformers with both DETC and LTC:
(i) Ratio tests at all connection positions of the tap changer for de-energized operation with the LTC on the rated voltage position.
(ii) Ratio tests at all LTC positions with the tap changer for de-energized operation on the rated-voltage position.
(iii) Impedance and load loss measurements at six combinations of DETC & LTC tap positions per Table 19 on page 50.
5. In CSA-C88-M90 and in C57.12.00-2010 following tests are not specified.
(a) Ratio test between the windings that will be permanently paralleled.
(b) SFRA.
(c) Overload test.

Many specifications ask for the sound level at load with full excitation voltage applied. In the factory it is not possible to do such a test. During load loss measurement sound level produced by shields and windings is measured. During these tests, the flux density in the core will be very low and does not give the sound level produced by the core at full excitation voltage. Sound level produced by the core is measured at no-load, during this measurement sound level produced by the shields and the windings is very small. From the sound levels measured from the above two tests, there is no universally agreed method to compute to obtain sound level at load with full excitation voltage applied.

TESTS (continued)

As such, the user and the manufacturer should agree to the method, preferably in the Design Review, to compute these tested values to obtain the sound level at load with full excitation voltage applied.

To determine whether sound enclosures are to be installed or not, some users specify sound level tests with the transformer de-energized with all the fans and the pumps running. Neither CSA-C88-M90 nor C57.12.00-2010 specifies these tests. If required, the specifications should clearly state these tests with a description of how they should be performed.

On three-phase transformers, the standards call for a three-phase induced test. If single-phase induced test is also required, then this should be stated in the specifications.

In autotransformers when the HV is impulsed, whether the LV line terminals are to be grounded through surge impedances or solidly grounded is not clear in the standards and had disagreements between users and manufacturers. In the Design Review meeting all of the tests connections should be discussed and agreed upon.

CSA-C88-M90 and C57.12.00-2010 list the routine and design tests. If the user wishes to perform some design tests as routine tests, then these tests should be stated in the specifications. Also, if the user wants tests on accessories then they should be listed in the specifications.

C57.12.90-2010 describes how the tests are to be performed. C57.12.90-2010 also gives partial discharge limits. If the user requirements are different to those in C57.12.90-2010 then the specifications should clearly state what is needed.

Tests before shipping, tests after receiving and tests before energization are different to different users. As such, suggest stating these tests in the specifications.

In the Design Review meeting, the user and the manufacturer should discuss all the tests to be performed, test equipment limitations, extra tests the user want to perform that are not specified in the specification, test connections etc., and come to an agreement. This saves time and aggravations during the testing.

Some specifications have stated the actions to be performed by the manufacturer when the transformer fails during the factory tests (investigation, corrective action, retesting, etc.). This is a good practice and suggests having this in all the specifications.

TENDER AND DESIGN REVIEWS

The purpose of the tender and design reviews should be to enable the user and the manufacturer to work together to produce a transformer that meets all of the system requirements, to maintain transformer reliability throughout its operational life and supply the transformers per the committed delivery dates.

Tender and design reviews cost money and time for both users and manufacturers. Based on the MV.A rating of the transformer, complication of the transformer, bidders list etc. the user should decide whether to include the requirement for Tender and Design Review meetings in the specifications.

Specifications should clearly state the requirements of the Tender review and the Design Reviews. This is important because the bidder can include them in their costing. Many specifications are stating the requirement of the Design Reviews and also what will be discussed in the Design Review. Very few specifications are stating the requirement of the Tender Review. A Tender Review is much more important and essential than a Design Review. This is because the manufacturer's designers were given very little time to do a tender design. Many users are of the opinion that with computers designs are done in a few minutes. They are allowing very little time to submit a bid. Often there is no time for the bidders to obtain clarifications to the specifications. Normally, the same analysis and checks as in a production design, are not done for a tender design. Many times the interpretation of the specifications by the user and the bidder is different. Usually the Tender Review meeting is done in the user's office. This gives an opportunity for the manufacturer to meet user's system, operation, protection and stations design engineers and to know how the transformers are being operated. This also gives the chance to know why certain requirements are specified in the specifications and to discuss the economic alternatives. In the Tender Review meeting, suggest discussing the following:

