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M S Thacker Memorial Lecture

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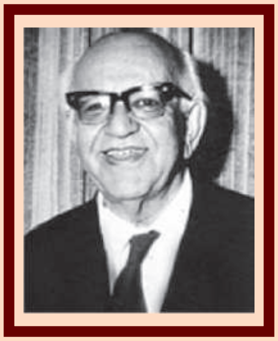

Background of
M S Thacker Memorial Lecture

Prof M S Thacker who was Director of the Indian Institute of Science, Bangalore, was appointed Director General of the Council of Scientific and Industrial Research, Government of India, in succession to the late Sir S S Bhatnagar.

Prof Thacker was the Chairman of the Electrical Section of the Institution, and the Section had vastly expanded under his vivid leadership.

Prof Thacker was the Chairman of the Mysore Centre and later the President of the Institution for 1955-56. He represented the Institution, at the Third Conference of Engineering Institutions of the Commonwealth in London in June 1954, and the Indian National Committee at the Sectional Meeting of the World Power Conference in Rio de Janeiro, Brazil, in July-August 1954. He was also the Chairman of the Papers Committee for the selection of articles from India for the Fifth World Power Conference held in Vienna, Austria in July 1956. He expired on July 6, 1979.

In memory of his dedicated service, The Institution of Engineers (India) instituted an Annual Memorial Lecture in his name during the National Convention of Electrical Engineers.

M S Thacker Memorial Lecture

presented during **National Conventions** of **Electrical Engineers**

Delivered during the Eleventh National Convention of Electrical Engineers on 'Environment Friendly Electric Power Generation' organized by Roorkee Local Centre, November 3-4, 1995

Metrological Infrastructure of Standards and Standardisation for Quality Management & Global Trade: The Indian Scenario

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ABSTRACT

There is a close relationship between the metrological standardization system, the technological capability and the industrial development of a country. The more industrially advanced the country, the greater is the part played by its 'National Measurement System'. When India became independent in 1947 after nearly two hundred years of alien rule, this particular concept greatly influenced the technology policy decisions of the leaders of the national government who had the urge and vision to develop the country into a highly industrial state so that the people of the country could be offered a quality of life commensurate with its rich national resources, talents and latent potential.

At the time of independence, India had a meagre metrological facility. To develop the proper metrological infrastructure the following steps were taken by the government: (a) adoption of the metric system for weights and measures and also in coinage system; (b) establishment of the Indian Standards Institution (ISI) which has been later renamed as Bureau of Indian Standards (BIS); and (c) setting-up of the National Physical Laboratory (NPL). These constituted the basic facilities essentially required for formulation of national standard, specifications for Indian products, and for calibration and testing facilities of the highest order of accuracy. Today, these facilities have been augmented and strengthened to grow up into a vast metrological infrastructure which caters for the assessment of the performance of Indian products and services taking into account of their 'Quality System' and 'Quality Assurance' aspect as advocated by the ISO-9000 and the EN-45000 series of international specifications, ultimately with the object to make Indian products competitive in quality and cost to the best of their counterparts in the world.

Starting from an almost 'zero' position in 1947, today India has developed itself as a leader in technology and industry, exporting industrial products, services and technologies. The metrological infrastructures developed during this period has played an essential role in the country's achievements. Obviously, standardisation constitutes the 'heart' of metrology.

1. INTRODUCTION: THE INDIAN INDUSTRY AND TECHNOLOGY

1.1 Pre-Independence Scenario

India became independent in 1947 after nearly two centuries of the British rule. At the time of independence India had very few industries worth the name. It was basically an agriculture-based country; even the prevalent agriculture technology was primitive with very low production as per modern standard. There were a few metallurgical industries mainly for the production of iron and steel, and aluminium. In the mining area, coal was the main industry along with some limited quantity of copper and gold mining. There were also a few chemical and pharmaceutical industries. All these were totally inadequate for the needs of a country like India which is vast in area and also very large in population: second only to China. Nevertheless, even at the time of independence, India had the potentiality of growing into an advanced country in the fields of science, technology and industry. It had a past history of highly developed cultural heritage in all the areas of human civilisation. Also, at the time of independence in 1947, it had a small group of extremely talented scientists, planners and industrialists who could rank high even amongst the best of their kinds in the world. The country was rich in mineral, oil and other natural resources and a huge pool of human resources hitherto untapped and unutilised.

1.2 Post-Indenpendence Initiation in Metrology

Immediately after independence science, technology and industry were, inter alia, given top priorities by the Government of India. Metrology, the science and technology of measurement, was considered to be the most important factor for the industrialisation of the country. This policy led to the establishment of the (a) lndian Standards Institution (ISI), (b) national Physical Laboratory (NPL) and the (c) Directorate of Weights and Measures (DWM) in the decade commencing 1950. These metrological infrastructures have contributed substantially to cater for the needs of the country's industrialisation in all spheres, viz. food, house, health care, oil, defence, transportation etc. on a massive scale.

Today, India is self-sufficient in the mother industry for production of basic metallurgical products like iron and aluminium, fertilisers, heavy chemicals, drugs and modern agricultural products. It has a large defence industry and produces practically all of its defence equipment starting from field guns through tanks for the army; frigates, destroyers and subrnaniners for the navy,' and practically all categories of fighter planes including the latest models of MiG-27, MiG-29 under Russian collaboration and Mirage-2000 under French collaboration for the air force. India has also made substantial progress in the areas of missiles and satellite technology by its own efforts. It has been able to develop commendable expertise in the matter of exploration of hydrocarbons, e.g. oil and natural gas, onshore and offshore. In addition to meeting its own needs, India exports substantial quantities of industrial and agricultural products. India's progress in the field of atomic research is also at a highly advanced level: At present, India has six nuclear power plants in operation and four more are in the construction phase. The design, fabrication and commissioning of atomic power plants are now done by India itself without any external assistance. The railways and automobiles industries of India meet the entire demands of country in their respective fields.

India has been able to develop adequate scientific manpower, starting from the technician level up to the highest sophisticated and advanced level during the last fifty years after independence for the proper establishing and manning of its industrial and scientific orgariisations. Today, India has, according to some estimates, an industrial base which ranks amongst the top ten of the most industrially and technically advanced countries of the world.

India's advancement in the various areas of 'Metrology' has played a very significant role in the industrialisation of the country, both quantitatively and qualitatively. The starting point of these endeavours was the decision to establish 'Standards of Weights and Measures' based on the 'metric system' in all scientific and technical activities around 1956. Concurrently, the 'decimal system' of coinage was also adopted.

2. ORGANISATIONAL STRUCTURE FOR METROLOGY IN INDIA

2.1 Indian Standards Institution (ISI): Bureau of Indian Standrads (BIS)

The Indian Standards Institution (ISI) is the first major national infrastructural facility in India the area of metrology. Indian Standards Institution was established in 1947 originally with the purpose to recommend to the Government of India, national documentary standards for measurement of length, weight, volume and energy. The ISI was later entrusted with completing the formalities of the introduction and implementation of the metric system in the country, after discarding the earlier non-scientific mixture of CGS and FPS systems prevalent during the pre-independence days of the British rule. However, modern industrial production process requires a 'System of Standardisation'. This is needed because modern technology is based on mass production of goods and services. The cornerstone of mass production is the production of interchangeable components. This is possible only if production is carried out in accordance with 'Standard Specifications'. The standardisation of components by clearly defined specification leads to efficient flow of production at reduced cost by cheeking wastage of material and labour.

The scope of the Indian Standards Institution (ISI) was later broadened. It was renamed as Bureau of Indian Standards (BIS) in 1987 with greater autonomy and flexibility to act more effectively as an agency for 'quality control and consumer protection and education'. The BIS is now the national standards body, which has so far formulated around 16000 national documentation standards covering varied aspects like glossary or terms, products specification, methods of tests, codes of practice and sampling. Product specifications lay down in detail the parameters for determining the (a) quality, (b) safety, (c) performance and (d) methods of practical evaluation: these may thus be used by the consumer as a very satisfactory basis of purchase.

The BIS-formulated standards specifications are sometimes distinct from any other national or international standards when 'special' environmental or other conditions of the country so demand. The Bureau of Indian Standards has very close liaisons with the two premier international standardising agencies, viz. the International Standards Organisations (ISO) and the International Electrotechnical Commission (IEG). It is a member of both these' organisations. Whenever appropriate, the present trend of BIS specifications is to align with the international specifications of ISO and IEC. This is particularly conducive for enhanced export.

BIS 'Product Certification Marks' scheme for the use of ISI-mark for industrial products and also the 'Agmark Scheme' as guarantee of the quality of purity of agricultural products are two examples of 'Certification Schemes' operating in India. Essentially these certification schemes provide independent thrid-party audit of the quality of the products bearing the designated marking. The BIS also operates an extremely useful 'Third-party Certification Scheme' which has been accepted worldwide as an independent mechanism for assurance of the quality of products as per prescribed standards.

The BIS has recently launched a 'Quality Systems Certifications Scheme' based on the ISO-9000 series (— the corresponding Indian specifications are IS-14000 series). The scheme envisage the establishment of a 'quality management system' for a comprehensive list of business functions. The multifold benefits accrued by implementing quality systems are being realised by Indian industry by opting for this certification scheme.

2.2 National Physical Laboratory (NPL)

The National Physical Laboratory (NPL) in New Delhi is the custodian of National Measurement Standards in physical form in India. It was established in 1950 by the Government of India with the object to strengthen and advance physics-oriented research for the overall development of Science and Technology in the country.

The NPL has been given the statutory responsibility, inter alia, for:

(a) Establishing, maintaining and improving continuously, for the benefit of the country, national Standards for Measurements and to realize the 'Units' based on the International System (SI),

(b) Determination of major physical constants,

(c) Development and evaluation of measurement techniques,

(d) Providing assistance to industries, governmental and other agencies in their developmental tasks by precision measurements and calibration, the development of devices and processes and other allied problems related to physics.

Under the Standards of Weights and Measures (National Standards) Rules 1988, the NPL has been further assigned the obligation to act as the custodian of the National Standards of Measurement (excepting those for lonising Radiations) compatible and traceable to the International System (SI) of units. The NPL fulfils this responsibility through development, maintenance and updating of these Standards through interaction and metrological intercomparison with other major standards laboratories in the UK, USA, (erstwhile) USSR and FRG, Italy, Netherlands, Japan, China, Australia, New Zealand, Canada and several other scientifically advanced countries.

The NPL represents India in the Bureau of International Weights and Measures (BIPM) and CGPM besides several other international committees on technical subjects in the areas of Time and Frequency, Vacuum and Pressure, Fluid Flow and a number of other parameters.

The nodal work done by the NPL in 'Metrication' of the entire measurement system of the country since 1956 forms the basis of 'Legal Metrology Functions' in the country coordinated by the Department of Weights and Measures of the Government of India. Measurement Standards, calibration service, specialised testing backup, technical advisory services and participation in the committees of the department of Weights and Measures form the bulk of NPL support for these important areas of consumer education and protection.

The principal activities of the NPL in the field of Metrology include, inter alia, development of:

(a) Physico-mechanical Standards viz. Dimensional Metrology and Length Standard, Standard of Mass, Volume, Density, Force, Photometry, Fluid Flow Measurement, Temperature Standards and allied parameters.

(b) Electrical and Electronic Standards viz. Josephson Voltage Standards, Quantum Hall Resistance Standard, DC Standards, AC (LF and HF) Standards, Microwave Standards.

(c) Time and Frequency Standard

(d) Reference Material Standard

(e) Characterisation of Materials

(f) Calibration and Specialised Testing Services

(g) Participation in International Metrology Activities.

The commendable level of competence attained by the NPL during the years, in terms of 'Accuracy of Standards and Calibration Capabilities' in respect of some major base units (SI) physical parameters are indicated in Table I. It should be noted that the list only serves as examples and is not at all exhaustive.

TABLE I

ACCURACY OF NATIONAL STANDARDS OF MEASUREMENTS AT NPL BASE UNITS (SI) : SELECTED PARAMETERS

	Parameter		Techniques used	Present Accuracy	
				NPL (New Delhi)	International (BIPM)
1.	Length (metre)	(a)	Radiation of lasers Stabilised by saturated absorptions	1 part in 10^9	1.3 part in 10^{10} to 1.3 part in 10^9
		(b)	Radiation of spectral lamps	1 part in 10^8	4 parts in 10^9 to 1 part in 10^8
		(c)	Copy No. 4 of International Prototype metre	2 parts in 10^7	—
2.	Mass (kilogram)	(a)	Copy No. 57 of International Prototype kilogram	8 parts in 10^9	—
		(b)	Copy of International Prototype kilogram kept at BIPM	—	8 parts in 10^9
3.	Time/Frequency (second)		Non-portable, Long Length C_S atomic clock	1 part in 10^{12}	2 parts in 10^{13}
4.	(i) DC Voltage (volt)		Josephson Effect	5 parts in 10^7 (Standard Cell Traceable to Josephson Standard)	1 part in 10^8
	(ii) DC Resistance		Calculable Capacitor	2 parts in 10^7	1 part in 10^7
5.	Luminous Intensity (Candela)	(a)	Standard Lamps calibrated at BIPM	2 parts in 10^2	—
		(b)	Black-body Radiation at Freezing Platinum temperature	—	0.5 to 1.0 part in 10^2
6.	Temperature K (Kelvin)		Some Fixed Points on International Temperature Scale	0.5 mK to 100 mK	0.01mK (Tripple point of Water) to 0.2 K (Gold point)

2.2.1 Bhaba Atomic Research Centre (BARC), Bombay

The nodal agency for the development of Standards for lonising Radiations is the Bhaba Atomic Research Centre (BARC) at Trombay near Bombay.

With the wide use of ionising radiations in medicine, industry and research, the measurement of these radiations and calibration of instruments used for these measurements became matters of prime importance. The maintenance of standards for ionising radiations, provision for allied calibration services and development of measurement techniques are essential from the point of view of optimal use of radiations and safe handling of radiation sources. The BARC also provides the necessary calibration services.

3. NATIONAL MEASUREMENT SYSTEM (NMS)

3.1 Basic Concept of a National Measurement System

In modern society which is technologically based, there are several interacting systems which affect the quality of life. Some of these systems are clearly visible in everyday life. Familiar examples are the political system, the legal system, the educational system, the communication system etc., all of which may be grouped together under the general heading of social system. There is, however, a system which is vital for the quality of life, but is not so visible by itself. This is the measurement system of the country which, in a way, pervades all other systems. Just as the social system has evolved in a particular country through its indigenous conditions so has its 'National Measurement System'. The more industrially advanced the country, the greater is the part played by its national measurement system. Indeed, there is a close relationship between the standardisation system, industrial development and technological capability of a country.

The National Measurements System of a country represent today as one of the key elements in the worldwide measurement system that links all major nations together in a consistent compatible network for communication and trade. The essential function of the National Measurement System is to provide a quantitative basis in measurement for (i) interchangibility and (ii) decisions for acting in all aspects of our daily life - public affairs, commerce, industry, science and engineering.

3.2 National Measurement System (NMS) of India

In India, a large number of calibration laboratories and testing laboratories had been set up in different parts of the country under various departments of the government and some also under private entrepreneurship with no established compatibility between the different test laboratories. In the early part of the 1980-decade, the Government of India decided to set up a National Measurement System consisting of (i) a National Calibration Service, (ii) a National Testing Service and (iii) Coordination of linkage between these two services; It was decided that the Department of Science and Technology (DST) of the Government of India, which acts as a promoter of science and technology in the country but has no direct involvement in testing and calibrating laboratories, be given the responsibility of evolving, growing and coordinating the above three activities. The DST in consultation and cooperation with other concerned ministries, formulated in 1982 a National Coordination of Testing and Calibration Facilities abbreviated as NCTFC. This is an integrated programme, a blending of the best aspects in the existing accreditation systems of different government departments and agencies. The broad objectives of this programme are to bring about a uniformity of assessment system, to optimise the use of testing laboratories, gain international recognition and enhanced acceptance of Indian products and services in foreign markets, to provide consumer protection and also to monitor the quality of imported instruments and test equipment. Figure 1 illustrates the operating principle of the Calibration Service Programme under this scheme.

3.2.1 National Coordination of Testing and Calibration Facilities (NCTFC)

The National Coordination of Testing and Calibration Facilities (NCTFC) scheme was set up in 1982 by the Government of India with the purpose to evolve a set of guidelines, criteria and procedures which are to be uniformly applicable to all testing and calibration laboratories in the country in order to ensure compatibility of test results between the various testing laboratories and their traceability to the accuracies of the 'National Standards' maintained at the National Physical Laboratory, New Delhi. The NPL has been assigned the responsibility to develop and operate the NCTFC scheme outlined above. A three-echelon network of calibration laboratories had been envisaged and set in operation for 'classification' and also for 'accreditation' of different laboratories of industry, research and development organisation including the testing laboratories under defence departments scattered all over the country.

