Degradation In Insulating Oil Gases Due To Stresses

Jashandeep Singh, Yog Raj Sood, Piush Verma

Abstract: This paper represents the experimental investigation on power transformer insulation based on accelerated electrical & thermal stresses. In this paper, the effect of accelerated thermal and electrical stresses on dissolved gas analysis has been experimentally investigated. A new terminology accelerated electrical aging factor (AEAF) & accelerated thermal aging factor (ATAF) is introduced which is mathematically correlated with dissolved gas analysis (DGA). DGA were determined experimentally for fresh and stressed oil samples.

Keywords: Power Transformer, insulation oil, dissolved gas analysis (DGA), accelerated thermal aging factor (ATAF), accelerated electrical aging factor (AEAF).

I. INTRODUCTION

The condition of oil & paper insulation is responsible to check the reliability of power transformer. During the working operation of the transformer, the combination of thermal, electrical, chemical, mechanical and environmental stresses plays a crucial role in its degradation. These stresses increase the failure probability by reducing its dielectric capabilities. From the above stresses, most influential stresses are thermal and electrical, which results in degradation of insulation. So, we are working in this crucial research field to understand the individual effect of electrical & thermal stresses, so that designing & modification in this field will be done accordingly. Some researchers are also working on the combined effect of thermal and electrical stresses. In this paper, the results of dissolved gas analysis (DGA) performed under individual thermal and electrical stresses are presented. The degradation in the dielectric properties at initial stage is detected by DGA, thereby it provides the useful information about the insulation quality [1]. The other causes of stresses are partial discharge, working under high temperature environments, due to poor thermal designs etc.

II. EXPERIMENTATION FOR ACCELERATED STRESSES

Power Transformer degradation process is very complicated process. To understand its degradation process, it needs to pass through series of tests which may not be possible on actual working transformers due to its cost effectiveness, service discontinuity, require long time experimentation to acquire credible failure data & also due to destructive nature. The best alternative to perform these tests are on prorated or scaled-down models of actual power transformers. These models are used to perform accelerated aging experiments to predict the insulation behavior under different operating conditions [2]. Under normal operating stress conditions, it require long time to acquired credible failure data but in order to obtain the failure data in much shorter time, magnitude of stress applied during the aging experiment should be carefully designed and controlled so that the laboratory scale experiments can cause the premature failure. This is another benefit of using scaled down model. In this paper, test cell model was specially designed, fabricated and used as scaled down model for experimentation in order to investigate the effect of accelerated stresses on oil insulation as shown in figure 1.

![Fig. 1. Test cell setup](image)

<table>
<thead>
<tr>
<th>Description</th>
<th>Material</th>
<th>Dimension/Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover plate</td>
<td>Mica sheet</td>
<td>5 mm</td>
</tr>
<tr>
<td>Sealing ring</td>
<td>Silicone rubber</td>
<td>5 mm</td>
</tr>
<tr>
<td>Tank</td>
<td>Mild steel (Coated with enamel paint)</td>
<td>235 mmx100 mmx150 mm</td>
</tr>
<tr>
<td>Round stud &amp; nut</td>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>Bolt</td>
<td>Mild steel</td>
<td></td>
</tr>
<tr>
<td>Transformer oil</td>
<td>As per IS: 333-1993 (2005)</td>
<td>3 liter/cell</td>
</tr>
<tr>
<td>Copper strip without paper wrapped</td>
<td>Copper</td>
<td>205 mmx12.5 mmx1.96 mm</td>
</tr>
<tr>
<td>Insulating paper</td>
<td>Electrical grade paper, as per IS 9335-1993 (0.056 mm/layer)x6 layers=0.336 mm</td>
<td></td>
</tr>
</tbody>
</table>

The description of test cell is detailed in table 1.

- It is having oil capacity of 03 liters.
- 05 mm thick mild steel plate is used.
- High temperature resistant enameled paint is used to paint the cell from inner surface.

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- Leakage of gases can be prevented at high temperature and at high voltage by using silicon sealing between the top cover plates.
- Two joined copper strips wrapped with paper were placed in the cell.

