# EXECUTIVE SUMMARY

0.1.1 Power transformers occupy a prominent position in a power system, as each unit of electrical energy generated passes through one or more transformers before reaching the end user. Hence the performance of the transformer is of prime importance for ensuring the reliability of the power system as a whole. It is also the single most expensive electrical equipment in a power distribution system.

0.1.2 Bulk AC power transmission necessitates the use of high voltages. Progressively, the transmission voltages have risen to 400 kV AC in India.

0.1.3 In India, system voltages upto 400 kV are well established and 800 kV AC transmission systems are being planned. This will require manufacturing of 800 kV transformers. Indian manufacturers are manufacturing power tranasformers upto 400 kV class.

0.1.4 International manufacturers are making power transformers for system voltages upto 1200 kV AC. A prototype transformer for a voltage of 1785 kV, for a test station, has been manufactured by ASEA, Sweden. Russia has 1150 kVA system and Japan 1200 kVA system.

0.1.5 Most of the major transformer manufacturers in India had collaborations with reputed international companies, such as Associated Electrical Industries (AEI,) U.K.; Alsthom, France; Hawker Siddely, U.K.; Hitachi, Japan and Siemens, Germany. Presently, Indian manufacturers have the know-how to design and manufacture transformers upto 400 kV indigenously.

## 0.2.0 STATE OF THE ART

0.2.1 There are about ten (10) manufacturers in India, who can manufacture transformers rated 110 kV and above. The transformers are of conventional oil filled type with CRGO (Cold Rolled Grain Oriented) laminated core, copper strip windings, insulation of paper and press boards all encased in a mild steel fabricated tank with integral or detached radiators. The quality and performance of these transformers are more or less comparable to those manufactured internationally. Indian manufacturers have been able to secure orders against stiff international competition, at least for global tenders floated in India. Several Indian manufacturers have performed well in the export field.

0.2.2 The manufacturers who can offer 400 kV transformer are :

a) Bharat Heavy Electricals Limited (BHEL)
b) Crompton Greaves
c) NGEF
d) TELK

0.2.3 There is adequate technical know how available with the above manufacturers for transformers upto 400 kV. These manufacturers have gained sufficient experience from their erstwhile collaborators and also from in-house R&D efforts.

0.2.4 Although some of the manufacturers have made some headway, certain areas which can accommodate modern technologies are :

0.2.5 Computation methods and analysis for electromagnetic fields, thermal fields, electrostatic distribution of stresses and vibration calculations. Computer aided designs can be extensively employed for better optimisation of design, manufacture and production techniques.

0.2.6 Some of the improved materials like laser scribed, high permeability 0.23 mm thick CRGO steel, for transformer core are presently not available in India.

0.2.7 Manufacturing technology in India is less automated and more labour intensive. More automation is desired in areas of core cutting., steel fabrication and winding.

0.2.8 Due to rail transport restrictions, transformers weighing more than 250 T cannot be transported by rail. Hence two winding transformers above 250 MVA range and auto transformers above 315 MVA are of single phase construction.

## 0.3.0 LATEST DEVELOPMENTS IN THE INTERNATIONAL SCENE

### 0.3.1 Specifications

Development and application of non-linear gapless metal oxide lightning arresters has led to better protective levels against lightning. In view of the better protective levels provided by modern arresters, the basic insulation level (BIL) of the transformer has been reduced resulting in lower costs.

0.3.2 The transformer unit's life is based on the reference temperature set by standards such that the hot spot temperature is 98° C. When the hot spot temperature is exceeded, the insulation of the windings is subjected to accelerated ageing, thus reducing the transformer's service life. Conversely, the transformer gains life when the hot spot temperature is actually lower than 98°C. The hot spot temperature is a function of load on the transformers, reference temperatures and temperature gradients. Taking advantage of lighter summer loads followed by the heavy winter loads in the U.K., there is a tendency among utilities to specify two ratings and the transformer is likewise loaded with the hot spot temperature during winter exceeding by about 10°C.

### 0.3.3 Design

Computer aided design techniques are extensively being employed by foreign firms and some Indian manufacturers for the following reasons:

(a) To study electrostatic and electromagnetic fields.

(b) For simulation of windings to study the voltage distribution under lightning and switching over voltages.

(c) To optimise manufacturing techniques and production levels.

(d) For evaluation of electro-dynamic forces on various parts during a short circuit.

(e) For thermal analysis.