The 'Three-Echelon Network' of calibration laboratories has been grouped in terms of their accuracy and performance with the NPL as the echelon-I laboratory for all parameters except 'Ionising Radiation' for which Bhaba Atomic Research Centre (BARC) serves as the apex l> echelon-I laboratory . Five areas of measurement for setting up the above hierarchy of calibration laboratories have been identified viz. (i) Electrotechnology Measurement, (ii) Mechanical Measurements, (iii) Fluid Flow Measurement, (iv) Thermal and Optical Measurements and (v)

Radiological Measurements. Figure 2 illustrates the modality of operation of the 'National Measurement System' under the NCTFC scheme.

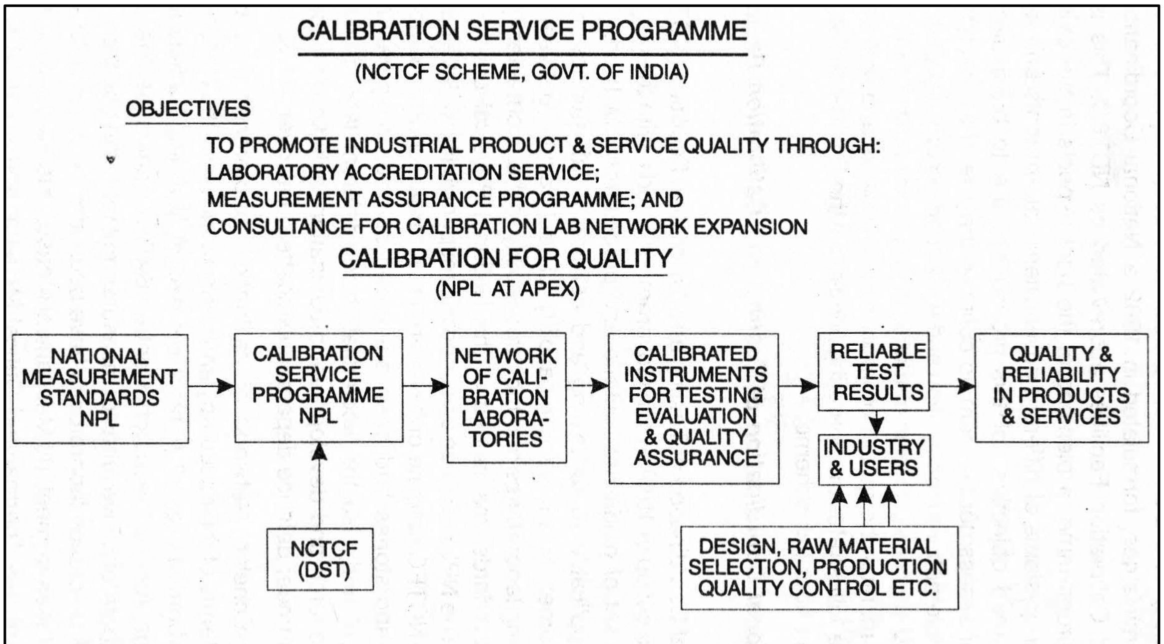

Fig. 1 Block Schematic of Calibration Service Programme

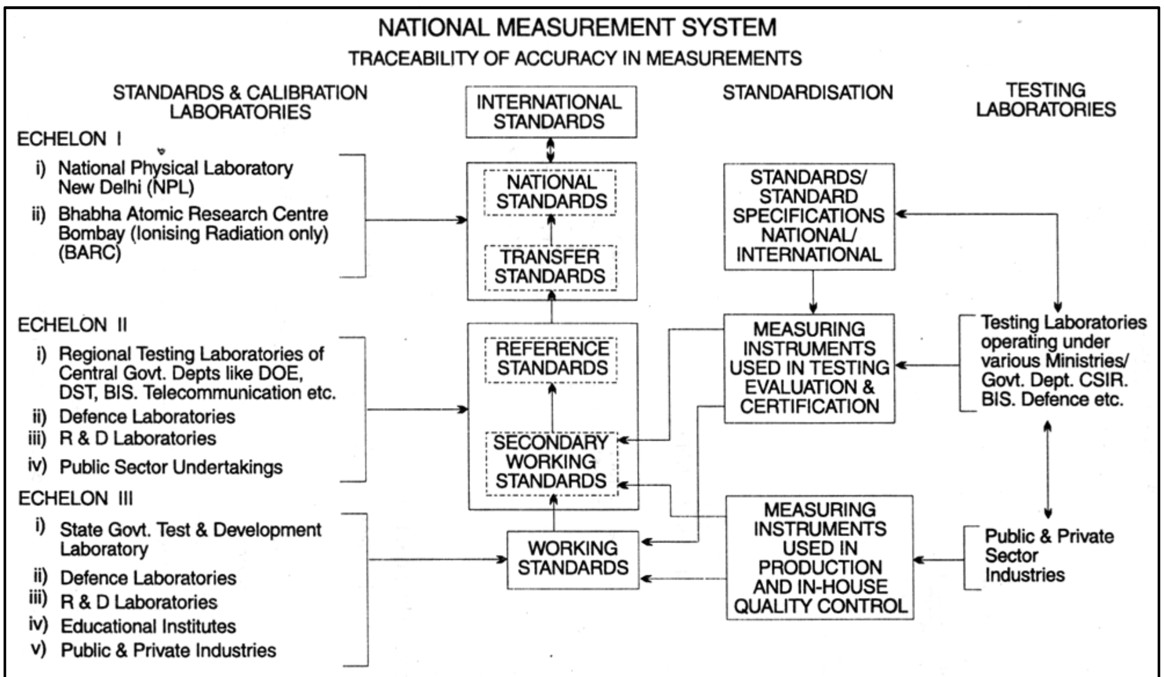

Fig. 2 National Measurements System : Hierarchy of Standards & Calibration Laboratories

As has already been stated, the Three-Echelon Network' of Calibration Laboratories has been grouped in terms of their accuracy and performance as indicated below:

Echelon I

- National Physical Laboratory
- Bhaba Atomic Research Centre (Ionising Radiation only)

Echelon II

- Regional Laboratories of Central Government (DOE, DST, BIS etc.)
- Selected Defence Laboratories
- Selected Advanced Research Laboratories
- Laboratories of Selected Public Sector Undertaking

Echelon III

- State Government Laboratories
- Some Defence and R & D Laboratories
- Laboratories of Academic Institutions, etc.

4. NATIONAL ACCREDITATION BOARD FOR TESTING AND CALIBRATION LABORATORIES (NABL)

The scope of the formerly described National Coordinations of Testing and Calibration Facilities (NCTFC) scheme has been further widened to incorporate the 'quality system' approach. In 1992 the NCTFC has been renamed as National Accreditation Board for Testing and Calibration Laboratories (NABL). The newly constituted NABL has formulated the 'Criteria for Laboratory Accreditation' based on ISO/IEC Guide-49 and 25 and EN-45000. European Commission (EC) support and guidance rendered to India by an European Expert Group have been extremely useful to align this programme to international norms. The Laboratory Accreditation Programme of the former NCTFC was managed by the various government departments and experts drawn mostly from the government or government-supported institutions. A major shift of policy has been introduced while formulating the working principles of the NABL. In the new Board (NABL), the apex body of the NABL programme has 1 : 1 representation from government and nongovernment bodies. Thus, the onus of the management of the programme has widened, making all sectors of economy of the country equally and meaningfully responsible. The Organisation Structure for policy implementation of the NABL is illustrated in Figure 3. The Accreditation Process of the National Accreditation Board of Laboratories (NABL) is illustrated in the flow chart shown in Figure 4.

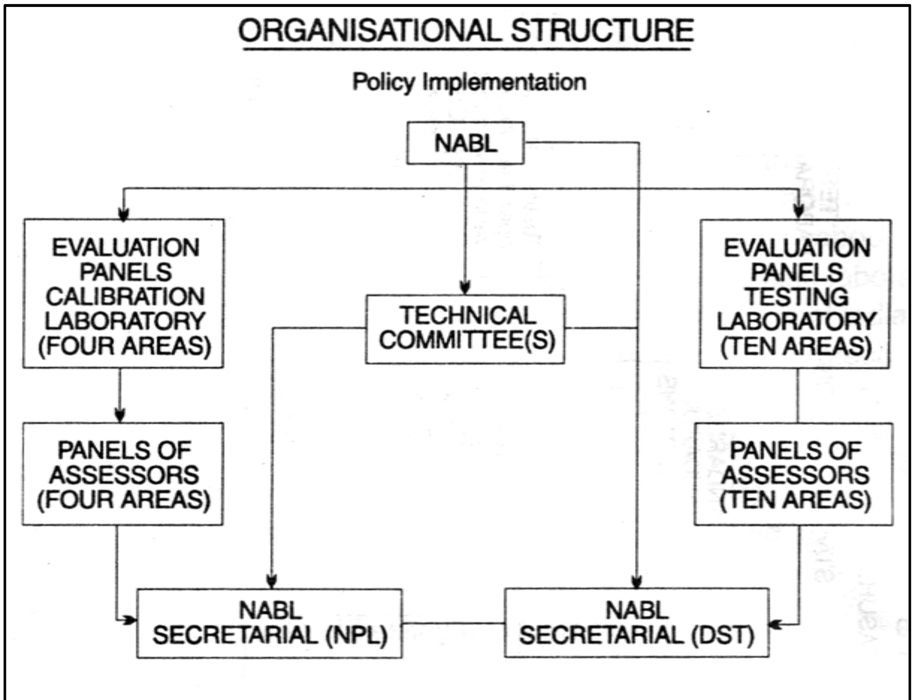

Fig. 3 Organisational Structure of National Accreditation Board of Testing & Calibration Laboratories

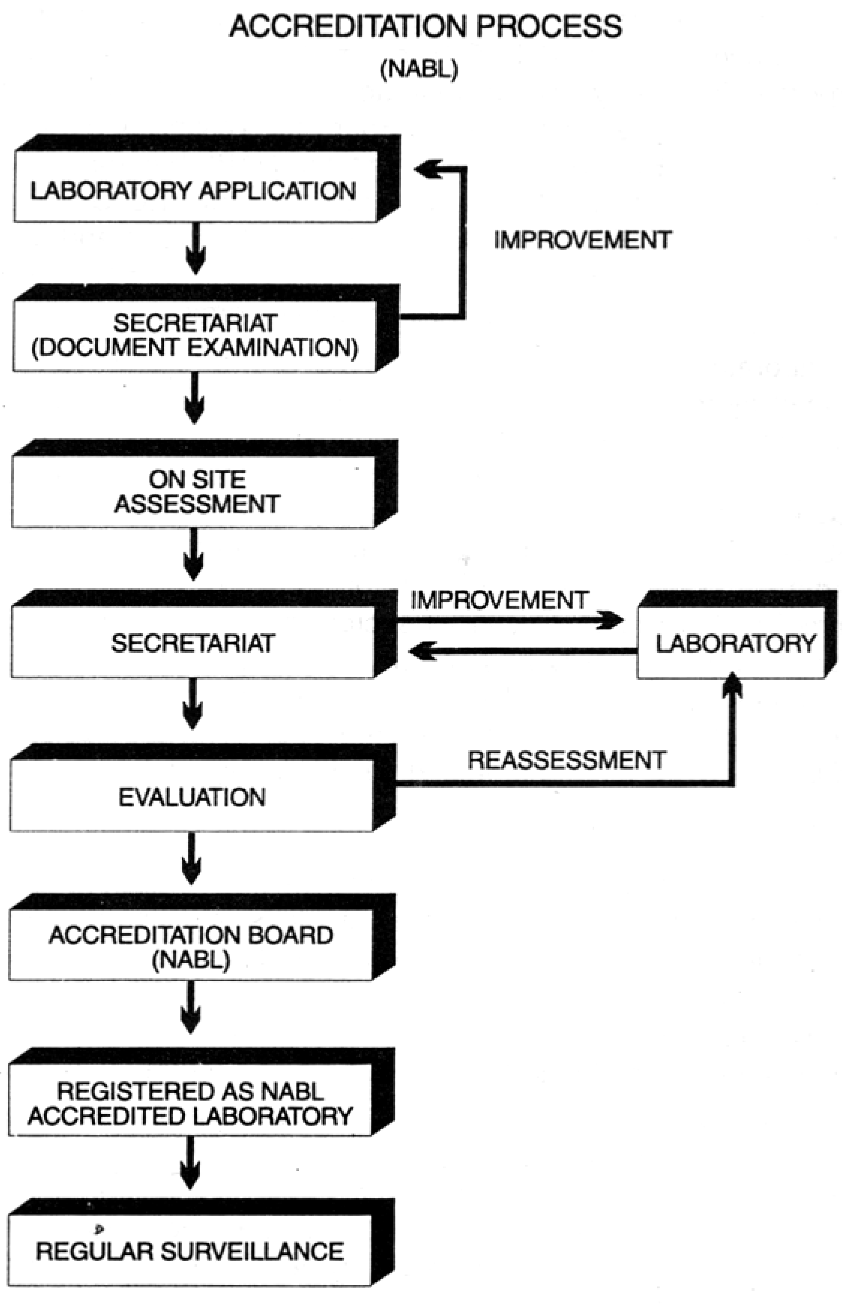

Fig. 4 Flow Chart of Accreditation Process of NABL

5. CONCLUSION

In a modern technologically based society metrology, which is the science and technology of measurement, plays an essential role. There is a definite relationship between the standardisation system, industrial development and technological capability of a country. The gradual evolution of the National Measurement System (NMS) of India has been outlined in the present paper.

Starting from a stage prevalent in 1947, where there was very meager infrastructural facilities for industry at the time of independence from the alien rule, India has made highly commendable achievments in the fields of science, technology and industry. Today, it is a major industrial country which has attained this position mostly by development of sophisticated technologies indigenously.

Evolution of its own metrological infrastructure starting with the introduction of the metric system of Weights and Measures (also the metric system of coinage) and the establishment of the Indian Standards Institution (later upgraded and renamed as the Bureau of Indian Standards - BIS) and the National Physical Laboratory at Delhi, India has been successful in evolving a National Measurement System for accreditation and classification of testing and calibration laboratories of the country in a very effective and coordinated manner to cater for the changing and challenging needs of that country. In the latest phase of the evolution of this activity, the concepts and practice of 'Quality System' and 'Quality Assurance' have been incorporated in conformity with the ISO and EN standards in order to upgrade the performance of Indian products and services to become competitive and cost-effective with respect to the best of their counterparts, both nationally and globally.

6. References

1. Verma, A N. "National Measurements and Standards", (A Book). Publisher: National Physical Laboratory, New Delhi, 1987.

2. Lal, H. "Standards India", Vol. 5, No.7, (12112) New Delhi, October 1991.

3. Choudhury, J K. "Measurement Standards & Calibration Service: The Indian Scenario", The P N Ghosh Memorial Lecture, The Institution of Engineers (India), West Bengal State Centre, July 1991.

4. "NABL Procedure and Guidelines for Laboratories", Department of Science and Technology (Govemment of India), New Delhi, 1995.

Prof M S Thakar Memorial Lecture - 1998

Mr A K Sah

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In this lecture dedicated to the memory of Prof. M.S. Thakar, one of the doyens of electrical engineering world, I would like to review the progress of electricity development in the country since independence and tell you something about the challenges which the electrical engineers of the present and coming generation will have to face.

You would of course be aware that electricity came to our country just a century back with the construction of the first hydro-electric power station of 130 kW at Sidrapong near Darjeeling in 1897 followed by first steam power station of 1000 kW capacity in Calcutta in 1899. The first fifty years of power development in the country was, however, confined to serving the affluent section of urban population and captive power generation for some industries. As a consequence, all that we could achieve by 1950 was 1737 MW installed generating capacity.

The history of development of electricity in the next fifty years since independence is marked by policy decision of the government to place electricity development at the apex of all developmental activities for achieving an all round economic growth, self sufficiency in food production and improving the quality of life of every citizen of the country whether in the urban or rural areas, whether in the fertile indo-gangetic plains or in the remotest wilds of the Himalayan mountains, whether along the extensive coast of the Bay of Bengal and Arabian sea or in the interior of the Southern plateau. India is rich in hydro-electric resources, with massive perennial rivers criss-crossing all over the country either snow fed from the Himalayan glaciers or rainfed in many other parts of the country. Harnessing the massive potential of these rivers not only for power production but also for irrigation and flood control was the first task undertaken by the founders of independent India founders of independent India.