To remove the moisture from tested oil, the insulating oil was heated in air circulating oven at 110°C for 12 hours in test cell. For experimental investigation of individual thermal and electrical stresses on transformer insulating oil, the fabricated test cell was kept in the air circulating oven for 0, 150, 300, 450, 600 and 750 hours at 190°C, 200°C and 210°C for thermal stresses and at 2 kV/mm, 4 kV/mm and 6 kV/mm for electrical stresses. The test cells were applied electrical stresses by connecting them to HV electrical source.

### III. ACCELERATED AGING FACTORS

The magnitude and duration of thermal or electrical stresses can cause the aging of insulation. The accelerated thermal aging factor (ATAF) is defined as

\[ \text{ATAF} = T \times D \text{ (deg C-hours)} \]  

(1)

Where \( T \) is temperature in °C of thermal stresses, \( D \) is the of thermal stress duration. The unit of ATR becomes degree C-hours (0C-hr).

Similarly accelerated electrical aging factor (AEAF) is defined as \( \text{AEAF} = E \times D \text{ (kV hr/mm)} \)  

(2)

Where \( E \) is electrical stress in kV/mm, \( D \) is electrical stresses duration. The unit of AEAF is kV hour/mm (kV hr/mm).

Based on equation 1 & 2, table 2 & 3 are presented which represents ATR and AEAF.

#### Table 2. Accelerated thermal aging factor (ATAF)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Aging (hours)</th>
<th>ATR (°C-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190</td>
<td>150</td>
<td>ATR=28500</td>
</tr>
<tr>
<td>200</td>
<td>150</td>
<td>ATR=30000</td>
</tr>
<tr>
<td>210</td>
<td>150</td>
<td>ATR=31500</td>
</tr>
<tr>
<td>190</td>
<td>300</td>
<td>ATR=57000</td>
</tr>
<tr>
<td>200</td>
<td>300</td>
<td>ATR=60000</td>
</tr>
<tr>
<td>210</td>
<td>300</td>
<td>ATR=63000</td>
</tr>
<tr>
<td>190</td>
<td>450</td>
<td>ATR=85500</td>
</tr>
<tr>
<td>200</td>
<td>450</td>
<td>ATR=90000</td>
</tr>
<tr>
<td>210</td>
<td>450</td>
<td>ATR=94500</td>
</tr>
<tr>
<td>190</td>
<td>600</td>
<td>ATR=114000</td>
</tr>
<tr>
<td>200</td>
<td>600</td>
<td>ATR=120000</td>
</tr>
<tr>
<td>210</td>
<td>600</td>
<td>ATR=126000</td>
</tr>
<tr>
<td>190</td>
<td>750</td>
<td>ATR=142500</td>
</tr>
<tr>
<td>200</td>
<td>750</td>
<td>ATR=150000</td>
</tr>
<tr>
<td>210</td>
<td>750</td>
<td>ATR=157500</td>
</tr>
</tbody>
</table>

#### Table 3. Accelerated electrical aging factor (AEAF)

<table>
<thead>
<tr>
<th>Electrical stress (kV/mm)</th>
<th>Aging (hours)</th>
<th>AEAF (kV hr/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>150</td>
<td>AEAF=300</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>AEAF=600</td>
</tr>
<tr>
<td>4</td>
<td>150</td>
<td>AEAF=900</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>AEAF=900</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>AEAF=1200</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
<td>AEAF=1200</td>
</tr>
</tbody>
</table>

