STANDARDS

SPECIFICATIONS

DESIGNS

AND

THEIR RELATIONSHIPS

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<u>**Outline**</u>:

Power transformer requirements stated in purchasing specifications, their effects on cost and complexity on design & manufacturing are discussed.

Alternate ways of specifying these requirements to reduce cost and complexity without sacrificing system requirements are suggested.

An attempt is made to pin point the limitations of standards and pit falls when standards are copied in to the specifications rather tailor made the specifications. Use of standards as guides in writing the specifications to obtain cost effective and reliable transformers is pointed out.

Power transformers being one of the equipment where the association of user and manufacturer starts from the planning stage to the life of the equipment, importance of buyer and supplier relations are discussed in depth.

Importance of fast communications, incentives and alternates are discussed. Ways to take advantage of improved materials, design and manufacturing practices are shown. Benefits of manufacturers knowing system requirements and limitations and users knowing design and manufacturing problems are highlighted.

Solution for both users and suppliers to be winners is suggested.

Standards:

In many specifications most of the standards like ANSI C57.12.00, IEC 76, CSA C88 etc., are listed and stated that the transformer should conform to these standards.

As there are many differences among the standards, if the specifications list only the relevant standards or clearly state which standard is applicable to which clause in the specifications, then the user's requirements will be clearer to the bidders.

To name a few that have different definition/details in different standards are:

- Rated power.
- Bushing dimensions.
- Tests.
- Overload capability at low ambient temperature.
- Over voltage conditions.

TOPICS

1. TAPS
2. IMPEDANCE
3. LOSS CAPITALIZATION
4. OVERLOADS
5. OVER EXCITATION
6. SHORT CIRCUIT
7. PARALLEL OPERATION
8. INSULATION LEVELS
9. ALTERNATES
10. ACCESSORIES
11. COMMUNICATION
12. CONCLUSIONS
13. SOLUTION

TAPS – PURPOSE

TO MAINTAIN THE OUTPUT

VOLTAGE CONSTANT FOR

FLUCTUATIONS IN INPUT VOLTAGE

AND/OR FOR LOAD VARIATIONS

TAPS-TYPE

A. BASED ON LOCATION AND FUNCTION

1. IN HV FOR HV VARIATION
2. IN LV FOR LV VARIATION
3. IN HV FOR LV VARIATION
4. IN LV FOR HV VARIATION
5. IN HV FOR COMBINED VOLTAGE VARIATION
6. IN LV FOR COMBINED VOLTAGE VARIATION

B. BASED ON TAP CHANGER TYPE

7. DE-ENERGIZED TAPS
8. ON-LOAD TAPS
9. LINEAR TAPS
10. REVERSING TAPS

TAPS-TYPE (cont…)

1. **Often specifications ask for taps in HV or in LV; but do not state whether the taps are for HV variation or for LV variation or for combined voltage variation.**

2. **For the same tap range, designs with taps in HV for LV or in LV for HV being variable flux designs they normally cost more, than the designs with taps in HV for HV or in LV for LV which are constant flux designs.**

   Certain transformers with taps for variable flux design could cost less than those with constant flux design. One example is, certain autotransformers with neutral end taps may cost less than line end taps; this is due to higher cost of line end tap changers, insulation level of tap leads to ground, bigger tank and larger oil volume etc.,

   Majority of the specifications specify the complete tap range either for constant flux voltage variation or for variable flux voltage variation though taps are used for combined voltage variation as both input voltage and load will be varying.

3. **Many specifications call for equal tap steps. In variable flux designs and in combined voltage variation designs it will be very difficult to get steps of equal voltages due to variable volts/turn at different tap positions.**

4. **In autotransformers with variable flux design, when taps are varied, the tertiary voltages will be varied. By using special designs the tertiary voltage can be kept constant, but these designs will cost more. If user wants the tertiary voltage to be kept constant when taps are varied then this requirement must be clearly specified in the specifications.**

SUGGESTION

Considering system requirements, transformer type, MVA, tap range etc., user to specify the type of taps that will aid manufacturers to offer least cost and least complex transformers.

TAPS-RANGE

1. Clause 4.5 of C57.12.10 suggests 2-2½% taps above and 2-2½% taps below rated voltage in HV for de-energized taps and ±10% in LV in 0.625% steps for on-load taps.

