WELCOME

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EVERYDAY SOLUTIONS

BUILDING RELIABILITY INTO DESIGN OF TRANSFORMERS FOR RELIABILITY OF ELECTRICAL SYSTEMS

Dr. Ir. Jan Declercq

PAUWELS
ENERGY IS OUR BUSINESS
QUALITY IS OUR MISSION

V.K. Lakhiani

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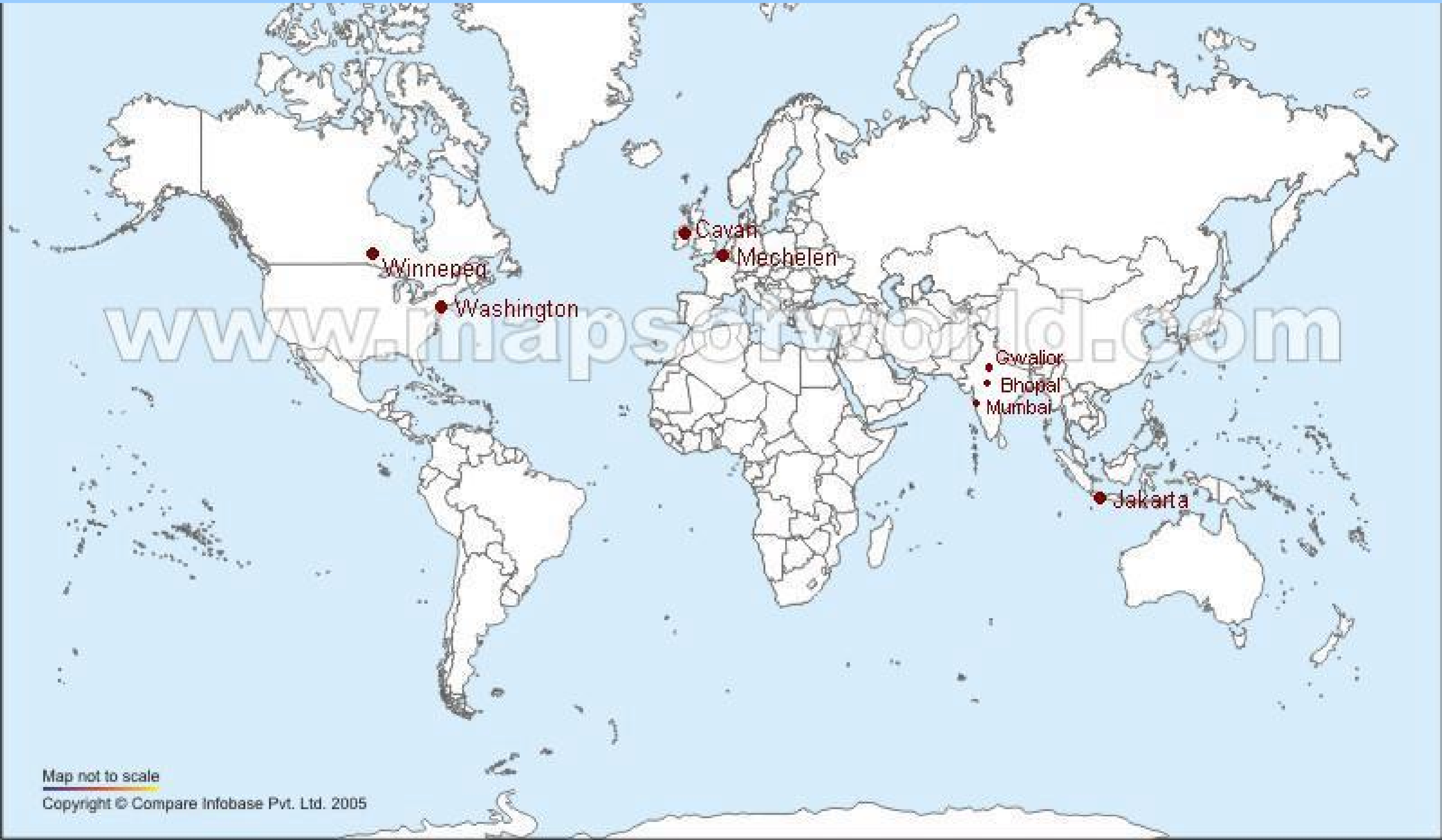
CG-PAUWELS ONE OF THE TOP TEN TRANSFORMER MANUFACTURERS IN THE WORLD