#### IV. DISSOLVED GAS ANALYSIS

Due to electrical & thermal stresses on power transformer, hydrocarbon gases are generated which get dissolved in transformer insulating oil. This happened due to deterioration in cellulosic paper & mineral oil which changes the oil & paper properties. The generated gases are hydrogen (H₂), carbon dioxide (CO₂), carbon monoxide (CO), ethane (C₂H₆), methane (CH₄), acetylene (C₂H₂), ethylene (C₂H₄), etc. [3, 4]. Gases due to incipient faults get detected in oil-filled electrical equipment by DGA. When the magnitude of fault is small, the generated gases get dissolved in the mineral oil, but when its magnitude increases, the gases get collected in the Buchholz relay. The quantity of gases varies with fault severity. Health of transformer is revealed by these gases. Gases also provide useful information if regular monitored [5]. Overheating, corona & arcing are faults which produce different quantity of gases. DGA results are interpreted by analysis of characteristic key gases, gas ratio & regression analysis. Key gas diagnostic criterion indicates the nature of fault in transformer. It is of qualitative nature. A semi-quantitative technique of DGA is gas ratio which identify the faults more specifically than the characteristic gases. Several ratio methods i.e. Dornenberg ratio, IEEE gas methods, Rogers ratio, Duval triangle are available for DGA analysis. The ratio method is generally applied to common conservator type transformer with expansion tank. In case of non-conservator type transformer with gas space, due to adjustment necessary ratio codes and fault classification could be affected [7, 8, 9]. Oil sampling from bottom drain valve was suggested by ASTM standard D3613-98. The apparatus used for measuring the DGA is portable dissolved gas analysis set model TRANSPORT X of Kelman make [10]. Gases in transformer also generated from rusting, uncoated surfaces, internal protective paints such as alkyd resins, chemical reactions using steel, modified polyurethanes containing fatty acids etc. Hydrogen is generated by reaction of moisture & steel. In literature, it has been recorded that some energized transformers also produced large quantity of hydrogen. Internal transformer paints, and [11].

In our experimentation, the dissolved gas analysis was carried out at individual thermal stress of 190°C, 200°C and 210°C and at electric stress of 2, 4 & 6 kV/mm respectively and samples taken out periodically after 0, 150, 300, 450, 600 and 750 hours of aging. The results of gases are discussed below:

#### A. Carbon di Oxide (CO₂)

The figure 2 to 5, CO₂ varies under individual electrical & thermal stresses.

<table>
<thead>
<tr>
<th>AEAF (kV hr/mm)</th>
<th>2</th>
<th>750</th>
<th>AEAF=15000</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>450</td>
<td>AEAF=18000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>300</td>
<td>AEAF=24000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>600</td>
<td>AEAF=27000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>750</td>
<td>AEAF=30000</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>600</td>
<td>AEAF=36000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>750</td>
<td>AEAF=45000</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2 shows the variation in CO\textsubscript{2} with aging at 190\textdegree C, 200\textdegree C & 210\textdegree C. From the graphs it is clear that the CO\textsubscript{2} contents are increasing with aging. At 210\textdegree C, CO\textsubscript{2} contents have higher values as compare with 200\textdegree C and 190\textdegree C. The CO\textsubscript{2} from virgin oil was 501 ppm. CO\textsubscript{2} increases to 1222 ppm at 190\textdegree C, 8720 ppm at 200\textdegree C and 24210 ppm at 210\textdegree C. It indicates that with increase in thermal stresses, the CO\textsubscript{2} increases from 501 to 24210 ppm. The maximum value of CO\textsubscript{2} is at 210\textdegree C after 750 hours of aging. Figure 3 shows the scattered results of CO\textsubscript{2} with ATAF with polynomial effective prediction model; the R\textsuperscript{2} value of ATAF is 86.1\%. The generated mathematical equation between CO\textsubscript{2} and ATAF is as follows:

\[ \text{CO}_2 = (2 \times 10^{-6}) \text{ATAF}^2 - 0.123 \text{ATAF} + 2179 \text{ ppm} \quad (3) \]

\[ y = 1.9 \times 10^{-5} \text{ATAF}^2 + 2179 \text{ ppm} \]

![Fig. 3. Variation of CO\textsubscript{2} with ATAF](image)