2. Many users specify both de-energized and on-load taps per C57.12.10 irrespective of the type of the transformer and its impedance etc.,

3. In many enquires ±10% on-load taps is not enough for regulation, specifically during the overloads.

4. In autotransformers depending on the auto ratio, 10% de-energized tap turns could be a large percentage of series winding turns, resulting in complicated and costly designs.

5. If user specifies the taps such that it gives the flexibility to designer to choose either linear taps or reversing taps then least life cycle cost transformers can be offered. One example is, instead of specifying taps of 138KV±10% in ±8 equal steps in HV for HV variation, specify that the taps are to be in HV for HV variation from 124.2KV to 151.8KV in 16 equal steps.

   138KV±10% implies that customer needs reversing taps. The alternate way of specifying is more general and implies that linear taps are also acceptable.

6. If user can accept lesser number of taps and higher percent tap steps then in most cases, economic designs can be produced. One example is, the user can check at the time of preparation of specifications whether 16 steps of 1.25% are acceptable instead of 32 steps of 0.625%.

7. When taps in LV for ±10% of LV variation in ±8 or ±16 equal steps are specified, then equal steps will force to choose the total tap turns to be multiple of 8 (8,16,24 etc.,). If approximate equal tap steps are acceptable then the designer can choose number of tap turns (between 8 and 16 or 16 and 24 etc.,) to produce the most economical design, still keeping the ratio error within ±0.5% of ANSI.

SUGGESTION

Specifications to give freedom to manufacturer to offer bids that may slightly deviate from the current practices (reversing taps, equal steps etc.,) but give overall benefit to the user.

TAPS – LOCATION

1. In general physical location of tapping winding in core type transformers can be next to the core, in between LV and HV windings, outer most winding, within the main winding etc.

2. In general electrical connection of taps can be at the neutral end, corner of delta, middle of the winding, in series winding, at LV line end etc.,

As there are too many variations depending on the physical location of the taps and how they are electrically connected, this topic itself can be a separate tutorial. As such I am not going in to the details on this topic. I want to mention that if the user is aware that the physical location and electrical connection of the taps influence the cost and the complexity of the transformer, then the user can gather the needed information and write the specifications to procure less costly and less complex transformers.

DE-ENERGIZED TAPS-DISADVANTAGES

If user knows the costs and reliability effects of de-energized and on-load taps, then it will help the user to prepare specifications to obtain best benefits.

Mostly the de-energized taps will be in the body of the main winding. If de-energized taps are in a separate winding then the cost will be generally more than the design with the taps in the body of the main winding due to the extra winding.

A few disadvantages of taps in the body of the main winding are:

--High impulse appears across the tap break.
--Higher forces.
--Due to the tap break and axial amp turn balance, turns in both HV and LV windings will not be normally spaced uniformly. This will result in reduced space factor, delays in winding and sizing of the windings.
-Increase in hot spot temperature and eddy loss due to the leakage flux.

Other disadvantages of de-energized are:

---At regular intervals (based on the tap changer, one to seven year intervals) the transformer should be removed from service to operate the tap changer to break the film formed on the contacts.

---Current ratings of de-energized tap changers available is limited.

If no on-load taps are required and only de-energized taps are required then there is no choice but to specify the de-energized taps.

SUGGESTION

Where economical and technically feasible, eliminate de-energized taps and extend the range of on-load taps.

LINEAR AND REVERSING ON-LOAD TAPS

1. With linear taps, contribution of losses by the tapping winding will be lower than the reversing taps. Thus energy savings to user will be considerable with linear taps. Linear taps will also reduce top oil rise and number of coolers.

2. In many cases (except on large MVA ratings and large tap ranges) it is possible to reduce the first cost of the transformer by using linear taps compared to the reversing taps.

3. Depending on the rating and type of the transformer, in certain cases the design with reversing taps will be less complicated and economical than linear taps.

4. With reversing taps the tapping winding must be a separate winding. With linear taps, depending on the tap range, MVA etc., it will be possible to design with the taps in the body of the main winding, thus eliminating an extra winding and reducing the transformer cost.

5. With linear taps (depending on the location of the taps, and the tap range) it will also be possible to reduce the number of tap leads compared to the reversing taps. In these cases, with linear taps it will also be possible to select a tap changer with less costly selector than with the reversing taps.