### 0.3.4 Manufacture

Superior manufacturing techniques as listed below, are being employed by foreign firms and some Indian manufacturers :

(a) High degree of automation is employed to achieve high dimensional accuracy for laminations, for reducing air gaps and to improve efficiency.

(b) Automatic and semi-automatic stacking for core construction.

(c) Vapour phase drying for effective cleaning of core and windings.

(d) Multiple spindle drilling and milling for heat exchangers.

(e) Pressurised halls used for winding and insulating parts to protect against pollution and dust.

(f) Vertical winding machines for winding large capacity transformer coil.

(g) Core banding machine for building the core banding tapes on limbs.

(h) Hot oil circulation set with multi stage vacuum pump and degassing facility.

### 0.3.5 Materials

Following improved materials are being used by international manufacturers and some Indian manufacturers :

(a) Laser scribed, treated silicon steel for cores, which has a core loss of 0.6 w/kg as against 0.9 w/kg of CRGO steel at 1.5 Tesla.

(b) Multiple wire transposed conductor to reduce unequal current distribution in windings and reducing skin effect and hence load loss.

(c) Epoxy coated conductor to increase the mechanical strength of windings.

(d) High grade pre-compressed boards.

(e) High stability naphthanic based oils.

### 0.3.6 Advances in Transportation and Erection

0.3.6.1 Foreign manufacturers have effected transportation of transformer upto 500 tonnes by rail.

0.3.6.2 At Dounreay Nuclear Power Station, U.K., site assembly of 350 MVA, 3-phase generator transformer was envisaged as early as 1971 due to limitations on transportation.

After testing the fully assembled transformer, it was dismantled into two principal transport components, namely; central sealed section and tank base carrying the bottom yoke and the limbs of core. The top yoke laminations, bushings, accessories and oil were transported separately. The central sealed section consisted of the outer steel shell which forms the tank, windings and fibre glass cylinders for the vertical core passages. This was sealed off on the top and bottom portions by using Permali wood, after filling with dry air or nitrogen, under slight positive pressure. On arrival at site, the section containing the tank and winding was placed on the core. The top yoke plates were reassembled and the tank cover was placed in position. The gas was released after the bushing was fitted. The other accessories were fitted to the transformer followed by oil filling.

0.3.6.3 BHEL has site assembled two generator transformers for their hydel jobs.

0.3.6.4 Recognising the need for site-assembly of large transformers, a committee of experts from universities, research institutes, electric companies and manufacturers was organised in Japan, by the Society of Electrical Co-operative Research, to standardise the site installation of transformers. The proposals of this committee has been well accepted in Japan and the procedures recommended by the commitee has been practically applied with satisfactory results.

### 0.3.7 New Types of Transformer Designs

0.3.7.1 To reduce over all size and core loss, GE (USA) Hitachi and Mitsubisi have already developed EHV transformers with SF6 gas insulation. 77 kV, 50 MVA SF6 gas insulated transformers have been in actual service in Japan since 1982.

0.3.7.2 Amorphous steel (Metal glass) for transformer cores have given a new dimension for core loss reduction. Presently they are restricted to transformers in the distribution class transformers in the lower voltage range, and may not find application in transformers above 110 kV voltage range in the near future. Presently, stacked design and core design (power stripcore) are available in USA for power transformers with amorphous steel. BHEL has also developed a distribution transformer with amorphous steel.

## 0.4 Future Score for Large Transformers

0.4.1 The unit sizes of turbo-generators in our thermal plants have increased from a mere 65 MW to 500 MW in the past 15 to 20 years. Still larger units upto 1000 MW is a distinct possibility in the near future. Inadequacies in transport, crane handling and test facilities are major constraints for Indian manufacturers to produce single 3-phase generator transformers for these large units.

0.4.2 With the introduction of 800 kV transmission systems in the near future, the Indian manufacturer will have to gear up for producing 800 kV class interconnecting transformers and generating step-up transformers.

0.4.3 In reducing the core loss both laser scribed CRGO steel and amorphous steel may be competing as core materials.

0.4.4 Mitred overlap joint optimisation which is achieved by steplap core construction, will be an important area to reduce the core losses for cores with both conventional and laser scribed CRGO steels.

0.4.5 There will be a need to seek an alternative for transformer oils, since the napthanic based crude is becoming scarce. SF6 gas insulated transformers will be an attractive alternative to oil immersed transformers since the former achieves reduction in noise as well as reduction in size. It may however be noted that SF6 gas is not being manufactured in India and the development of gas insulated transformers is, at present, in a primary stage.