The task before the planners of the early fifties was indeed gigantic. The pace of electricity generation and supply had to be stepped up manifold, for which not only new generating capacity had to be added but the power transmission and distribution network had to be spread all over the country within the shortest possible time frame. For this purposes, on an average about 20% of the country's total plan resources were committed for electricity development and this process has been going on since then. To achieve this objective, the Government of India's Industrial Policy Resolution of 1956, placed all electricity development activities in the public sector, for which the entire financial assistance was provided through government's budgetary support or government controlled financial institutions.

The total investment in the Indian power sector from 1950 onwards till the end of the Eighth five year plan period (March 1997) is of the order of Rs 150,000 crores. During this period of planned economic development the achievements of the Indian power sector in growth of generating capacity, spatial spread of transmission and distribution network and electrification of rural areas has been very impressive.

1. The generating capacity has gone up to more than 86000 MW.
2. The transmission and distribution network spanning the length and breadth of the country is more than 5 million ckt. kms.
3. Electricity has reached more than 86% of the villages.
4. The per capita consumption of electricity is around 350 kWh per annum.

Technologically also the country has cornea longway since the early years of independence when every power equipment from small distribution transformers and line materials to generating units had to be imported. We have now achieved self sufficiency in the manufacture of largest sizes of generating units up to 500 MW capacity and transmission and distribution equipment from the lowest distribution level of 220 Volts upto the highest transmission voltage of 400 kV. We now have the capability to transmit bulk power over long distances through high voltage DC system and interconnect regional and state power systems through HYDC back - to – back technology. We have developed boiler designs suited to burning high ash coal with 40% or higher ash content produced in our country and the performance of large thermal power stations constructed during the last 10 to 15 years is comparable with the best in the world.

The Industrial Policy Resolution also resulted in establishment of a string of heavy electrical engineering industries at Haridwar, Bhopal, Hyderabad and Tiruchirapalli with a view to achieving self sufficiency in the design and manufacture of all heavy electrical equipments for generation, transmission and distribution of electricity. Haridwar brought in Soviet technology for manufacture of thermal power generating units of 100 and 200 MW capacity, Bhopal was established with British technology for 120 MW units, Hyderabad with Czechoslovakian technology for 55 and I10 MW units while Thiruchirapalli was established for manufacture of boilers for all these generating units with Czechoslovakian collaboration.

It is a fact that the technologies provided by these countries were not state-of-the-art, but since the country, and indeed the entire world was then passing through a phase of reconstruction after World War II, there was perhaps no other alternative but to accept this technology to put India on the Industrial map specially as it was available on Rupee payment barter basis. The technological collaborations were subsequently changed for large size thermal generating units upto 500 MW size with Siemens and for large size steam generators with combustion Engineering USA. BHEL today ranks among the largest power plant manufacturers in the World, but unfortunately it has not come up as a commercial giant with a global network of sales and services. One of the reasons is that it has been mainly catering to domestic requirements where it has a captive market. It has not oriented itself to international competitive business environment.

Though the physical achievements of the power sector has been substantial, it has not been able to fulfil the primary obligation of providing quality power in the required quantities to different consumer categories. The SEBs are caught in vicious cycle of .shortage of resources and poor operational and financial performance. Resource constraints have not only led to delays in capacity additions but have also affected the performance of existing capacities. Unrationalised tariffs without regard to rising cost of production and supply of power, primarily due to social and political considerations have resulted in huge accumulation of losses in the SEBs.

According to a study by Tata Energy Research Institute, the time and cost overruns in commissioning of thermal and hydro projects, there is an urgent need for a complete reassessment of the existing structure of the Indian power sector.

Some of the major issues which have to be addressed are the following:

• Correcting the imbalance in hydro-thermal mix in order to mitigate the peaking shortage and exploit perennial source of energy which is abundantly available in the country.

• Refurbishment, renovation and modemisation of old thermal and hydro power plants to improve their availability, efficiency and reliability.

• Reduction in T&D losses from the present level of 22 percent plus to a reasonable level of about 16 percent or so, through technical upgradation of distribution system and improved maintenance management.

• Introduction of effective demand side management through rationalised tariff and improved metering system.

• Adoption of modem management systems and cashflow discipline to eliminate time and cost over-runs.

Although requisite technical and managerial expertise is available in the power sector, the public sector working system with shared responsibilities and diluted accountability is not conducive to efficient functioning of such a complex industry which touches the life of every individual and whose performance is a measure of the country's economic prosperity. It is for this reason that a major policy change for liberalisation of economy by opening the power sector for private investment was initiated in 1991.

The need for power sector reforms had been felt for a number of years as majority of SEB's had been recording very low operational efficiency and poor financial health. In 1991 a policy was formulated in the Ministry of Power to encourage greater investment by private entrepreneurs with a view to mobilising additional resources for capacity addition in power generation and distribution to bridge the rapidly growing gap between demand and supply of electricity. The legislation governing the electricity sector was amended and a number of incentives were offered. It was, however, realized that unless the solvency, liquidity and general financial health of SEBs improves the response for private investment would not be encouraging. The private investors have to be fully assured of their cash flows and returns. Provisions of counter guarantees by the Central Government was used as comfort because of poor health of SEBs. Now that this provision is no more available, there is no alternative to making SEBs financially viable to inspire confidence amongst the private investors. Reforms have become all the more necessary because

SEBs owe a colossal amount of Rs. 10,000 crore to Central sector undertakings for purchase of coal, power and equipments etc., which is about 30 percent of the annual turnover of SEBs. The reforms recommended by consultants appointed by a number of SEBs substantially follow the following pattern:

(1) Separation of generation, transmission and distribution activities into independent corporate entities.

(2) Rationalism of tariff structure to achieve financial viability of electricity sector through independent regulatory authority.

(3) Invitation of massive private investments not only in generation but also for transmission and distribution.

In fact, private investment 10 distribution and depoliticisation of power distribution system is the most important aspect of restructuring of the electricity sector. There can be no two opinions that rural electrification is essentially required for boosting agricultural production and improving the quality of life of the majority of Indian people who live in villages. However, this cannot be treated as commercial activity of the electricity utility unless SEBs are allowed to charge cost based tariffs. It can best be treated as development activity of the government. The commercial losses of rural electrification have to be met by the government and not by the electricity utility except to the extent this can be reasonably cross subsidised by other consumer classes. Once the SEBs can be assured of remunerative tariffs based on reasonable norms of operation, their accountability for supply of reliable power in adequate quality can also be established. It will also then be possible to attract private investment on commercial prudence rather than on the crutches of government guarantees etc. While inviting private investment in generation, transmission and distribution is essential to mobilise resources and latest technological inputs, it is my considered opinion that both public and private sectors must co-exist and the country should not go in for wholesale privatisation.

In the electricity sector as it exists today, the key areas of concern are:

a) Imbalance in Hydro-Thermal Mix

Since electricity generation has to follow the pattern of electricity consumption, adequate generating capacity has to be created to meet the peak requirements. It is recognised that a proper mix of hydro and thermal generating capacities in an integrated power system best meets this requirement, because hydro generating units can be put on or off at short notice in accordance with fluctuating power demand pattern. A 40:60 hydro-thermal mix is generally accepted as a thumb rule. During the first three Plan periods when there was emphasis on multipurpose hydro-electric development, the proportion of hydro share had gone as high as 46 percent in 1965-66. Since then it has steadily declined and is now around 25 percent causing serious peaking shortage. Although Government had announced a policy for accelerating hydro development there are many impediments in its implementation, the most important of which relate to the socio-economic aspect of rehabilitating displaced persons and ecological degradation of the area.

b) High Transmission and Distribution Losses

The power lost in transmission and distribution of electricity is very high not all of which can be attributed to inadequacy of T&D system. A large proposition of these losses are due to theft and pilferage of electricity. Both technical and administrative measures are required for bringing down these losses within acceptable limits.

c) Poor Performance of Old Thermal Stations

A large number of old power stations with low thermal efficiency boilers which are now burning coal of much lower calorific value than its design are still in operation. They are operating at low availability and high cost. A concentrated programme of renovation and rehabilitation of these stations is required to be undertaken. Power Finance Corporation has taken a lead in respect of providing finance for this work and the Ministry of Power, GOL has also expressed its intention to accelerate this programme.

d) Lack of Demand Side Management and Energy Conservation

The growing peak shortage and low utilisation factor of available facilities calls for scientific demand side management in order to even out the wide load fluctuations which take place on diurnal as well as seasonal basis. This is possible to a large extent through rationalisation of tariff structure with incentives to reduce or shift their peak demand. Time-of-the-day metering system will induce customers to opt for off-peak tariffs and shift their loads to off-peak hours. Similarly there is a large scope for energy conservation through tariff incentives. The present system of charging for agricultural supplies at fixed per horse-power tariff leads to wastage of energy which must be curtailed. Installation of capacitors on LT induction motors and at 11 kV and 33 kV substations will also reduce reactive power generation to a very large extent.

e) Deteriorating Financial Condition of SEBs

There is rather a complex issue which originates with lack of financial resources, the main causes of which are irrational tariff structure, highly politicized distribution system management, rampant theft of electricity and unauthorized connections with the connivance of SEB staff. Other major factor is the financial structure of SEBs which is totally based on loans with no equity. Earlier when almost 100 percent concessional financing was available to SEBs from their governments and cost of generation, which was primarily based on hydroelectricity was low, there was no problem. With increasing capital intensity of electricity sector, growing cost of generation of power from coal based thermal power stations and substantial high cost institutional financing being made available to SEBs, their financial position is bound to deteriorate. This has also led to non-accountability for performance deterioration and inefficiency. It is not as if these problems are not well known to the authorities concerned. Several seminars and conferences have been held in which various international financing agencies have participated. The last such conference was held on January 17-18, 1997, but there appears to be lack of political will and determination, specially at the state level to implement the reform measures.

The electricity sector today is at the cross roads. Major liberalised policy initiatives have been taken which have not yet started yielding benefits. Condition of power supply has in fact deteriorated. Political will to take and implement hard decisions is lacking. Private investors both from within the country and outside are getting disillusioned. They are still being perceived as pirates who are invading into the strong hold of the public sector. No one government, bureaucrat or technocrat, wants to take unpalatable decisions for fear of being persecuted. Through this concluding paragraph, I do not want to sound a note of despair but of caution in the hope that positive steps for on-the ground improvements as distinct from on-the-paper improvements which have now been set in motion will be accepted by all the states without any further delay and the country will enter into the new millenium with bright prospects of future growth.

Delivered during the Seventeenth National Convention of Electrical Engineers on 'Economics of Development in Power Sector in Developing Nations Indian Scenario' organized by Nagpur Local Centre, November 24-25, 2001

Energy Conservation — A Simple Tool to Solve Problems of Power Shortage

Dr M Ramamoorty

ERDA, Vadodara

Modern society cannot live without electricity. Electrical Energy consumption is on the rise throughout the world. So efforts are necessary to use efficiently.

Present installed capacity in India has crossed 100,000 MW. It is a substantial rise from a meagce level of 1700 MW in 1950. However, the growth in capacity has fallen short of the planned target by more than 50% due to delays in the execution of power projects. We are not able to meet the present peak demand of 80,000 MW. There is 10 to 20% shortage in energy and demand reflecting the poor performance of power sector.

Economists say that the growth in power should be about 1.5 times the projected GDP growth to provide supporting help to all the core sectors. Thus for maintaining GDP of 6% there should be 10% annual growth in the installed capacity. Unfortunately this has not happened. Result was severe shortages causing slow down in economy. There are many reasons for the inadequate growth in power sector. Poor management, lack of financial resources, social commitments, un-remuneration tariff etc. Power cuts both scheduled and unscheduled have become the order of the day.

SEBs have become financially weak and are not in a position to add generation or improve the T&D systems. They suffer huge financial loss due to theft and free supply of energy to some consumers. Technical losses also very high (of the order of 40%) due to poor transmission and distribution systems.

The projected requirement of additional generation by 2012 is 100,000 MW requiring an addition of 10,000 MW per year for the next to years. Looking at the past experience, it is impossible to achieve this target, so we can expect the present shortages to continue.

Under these conditions, one should explore the various alternatives to mitigate the effect of shortages in conventional generation and there by improve even slightly the performance of power sector. Energy conservation is one such alternative which is simple, effective and yields results very fast.

Use of non-conventional power generating systems e.g. wind, solar, biogas, micro hydel should be encouraged. They have short gestation time. Technology is available in the country. There is enough potential to be exploited. Cost of generation is comparable with that of conventional systems. The balance will tilt towards non-conventional systems in the near future since the cost of conventional fuels will go up with time. Further we cannot depend for ever on the conventional fuels since these have limited availability and in the long run we have to depend only on the inexhaustible or renewable sources of energy e.g. solar, wind, Hydel and Biogas. Further these plants can be put into operation very quickly compared to conventional plants and so from the point of meeting the problem of shortages the non-conventional plants will be more beneficial. However, these plants suffer form the problem of poor plant load factor.

There are many old thermal/hydro power plants which can be modernised/renovated with some repairs to extend their operating life with increased capacity. If the cost of new conventional power plant is about Rs. 4 crores/MW, the cost of renovated plant is only about Rs. 1 crore/MW and the time taken for putting the renovated plant online considerably less than that of the new plant.

Therefore renovation and modernization of old plants is one of the methods to get over the present problems of power shortage. However, this cannot provide a permanent solution.

Due to financial constraints on SEBs, the existing T&D systems are not adequate. Improvements to these systems will result in reducing technical losses in the power supply and improve the operating efficiency. This requires additional investments in adding transmission lines, substations, distribution transformers, static meters etc. In addition to reducing the losses these measures will improve the quality of power supply. However, these will not be able to provide immediate relief against shortages but reduction of losses even by 10% from the existing level of 40% will save about 50 BU per annum which is equivalent to an annual saving of Rs. 15000 crores.

The present consumption of electrical energy in the country has reached very high level of 500 BU per year. Even then our per capita consumption is perhaps the lowest in the world. Of this nearly 40% is consumed by industry, 30% by agriculture 20% by domestic and commercial consumers and the rest by public utilities like transportation systems. By the use of energy efficient equipment, motors, pumps, lighting systems, improved chemical processes and energy conservation measures 10 to 20% of energy consumption can be saved. This is substantial benefit to the country facing severe financial constraints. Further the additional capital investment required due to the adoption of conservation measures can be recovered in a matter of less than 5 years and in some cases even in one year by the savings in energy costs. The implementation of these measures in not very complex and the results of implementation can be seen immediately. As per the experts in the field of energy auditing the elasticity ratio for Indian industries is about 20% more than acceptable world norms. So we consume more energy for the same output. Therefore there is an immense possibility to reduce consumption through conservation.

Energy conservation does not mean consuming less energy at time cost of production. For the same output one should consume less energy input to reduce the elasticity ratio. Our planners have predicted that it is possible to save about 200 BU of energy annually through conservation measures by 2010.

Thus from all possible angles, energy conservation is the best option we have to reduce the present day shortages in demand and energy. Looking at the immediate need to implement energy conservation measures, Govt. of India has recently got the energy Conservation Act 2001 passed in the parliament. The Act seeks to establish a Bureau of Energy Efficiency with the authority to form guidelines for use and manufacture of energy efficient equipment, improve. general awareness about energy conservation and make energy audits mandatory.

Thus energy conservation offers a very simple and effective tool to get over the present problems of shortages in Power sector.

This paper/presentation deals with various electricity conservation measures and methods which will be helpful to all types of consumers.

Thakkar Memorial Lecture

Mr Yogendra Prasad

It is a delight to join you all today on the 20th National Convention of Electrical Engineers. I am all the more privileged to deliver the Thakkar Memorial Lecture on this important occasion.

Energy today holds key to the stairway of future development of our nation. It plays a pivotal role by supporting the quality of life, we enjoy. Uninterrupted and Quality power are the basic requirements that are often taken for granted by the consumers. The technical parameters such as frequency & voltage that regulate the grid conditions are also the factors that gauge the healthiness of a power system. For a stable power system it is to be ascertained that these parameters are within prescribed limits.

Indian power sector has made tremendous growth in due course of time. The present installed capacity in India is 113506.64 MW, which was mere 1362 MW at the time of independence. But the Indian power system is fickle, unstable and unhealthy. The operating frequency of grid reaches as low as 48 Hz in the North and rises as high as 51 Hz in the East against optimal frequency band of 49.5 to 50.5 Hz. Wide frequency and voltage excursions in the electrical grid are detrimental to the generating and other associated equipments of the power system. The adverse grid conditions lead to tripping of generators in cascade manifesting grid collapses.