Figure 4 indicates the variation of CO\textsubscript{2} with aging at 2, 4 & 6 kV/mm. The CO\textsubscript{2} changes to 467 ppm for 2 kV/mm, 561 ppm at 4 kV/mm and 1429 ppm at 6 kV/mm, it indicates that 6 kV/mm have countable effect on the generation of CO\textsubscript{2}. The CO\textsubscript{2} increases from 501 to 1429 ppm at 6 kV/mm after aging of 750 hours. The presence of higher CO\textsubscript{2} is mainly due to decomposition of cellulosic paper. The variation of CO\textsubscript{2} with AEAF is shown in figure 5, which has R\textsuperscript{2} value of 91.1\%. The mathematical equation between CO\textsubscript{2} and AEAF is as follows:

\[ \text{CO}_2 = (8 \times 10^{-5}) \text{AEAF}^2 - 0.169 \text{AEAF} + 525.2 \text{ ppm} \quad (4) \]

\[ y = 2.8 \times 10^{-5} \text{AEAF}^2 + 2179 \text{ ppm} \]

![Fig. 5. Variation of CO\textsubscript{2} with AEAF](image)

**B. Carbon mono Oxide (CO)**

Figure 6 shows the variation of CO with aging at 190\textdegree C, 200\textdegree C & 210\textdegree C. From the graph it is clear that the CO contents are increasing with aging & thermal stresses. The CO of virgin oil sample was 01ppm. It increases to 156 ppm at 190\textdegree C, 1382 ppm at 200\textdegree C and 2168 ppm at 210\textdegree C. It indicates that after 750 hours of aging CO increases from 01 to 2168 ppm with increase in thermal stresses. As clear from the figure 6, CO contents increases with increase in stresses at all aging (300h, 450h, 600h and 750h), except at 150 hours, which may be due to some experimental error.
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The $R^2$ value of CO with ATAF is 91.8% as shown in figure 7. The mathematical equation between CO and ATAF is as follows:

$$CO = (1 \times 10^{-7})ATAF^2 - 0.011ATAF + 206.4 \text{ ppm} \ (5)$$

In figure 8, the variation of CO with aging at 2, 4 & 6 kV/mm is indicated. The CO increase to 1 ppm at 2 kV/mm, 5 ppm at 4 kV/mm and 111 ppm at 6 kV/mm. It indicates that with increase in electrical stresses, CO increases from 01 to 111 ppm at 6 kV/mm after aging of 750 hours. The most effective prediction model for CO with AEAF is polynomial with $R^2$ value 87.2% as shown in figure 9. The mathematical equation between CO and AEAF is as follows:

$$CO = (9 \times 10^{-6})AEAF^2 - 0.019AEAF + 9.891 \text{ ppm} \ (6)$$

C. Ethylene ($C_2H_4$)

Figure 10 shows the variation of $C_2H_4$ with aging at 190°C, 200°C & 210°C. The $C_2H_4$ of virgin oil sample was 02ppm. It increases to 61ppm at 190°C, 111ppm at 200°C and 226ppm at 210°C. It indicates that after 750 hours of aging $C_2H_4$ increases from 02 to 226 ppm with increase in thermal stresses. The $R^2$ value of $C_2H_4$ with ATAF is 81.4% as shown in figure 11. The mathematical equation between $C_2H_4$ and ATAF is as follows:

$$C_2H_4 = (8 \times 10^{-9})ATAF^2 - 0.0001ATAF + 22.16 \text{ ppm} \ (7)$$

In figure 8, the variation of CO with aging at 2, 4 & 6 kV/mm is indicated. The CO increase to 1 ppm at 2 kV/mm, 5 ppm at 4 kV/mm and 111 ppm at 6 kV/mm. It indicates that with increase in electrical stresses, CO increases from 01 to 111 ppm at 6 kV/mm after aging of 750 hours. The most effective prediction model for CO with AEAF is polynomial with $R^2$ value 87.2% as shown in figure 9. The mathematical equation between CO and AEAF is as follows:

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$$C_2H_4 = (8 \times 10^{-9})ATAF^2 - 0.0001ATAF + 22.16 \text{ ppm} \ (7)$$
These gases are generated mainly due to overheating. Its mathematical equation generated between thermal and electrical stresses has significant effect on the generation of C$_2$H$_6$ gas. Due to overheating, these gases are generated. The mathematical equation generated between C$_2$H$_6$ and AEAF is as follows:

$$C_2H_6 = (5 \times 10^{-7}) AEAF^2 + 0.00016 AEAF + .663 ppm$$  \hspace{1cm} (8) ppm