1. Core details:
(a) Calculated and measured losses and excitation current on recently manufactured units with the same grade of core steel of the units of the bid.
(b) Flux density at maximum system voltage, calculated maximum surface temperature and maximum temperature in any part of the core (inside the core etc.).
(c) Difference in losses and the excitation current before and after the dielectric tests on recently manufactured units with the same grade steel of the units of the bid.
(d) General design philosophy in core clamps design.
2. Proposed winding types for trouble-free operation throughout the life of the transformer.
3. Thermal and short-circuit withstand characteristics of the materials proposed.
4. Location of taps and the effects on transformer parameters based on how the taps are used in the operation.
5. Variation of impedance over the tap range.
6. Suitability of reduced or minimized risk in transportation.
7. Manufacturing and testing capabilities and limitations.
8. Assembly and processing practices of core and coils. Also processing practices of oil.
9. Recent (past five years) shop failures, investigations, and how corrected.
10. Past delivery delays and recent track record.

TENDER AND DESIGN REVIEWS (continued)

11. Philosophy of design and manufacture to withstand short-circuits forces.
12. Thermal and overload calculations.
13. Quality and inspections.
14. Knowledge and experience of erection consultant.
15. Recent field problems and how they are rectified including service after the warranty.

Once the order is placed it is difficult for the user to influence any changes to technical and non-technical issues. Users have experienced that to include a feature or to modify a parameter after the order is placed is often costly and causes delay in delivery. If a thorough Tender Review has been done, then only a few discrepancies may have to be resolved at the Design Review.

Normally a Design Review is done just before ordering the materials. As such, users should insist on only the meaningful changes when essential. The user should not allow the manufacturer any quick fix to maintain the delivery. This often affects the reliability.

When an external consultant is employed by the user to conduct the Design Review, the consultant should not be biased and insist on changes based on the consultant's previous experience. New design practices and new production methods will be evolving continuously. If the user wants to employ a consultant for the Design Review then it is very strongly recommended that the same consultant must be present at the Tender Review also. Then the consultant can ask all the technical clarifications in the Tender Review and recommend the best bidder to place the order. With this very few disagreements will occur at the Design Review. It is important that the user should not insist on changes based upon the practices of another manufacturer that had supplied the transformers.

In the Design Review meeting it is suggested to discuss the following. The following may not be needed at the time of preparation of the specifications, but are included as they will be useful to the users at later stages.

<u>1. Magnetic circuit</u>
--Flux density in legs, yokes, outer legs etc. at maximum system voltage.
--Core construction (type of step/lap). Core construction in split core and flux density at different sections.
--Calculations of leakage flux entering the core and the method that will be adopted to eliminate occurrence of undesired hot-spots.
--Grade of core steel, the supplier and laminations surface insulation details.
--Core clamping structure design, especially to minimize the circulating currents in these parts.
--Core temperature (on the surface and inside core) at maximum flux density in service.
--Number and method of construction of cooling ducts. Oil flow in the ducts to provide cooling to avoid formation of hot-spots.
--Grounding details of the core and other parts.
--Core lifting method after completing the stacking of the core (hydraulic tables or other methods).
--Method of core and yokes binding (resiglass tape, dowels etc.).

TENDER AND DESIGN REVIEWS (continued)