0.4.6 Construction of cores and windings will be directed towards reduction of space to achieve reduce dimensions, low noise and interleaved windings towards improved impulse distribution.

0.4.7 Site assembly of transformers may become a suitable alternative to transportation limitations posed on large transformers.

## 0.5 TECHNOLOGY ABSORPTION/INDIGENISATION

0.5.1 Four major Indian manufacturers are presently capable of manufacturing transformers upto 400 kV class. They have acquired sufficient know-how for this from their erstwhile collaborators.

M/s BHEL who are one of the leading manufacturers of EHV transformers, envisage testing of a 800 kV transformer proto type in the near future.

0.5.2 Certain important raw materials and components are still being imported by Indian manufacturers. A list of such major items appear in Table-1.

### TABLE-1
### LIST OF MAJOR RAW MATERIALS & COMPONENTS THAT ARE STILL BEING IMPORTED

| Sl. No. | Description |
|---|---|
| A. | RAW MATERIALS |
| 1. | CRGO steel |
| 2. | Steel plates of 20 mm tick and above |
| 3. | Copper Ingots |
| 4. | Moulded insulating components of complicated shapes |
| 5. | Pre-compressed high density press board. |
| B. | COMPONENTS |
| 1. | Air cell |
| 2. | Resistance temperature detector |
| 3. | High capacity radial oil pumps |
| 4. | Sudden pressure relay |
| 5. | Buchholtz relay for seismic zones |
| 6. | Shock recorders required during transportation |
| 7. | Low voltage high current ( >12.5 kVA) bushings. |
| 8. | Special conductors. |

## 0.6 TECHNOLOGY GAPS

0.6.1 An effort is made below to compare the current technology level of Indian manufacturers with the contemporary international technology and to identify the technological gaps mainly in the area of design, materials, manufacturing, testing and transportation.

### 0.6.2 Design

As indicated earlier, all leading manufacturers had collaborations in the past, and as such the technology gap for EHV transformers upto 400 kV is quite narrow. The know-how received from the collaborators needs updating, in order to be in line with contemporary international design techniques. A major area which needs attention is the development of software for electromagnetic field analysis, electric field, thermal and electro-dynamic stress analysis and the study of dielectric withstand phenomena. It may however be noted that some Indian manufacturers have already made progress in this direction.

### 0.6.3 Materials

In the international scene, there have been substantial strides in the development of improved materials for core construction like laser scribed, high permeability CRGO steel and better insulating materials like moulded press boards and impregnated glass tapes. Indian manufacturers will have to depend on imports only for these items for a long time to come, as developing these items indigenously may not be practical or economical, considering the demand. However, some of the items which can definitely be improved are insulating oil, press boards and indicating & recording instruments.

### 0.6.4 Manufacture

Manufacturing methods in India are more labour intensive. More automation could be achieved in areas of core cutting, lamination building, steel fabrication, welding and winding methods.

### 0.6.5 Testing

All manufacturers have in-house test facilities for conducting routine tests as per Indian Standards. Impulse testing facilities are available at CPRI, Bangalore; BHEL, Bhopal; TELK, Angamally; NGEF, Bangalore and Crompton Greaves Ltd., Bombay. The short circuit generator available at CPRI, is suitable only for testing equipment for short circuit levels of 1000 MVA, for voltages upto and including 72.5 kV and 600 MVA at 145 kV. A 2500 MVA direct on line short circuit testing generator is being commissioned at CPRI, Bangalore.

### 0.6.6 Transportation

One of the major bottle necks for going in for large 3-phase transformers of above 250 MVA, is the non availability of suitable well wagons for movement on rails. The maximum capacity of well wagons available with the transformer manufacturers is 180 tonnes. BHEL, Hardwar has employed 240 tonnes well wagons to transport 500 MW generator stator. This wagon could be employed for movement of transformers upto 240 tonnes, with suitable improvisations. The 5200 mm vertical clearance, enforced by Indian Railways, is also a restraint in designing taller transformers. There is also a dearth of multi-axle road trailers to overcome the constraints of road transportation. It is recommended that Indian Railways may procure a 250 tonne wagon for transport of heavy equipment like transformers and generator stators.

## 0.7 CONCLUSIONS

0.7.1 In India, manufacture of power transformers is restricted upto 420 kV voltage range. In other countries, the established voltage range is currently upto 1200 kV.

0.7.2 There are other gaps in technology which are currently prevalent in the Indian industry for meeting the present as well as future needs of the country. 800 kV systems are now being planned. BHEL is developing transformers in this category. Facilities for developing and testing such transformers need to be set up by augmenting existing facilities.