There are numerous other concerns, the Indian power sector is confronting with. The gap between demand and generation has been always on the rise, which has resulted in high peaking and energy shortages. The nation had an Energy deficit of 7.2 % and peaking deficit 11.2 % during the previous year. Hydro: Thermal mix of 27:73 is also an issue, which should be 40:60 at the optimum level for grid stabilization. Indian grid engulfs less capacity of peaking and pumped storage plants. Underdevelopment of such plants has a large impact on the erratic behavior of the present power system. Low operating plant load factor of thermal power plants is due to operation of these plants for meeting peaking loads and undue backing down of units for off peak loading periods. Conventional Thermal power plants (Coal fired) are constructed with the intent to launched a "50 000 MW Hydroelectric Initiative" for capacity addition in 11^{th} and 12th plan. CEA also undertook ranking studies to facilitate identification of the projects for implementation in order or priority so that hydropower development could be taken in proper sequence.

I strongly believe that the approach taken by government to rejuvenate hydropower will greatly speed up the development process. However, many Challenges and hurdles remain before hydropower, which should be dealt with positive approach, Let us join hands tor development of hydropower, which is the only solution left to provide the future generation energy security.

At the end, I take this opportunity to express my congratulations to the organizers for organising thus important convention and sincere thanks for giving me this opportunity.

Thanking you.

An Introduction to Availability Tariff

Er Bhanu Bhushan

Member, Central Electricity Regulatory Commission

The term Availability Tariff, particularly in the Indian context, stands for a rational tariff structure for power supply from generating stations, on a contracted basis. The power plants have fixed and variable costs. The fixed cost elements are interest on loan, return on equity, depreciation, O&M expenses, insurance, taxes and interest on working capital. The variable cost comprises of the fuel cost, i.e., coal and oil in case of thermal plants and nuclear fuel in case of nuclear plants. In the Availability Tariff mechanism, the fixed and variable cost components are treated separately. The payment of fixed cost to the generating company is linked to availability of the plant, that is, its capability to deliver MWs on a day-by-day basis. The total amount payable to the generating company over a year towards the fixed cost depends on the average availability (MW delivering capability) of the plant over the year. In case the average actually achieved over the year is higher than the specified norm for plant availability, the generating company gets a higher payment. In case the average availability achieved is lower, the payment is also lower. Hence the name' Availability Tariff'. This is the first component of Availability Tariff, and is termed 'capacity charge'.

The second component of Availability Tariff is the 'energy charge', which comprises of the variable cost (i.e., fuel cost) of the power plant for generating energy as per the given schedule for the day. It may specifically be noted that energy charge (at the specified plant-specific rate) is not based on actual generation and plant output, but on scheduled generation. In case there are deviations from the schedule (e.g., if a power plant delivers 600 MW while it was scheduled to supply only 500 MW), the energy charge payment would still be for the scheduled generation (500 MW), and the excess generation (100 MW) would get paid for at a rate dependent on the system conditions prevailing at the time. If the grid has surplus power at the time and frequency is above 50.0 cycles, the rate would be lower. If the excess generation takes place at the time of generation shortage in the system (in which condition the frequency would be below 50.0 cycles), the payment for extra generation would be at a higher rate.

To recapitulate, the Indian version of Availability Tariff comprises of three components: (a) capacity charge, towards reimbursement of the fixed cost of the plant, linked to the plant's declared capacity to supply MWs, (b) energy charge, to reimburse the fuel cost for scheduled generation, and (c) a payment for deviations from schedule, at a rate dependent on system conditions. The last component would be negative (indicating a payment by the generator for the deviation) in case the power plant is delivering less power than scheduled.

How do the beneficiaries share the payments

The Central generating stations in different regions of the country have various States of the Region as their specified beneficiaries or bulk consumers. The latter have shares in these plants calculated according to Gadgil formula, and duly notified by the Ministry of Power. The beneficiaries have to pay the capacity charge for these plants in proportion to their share in the respective plants. This payment is dependent on the declared output capability of the plant for the day and the beneficiary's percentage share in that plant, and not on power / energy intended to be drawn or actually drawn by the beneficiary from the Central station.

The energy charge to be paid by a beneficiary to a Central station for a particular day would be the fuel cost for the energy scheduled to be supplied from the power plant to the beneficiary during the day. In addition, if a beneficiary draws more power from the regional grid than what is totally scheduled to be supplied to him from the various Central generating stations at a particular time, he has to pay for the excess drawal at a rate dependent on the system conditions, the rate being lower if the frequency is high, and being higher if the frequency is low.

How does the mechanism work

The process starts with the Central generating stations in the region declaring their expected output capability for the next day to the Regional Load Dispatch Centre (RLDC). The RLDC breaks up and tabulates these output capability declarations as per the beneficiaries' plant-wise shares and conveys their entitlements to State Load Dispatch Centres (SLDCs). The latter then carry out an exercise to see how best they can meet the load of their consumers over the day, from their own generating stations, along with their entitlement in the Central stations. They also take into account the irrigation release requirements and load curtailment etc. that they propose in their respective areas. The SLDCs then convey to the RLDC their schedule of power drawal from the Central stations (limited to their entitlement for the day). The RLDC aggregates these requisitions and determines the dispatch schedules for the Central generating stations and the drawal schedules for the beneficiaries duly incorporating any bilateral agreements and adjusting for transmission losses. These schedules are then issued by the RLDC to all concerned and become the operational as well as commercial datum. However, in case of contingencies, Central stations can prospectively revise the output capability declaration, beneficiaries can prospectively revise requisitions, and the schedules are correspondingly revised by RLDC.

While the schedules so finalized become the operational datum, and the regional constituents are expected to regulate their generation and consumer load in a way that the actual generation and drawls generally follow these schedules, deviations are allowed as long as they do not endanger the system security. The schedules are also used for determination of the amounts payable as energy charges, as described earlier. Deviations from schedules are determined in I5-minute time blocks through special metering, and these deviations are priced depending on frequency. As long as the actual generation/drawal is equal to the given schedule, payment on account of the third component of Availability Tariff is zero. In case of under-drawal, a beneficiary is paid back to that extent according to the frequency dependent rate specified for deviations from schedule.

Why was Availability Tariff necessary

Prior to the introduction of Availability Tariff, the regional grids had been operating in a very indisciplined and haphazard manner. There were large deviations in frequency from the rated frequency of 50.0 cycles per second (Hz). Low frequency situations result when the total generation available in the grid is less than the total consumer load. These can be curtailed by enhancing generation and/or curtailing consumer load. High frequency is a result of insufficient backing down of generation when the total consumer load has fallen during off-peak hours. The earlier tariff mechanisms did not provide any incentive for either backing down generation during off-peak hours or for reducing consumer load I enhancing generation during peak-load hours. In fact, it was profitable to go on generating at a high level even when the consumer demand had come down. In other words, the earlier tariff mechanisms encouraged grid indiscipline.

The Availability Tariff directly addresses these issues. Firstly, by giving incentives for enhancing output capability of power plants, it enables more consumer load to be met during peak load hours. Secondly, backing down during off-peak hours no longer results in financial loss to generating stations, and the earlier incentive for not backing down is neutralized. Thirdly, the shares of beneficiaries in the Central generating stations acquire a meaning, which was previously missing. The beneficiaries now have well-defined entitlements, and are able to draw power up to the specified limits at normal rates of the respective power plants. In case of over-drawal, they have to pay at a higher rate during peak load hours, which discourages them from over-drawing further. This payment then goes to beneficiaries who received less energy than was scheduled, and acts as an incentive/compensation for them.

How does it benefit everyone

The mechanism has dramatically streamlined the operation of regional grids in India. Firstly, through the system and procedure in place, constituents' schedules get determined as per their shares in Central stations, and they clearly know the implications of deviating from these schedules. Any constituent which helps others by under-drawal from the regional grid in a deficit situation, gets compensated at a good price for the quantum of energy under-drawn. Secondly, the grid parameters, i.e., frequency and voltage, have improved, and equipment damage correspondingly reduced. During peak load hours, the frequency can be improved only by reducing drawals, and necessary incentives are provided in the mechanism for the same. High frequency situation on the other hand, is being checked by encouraging reduction in generation during off-peak hours. Thirdly, because of clear separation between fixed and variable charges, generation according to merit-order is encouraged and pithead stations do not have to back down normally. The overall generation cost accordingly comes down. Fourthly, a mechanism is established for harnessing captive and co-generation and for bilateral trading between the constituents. Lastly, Availability Tariff, by rewarding plant availability, enables more consumer load to be catered at any point of time.

Road Map for Smart Grid Deployment in India

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In the time to come increased use of fossil fuel demand will increase concern over emission of carbon dioxide (CO_2) and it is estimated that it may double by 2050. Present trend in energy supply and use are unsustainable in all respect especially environmentally. The need of the hour is to adopt low carbon emission technologies deployment of energy efficiency renewable energy technologies, transport technologies may help us to reach our goal of our green house gas emission goal. For the last 10 years drive was to optimize energy. Further as the grid capacity is increasing leaps and bound there is an urgent need Widespread technologies, new to secure grid from any interruption. Utilities all over the world are in the process of deployment of a broad range of solutions and deployment of Technologies that optimize the energy value chain.

With the increased use of IT and communication technologies smartness in the grid is built. Amazingly, much of the thinking behind Today's Power Grid is based on design decisions originally published by Nikola Tesla in 1888. While valid for his time, Tesla's assumptions like centralized power generation, demand-driven control and unidirectional transmission are now considered obsolete.

First instance which made policy makers to think of energy security was the oil embargo during 1973. Further blackout and concern for environment made policy makers to introduce various legislations. One among them was PURPA -1978 (Public Utilities Regulatory Policies Act: a) Energy conservation, b) Find alternate technologies like solar photo voltaic, biomass, wind, tide, renewable c)Federal Energy Administration which was established to counter the crisis introduced the concept for Time-of -use (TOU) concept to reduce peak load. etc. d) It is to reduce peak load and hence usage of fuel oil could be reduced. e) This established that time- differentiated rates would bring down peak load and became a powerful tool to reduce dependence on foreign oil. The Energy Policy Act (EP Act) of 2005 mandated that each state evaluate the business case for advanced metering infrastructure (AMI). Energy Independence and Security Act of 2007 expands support from the U.S. government for investments in smart grid technologies.

Salient features of EISA 2007 are as follows:

1. Increase use of digital information and controls technology to improve reliability, security, and efficiency of the grid.

2. Dynamically optimize grid operations and resources with full cyber-security.

3. Deploy and electric integrate distributed resources and generation, including renewable resources.

4. Develop and incorporate demand response, demand-side resources, and energy-efficiency resources.

5. Deploy "smart" technologies realtime, utomated, interactive technologies that optimize the physical operation of appliances and consumer devices for metering, communications concerning grid operations and status, and distribution automation.

6. Integrate "smart" appliances and consumer devices.

7. Deploy and integrate advanced electricity storage and peak- shaving technologies, including plug- in electric and hybrid electric vehicles, and thermal-storage air conditioning.

8. Provide timely information and control options to consumers.

9. Develop standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

10. Identify and lower unreasonable or unnecessary barriers to adoption of smart grid technologies, practices and services.

However with many IT equipment interoperability is a major issue. Without standards, there is the potential for these investments to become prematurely obsolete or to be implemented without necessary measures to ensure security.

Smart Grid work involve the following:

1) Smart Grid project guideline describing (Requirement, Design, Integration, Testing, Validating), and how to define the boundaries and the appropriate level of interoperability.

2) User Requirements level. This area is the newest and therefore the development of the standards can be directed more easily.

3) Technical Design and Specification level. This is where too many standards exist, and cross-cutting compatibility must be demonstrated in great detail. The value of a framework here is to provide a catalogue of compatible guaranteed short listed standards, (or parts of standards). There are many international standards have come to address SG interoperability.

Components of Smart Grid are as follows:

1. Transmission Automation,

2. Distribution Automation,

3. Renewable Integration,

4. Demand Participation,

5. Small appliances / PVEV/ Storage,

6. Distributed Generation & Storage,

7. Energy Efficiency,

8. System operation. We have achieved reasonable maturity in 1 &2.

However we need to improve a lot in the rest.

What we need to do to achieve Smart Grid frame work are as follows:

1. Sensitise all stake holder about global developments.

2. Insist and mandate to procure equipment based on open standards)Work with National & International bodies driving SG concepts.

3. Standardise software / Hardware devices based on international standards (Meter to Control Room) - No proprietary.

4. Implement Security standards

5. Go for few pilot projects covering large area as in other countries

6. Replace equipments not suitable for integration.

Distributed Generation Environment for the Smart Grid

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This proposed topic covers the general aspects of smart grids and mainly focuses on some distribution level smart grid features, such as interconnection of distributed generation and active distribution management, using automated meter reading (AMR) systems in network management and power quality monitoring.

Currently, the main source of electrical power generation is fossil fuel producing carbon dioxide ($CO2$) emission and other gases, which lead to global warming. Due to environmental issues in reducing green house gases (GHG), the utilisation of renewable energy sources (RES) is now growing rapidly and is being widely accepted as an alternative power supply.

Traditionally power generation, distribution network management and loads have been considered as quite independent processes. Along with an increasing amount of distributed generation, the traditional approach is gradually changing. A considerable amount of renewable energy resources represent distributed generation, but also active energy resources such as loads, storages and plug-in hybrid vehicles will be increased. One of the main barriers for the penetration of active resources at distribution network level is the complexity of the interconnection process.

Smart Grid refers to the modernization of the electric power grid through the integration of digital and information technologies. Smart Grids use instruments and sensors for advanced monitoring capabilities in real time that can lead to more efficient and reliable management of electrical power systems and optimizing the operations of its interconnected elements from the central and distributed generations, through the transmission and distribution network, to end-use consumer equipments. Example of these instrumentation include phasor measurement units that can sense grid instability within seconds, smart meters installed at consumer locations for real time bi-directional communication, and programmable smart appliances that can report their usage and status.

Implementation of Smart Grids strategies by power utilities necessitates skills, experiences and knowledge. Understanding the Smart Grids requires knowledge of numerous key engineering topics in electrical and power engineering, telecommunications and information technologies. Such key engineering disciplines also must intersect other disciplines including sciences, markets, business strategies and processes, energy regulated policies and regulation. The Smart Grid requires a suite of new standards to be developed and implement from the technical point of view. Moreover, the Smart Grid is a customer-centred transformation of aged electricity grids and promises to deliver many costumers, hence consumer behaviour and social sciences also plays an important role in smart Grid. Professionals and engineers working in power industry and information and communications technologies will seek to upgrade and expand their practical skills to meet unprecedented market demand.

A Smart Grid impacts all the components of a power system. Generation is likely to change with a drive towards more renewable generation. of course, some renewable like wind farms are large and interface with networks, but many renewable are small scale, and hence and appropriate for interconnecting at the distribution level. Other changes in a distribution system include greater automation and switching, allowing for more physical control over with lines are opened or closed. Smart systems allow also better use of variable capacitor banks and static VAR compensators, automatic reclosers etc.

Smart grid makes distributed generation more practical through demand management which can absorb large fluctuations in generator output. Demand response is a customer action to control load to meet a certain target. This is different from demand side management where the load is controlled by the electric utility and the customer has no control beyond the initial consent.

An Overview of the Wind Energy Industry

Mr T Pradeep Kumar

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A country's progress is often measured by its electric power generation capacity. Energy, in any form, is the most important input to various economic facets - be it industry, agriculture, transportation, commercial units and public health or even for social development of the nation. However, it is of utmost importance that the generation of energy does not lead to the environmental degradation or concerns on ecology, such as greenhouse gas emission, increased carbon foot-print, SOx and NOx emission, particulate pollution, soil erosion, as the case may be.

The economic prosperity of a country is generally measured by the quality of living standards and more specifically quantified by GDP. One of the indicative parameters that determines the productivity of the country is 'per capita power generation' and 'per capita power consumption'. All the developed nations have a very high per capita power consumption expressed as PC Kwh. As can be seen by the table below, India ranks one of the lowest in PC Kwh and we have many more miles to go both in augmenting energy generation capacity and its utilization.

2013

Country	P C Kwh	Country	P C Kwh
Iceland	52980	Saudi	8741
Norway	27452	S.Africa	4389
USA	12988	China	3762
Australia	10199	Brazil	2529
S.Korea	10428	India	765
Austria	8513	Sri Lanka	526
Japan	7836	Pakistan	450
In 1983.....			
China	394	India	372

Table 1 : Per Capita power consumption of some of the countries

1.0 Power: Aperennial dilemma

On the installed power capacity base, India is yet to compare favourably with both developed and many developing economies. Energy continues to be a scarce commodity across the country, India requires about 380,000 MW of gross installed capacity by 2020, while we are able to add only 10000 MW annually. Table 2 summarizes the installed capacities of some of the countries.