6. While evaluating tenders, if users evaluate losses on the normal tap and on the minimum turns tap, it will give incentive to the manufacturers to explore the best options to reduce transformer capitalization cost.

SUGGESTION

Adopt linear taps when technically feasible and economical.

INTANK AND TANK MOUNTED ON-LOAD TAP CHANGERS

Some details of in-tank and tank-mounted on-load tap changers are given below.

1. In-Tank on-load tap changer

    --Considerable number of large transformers with in-tank on-load tap changers are operating satisfactorily for many years.

    --Tap changer diverter oil is completely isolated from the main transformer oil.

    --Wide varieties and capacities of on-load tap changers are available.

2. Tank-mounted on-load tap changer

    --Types and capacities available are limited.
    --Internal lead work is not always easy.

Some specifications state that tap changers must be mounted in a separate compartment and not in the main tank. Due to current or KVA/step or BIL between phase etc., if in-tank tap changer has to be used then it will be very costly and less reliable to meet this requirement.

SUGGESTION

Specifications to give freedom to designer to choose in-tank or tank-mounted tap changer based on economics and simplicity of the design.

IMPEDANCE

1. Though many specifications specify the impedance value, considerable number of specifications still state the impedance per C57.12.10. Some specifications state that manufacturer to choose the best impedance value.

2. Table 10 of C57.12.10 gives impedance based on BIL and not on MVA, system requirements etc.,

3. As per this table, a 10MVA, 650KV BIL and a 100MVA, 650KV BIL transformers will have same impedance.

4. Lower impedances give higher short circuit forces and make the transformer design difficult and costly.

5. Higher impedances give more winding eddy and tank stray losses and also hot spot problems.

6. Neither a low value of impedance nor a high value of impedance gives the lowest evaluated cost transformer. This depends on MVA, impedance value and other parameters.

7. Before user finalizes the impedance value, it will be beneficial to have manufacturers input based on MVA, type of transformer etc.,

8. In most specifications the impedance needed on normal tap only is specified. For the following reasons if the user specifies the impedance values on extreme taps also then there will not be any surprises.

   --If the required impedance on extreme taps is not stated, then location of taps in bid designs will be mostly based on economics. This could result in impedances at extreme taps that are not acceptable for system operation.

   --If the impedance at any extreme tap is much lower than the value at the normal tap, then the short circuit current on this tap may exceed the system limitation (breakers capacity, short circuit value at the station etc.,).

   --If the impedance value at any extreme tap is of much higher value than at the normal tap, it may not be possible to get the needed regulation on this tap.

9. In some specifications impedance in ohms is stated but whether it is referred to input side or output side (HV side or LV side) is not stated.

10. In considerable number of specifications the impedance value is stated but the reference MVA is not stated.

CAPITALIZATION OF LOSSES

1. Almost all the specifications state that if the tested losses are above the guaranteed values then penalty will be imposed at the rate of capitalization of losses and if the losses are tested lower than the guaranteed values then no compensation will be given.

2. During the production design, the designer may come up with an idea to reduce losses, but this may need extra labour and/or materials. If the savings in loss capitalization is more than the extra labour and/or material cost, then it will be a win/win situation if the idea is implemented. This will be possible only if the user compensates the manufacturer for the extra labour and/or materials. If such compensations are given, then it will be a good incentive to the manufacturer to come up with good ideas.

3. Some specifications state that losses are not evaluated. In such cases there is no guarantee that user will get a transformer with lowest life cycle cost as losses in different bids could be different.

4. Some specifications give many details like KWH loading, KWH rate, duration of return on assets etc., and expect the bidders to calculate loss capitalization values. Often the information is not enough to calculate capitalization values. Also there is no guarantee that all the bidders will come up with the same capitalization value. So, in user’s own interest it will be beneficial if the user gives the capitalization values in the specifications.

5. In considerable number of specifications $/KW for load loss is stated but the MVA reference is not stated.

OVERLOADS

1. Most of the specifications state that over load requirement should be per C57.91.

2. C57.91 is a guide and not a standard. It is advisable that user to specify an overload profile in the specifications.

3. Clause 6.4 and Table 4 of C57.91 states that when the ambient temperature is below +30ºC then for each ºC lower in temperature, the OA transformer should be good to increase the load continuously by 1% up to -30ºC. This amounts to 60% more continuous load at -30ºC than at +30ºC.