2. Windings, leads exits, arrangements of leads and their connections
--Type of coils (disk, helical etc.) and their suitability for the application.
--Physical locations of taps and its impact on impedance swing across the tap range short-circuit forces and impulse voltage distribution.
--Type of winding conductors (CTC with or without paper covering, magnet wire single, twin triple etc.).
--When epoxy bonding is used (for CTC, twin conductors etc.), then the temperature rating of the epoxy is to be checked (not below the winding hot-spot temperature).
--Current densities, cooling, average and hot-spot gradients.
--Conductor (or strand for CTC) dimensions and eddy losses.
--Method to control the impulse voltage distribution (shielded, interleaved etc.), formulae in the impulse voltage distribution program, oscillations, stresses and strengths,
--Stress in oil and stress in solid insulation of the radial gap between the windings.
--Static shields, static cylinders, stress rings etc: construction, location and intended use.
--Cooling (no pumps, with pumps oil directed into the windings, oil velocities to avoid static buildup, hot spot calculations etc.).
--For OD cooled units, coordination of time constant of windings and the time constant of winding temperature indicator.
--Leads exits (currents induced in other parts, gradients and insulation withstand).
--Selection criteria on number of non-linear devices and the method of their assembly.
--Joints (joints in the winding and the joints in external connections).
--Calculation of short-circuit forces (off-sets, modeling, asymmetry factor etc.).
--Coils supports (number of supports radial and axial, details of the supports etc.) and the clamping pressures for lifting and for short-circuits.
--Details of the counter shield, interleaved etc.
--Number and type of transposition and their locations in the windings.
--Winding conductor supplier and insulation details (to go through the purchasing specification details of the winding conductors and the insulation).

3. External to the coils
--Design of current limiting reactors.
--Design of series transformer.
--Design of tap changer reactor (preventive auto).
--Design of compensating transformer.
--Design and mounting details of core shunts, clamp shunts and tank shields.
--Leads layout to avoid flashover to other parts, mechanical stability and prevention of induced currents in to other parts.
--Deflectors to channel the gasses in to the gas relay.

4. Accessories
--Tap changer type, make, selection to meet the specifications (overloads, step capacity, BIL withstand values etc.), tie-in resistors or potential switch, suitability of the increase in the rating at low temperature, effects of physical location of the taps etc.
--Bushings type, make, selection to meet the specifications (overloads, creepage distance, suitability of increase in rating at low temperatures etc.).
--WTI (winding temperature instrument) type, make etc. to meet the specifications. For OD (oil directed in to the windings) cooled units to check the correlation of its time

TENDER AND DESIGN REVIEWS (continued)

constant with the time constant of the windings. IEEE WTI Task Force has done very good work on this and is available at www.transformerscommittee.org
--On-line monitoring devices.
--CTs (current transformers) design, cooling, meeting the overloads etc.
--Pressure relief devices and other safely devices.
--Locations of bushings, coolers, fans, control box, conservator, tap changer etc.
--Location of fall arrest systems.
--Design of gaskets, flanges etc.

5. Manufacturing and processing
--Core: type of core configuration, machinery for cutting the laminations and for the assembly, burrs, shorting of the laminations, air gaps during the assembly, lifting after the assembly, relacing the top yoke, rigidity of the cooling ducts, splitting of outermost core packets, core tightness, grounding etc.
--Windings: tightness during the winding, maintaining the tightness after removing from the lathe, making the joints, installation of shields/interleaved workmanship, crossovers, sizing of the coils, storing of the coils till the assembly etc.
--Type of vapour phase process, pre-tanking works, tanking time etc.
--Oil processing and filling methods.
--Paint system and painting specifications.

6. Inspection and testing
--Quality standards and procedures.
--Inspection points at various stages of production.
--Inspection and tests on raw materials and accessories.
--Pre vapour phase tests (ratio, vector group etc.)
--Oil tests before filling.
--Tests after oil filling and processing (measurement of losses & impedance, thermal, dielectric etc.).

7. Shipment and installation
--Disassembly, marking, packing and shipment of the parts.
--Preparation of the main unit for shipment (oil filled, dry air filled, nitrogen filled etc.).
--Transportation method (rail or truck) and the route of the shipment.
--Type and location of impact recorders.
--Pre-shipment tests (SFRA, core megger etc.).
--Tests and inspections at site before unloading the main unit from the rail car/truck.
--Erection steps and processing procedure at site.
--Pre-commissioning tests.
--Precautions during energizing.

For successful Tender and Design Reviews mutual trust and respect between the users and the manufacturers are of the utmost importance.