2014

Country	Installed GW	Country	Installed GW
USA	1068.4	Russia	680.3
China	1505.3	India	302.4
Japan	310.3	Brazil	102.7

Table 2 :Installed power capacities

Some of the noteworthy observations from country's power demand requirements are:

* Energy availability is clearly in shortage. Almost 18-20% shortfall across the board.

* India needs atleast 380,000 MW by end 2020. Current capacity stands at 302000 MW

* We are able to add about 10000 MW p.a. while the requirement is 20000 MW p.a.

* The demand for electricity is growing @ 15 -18% p.a.

The transmission network penetration, stability is poor while the T&D losses are high.

2.0 Conventional Energy Sources -A critical review

2.1 Thermal Power - Limited choice

Today, the major source of country's energy (69%) is supplied by Thermal Power plants comprising of fossil fuels (such as coal, lignite, wood etc). Hydel Power plants (Mega, Mini and Micro) and Nuclear as well as Renewables make up for the rest. While the fossil fuel source availability continues to dwindle year after year, the pollution caused by them goes unabated. There arc severe environmental issues and challenges posed by the thermal power - fossil fuels in particular. They are as under:

* The naturally available coal in the country has low calorific value (< 3500 Kcal/kg)

* High ash content in the coal in excess of50% by weight.

* High ash content leads to higher particulate pollution.

* Environmental norms require pollution levels to be restricted to less than 50 - 100 mg/nm^3.

* The particulate pollution abatement calls for expensive cleansing mechanisms involving electrostatic precipitators and multi-cyclones.

* Lignite and some of the imported coals (for higher calorific value) also contain high sulphur composition leading to SOx pollution and acid rains in the extreme. This requires expensive scrubbers and DeSOx systems that needs continuous water source for operation.

* Scrubbers help to convert air pollution into water pollution. But, the menace of pollution continues to subsist in one form or the other.

* Therefore, it's a practice to locate thermal power plants at a safe distance from the urban centres to protect the populace from the effects of pollution. Obviously, this means higher T&D costs and rising Rupee per Kwh.

* All the 3 raw materials — coal. oil and gas have been spiralling upwards with time, in terms of cost.

* It is estimated that for generating about 1000 units of electricity, a carbon foot-print 0[8500 kgs is caused on the environment. India, at current level, produces more than 570 million tons of CO_2 p.a. that require about Rs.88000 crores per annum for cleansing up!

2.2 Hydel Plants - Issues and Challenges

Hydro-electric plants are yet another option to harness energy under the conventional scheme of things. While they are relatively clean compared to thermal power plants, they are much more expensive and do challenge ecological balance. Some of the key factors under consideration are:

* Capital intensive: Since a large hydro-electric plant involves a huge back up reservoir of water spread on a large catchment area and long pen-stocks to ferry the water to the turbines, the gestation period as well as capital outlay becomes very high.

* A Hydro Plant is always preceded by studying the rainfall pattern of several years and analysing the hydro-data for a consistent water potential. Despite the same, some projects are always subject to the vagaries of rainfall.

* The large catchment area required for hydel project often submerges many local villages around, displacing the local population. The re-habitation cost is prohibitive and time consuming. This also impacts the project cost adversely.

* The flow of water in a Hydro system deposits large amounts of silts due to soil erosion and this can cause ecological imbalance on a long run. Also, the leaves, bark, wood, bamboo and other forms of vegetation washed by the gush of water often rot and result in emission of methane and / or mercury.

* As the hydro plants are generally located in an area where the rainfall is relatively high, they often fall in the forest-area or in gorges and hilly regions that have a high potential to receive the rainfall. This means, the places are generally away from urban load centres leading to high T&D cost.

3.0 NUCLEAR ENERGY - A critical review

Many of the developed countries are embarking on the option of harnessing energy from nuclear fissionable materials to meet their electric power requirements. While a country like France generates 90% of its energy requirements from nuclear fuels, India has very insignificant nuclear penetration of less than 0.5% in its overall energy generation mix. From an Indian point of view, some of the issues and challenges related to this option are as under:

* Long gestation period from concept to actualization.

* Needs importation of critical equipment for reactors, nuclear pumps, etc.

* High capital cost (Rs. 20-25 cr./MW)

* Only few suppliers worldwide for supplying materials and strongly governed by NSG.

* India has good availability of Thorium ores-needing conversion to fissionable Uranium or plutonium.

* A nuclear plant requires multi-layered safety back-up.

* Requires enriched Uranium/ heavy water.

* There is always a risk of radiation contamination and a challenge to keep the operating personnel to guard their exposure to nuclear radiation levels much below the permissible limits.

* Nuclear waste disposal continues to be one of the biggest challenges.

* Nuclear plants need additional protection from espionages.

* There is a strong public resentment against nuclear plants both in India and abroad.

* Some of the irreparable and irreversible damages that have occurred on humanity from disasters such as Three mile, Chernobyl and Fukushima are still green in the people's mind.

4.0 Renewable Energy - The Nature's Choice!

In order to circumvent the various problematic issues and challenges posed by conventional power generation sources and nuclear power, there has been an increasing awareness to look at possible power resources that are environment friendly and available for longer duration of time. In this context, the mother nature is the best example for tapping energy resources that are aligned towards ecological balance and reliable on a longer term. Renewable energy, thus far, stands out the best option for exploration and commercialization in the light of advent of new technologies such as nano-technology, super-conductivity, improvements ill data based real time information systems with new approaches in aerodynamics and aero-elastics. Briefly, the renewables offer following advantages:

* Renewable Energy source does not deplete with time and usage.

* Bountiful energy is available from nature most of the time.

* Renewable energy is environment friendly.

* With improvements in technology, harvesting IS becoming easier and economical.

* Hybrid Technologies are possible! (like Solar + Wind)

* Projects with low gestation period.

* In harmony with people's livelihood.

* Modular construction and up-scaling possible easily.

* The Renewal Energy resources are widely distributed in nature.

Some of the renewable energy sources that are currently being harnessed include the following:

* Solar (PV, Thermal, Concentrated solar, etc.)

* 9 Wind Energy (onshore and offshore)

* Tidal power

* Geo thermal

* Bio-mass

* Fuel Cells (still in nascent stage of development)

5.0 Wind Energy - The obvious choice

Two of the most promising sources of renewable energy are the Sun and the Wind. Both the energies are abundantly available throughout the world and can be harnessed advantageously. Wind energy was harnessed in Europe in the earlier days for water lifting and irrigation. Similarly, it was also used for grinding cereals and grains in the flour mills. However, the idea of electricity generation from wind mills is relatively recent and dates back to about 40 years.

During the last 2 decades, enough improvements and innovations have come about in the design of wind turbines that has made this form of energy commercially viable. With the advent of economical energy storage systems, there is no doubt that both wind and solar will be the most preferred types of energy for electricity generation. The usage of conventional energy continues to drop down while renewables are slowly catching up in many parts of the world.

There are countries where the renewables have already penetrated more than 20% in the overall energy mix. The growing trend of renewables in the recent years is depicted in the figure below :

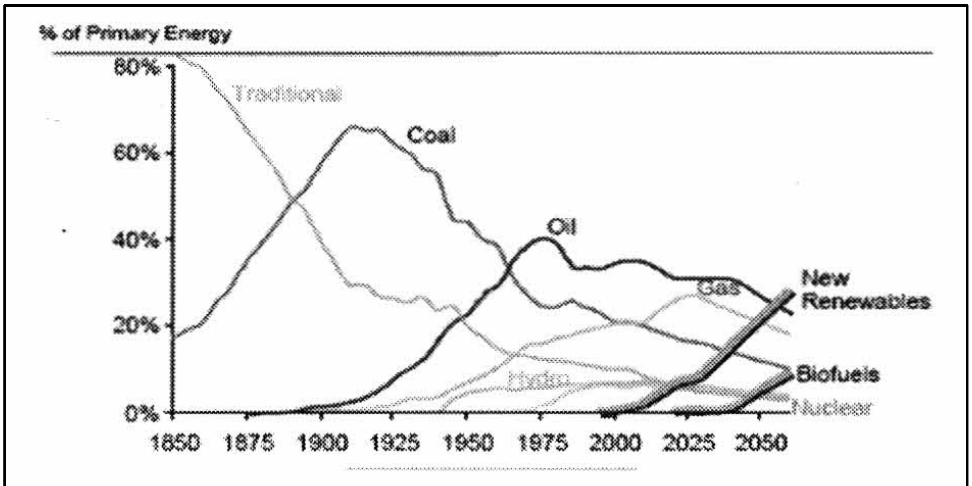
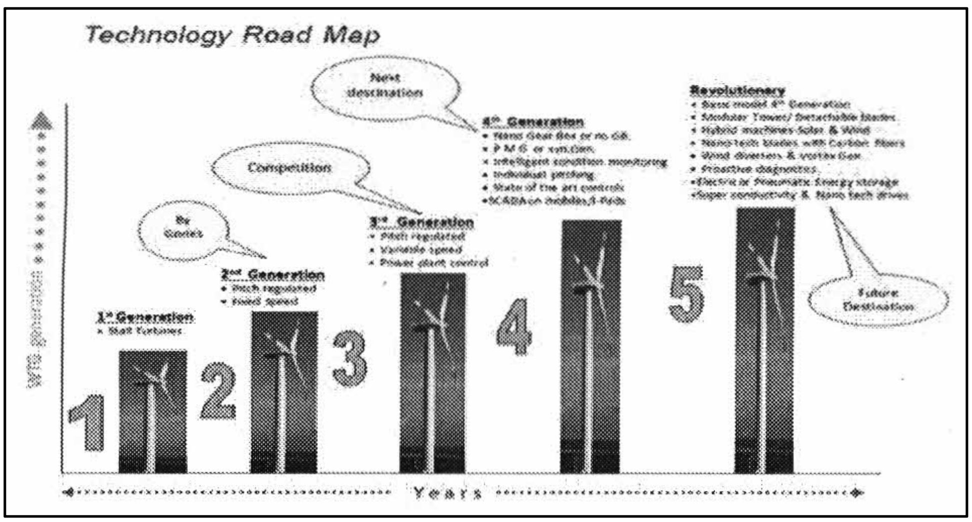


Figure 1 : The changing pattern of usage of different energy sources with time.

5.1Windmills Technology Evolution:

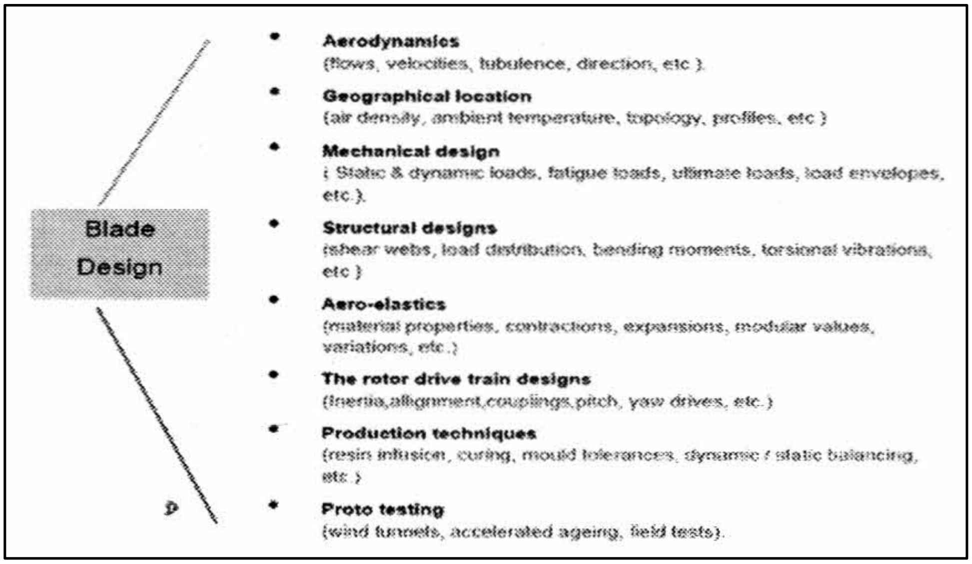
The earliest f0l111of windmills were with 'stall regulation' that soon transformed into 'pitch speed regulation' for better control of turbine performance.

The 3rd generation turbines of last decade embarks extensively on variable speed drives with power plant controls. Further, innovations such as permanent magnet generators (PMG), intelligent condition monitoring, individual pitch controls and SCADA usage for monitoring and control has now become the order of the day. Many radical innovations are currently being studied for defining tomorrow's wind energy turbines and these efforts are as depicted below.



5.2 Blade Technology

Blade is the heart of the wind turbine, responsible for converting kinetic energy of the wind to rotational energy (torque) to drive a generator with / without a gear box. The classic blade design is an amalgamation of several factors from various disciplines and highlighted as under:



reinforced fibre blades have performed well in the field with both epoxy or polyester materials.

5.3 Blade diameter and hub height.

The modem turbines have a large 'swept diameter' of the blades and longer turbine hub heights. Both the above factors result in turbine delivering higher output. Thus, for a giver MW size of the project, the number of turbine footprints can be reduced, resulting in economy of scales and lower cost of energy generated. Needless to mention that the turbine layout for the project (micro-siting) plays a vital role in lowering the cost of energy.

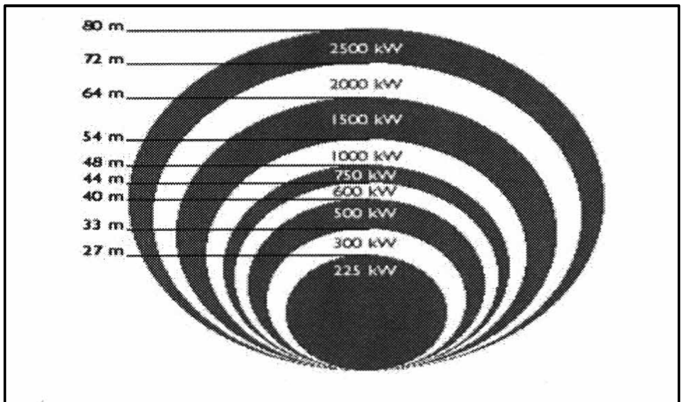
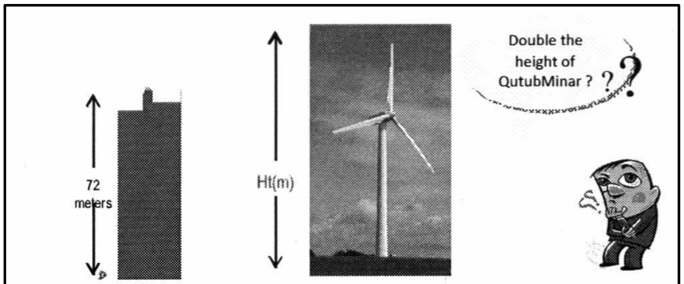


Figure 2: Indicative relationship between the power rating of the wind turbine and its blade swept diameter.



kW	350	600	1000	1250	1500	2100	2500	3000
Ht(m)	50	60	66	66	70	80	110	140

5.4 Innovations lead to lower energy costs

The new design approaches coupled with the new materials enable a modern turbine design to be cost effective- both in terms of Capex and Opex. Substantial value engineering and cost reduction techniques have been applied in the last 2 decades and the price per unit of power has substantially dropped down. Graph shown below is an indicative representation of energy costs for an onshore geared turbine.