4. As the tap changer capability depends not only on the low ambient temperature but also on the switching KVA per step, careful consideration is needed in selection of the tap changer as the continuous KVA per step at -30ºC will be 60% more than that at +30ºC.

5. During low ambient temperatures, the temperature of the oil surrounding the in-tank tap changer will be nearly same as that of transformer main oil, whereas for tank mounted tap changers the temperature of the oil in the tap changer will be much lower than the transformer main oil. This difference in in-tank and tank mounted tap changers has to be considered in determining the tap changer overload capability. It is advisable to check with tap changer manufacturer regarding the tap changer overload capability at low ambient temperatures.

6. Current ratings of bushings at -30ºC for OA units being 60% more than that at +30ºC, also need special attention, specially in draw lead bushings.

7. For many southern states in U.S.A. and the countries that do not see -30ºC temperatures, it will be economical if they specify the specific low ambient temperature requirement in line with the temperatures in their states and countries rather referencing C57.91.

OVERLOADS (continued)

8. In many specifications overloads in MVA or P.U. are specified but the duration of each MVA or P.U. is not specified. Often the pre-load value and its duration are also not specified. In some cases the ambient temperatures (winter and summer ambient temperatures) are not specified.

9. Some specifications state that the continuous current rating of the tap changer should be twice the maximum continuous current rating of the transformer. In number of cases this requirement forces to use a series transformer. Use of series transformer increases the first cost and the losses. The series transformer will also reduce the reliability as a series component is added. So, it will be economical and more reliable if user checks the currents of the transformer and the continuous current ratings of tap changers available and remove this requirement depending on the case.

11. In many specifications for autotransformers the MVA rating of HV, LV and TV are stated but whether the vector sum or Arithmetic sum of LV MVA and TV MVA not to exceed HV MVA Rating is not stated.

OVER-EXCITATION

1. Number of specifications specify high over excitation requirement. One example is over-excitation of 1.35 P.U. for 2 hours. In this case for constant flux voltage variation design the normal flux density in the core will be around 1.5 Tesla and this makes the transformer costly and increases the load losses. In variable flux voltage variation design, the flux density at normal tap will be lower than 1.5 Tesla.

2. Once the core saturates it will take only a few minutes for other iron parts like core clamps, tank etc., to reach very high temperatures. So, the duration of over excitation also has a great bearing on the selection of the flux density.

   The user can get less costly transformer by not over specifying the over excitation requirement and also the duration of the over excitation.

3. Some specifications specify the linearity of the core.
   One example is: Excitation current at 135% volts should be less than 7 times the excitation current at 100% volts.

   To meet this condition normally the flux density should be very low. With the present laser etched steel and step-lap construction, the excitation currents are very low compared to the older transformers. If the user specifies the maximum percent excitation current limit at 135% volts at no-load, rather the relationships then less costly transformers can be offered.

   Some users have removed such clauses of relationships from their specifications, where as some specifications still have such clauses.

4. Even with LTC on input side some specifications state over excitation of 135% on all the taps. When the input voltage goes up the LTC moves to a position to keep the output voltage constant, thus the core does not see often 135% over excitation.

   If user specifies the exact over excitation the core sees in service, then transformer cost can be reduced.

SHORT CIRCUIT

1. In many specifications the system impedance is not stated. Some specifications state to consider infinite bus or fault MVA per C57.12.00. On low impedance transformers the system impedance helps to reduce the short circuit currents considerably thus reducing the transformer cost. As the system impedance value per C57.12.00 being a low value it is advisable that user specifies the system impedance at the transformer station.

2. As the short circuit test is not a routine test, the user has to depend on the design (off-set value, perfect amp turn balance etc.,) and the manufacturing practices (clamping structure, drying process, coil sizing practices etc,) at a company for the short circuit strength of the transformer. So, it is very important for user to know the philosophies each manufacturer adopts in calculating short circuit currents, forces etc. This is critical because in most cases by the time the transformer experiences a fault with full asymmetry and with the maximum pre fault voltage the warranty would have expired.

3. In many specifications for three circuit transformers, often whether the in-feed is from one circuit or from both the circuits is not stated. Though ANSI gives some guidelines, as this has a big impact on the transformer cost it is advisable that user specifies in the specifications whether the in-feed is from one circuit or from both the circuits.