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5 POWER TRANSFORMER PLANTS
40000 MVA INSTALLED CAPACITY

{

	MVA
• CANADA	7500
• BELGIUM	10000
• INDONESIA	5000
• INDIA (MUMBAI)	12000
• INDIA (BHOPAL)	5500

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RANGE OF MANUFACTURE – POWER TRANSFORMERS

- POWER TRANSFORMERS 20 MVA-1000 MVA,500 kV CLASS
- HVDC CONV. TRANSFORMERS ± 500 kV DC
- SHUNT REACTORS UPTO 100 MVAr 500 kV
- PHASE SHIFTING TRANSFORMERS
- FURNACE TRANSFORMERS
- TRACTION TRANSFORMERS
- MOBILE SUBSTATIONS, 110 kV

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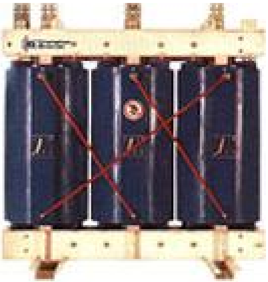
4 DISTRIBUTION TRANSFORMER PLANTS
20,000 MVA CAPACITY

- USA
- BELGIUM
- IRELAND
- MALANPUR



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RANGE OF MANUFACTURE – DIST. TRANSFORMERS

- SINGLE PHASE HV DISTRIBUTION TRANSFORMERS
  15 kVA AND ABOVE, 11, 22 kV
- 3 PHASE OIL IMMERSED DISTRIBUTION TRANSFORMERS
  UPTO 20 MVA, 33 kV
- 3 PHASE RESIN CAST/CONVENTIONAL DRY TYPE DISTN.
- SLIM TRANSFORMERS FOR WINDMILLS
- UNITISED SUBSTATIONS

RELIABILITY IS A KEY WORD WITH CG-PAUWELS !

CONTENTS

- RELIABLE SYSTEM NEEDS A RELIABLE TRANSFORMER !
- WHAT IS A RELIABLE TRANSFORMER ?
- RELIABILITY OF DIELECTRIC DESIGN – WITHSTAND AGAINST OVER-VOLTAGES
- RELIABILITY OF ELECTROMAGNETIC DESIGN – EDDY AND STRAY LOSS CONTROL
- RELIABILITY OF ELECTRODYNAMIC DESIGN - WITHSTAND AGAINST SHORT CKT FORCES
- RELIABILITY OF THERMAL DESIGN – HOT SPOT CONTROL
- RELIABILITY OF STRUCTURAL DESIGN – VACUUM, PRESSURE, SEISMIC WITHSTAND CAPABILITY
- CONCLUSION

RELIABLE ELECTRICAL SYSTEM NEEDS A RELIABLE TRANSFORMER

- TRANSFORMER IS ONE OF COSTLIEST EQUIPMENT IN A POWER PLANT OR A SUBSTATION
- REPAIR IS TIME CONSUMING AND COSTLY
- TRANSFORMER FAILURE LEADS TO BLACKOUTS, LONG OUTAGES AND LOSS OF REVENUE
- A RELIABLE TRANSFORMER DESIGNED TO MEET SYSTEM ONEROUS CONDITIONS WORKS UNINTERRUPTEDLY AND ENSURES RELIABLE OPERATION OF ELECTRICAL SYSTEM

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- RELIABLE SYSTEM NEEDS A RELIABLE TRANSFORMER !
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- CONCLUSION

WHAT IS A RELIABLE POWER TRANSFORMER !

1. WITHSTAND AGAINST TRANSIENT OVERVOLTAGES AND POWER FREQUENCY TEST VOLTAGES
2. EDDY & STRAY LOSS CONTROL
3. SHORT-CIRCUIT WITHSTAND CAPABILITY
4. THERMAL HOT-SPOT CONTROL
5. STRUCTURAL DESIGN ADEQUACY & SEISMIC WITHSTAND CAPABILITY

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- CONCLUSION

GENESIS OF A RELIABLE TRANSFORMER

1. WITHSTAND AGAINST SYSTEM TRANSIENTS AND TEST OVER VOLTAGES

A RELIABLE DESIGN TO ADDRESS :

- PART WINDING RESONANCE & WAVESHAPE SENSITIVITY ANALYSIS UNDER TRANSIENT VOLTAGE DISTRIBUTION

- TRANSFERRED VOLTAGES TO TERTIARY/REGULATING WINDINGS DURING TRANSIENT VOLTAGES

- “PD” FREE STRESS LEVEL AT VARIOUS WINDING LOCATIONS (MINOR & MAJOR INSULATION)