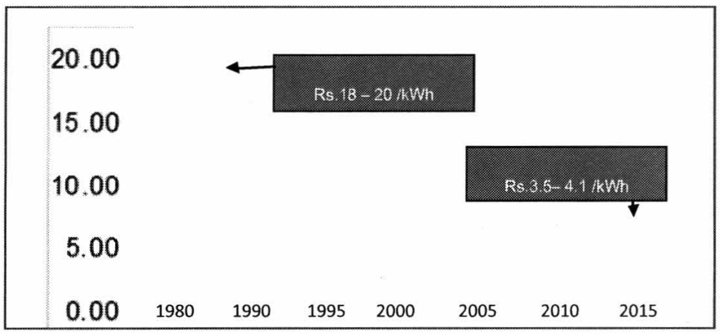


Figure 3 :levellizedcosts of generated energy

5.4 Global Wind Power Development

Due to enhanced reliability of wind turbines over the years as well as optimization in the size and ratings of the turbines coupled with SCADA controls that minimize turbine downtime, the availability of wind turbines has improved substantially. It is quite common that the modern turbines maintain a state of readiness to generate power throughout the year and the availability factor can be as high as 98-99% annually. Consequently, the cost per Kwh has decreased appreciably enabling wind energy to compete economically with other conventional energy sources. Therefore, many countries have embarked on, wind energy installations and the current scenario is summarized below:

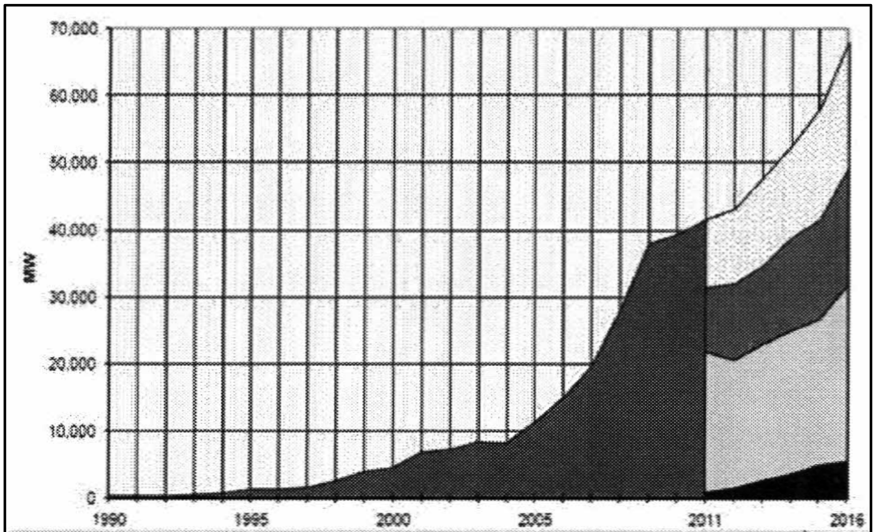
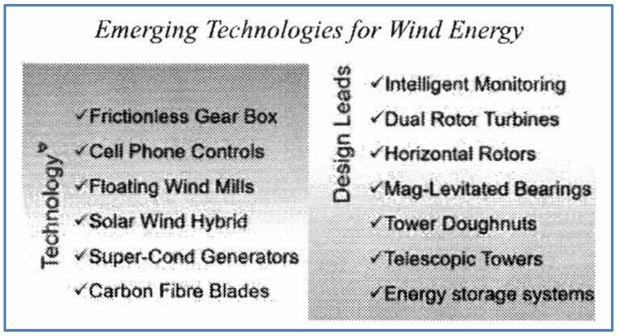


Figure 4 : Global Installed wind power capacities as on end 2016.

5.S Emerging Technologies for future wind business

Wind energy has made rapid strides in gaining global acceptance as all alternative form of electrical energy generation that is compatible with environment and lending itself to easy upscaling due to modular construction. Since, wind energy does not require large tracts of land (like solar projects) but needs only for footprints and internal pathways, conjunctive usage of land is possible for agriculture, horticulture, floriculture or for any other purposes. Smaller countries in Europe and in American continents that are affluent are also heading for offshore projects. In the last fortnight, an offshore project of 200 MW is also announced in India and competitive biddings are being called for the same. In a nutshell, wind energy is gaining acceptance at a rapid rate both for onshore and offshore.



The emerging technologies also offer greater latitudes in the renewable energy space. Amajor development is the hybrid solar- wind energy farms that bring down the installation costs substantially and ensure better utilization of capacity factors (similar to PLF) making cost per Kwh attractive. The new battery technologies are now enabling the economical storage of energy, thus making possible for more sustained levels of power supply. Pneumatic and hydraulic options for energy storage is also being explored.

One of the revolutionary concept that is likely to gain immense attention in the offshore wind energy arena is the 'Floating Wind turbines' that does away with marine foundation and offshore construction complexities. Equally interesting is the floating substation in the sea to reduce T&D losses as well as to reduce Capex costs. Nano technology can usher near frictionless gear boxes with synthetic lubricants in the future. New heat exchangers with nitrogen and hydrogen are also being studied to improve heat transfer, consequently reducing the generator size.

Solar and wind energy complement each other. While solar energy is economically tapped during the day time, the wind breeze can be more pronounced during the evenings and the nights. This dual advantage with economic power storage option shall revolutionize the future world energy off take. India is contemplating to be an economic super power and therefore, has a greater role to play in terms of its own energy policies, R&D incentives besides becoming a large manufacturing hub for rest of the world to harness economy of scale in power generation, transmission and utilization.

Classical Variable Speed Drives

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Abstract:

Right from the time Electricity is put to Industrial use Variable Speed operation of the Driving Motor has become of paramount importance. Fig.1 illustrates the necessity to have variable speed drives. Most of the Industrial operations demand control of some Fluid Flow to change the rate of production. Throttling, Bypass Valves were used earlier for fluid control. But both operations have poor efficiency. As can be seen from Fig.1 if the pump is driven by a variable speed motor the control is smooth and efficient.

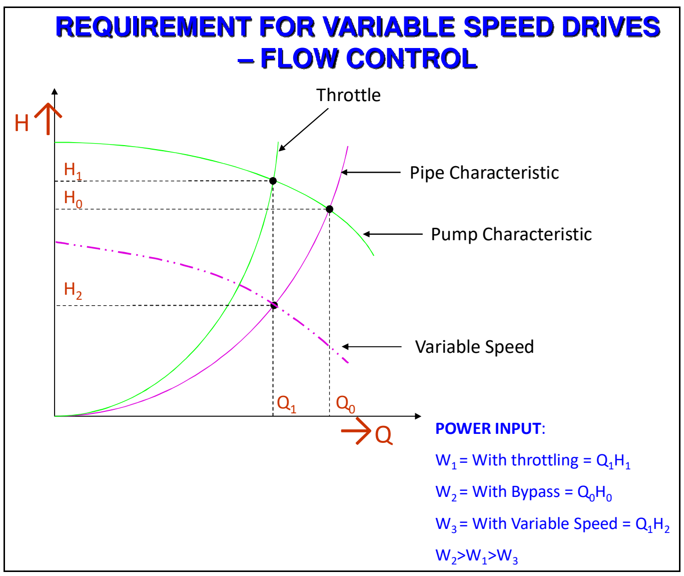


Fig.1 Fluid Control

With DC Motors, Variable speed operation is achieved through Armature or Field Voltage Control. The Torque-Speed Characteristic is shown in Fig.2. Of these two Armature control produces better Dynamic Response and is Widely Used. However this requires special machines to produce variable DC Voltage.

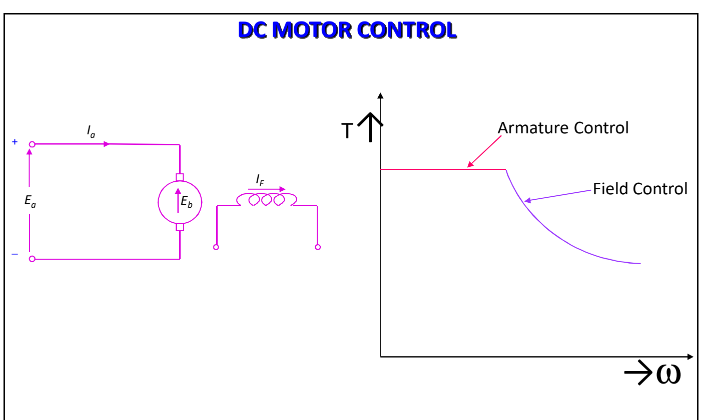


Fig.2. DC Motor Characteristic

Before the advent of Controlled Rectifier using Solid State Power Devices this is done through Cross Field Machine

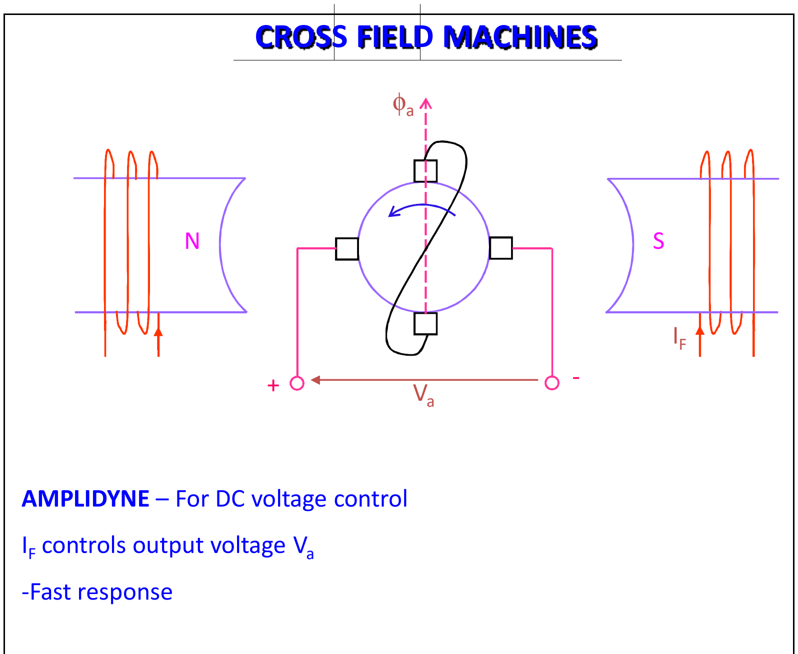


Fig.3 Amplidyne

Fig.3. illustrates the principle of operation of this machine.

With the development of Induction Motor which is more reliable and cheap compared to DC Motor Industrial applications have tilted towards Induction Motor. Variable speed operation of Induction Motor is through Stator Voltage Control as shown in Fig.4

Stator Voltage Control is lossy and requires bulk equipment. Further the characteristics obtained are not suitable for many Industrial applications.

The other methods like Pole Changing or Cascade connection produce only step change in speed and also require additional equipment.

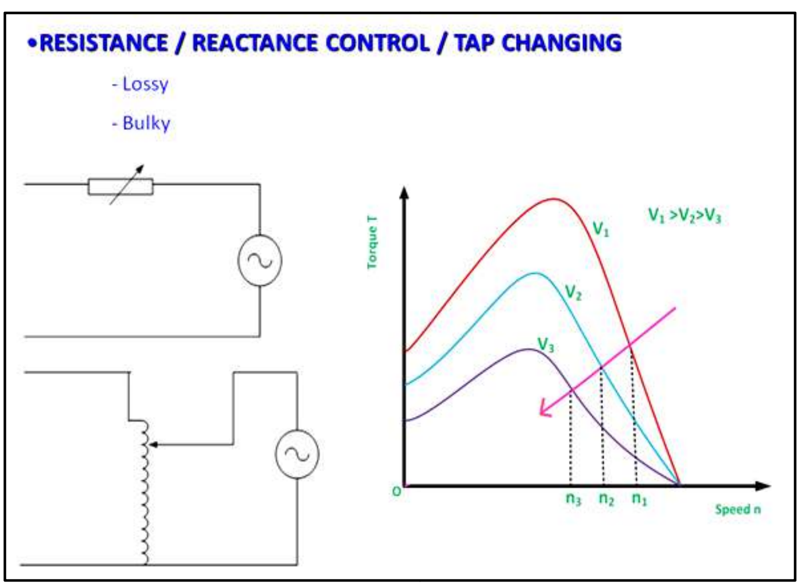
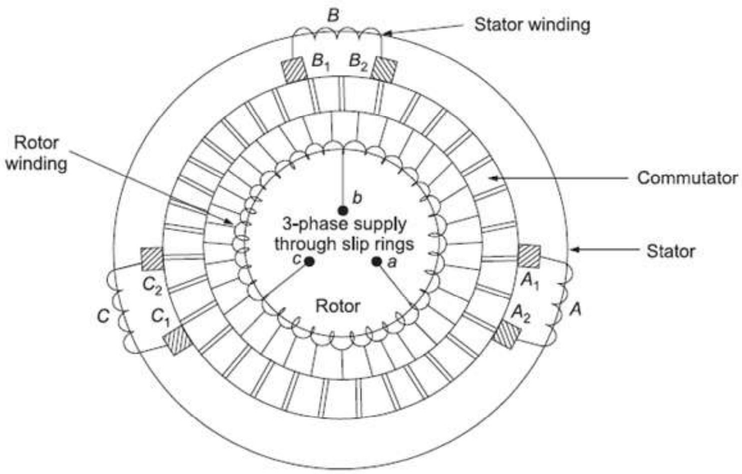


Fig.4 Stator Voltage Control of Induction Motor

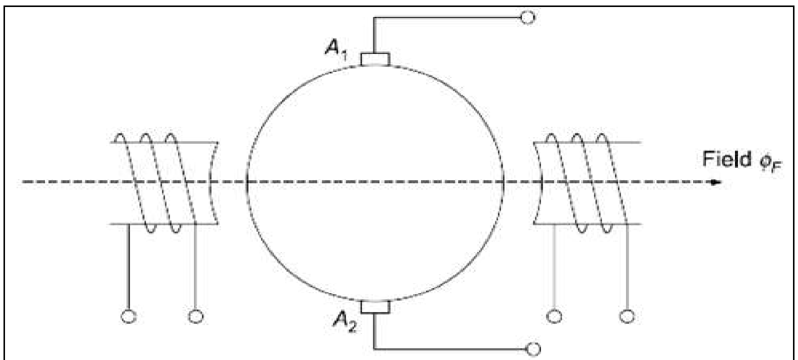
The application of Variable Frequency supply to stator or Rotor of Induction Motor is known to produce better characteristics compared to that of DC Motor but there were no suitable equipment to achieve this. Rotor Voltage injection at slip frequency as illustrated in Fig.5 was attempted through special design of Induction Motor. This Motor with modified winding design was called the SCHRAGE Motor and was made commercially available to Industries during 1920s much before the World War 2.The operation is based on the Inverted Operation of Induction Motor with AC supply given to Rotor windings and slip frequency Voltage obtained through an ingenious and simple method is injected into the stator windings. The voltage injected was made variable to control the speed.Fig.5 shows the schematic diagram of this machine which produces sub synchronous and super synchronous speeds with good efficiency.



AC commutator (Schrage) motor

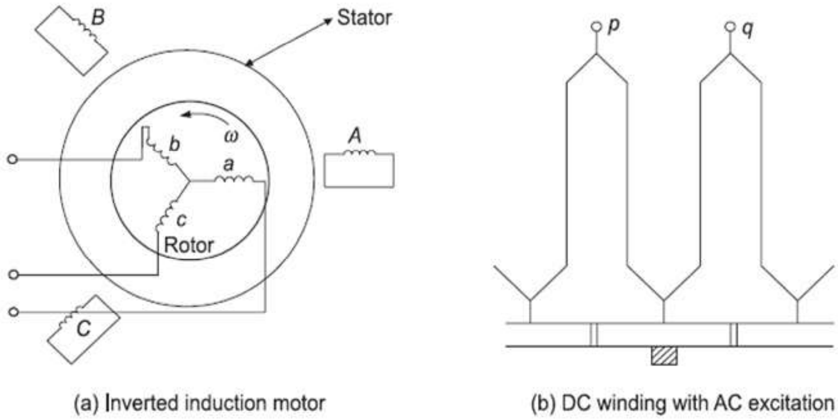
Fig.5 SCHRAGE MOTOR

Figs.6 and 7 illustrate the basic principle of generating variable slip frequency voltage which is the heart of this Motor. A modified winding called the Ring Winding was used which is able to be connected on one side to AC Supply through slip rings and has Brushes on the other side of the winding which are connected to the stator and supply variable slip frequency voltage.



DC machine schematic

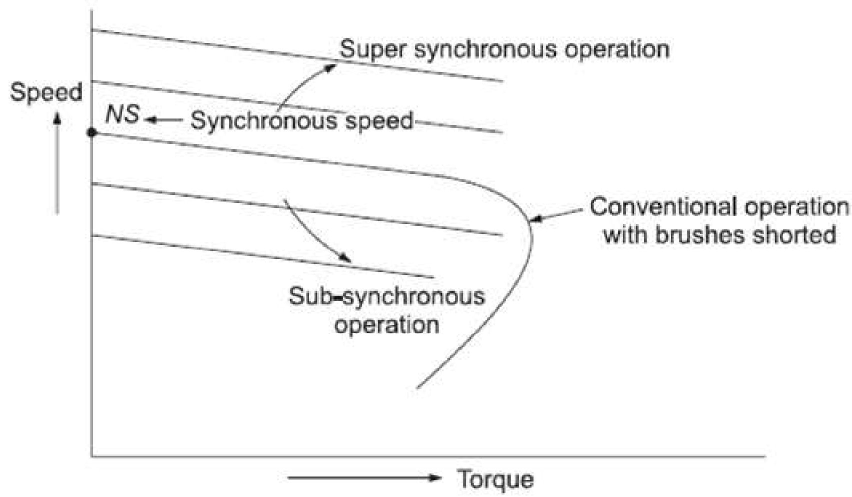
Fig.6 Generation of Slip Frequency



Inverted induction motor with commutator

Fig.7 Inverted operation of Induction Motor and Winding Configuration

Fig.8 shows the Torque-Speed Characteristics of this motor which are similar to that of conventional Doubly fed Induction Motor



Torque-speed characteristic

Fig.8. Schrage Motor Characteristics

After the successful development of Power Electronic Devices and availability of Variable Voltage and Frequency Inverters, these Classical Electromagnetic Machines with efficient Variable Speed operation are replaced by Electronic Controllers.