4. In considerable number of autotransformer specifications it is specified that tertiary has to be brought out to supply station loads of a few KVA. If the tertiary is brought-out then irrespective of its rating it has to be designed to withstand a three phase fault on its own terminals. This will increase the tertiary winding size considerably and will increase the autotransformer cost. In some cases it may be economical to the user to supply the station loads from some other source.

PARALLEL OPERATION

1. In many specifications the requirement of parallel operation with the existing units is specified but all the details of the existing transformers are not given in the specifications.

2. If parallel operation is needed then specifications should give all the data on the existing transformers. Many standards and test books list the data needed to check correct parallel operation.

3. Parallel operation of transformers with taps in HV with those with taps in LV and also the parallel operation of star/delta units with delta/star units cause additional problems. In such situations, while writing the specifications a discussion between user and designer will eliminate potential problems.

4. While writing a specification with 65ºC rise transformer to parallel operate with the existing 55ºC/65ºC rise transformers, the MVAs and impedances are to be correctly matched.

5. User should realize that parallel operation is user’s responsibility and design engineer is not a system engineer.

INSULATION LEVELS

1. Insulation levels have a big impact on the cost.

2. In the specifications for 230KV transformers, BIL level varies any where between 750KV to1050KV. To be economical user should specify the BIL level needed and not to over specify the BIL level.

3. Because of the protection offered by modern arrestors some standards do not call for chopped wave tests. It will be advisable for user to check with their system engineers before specifying the chopped wave tests.

4. Some specifications still call for front of wave tests. This requirement costs money and the user should have a good look before specifying front of wave tests, considering that this test is not called as a routine test in ANSI standards any more.

5. In some cases there were difference of opinions between the user and the manufacturer on internal clearances, specifically those between the windings. With the aid of computers it is now possible to calculate voltage stresses more accurately. With improved insulation structures it is possible to reduce the clearances compared to those on the older transformers. To avoid disagreements in design review meetings, it is advisable that the user and the manufacturer discuss at the tender stage the improved insulation structures, impulse and power frequency voltage stresses verses strengths and agree on clearances. The user should realize that if the transformers must be designed the same as the old ways then there would not be any progress and cost savings.

6. At the tender stage it is advisable that user goes through with the potentially successful bidder complete test details and mutually agree on tests, test levels etc., This will avoid costly delays and misunderstandings at the time of testing.

ALTERNATES

1. The following was stated in different specifications.

   --No alternates will be considered.

   --Alternates will be considered provided the main bid is exactly to the specifications and alternates with a clear explanation of technical and economical advantages to the user.

   --Bidders are encouraged to quote different to the specifications detailing the benefits to the user and meeting all the requirements of the user.

   From the above it is clear which user gets the bids with least cost and less complicated transformers.

2. When an alternate is offered there is no guarantee that the order will be placed on the alternate even when it's price is attractive and technically acceptable.

3. Due to the time and the money involved in submitting the bids, it is always not practical for the manufacturer to come-up with good alternates.

4. If user gives good incentives, then manufacturer will have better encouragement to come-up with good alternates.

5. Some specifications ask bids for many alternates, in an enquiry bids for about 25 alternates with different MVA, impedances etc., were asked. While preparing the specifications if user discusses with manufacturer and narrows the number of alternates to one or two, then both the user's and the manufacturer's time will be spent effectively.

ACCESSORIES

1. Number of CTs and their accuracies affect the cost and construction of the transformer. It will be advantageous to both user and supplier if the specifications specify only the minimum number required CTs and with the least acceptable accuracies.

2. Where possible specifications should give freedom to manufacturer to offer the most advantageous cooling arrangement. Examples are with or without pumps, directed or non-directed, vertical or horizontal mounting of fans etc. User can explore the advantages and disadvantages of each type/arrangement and then decide on the best and the most economical alternate.

   At present as many users are specifying high load loss capitalization values, in many cases winding current densities and gradients are low and pumps are not needed. If specifications insist pumps (OFAF or ODAF cooling) then cost will be increased almost with no benefits.