D. Ethane (C$_2$H$_6$)

In figure 14 to 17, the variation of C$_2$H$_6$ under individual electrical & thermal stresses. Figure 14 shows the variation of C$_2$H$_6$ with aging at 190°C, 200°C & 210°C. The C$_2$H$_6$ of virgin oil sample was 06 ppm. The C$_2$H$_6$ increases to 333 ppm at 190°C, 467 ppm at 200°C and 1344 ppm at 210°C. With aging after 750 hours, it increases from 06 to 1344 ppm with increase in thermal stresses. The R$^2$ value of C$_2$H$_6$ with ATAF is 94.8% as shown in figure 15. The equation generated between ATAF & C$_2$H$_6$ is as follows:

$$C_2H_6 = (4 \times 10^{-8}) ATAF^2 + 0.002 ATAF + 31.27 ppm$$  \hspace{1cm} (9) ppm

In figure 16 indicates the variation of C$_2$H$_6$ with aging at 2, 4 & 6 kV/mm. The C$_2$H$_6$ increases to 16 ppm at 2 kV/mm, 28 ppm at 4 kV/mm and 99 ppm at 6 kV/mm. In case of electrical stresses, the C$_2$H$_6$ is increased from 06 to 99 ppm. It indicates that electrical stress in not much responsible for the production of C$_2$H$_6$ as compared to thermal stresses. In figure 17, C$_2$H$_6$ very with AEAF with R$^2$ value of 94.7%. The thermal and electrical stresses have significant effect on the C$_2$H$_6$ of oil, but as shown in figures it indicates that the thermal stresses contributes much more as compared to electrical stresses for the generation of C$_2$H$_6$ gas. These gases are generated mainly due to overheating. Its mathematical equation becomes:

$$C_2H_6 = (3 \times 10^{-6}) AEAF^2 + 0.009 AEAF + 0.672 ppm$$  \hspace{1cm} (10) ppm

FIG. 13. Variation of C$_2$H$_6$ with AEAF

FIG. 14. Variation of C$_2$H$_6$ with aging at 190°C, 200°C & 210°C

FIG. 15. Variation of C$_2$H$_6$ with ATAF

FIG. 16. Variation of aging with C$_2$H$_6$ at 2, 4 & 6 kV/mm

FIG. 17. Variation of C$_2$H$_6$ with AEAF
E. Methane (CH\(_4\))

In figure 18, the variation in aging with CH\(_4\) at different thermal stresses is graphically represented. The CH\(_4\) of virgin oil was 0.1 ppm. The CH\(_4\) increases to 190 ppm at 190\(^\circ\)C, 1109 ppm at 200\(^\circ\)C and 3196 ppm at 210\(^\circ\)C. The CH\(_4\) increases from 0.1 to 3196 ppm with thermal stresses and aging. The test results are very much scattered with R\(_2\) value of CH\(_4\) with ATAF is 70.9\% as shown in figure 19. Its mathematical equation becomes:

\[
\text{CH}_4 = (2 \times 10^{-7}) \text{ATAF}^2 - 0.015 \text{ATAF} + 318.8 \text{ ppm (11)}
\]

In figure 20, the CH\(_4\) is 0.2 ppm at 2 kV/mm, 0.8 ppm at 4 kV/mm & 67 ppm at 6 kV/mm. CH\(_4\) increases from 0.6 to 67 ppm with increase in electrical stresses and aging, which is quite low as compared to thermal stresses. Figure 21 represents the variation of CH\(_4\) with AEAF with R\(_2\) value of 93.3\%. Its mathematical equation becomes:

\[
\text{CH}_4 = (6 \times 10^{-6}) \text{AEAF}^2 - 0.010 \text{AEAF} + 4.698 \text{ ppm (12)}
\]