TRANSPORTATION AND LIMITING DIMENSIONS/WEIGHTS

Specifications should clearly give the FOB point and all the details required to transport the transformer to the destination safely and in the minimum possible time. The specifications should also give nearest rail siding address, dimensional and weight restrictions for the transport and in the transformer station. While specifying these limitations users should consider transport of the transformer to different stations within the user system. A detailed schedule when different drawings (civil drawings, control drawings, rating plate, outline etc.) are required should be given in the specifications. To get the drawings per schedule, some users include incentives in the specifications.

When the new transformer has to replace an old unit, users often increase the transformer MV.A rating and say that the dimensions and weights should not exceed that of the old unit. With the new requirements like free buckling etc. often it is not possible to increase the current density in the windings even when the specification states that the loss evaluation is zero. Considering the total benefits the users should make changes to foundations etc. when required. Suggest including foundation, outline and other critical drawings of the old transformer in the specifications.

Manufacturers should realize that after receiving the transformer outline drawings (or civil drawings) the user has to go for tenders for foundations, oil spill containments etc. and have them all ready before the transformer arrives. There were many incidences where the dimensions and weights on the final drawings were much higher than those on the drawings first submitted. The users have to make modifications to the foundations, construct auxiliary spill containments to accommodate excess quantity of oil etc. There were many incidences that the manufacturers submitted the drawings per schedule but with many mistakes. Manufacturers often ask users to mark the discrepancies and return the drawings. Manufacturers also say that if the drawings are not approved quickly then the delivery will be delayed. Manufacturers should realize the problems of the users; submit the drawings with minimal mistakes and avoid using the users as checkers for the drawings.

After receiving the control drawings, CT details etc. the protection department of the user has to design the protection scheme, tender and install by the time the transformer is delivered.

The specifications should also give details like method of preparations of the parts for transport, dimensions and weight limitations on the parts. Preference whether the transformer should be filled with dry air or dry nitrogen should be specified. Based on user experience, the number and type of impact recorder, (electronic, three dimensional etc.) and where they should be mounted should be specified.

When a transformer needs to be moved in a confined space or to be installed at a place which is not accessible by normal transport, then to have a pre-tender site meeting with the bidders is a good idea. When the transformer parameters are complicated (specific impedance requirement, very low sound level, reconnections for different voltages, etc.) then also a pre-tender meeting with bidders is recommended.

CONCLUSIONS

1. In general, user's Purchasing Department is satisfied to place the order on the lowest bidder. The user's management should provide adequate resources and time to their Technical Department to prepare specifications by which cost effective transformers meeting the system needs can be procured.

2. There are many ways to meet the system needs. At the time of preparation of specifications, users will benefit by interacting with manufacturers and by choosing the most cost effective and technically acceptable parameters to include in the specifications.

3. Standards are to complement the specifications and are not a substitute. System engineers and operating engineers should be a part in deciding which clause of the standard to be referenced in the specifications.

4. Specifications should be tailor made to the specific need. Only a few general requirements can be standardized.

5. Like IEEE, CSA should also have Working Groups for continuous improvement of CSA-C88.

6. Clarity in specifications will help to get the least costly and most technically acceptable bids.

7. Before calling for the bids, the specifications must be updated based on the work done on the standards and the developments in other countries.

8. By knowing the new developments in the design, manufacturing, materials and accessories the specifications can be updated to take advantage of these developments.

9. Specifications should give freedom to the bidders to offer the best alternatives without a main bid as exactly stated in the specifications.

10. Users should provide incentives to the manufacturers to come up with new innovations. When users work with the manufacturers, the most cost effective innovations will evolve.

11. Manufacturers should realize that in most of the situations there is a specific reason for a specific clause in the specifications. It is important that the manufacturers not to make any assumptions in interpreting the specifications, but rather check with the user if a clarification/explanation is needed.

12. Technical Departments of the users and manufacturers must have direct, fast and reliable communication paths.

13. Users and manufacturers to have mutual trust and respect.

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