3. Use of non-linear protective devices (zinc oxide discs) is another subject with different views. Some specifications state that use of internal protective devices is not acceptable; where as many other users have no objection for use of non-linear protective devices. Many transformers with non-linear protective devices are in trouble free operation for many years. User can get the application details like operating voltage per disc, maximum impulse per disc, cooling area of the disc and then decide whether to accept the internal nonlinear devices or not.

4. For transformers with ONAN/ODAF cooling also the normal type of WTI with slow time constant (about 45 minutes) and with the same temperature settings as that of no pumps is being specified. The Task Force on WTI has showed that with slow response WTI with same temperature settings as that of no pump units, windings with ONAN/ODAF cooling will reach high temperatures in a short time when MVA suddenly changes from natural oil cooling range to forced oil cooling range. It will be beneficial to the user to discuss this with the manufacturer at the time of writing the specifications and specify a WTI with response characteristics matching the cooling type or decide on settings for safe operation of the transformer.

5. In many specifications it is stated that the transformer should have provision for future sound enclosure, gas-in-oil monitoring systems etc., but what exactly the manufacturer has to provide is not stated (ex. number, size and type of valves, extra brazing etc.,).

6. If certain type/make of parts (ex. certain type of valves, certain make of couplings etc.,) are only acceptable then this should be stated in the specifications. Often these specific requirements are marked on the approval drawings; this will cause inconvenience to the manufacturer to change the drawings, delays in procurement of these specific components causing delays in manufacturing.

COMMUNICATIONS

1. Some specifications state that their policy is that the manufacturer's engineer cannot talk to the user's engineer. All clarifications needed technical or otherwise should be sent in writing to the user's Purchasing Department and they will answer in writing. This policy normally delays the matters and many times the clarifications are not correctly clarified.

2. Some specifications say that on technical matters they encourage manufacturer's engineer to talk directly with the user's engineer and the user's engineer's name, telephone number and E-Mail are given in the specifications.

3. For mutual benefit there should be proper and fast communication between user and manufacturer during the preparation of the specification, during the tender process, during the manufacturing and also during the transformer in service.

4. The relationship between user and manufacturer should be such that they both look forward to meet in design review meetings and at other times.

5. Delay in delivery will cause considerable economic losses and many inconveniences to users. So, users are as much interested as manufacturers not to have any manufacturing or test problems. Some of the hardships users face due to delay in delivery are listed below.

---Users have to post pone the promised in-service dates to their customers.

---Users have to reschedule all their works.

---In many cases till the station is commissioned the interest costs for the whole station will be charged to the station construction cost. Thus even a month delay in delivery of the transformer will increase the station cost considerably.

---In turnkey projects the delay in delivery will cause problems to contractor as in many cases the contractor will not be paid for the other equipment delivered till the whole station is commissioned.

---The delay in delivery of the transformer will cause the warranty on other equipment like breakers, PTs, CTs etc., to expire earlier.

6. Often manufacturers feel that users are putting too much pressure on drawing submittal at agreed dates. Manufacturers should realize that only after getting the drawings, the user could design foundations and the final station details. Then the user has to go for tenders for these items and make everything ready by the time the transformer arrives at the station.

7. Often drawings are submitted on time but they will not contain the information user needs and also they will have many errors. On record the manufacturer has submitted the drawings on time but they will be of little use to the user. Manufacturer has to realize this and submit the drawings with all the details and with minimum errors first time.

8. Depending on the complexity of the design, user should give sufficient time for the manufacturer to prepare the bid.

CONCLUSIONS

1. Standards are not a safety net to the specifications. If used as a safety net there could be surprises.

2. Specifications should be tailor made to the specific need, rather being general.

3. Clarity in the specifications will help to bring the best bids.

4. User to interact with the manufacturer during the preparation of the specifications.

5. Specifications to give freedom to the manufacturer to offer the best design.

6. User to give incentive to the manufacturer to come up with new innovations/alternates.

7. Manufacturer to realize that in most of the cases there is a specific reason for a specific clause in the specifications. It is advisable that the manufacturer not to make any assumptions and to check with the user for clarification/explanation.

8. User and manufacturer to have fast and reliable communication paths.

9. User and manufacturer to have mutual trust and respect.

SOLUTION FOR BOTH USERS & MANUFACTURERS TO BE WINNERS

POWER TRANSFORMER

USERS & MANUFACTURERS

ARE NOT, JUST

BUYERS & SUPPLIERS

THEY ARE A

TEAM

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