State-of-the-Art Non-invasive Electrical Techniques for Transformer Insulation Monitoring

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Abstract

Failure of power transformers due to insulation degradation is an issue of major concern among power utilities. Over the past two decades, quite a few electrical diagnostic techniques have been developed for the evaluation of insulation health of power transformers and minimize the risk of power outage. As the cellulosic insulation within power transformer cannot be accessed from outside, the prime objective of modern diagnostic technique is to perform measurement without opening it. With continuous improvisation from researchers across the globe, some of these non-invasive electrical techniques have now reached maturity and are being successfully used in practical diagnostic testing. The paper presents brief overview of various state-of-the–art non-invasive techniques used for condition monitoring of power transformer.

Keywords: Transformer Insulation, Moisture, Condition Assessment Techniques, PDC, RVM, FDS

Introduction

A large portion of the power industries at various countries throughout the globe is getting old. Collected statistics reveal that the most of the high voltage transformers were installed at early stage of 1960s and '70s. Significant numbers of equipment, particularly transformers, are close to the end of their designed life or have already surpassed it. More than 40% of the high voltage transformers are more than 30/40 years old in many power utilities through the world including India.

Independent power producers, transmission as well as distribution companies are optimizing the asset utilization, consequent upon the deregulation of electricity market. It is done by employing existing equipments in operation at ever-higher capacity levels. However, in many cases, nameplate ratings are exceeded to defer the capital investment for new facilities or in the refurbishment of existing facilities. Therefore, majority of the power utilities have focused on developing various advanced condition assessment techniques of HV equipment to extend the operating life of the existing infrastructure. Extension of transformers life can be possible only if utilities can assess the present condition properly. Reliable diagnostic tools for condition monitoring of high voltage equipment such as transformers is also quite important from the point of view of reduction of maintenance.

Moisture in Transformer Insulation

The operating life of an in-service transformer primarily depends on its composite oil-paper insulation. However, transformer insulation undergoes various stresses including chemical, electrical, mechanical, environmental stresses during its operation resulting gradual degradation of its dielectric properties. The degradation is primarily a scission reaction of cellulosic insulation, which is greatly accelerated by heat as well as the presence of moisture and oxygen. Among them, moisture is particularly responsible for detrimental of the cellulosic parts of insulation, as it can initiate hydrolysis and scission reaction of it [1-4]. Presence of moisture in oil-paper insulation and its adverse effect has been recognized since 1920s. According to Clark (1942), the operating life of cellulosic insulation in terms of mechanical strength is halved if the moisture content in it becomes doubled. Fabre and Pichon (1960) reported that, the rate of the thermal aging of cellulosic insulation is proportional to the presence of moisture content in it. Based on the moisture presence, insulation is categorized into three groups, viz. Thick Insulation, Thin Cold Insulation and Thin Hot Insulation.

Moisture Content in Transformer Insulation

During manufacturing of transformer in factory, the paper insulated windings undergo extended drying process prior to oil-impregnation. At this stage, the new transformer contains moisture content of less than 0.5% by weight in the cellulosic parts and 6 ppm in oil [2-3]. However, due to aging of transformer insulation, the moisture content increases gradually. In the case of severely deteriorated transformer insulation, the moisture content of cellulosic insulation can be more than 4%.

Moisture in Transformer – Where?

Moisture generally resides in oil in dissolved state. Sometimes, it is absorbed by polar aging products (bonded water) and forms hydrate. Besides, cellulose fibers residing in the oil may contain some moisture. In a transformer, the total moisture is distributed among the cellulosic insulation and oil. However, majority of moisture is contained within the cellulosic insulation.

Moisture Distribution in Transformer

Under steady working conditions, thermodynamic equilibrium between moisture absorbed by insulating paper and moisture dissolved in oil is maintained. However, moisture transfer between oil and paper can be caused by temperature gradient, moisture concentration gradient and pressure gradient.

Moisture Transfer Mechanism

Under normal operation, the temperature gradient is primarily responsible for moisture transfer dynamics. As temperature increases, fraction of the moisture in paper migrates to oil. When temperature decreases moisture returns to paper [2]. This moisture migration from oil to cellulose at lower temperatures is very slow and may result in free water in bulk insulation of transformer.

Effects of Moisture in Transformer Insulation

Water is a polar liquid with high permittivity. It is aligned in the direction of strong electrical field. The migration of moisture from cellulose to oil has been found to be associated with the phenomenon of static electrification that appears when charge accumulated at the interfaces between dry and moist zones. Cellulose has greater affinity for moisture than oil. Therefore, water molecules replace the oil in oil impregnated cellulose. Thus, both oil and paper lose their dielectric properties due to ingress of moisture.

Serious Problems due to High Moisture Content

High moisture content often makes the results of other condition monitoring methods, such as furan measurement, ambiguous. Free water in oil accumulates at the bottom portion of transformer tank. However, if the water is directed onto windings suddenly through oil pump operation, major electrical breakdown or short-circuit may occur due to insulation failure. Moisture production and aging increases with temperature – thus a moist transformer needs to be de-rated.

Moisture Detection

A. Crackle Test: A classical method for detecting moisture in oil is the 'crackle test' [5]:

A red hot glass rod is dipped into the collected oil sample. With low moisture content a slight hissing noise is generated, but for high moisture content such test produces a distinctive 'crackling' sound as the water boils. Crackle test could detect only large amounts of water, typically above 50 ppm. B. Karl Fischer Titration (KFT): A widely used automatic coulometric method for estimation of very small concentrations of moisture in oil [2], which can be lower as 1-2 ppm. As the moisture migration between the cellulose and oil is very slow, the Karl Fischer test provides, close estimation of the insulation quality of the oil alone. However, Karl Fischer test does not provide no indication virtually of the moisture content in cellulosic insulation system. A transformer at 20°C may have only 20 ppm of moisture in oil, but the paper could have moisture content as high as 4% by weight, indicating severe degradation of the paper.

Problems with Karl Fischer Titration

KFT measures the amount of moisture dissolved in transformer oil. Some of the moisture is chemically bonded to the agents as byproducts of oxidation. However, this bound water is only partially available for measurement by KFT. With the increase in aging status of the oil, the moisture gets bounded at the sites provided by degradation of ageing byproducts. A portion of the moisture gets bounded to the particles suspended in oil and these moistures would not be readily available for KFT measurement.

MOISTURE MIGRATION BETWEEN PAPER AND OIL

When a large transformer is dried on site by hot oil circulation, the moisture content of the oil may quickly be reduced to a very low level. But measure the oil moisture content again in a few months' time; it may well go back to its pretreatment value. Because the paper holds the majority of the moisture, while the oil take up only a small fraction of that. The oil directly in contact with the paper reaches saturation quickly and moisture exchange is inhibited until fresh unsaturated oil replaces it.

As the total insulation system attempts to reach equilibrium again after oil-processing, more moisture will migrate slowly from the still moist paper into the now very dry oil.

Moisture Equilibrium between of Paper and Oil

As reported in several literatures, equilibrium curves show amount of moisture present in paper versus oil at different temperatures.

Equilibrium Curves:

- Fabre-Pichon curve [2]
- Weidmann curve [6]
- Oommen curve [7]
- Griffin curve [8]

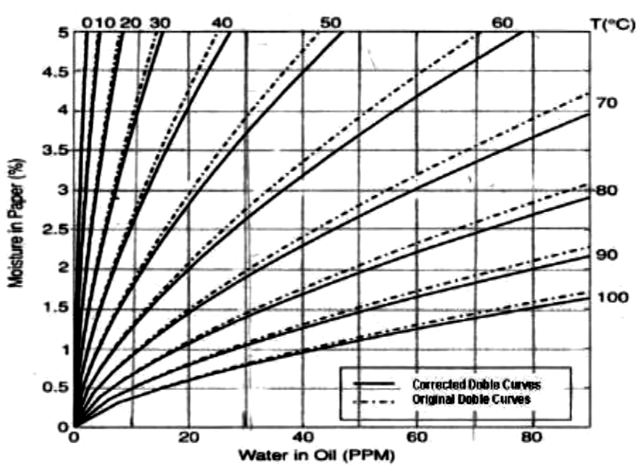

Fig.1. Typical equilibrium curve of oil-paper insulation [8]

Through these curves, the moisture in cellulose can be estimated through determining the moisture in oil.

Method of Conventional Estimation:

- Take oil sample.
- Determine moisture in oil by Karl Fischer test.
- Moisture estimate in cellulosic insulation from moisture equilibrium curves.

With inaccuracies of 2 ppm in the Karl Fischer test and 5 degrees in temperature measurement, the moisture assessment from the equilibrium curves can easily be placed in the incorrect zone. Problems in relation to Moisture Equilibrium Moisture equilibrium requires a long time to attain. Time required to reach equilibrium varies from hours to several days based on temperature. Moreover, the time to equilibrium can vary with the direction of water flow. The process of water absorption from oil to paper is slower than the reabsorption of water by the paper from oil. Besides, the temperature within transformer varies with time as the load is changed continuously along with ambient temperature.

TRANSFORMER INSULATION DIAGNOSTICS

Transformer insulation diagnosis tools may be divided into two groups: i) those characterizing the overall state and ii) those characterizing local defects present in the insulation system. Insulation diagnosis through dielectric response measurement provides information on the overall condition of the insulation, whereas local defects inside the insulation can be better localized partial discharge tests and the frequency response analysis (FRA-method).

While traditional oil examination methods are still an important basis for the observation of insulation ageing, however, the following methods are the main issue of this article as effective tool for multi-layer composite insulation diagnostics:

i) Polarization and Depolarization Current (PDC) Measurement.

ii) Recovery Voltage Measurement (RVM).

iii) Frequency Domain Spectroscopy (FDS).

These three standard methods collectively known as the dielectric spectroscopy are used for condition assessment of the composite insulation. Methods (i) and (ii) are in time domain, while method (iii) is in frequency domain.

TIME-DOMAIN METHODS

PDC Measurement

Polarisation and depolarisation currents (PDC) measurement is direct and simple technique for the condition monitoring of transformer insulation [9-12]. Through the technique, the “dielectric response function” of composite oilpaper insulation system is quantified in time domain and most significant parameters of the different components of the composite insulation can be evaluated by post processing. This PDC measurement technique can well be employed for assessing the condition of transformer insulation under on-site conditions using appropriate instrumentation.

A steady charging voltage having magnitude of U_0, which is ripple free, is applied to the test object. The test object is fully discharged prior to the measurement to eliminate memory effect. The polarization current $i_{pol}(t)$ flowing through the test object is given as follows

$$i_{pol}(t) = C_0 U_0 \left[\frac{\sigma_0}{\varepsilon_0} + \varepsilon_\infty \delta(t) + f(t) \right] \tag{3}$$

where, C_0 represents the geometric capacitance of the insulation under test, and $\delta(t)$ is the delta function arising due to application of steady voltage at $t = t_0$.

The current (as shown by eqn.3) has three components: The first part is dependent on the conductivity of the insulation, which does not depend on any polarization process. The last part of the polarization current is due to various polarization processes. The second part (the delta function) is quite difficult to record in practice.

Once the magnitude of the polarization current becomes very low or is nearly constant due to the dc conductivity or, the measurement process is stopped. After that, the test object is short-circuited for a certain period ($t = t_p$) and the depolarization (or discharging) current i_{depol} is measured. During measurement of depolarization current, change of the voltage from U_0 to zero can be treated as negative voltage step at the time instant of $t = t_p$. If the second term in eqn.3 is neglected, which is quite negligible, the depolarization current can be represented as

$$i_{depol}(t) = -C_0 U_0 \left[f(t) + f(t + t_p) \right] \tag{4}$$

However, the second component of eqn. (4) can be neglected, if the completion of all polarization processes takes longer charging period. Hence, the depolarization current in eqn. (4), becomes proportional to the dielectric response function f(t). Eqn. 3 and eqn. 4 are thus basis for the evaluation of the dielectric response function f(t), i.e. for investigation of dielectric materials properties in the time-domain. The typical nature of the polarization and depolarization current has been shown in Fig. 2.

Typical PDC measurements

The PDC can be measured by “two electrode” system as shown in Fig.4. Both the currents are recorded from starting at not less than at 0.1 to 1s after the switching processes and measurements are made up to hours. The magnitude of the applied voltage during polarization current measurement (as shown in Fig.3) is kept nearly 1000V [10-12].

However, the power supply used in PDC measurement must be free of ripple and provide very stable voltage once the switching is done. In case of PDC measurement, switching is done through using relays. The magnitude of the polarization and depolarization current is in pA range. Therefore, electrometer is used to record the currents.

The connection diagram for PDC measurements in the case of real-life transformers is shown in Fig.4.

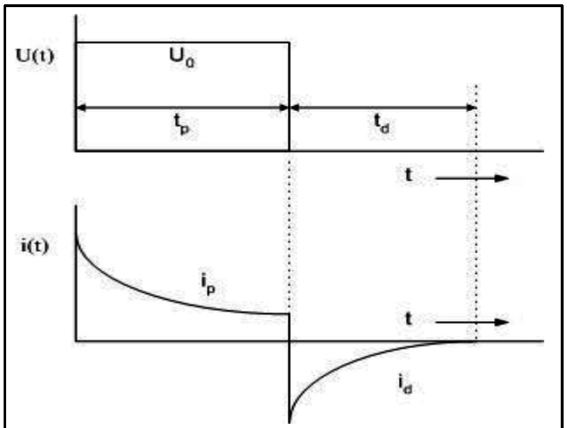

Fig 2. Polarization and Depolarization current of composite insulation [10]

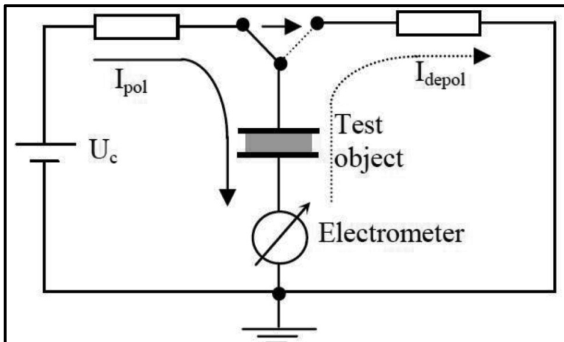

Fig 3. Two active electrode test set-up for PDC Measurement [10]

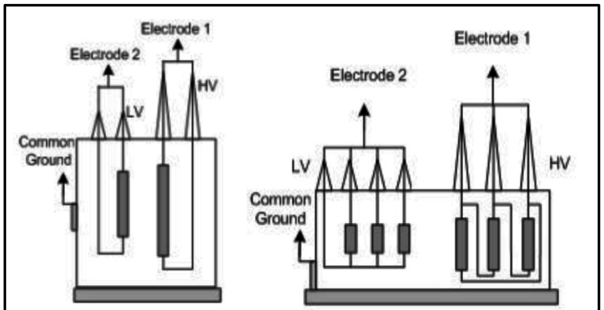

Fig 4. PDC measurements on a transformer with two-active electrodes[10]

Measurement of Recovery Voltage

The fundamentals of the RVM technique resulting in a "polarisation spectrum" were presented by Bognar, Kalocsai, Csepes, Nemeth and Schmidt at the 1990 CIGRÉ Session [13-15]. The typical waveform of recovery voltage is shown in Fig. 5. Similar to Fig. 3, a dc voltage having known magnitude of U_0 is applied to the insulation under test (which is discharged completely through short-circuiting the terminals) during a particular time interval t_1, which must be long enough to disperse completely the after-effects due to the application of the voltage. After a small short circuiting period a "return" or "recovery" voltage, $U_r(t)$, is measured across the terminals of test object with a voltmeter having very high input impedance [16-17].

The recovery voltage within insulation is developed due to the active relaxation process of dipoles within it, which are not completely relaxed during short-circuit period. The shapes and magnitudes of the recovery voltages, $U_r(t)$, may vary depending on the magnitude of the applied voltage as well as the duration of t_1 and short-circuit period. Therefore, for making any analysis based on the quantitative results of this technique, all three factors need to be considered into account.