F. Acetylene (C\(_2\)H\(_2\))

In case of C\(_2\)H\(_2\), only electrical stress at 6 kV/mm is presented (in figure 22) because value of C\(_2\)H\(_2\) at thermal stress of 190\(^\circ\)C, 200\(^\circ\)C and 210\(^\circ\)C and at electrical stress of 2 and 4 kV/mm is 0.5. At 6 kV/mm, the C\(_2\)H\(_2\) increases from 0.5 to 1.5 ppm. It indicates that electrical stress can contributes in the production of C\(_2\)H\(_2\) gas. These gases are generated mainly due to arcing. Figure 23, indicates the variation of C\(_2\)H\(_2\) with AEAF.
G. Total Dissolved Combustible Gases (TDCG)

A sum of all combustible gas components is represented as Total dissolved combustible gases (TDCG), i.e. \( \text{H}_2, \text{C}_2\text{H}_6, \text{CO}, \text{CH}_4, \text{C}_2\text{H}_2, \text{C}_2\text{H}_4 \). TDCG is an important degradation indicator of danger signal. As per experience, a particular type of fault is suggested by revealed hydrocarbon gases.

\[
\text{TDCG} = (2 \times 10^{-5}) \text{AEAF}^2 - 0.048\text{AEAF} + 42.35 \text{ ppm (14)}
\]

![Graph showing variation of TDCG with ATAF and AEAF](image)

Fig. 24. Variation of TDCG with aging at 190°C, 200°C & 210°C

Fig. 25. Variation of TDCG with ATAF

Fig. 26. Variation in aging with TDCG at 2, 4 & 6 kV/mm

Fig. 27. Variation of TDCG with AEAF

V. CONCLUSION

In this paper, the effect of individual accelerated electrical & thermal stresses on dissolved gas analysis (DGA) of insulating oil of transformer has been experimentally investigated. In order to understand the insulating degradation process, test cell model have been fabricated. Due to insulation deterioration, the hydrogen, carbon dioxide, carbon monoxide, ethane, methane, acetylene ethylene gases are generated. These gases are detected by portable dissolved gas analysis set model Transport X of Kelman make. In order to quantify the electrical & thermal stresses, accelerated electrical aging factor (AEAF) & accelerated thermal aging factor (ATAF) is introduced. In the experimental work, DGA was carried out at individual thermal stresses of 190°C, 200°C and 210°C & electrical stresses of 2, 4, & 6 kV/mm. The samples were taken out periodically after 0, 150, 300, 450, 600 and 750 hours of aging. The graphically representation between the above mentioned gases with AEAF and ATAF have been presented, further it is concluded that these gases increases polynomially with ATAF and AEAF. It is also concluded that all gases except \( \text{C}_2\text{H}_2 \) the effect of electrical stresses is less in comparison with thermal stresses. In the paper, it is experimentally seen that both thermal & electrical stresses contributed in degradation of insulation and follow same pattern in property.
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change. But the degradation in thermal stresses is comparatively more as compared with electrical stresses.

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REFERENCES


6. S.D. Myers, J.J. Kelly and R.H. Parrish, Guide to transformer maintenance, Transformer Maintenance Institute, Akron, Ohio, USA.


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Dr. Yog Raj Sood obtained his Ph.D. from IIT Roorkee in 2003. He is working as Professor, EED, NIT, Hamirpur (H.P.), India. He has more than 25 years teaching and research experience. He has published a number of research papers. He is recipient of several commendations, appreciation letters & awards for his excellent educational and research work. His research interests are in the area of condition monitoring of power transformer, deregulation of power sector, AI application to power systems, power system optimization, high voltage engineering and non-conventional sources of energy.

Dr. Plush Verma got his Ph. D. in Electrical & Instrumentation Engineering from Thapar University, Patiala, Punjab (India) in 2005. He has over 22 years of experience in Research, Industry and Academia. He is working as Vice Chancellor, BU Shimla. His research interests are in the area of Transformer Diagnostics study and Non-Conventional Sources of Energy.