0.7.3 Manufacturing facilities in the country are currently over loaded. Besides, the procurement time for imported raw materials is very long. These failures have primarily contributed to increasing the lead time for manufacture of transformers.

0.7.4 Computer aided design (CAD), techniques are widely employed elsewhere. Computer aided manufacture (CAM) is also widely prevalent in countries abroad. These techniques need to be employed in the country . Otherwise—the design technology in India is on par with the technology in advanced countries.

0.7.5 Indian manufacturers are not fully equipped with modern manufacturing and processing equipment. The quality of lamination cutting machines, vertical winding machines, induction brazing machines and tools used in the country are not sophisticated. The product quaility is thus effected.

0.7.6 Testing equipment, as available with the manufacturers is also not adequate to meet all the mandatory requirements. Optical fibre hot spot measuring equipment, dissolved gas analysis equipment, particle count equipment and other such sophisticated test facilities are generally lacking. Testing of large transformers is thus a problem.

0.7.7 The research work undertaken so far in this field has been at a relatively low key. Hence, the transformers manufactured in the country are neither cost competitive nor energy efficient. The manufacturers face a lot of difficulty in procuring advanced raw materials for the core, like laser scribed CRGO steel, plasma treated steels and others. Currently, SAIL has plans to manufacture CRGO steel.

0.7.8 Amorphous steel cores are widely used in advanced countries as they are highly energy efficient. The manufacture of such transformers in the country has just begun.

0.7.9 Research in several areas is lacking. Concerted research programmes in the following areas are lacking :

(a) Hot spot measuring techniques.

(b) Computer software development for optimised design, 3-D field plotting and analysis of forces.

(c) Improved quality and substitutes for transformer oils.

(d) Predictive method of testing transformers for short circuit withstand capability.

(e) Aluminium windings for EHV transformers

(h) Flux density variations with different core materials.

0.7.10 Site assembling of very large transformers is generally employed in other countries as it becomes difficult to negotiate distances.

0.7.11 Computer software is widely used for 3-dimensional field plots, mechanical design, short circuit force on large transformers, magnetic field distribution.

0.7.12 400 kV design of transformer has been standardized successfully. Standard specifications along similar lines need be developed for lower kV classes.

0.7.13 The size of transformers manufactured in the country are generally over size.

0.7.14 Export figures are dismally low and require to be boosted.

## 0.8 RECOMMENDATIONS

0.8.1 Indigenisation sources may be developed for raw materials. The existing manufacturing capacity may also be increased.

0.8.2 Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) techniques may be extensively employed together with improvement in software.

0.8.3 Existing facilities may be augmented at the manufacturer's end to include sophisticated equipment like lamination cutting machines, vertical winding machines, induction brazing machines and others.

0.8.4 Test facilities may be established at a national level or existing facilities may be augmented to include optical fibre hot spot measuring equipment, dissolved gas analysis equipment, particle count equipment and others.

0.8.5 Research and development may be accorded a higher priority by the manufacturers. This is because currently R&D at the manufacturers end is at a low ebb.

0.8.6 Materials like laser scribed CRGO steel, plasma treated steel may be made available by development of sources.

0.8.7 A higher priority may be accorded to the development of amorphous steel cores.

0.8.8 Production know how for SF6 insulated transformers may be developed.

0.8.8 R&D in the following areas may be taken up by the manufacturers on a cooperative basis or on sponsorship basis or through inhouse R&D efforts :

(a) Hot Spot measuring techniques.

(b) Computer software development for optimised design of transformers, 3D field plotting and analysis of forces.

(c) Improved quality and substitutes for transformer oils.

(d) Predictive method of testing transformers for short circuit withstand capability.

(e) Aluminium windings for EHV transformers.

(f) Flux density variations with different core materials.

(g) 800 kV class Transformers

0.8.10 Site assembling of large transformers may be examined. Railways may explore the possibility of providing suitable wagons upto 250-300 tonne capacity for transportation.

0.8.11 A cell may be established at the association level to analyse causes of transformer failures and to recommend counter measures wherein manufacturers, users and the national bodies would actively participate.

0.8.12 Computer software for 3-dimensional field plots, mechanical design, shortcircuit force on large transformers, magnetic field distribution need be developed.

0.8.13 Standard specifications may be developed for lower than 400 kV classes.

0.8.14 Sizes of transformers may be optimised.

0.8.15 Special efforts may be taken to boost exports.