The results of RVM could be explained by representing the dielectric with the equivalent circuit as shown by Fig. 6. If dc voltage U_0 is applied to the equivalent circuit (as shown in Fig. 6) during $0 \le t \le t_1$, the polarization of various dipoles within insulation occur. As a result, polarization currents along with the conduction current through R_0 flow into the circuit. In the case of C_0, the polarization process occurs instantly, whereas the branch capacitors are charged with some delay according to their time constants (R_iC_i). Based on the duration of charging period (t_1), the various dipoles within insulation are either fully or partially polarized. However, during short-circuit period C_0 discharges instantly whereas dipoles takes finite duration for discharging based on their corresponding time period. After a finite shortcircuit period, when the circuit is made open for $t > t_2$, the recovery voltage $U_r(t)$ is developed due to the partial relaxation of dipoles. The magnitude of the recovery voltage, which is thus not only dependent on to U_0, but also dependent on the charging time as well as short-circuiting time. The initial slope of the recovery voltage is proportional to the duration of depolarization current (t_2), which is thus related with the polarization process intensity for a specific instant.

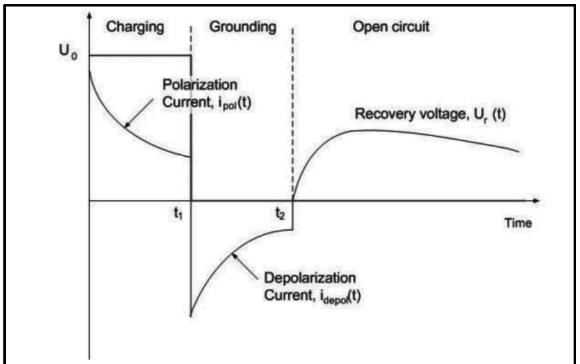

Fig 5. Nature of Recovery Voltage waveform [10]

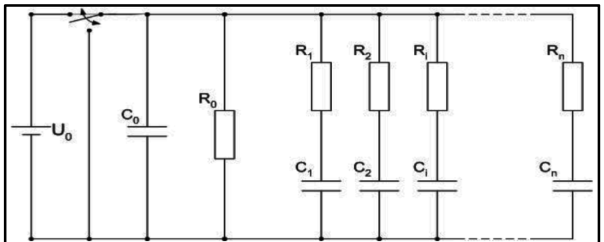

Fig 6. Equivalent model of transformer oil-paper insulation system [10]

The moisture in the cellulosic parts in the transformer's insulation system can be estimated through analyzing "polarization spectrum" obtained from the RV measurement [18-20]. This spectrum is generally obtained through applying a numbers of individual charging voltages U_0 to the insulation, followed by a discharging period. In practice, the charging period (T_c) and the discharging period (T_d) are enhanced, keeping a fixed ration of $(T_c/T_d) = 2$ for the measurement steps. However, it is to be mentioned here that, no measurements are taken during the individual charging short-circuiting period.

After short-circuiting period of T_d, the recovery voltage for a particular cycle is measured and recorded based on its peak value. The amplitude of the polarization spectrum U_{rmax} is employed along with the charging period T_c for that cycle for assessing the insulation condition. In order to obtain polarization spectrum, some kind of interpolation is needed through combining the individual measuring points.

FREQUENCY DOMAIN METHOD

Transformer insulation aging byproducts are mostly polar in nature. Hence, they affect dielectric dissipation factor (tanδ) as well as capacitance in quite different way in different frequency ranges. The knowledge of variation of tanδ and capacitance at different frequencies forms the basis of condition assessment of oil paper insulation in Frequency domain spectroscopy (FDS). For this purpose, the composite insulation is subjected to a sinusoidal excitation over a wide range of frequencies typically from (1 mHz - 1 kHz) for a minimum of two cycles and the corresponding response current is measured [10]. The dielectric response current is then transformed from time domain to frequency domain by using either Laplace or Fourier transformation. For a sinusoidal excitation voltage of $\bar{U}(\omega)$, the current that flows through the insulation for a particular angular frequency (ω) can be written as

$$\bar{I}(\omega) = j\omega\bar{C}(\omega)\bar{U}(\omega) \qquad (5)$$

where $\bar{C}(\omega)$ is the complex capacitance. The complex capacitance can be further split into real and imaginary parts as

$$\bar{C}(\omega) = C'(\omega)\, jC''(\omega) \qquad (6)$$

Since $C'(\omega)$ and $C''(\omega)$ are related to the complex permittivity of the insulating medium, hence equation (6) can be further written as

$$\bar{C}(\omega) = C_0 \left\{ \varepsilon_r'(\omega) - j\left[\varepsilon_r''(\omega) + \frac{\sigma_0}{\varepsilon_0 \omega}\right]\right\} \qquad (7)$$

where C_0, ε_0 and σ_0 represents geometric capacitance, permittivity of free space and dc conductivity, respectively. Now, the dielectric dissipation factor (tanδ) can be represented as

$$\tan\delta(\omega) = \frac{C''(\omega)}{C'(\omega)} \qquad (8)$$

It is evident from equation (8), that $\bar{C}(\omega)$ and tanδ are both frequency dependent parameters. FDS results give a spectrum, a set of values of $\bar{C}(\omega)$ and tanδ measured for a range of frequencies, which are often presented as the real and imaginary parts of capacitance or relative permittivity. Fig. 7 shows the typical FDS spectrum obtained for composite oil paper insulation [21]. It is to be noted that the percentage paper moisture content is related to the dielectric dissipation factor by the following equation [22].

$$\%pm = 15.297 + 2.53267 \times \ln(\tan\delta_{min}) \qquad (8)$$

Hence, the paper moisture content can be estimated from the dielectric dissipation factor profile of the insulation. From Fig. 7, it can be pointed out that different sections of FDS spectrum are an indicator of properties of both oil as well as the solid parts of insulation.

Typical FDS measurement

Fig. 8 shows the typical arrangement of FDS measurement on site. The sinusoidal excitation voltage from 1 mHz-1kHz is impinged on the high voltage bushing of the transformer for two cycles and the corresponding response current is recorded from the low voltage terminal. The tank and the core of the transformer is connected to guard terminal of the measuring equipment. The supply voltage may vary from 5V-200V (r.m.s.). From the amplitude and phase of the applied excitation and the response current, different dielectric parameters (dielectric dissipation factor, complex capacitance, etc.) are calculated for different frequencies.

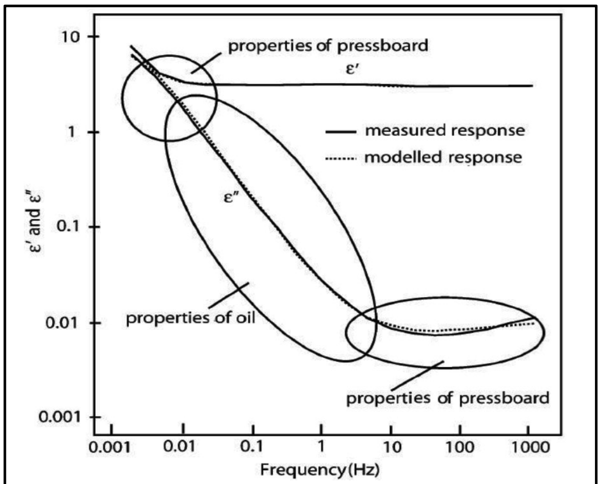

Fig 7. Typical FDS spectrum obtained for composite oil-paper insulation [21]

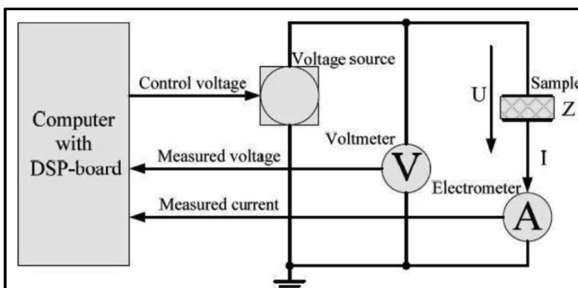

Fig 8. FDS measurement set-up [23]

Salient features of FDS measurement

Apart from estimation of moisture content of the solid parts of insulation, another important aspect of FDS measurement is that the method enables to calculate the Capacitance ratio for a given transformer. Capacitance ratio (CR) is defined as the ratio of the capacitance measured at 1 Hz to capacitance at the power frequency. The typical value of CR for a good transformer is about 3-5 [24]. Since a complete frequency spectrum is available, it is plausible to discriminate different polarization mechanisms. Effect of moisture content and aging can be separated. Since, FDS is robust against noise, hence it is a preferred choice to be performed on site. Effect of surface creepage currents on transformer bushings are eliminated as the measuring equipment employ a three terminal device. However, FDS results are severely affected by changes in temperature during measurement. FDS measurements can become quite lengthy at very low frequencies. During FDS measurement, at least two cycles of ac voltage is required for measuring the phaseshift and magnitude of voltage and currents. Hence, measurement of single value of "C - tanδ" at 1 mHz requires more than 2000s [11].

Conclusions

Considering the importance of condition based maintenance, measurement of dielectric response offers new possibilities of on-site noninvasive assessment of insulation high voltage transformers. This paper discusses three such methods used for condition monitoring. However, it should also be noted here that one method is not sufficient to gather complete information about the composite insulation system of high voltage power equipment. Further researches are necessary in this direction.

References

1. F.M.Clark, "Factors affecting the mechanical deterioration of cellulose insulation", Trans. Elect. Engg, Vol. 61, pp 742-749, Jan-Feb, 1942.

2. J.Fabre and A.Pichon, "Deteriorating processes and products of paper in oil. Application to transformers", Proc. of Int. Conf. Large High Voltage Electric System, Paris, France, Paper 137, 1960.

3. E.J.Murphy, "Thermal decomposition of natural cellulose in vacuo", J. Polymer Science, Vol. 58, pp 649-665, 1962.

4. W.Lampe and E.Spicar, "The oxygen-free Transformer, Reduced Aging by Continuous Degassing", CIGRE, Paper. 12-05, 1976.

5. J. Fitch, "Oil Analysis for Maintenance Professionals", Tulsa OK, Noria Corp, 1998.

6. Y. Du, M. Zahn, B.C. Lesieutre and A.V. Mamishev, "Moisture Equilibrium in Transformer Paper-Oil Systems", IEEE Electrical Insulation Magazine, Vol. 15, No. 1, 1999.

7. T.V.Oommen, "Moisture Equilibrium in Paper- Oil Insulation Systems", Proc. of Electrical Electronics Conference, Chicago, October 1983.

8. P.J.Griffin, "Water in transformer – so what! National Grid Condition Monitoring Conf, May, 1996.

9. A.J.Kachler, "Onsite Diagnosis of Power and Special transformers", Proceedings of IEEE International symposium on Electrical Insulation, Anaheim, California, USA, 2000.

10. W.S. Zaengl, "Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment: Theoretical Considerations", IEEE Electrical Insulation Magazine, Vol. 19, No.5, 2003.

11. T.K. Saha and P. Purkait, "Investigation of Polarisation and Depolarisation Current Measurements for the Assessment of Oil-Paper Insulation of Aged transformers", IEEE Trans. Dielectrics and Electrical Insulation, Vol.11, No.1, 2004.

12. T.K. Saha, P. Purkait and F. Mueller, "Deriving an Equivalent Circuit of Transformers Insulation for Understanding the Dielectric Response Measurements", IEEE Trans. Power Delivery, Vol. 20, No. 1, 2005.

13. A. Bognar, L. Kalocsai, G. Csepes, E. Nemeth and J. Schmidt, ''Diagnostic Tests of High Voltage Oil-paper Insulating Systems in Particular Transformer Insulation using DC Dielectrometrics'', Proc. 33rd Int. Conf. Large High Voltage Electric Systems. CIGRE, Paris, France, Vol. 2, Paper 15.33-08, 1990.

14. A. Bognar, G. Csepes and I. Hamos, ''Comparing Various Methods for the Dielectric Diagnostics of Oil-paper Insulation Systems in the Range of Low-Frequencies or Long Time Constants'', 8th Int. Symp. HV Eng., Yokahama, Japan, pp. 99- 105, 1993.

15. U. Gafvert and E. Ildstad, ''Modelling Return Voltage Measurements of Multi-layer Insulation Systems'', IEEE 4th Int. Conf. Properties Appl. Dielectric Materials (ICPADM), Vol. 2, pp. 123- 126, 1994.

16. V. Der Hohuanesian and W. S. Zaengl, ‘‘Time Domain Measurements of Dielectric Response in Oil-paper Insulation Systems’’, IEEE Intern. Symp. Electr. Insul., Vol. 2, pp. 47-52, 1996.

17. P. R. S. Jota, S. M. Islam and F. G. Jota, ‘‘Modeling the Polarization Spectrum in Composite Oil-paper Insulation Systems’’, IEEE Trans. Dielectr. Electr. Insul., Vol. 6, pp. 145-151, 1999.

18. B.Chatterjee, D.Dey and S.Chakravorti, “Implementation of integrated, portable transformer condition monitoring instrument in the classroom and on site”, IEEE Trans. on Education, Vol. 53, No.3, pp 484-489, 2010.

19. D. Dey, B Chatterjee, S. Chakravorti and S. Munshi, “A Hybrid Filtering Scheme for Proper Denoising of Real-Time Data in Dielectric Spectroscopy”, IEEE Trans. on Dielectr. and Electr. Insul., Vol. 14, No. 5, Oct, pp 1323-1331, 2007.

20. D. Dey, B Chatterjee, S. Chakravorti and S. Munshi, “Importance of Denoising in Dielectric Response Measurements of Transformer Insulation: an Uncertainty Analysis based Approach”, Measurement, Elsevier, Vol. 43, pp 54-66, 2010.

21. Blennow, C. Ekanayake, K. Walczak, B. García and S. M. Gubanski, “Field Experiences With Measurements of Dielectric Response in Frequency Domain for Power Transformer Diagnostics”, IEEE Trans. Power Delivery, Vol. 21, No. 2, pp. 681-688, 2006.

22. W. S. Zaengl, “Applications of Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment”, IEEE Electrical Insulation Magazine, Vol. 19, No. 6, pp 9-22, 2003.

23. S. Chakravorti, D. Dey and B. Chatterjee, “Recent Trends in the Condition Monitoring of Transformers:Theory, Implementation and Analysis”, Springer, ISBN 978-1-4471-5550-8, 2013.

24. I. Fofana, H. Hemmatjou, F. Meghnefi, M. Farzaneh, A. Setayeshmehr, H. Borsi and E. Gockenbach, “On the Frequency Domain Dielectric Response of Oil-paper Insulation at Low Temperatures”, IEEE Transactions on Dielectrics and Electrical Insulation., Vol. 17, no.3, pp. 799- 807, Jun. 2010.

Grid-Storage Implications: What Is It? What Will It Cost?

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Today, India's electrical power is primarily produced using coal, though the cost per unit is not less that that produced using renewable sources like solar and wind? This is so, even when it is recognised that coal-power is highly polluting and is severe contributing to green-house emissions. The primary reason is because the renewable energy from solar and wind is available is not controllable and the time and extent of availability is God's will. The power is not necessarily produced when there is a demand and there is no way to match load with generation.

The only way to change is to use "electric storage." Massive amount of storage is needed to store electric energy when generated so as it can be used when needed. The grid-storage, the terms used for grid-level storage of electrical energy, has to be very large, of the order of hundreds of GWh or more. Is this possible? What will it cost today and tomorrow? How much will it add to the cost of renewable energy? Will renewable energy with storage still be competitive to energy from fossil fuels like coal, gas and oil?

The presentation will look at the costs today and the possible costs tomorrow. It will also present a short-term opportunity to have energy-storage at campus or at commercial complex level. The first benefit would be to get rid of diesel generator. This itself would amount to significant savings of energy-costs. On top of it, if city power-utilities enables "Time of Use Metering" based on demand-supply gap, the return of investment on storage would be shown to be very quick.

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- Recent Development in Cleaner Nuclear Technology
- Smart Grid in our villages, in context to Indian Scenario
- Sustainable Development and Renewable Energy
- Distributed Generation and Power Quality
- FACTs Controller
- Integration of Communication Technology in Power Sector
- Energy Conservation
- Use of Transducers in Electrical Systems
- Grid Management in a Multiple Energy Resources Scenario
- Industrial Automation
- High voltage Engineering in Direct Current
- National and International Power Market
- Electrical Energy Conservation and Management in Process Industry
- Micro Hydel Projects for isolated areas
- Usage and Restrictions for LED fixtures
- Electric vehicles
- Solar based Electric vehicles
- Conversion of electromagnetic energy into direct current (Rectennas- part antenna & part rectifier)
- Embedded Systems for Real-Time applications in power plants
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- Green Energy and Clean Energy for new India
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