1. WITHSTAND AGAINST SYSTEM OVER VOLTAGES AND TEST OVERVOLTAGES (CONTD.)

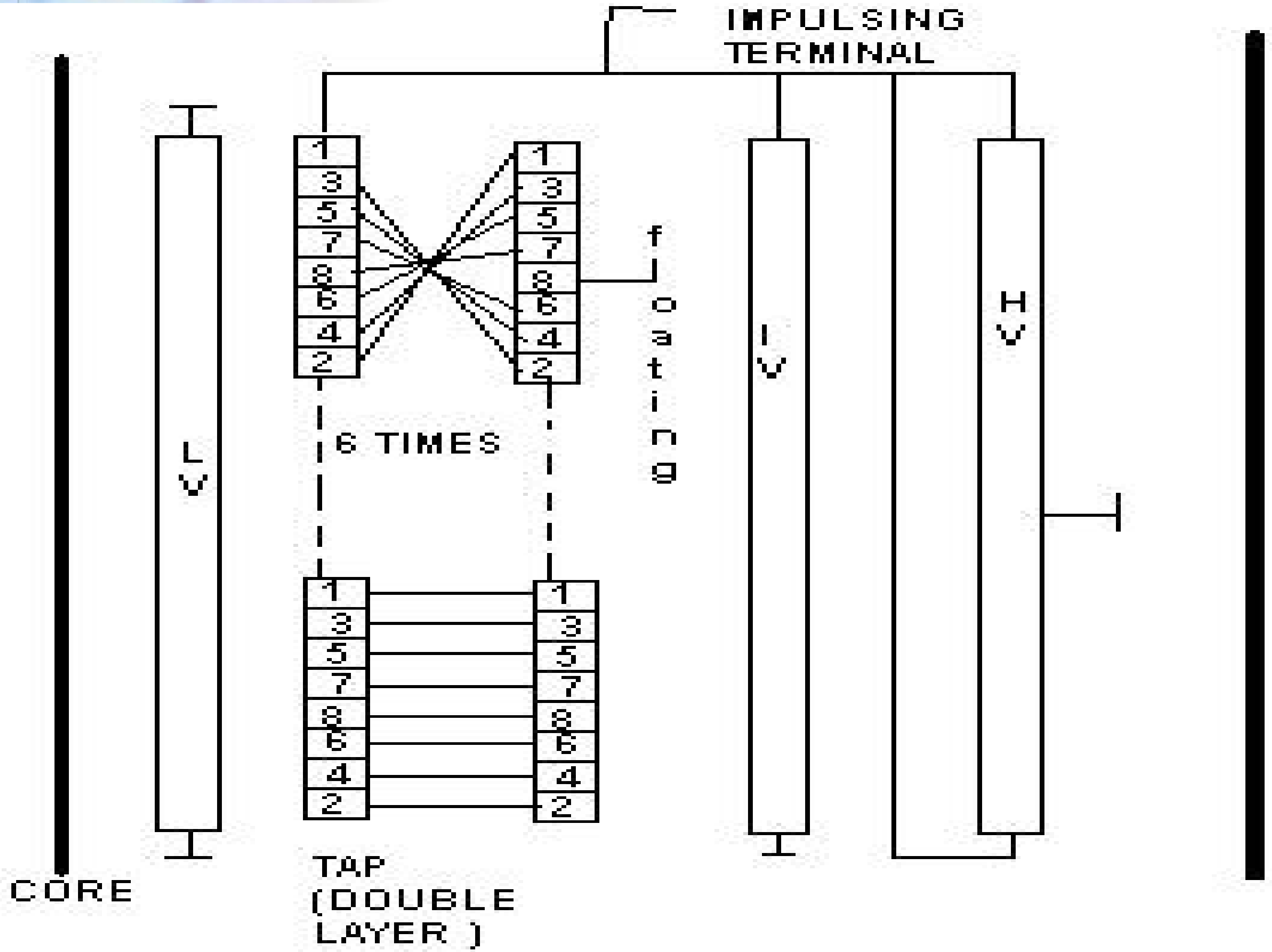
ANALYTICAL TOOLS AVAILABLE WITH CG-PAUWELS

A. TRANSIENT VOLTAGE DISTRIBUTION

- SOFTWARE TO ESTIMATE VOLTAGE LEVELS ALONG WDG HEIGHT
  - ✓ ' VLN' (VIT)
  - ✓' HYBRID' (IN-HOUSE DEVELOPMENT)
  - ✓ 'COUNTERSHIELD' (IN-HOUSE)
  - ✓'PULSE' (OR DEGENEFF)

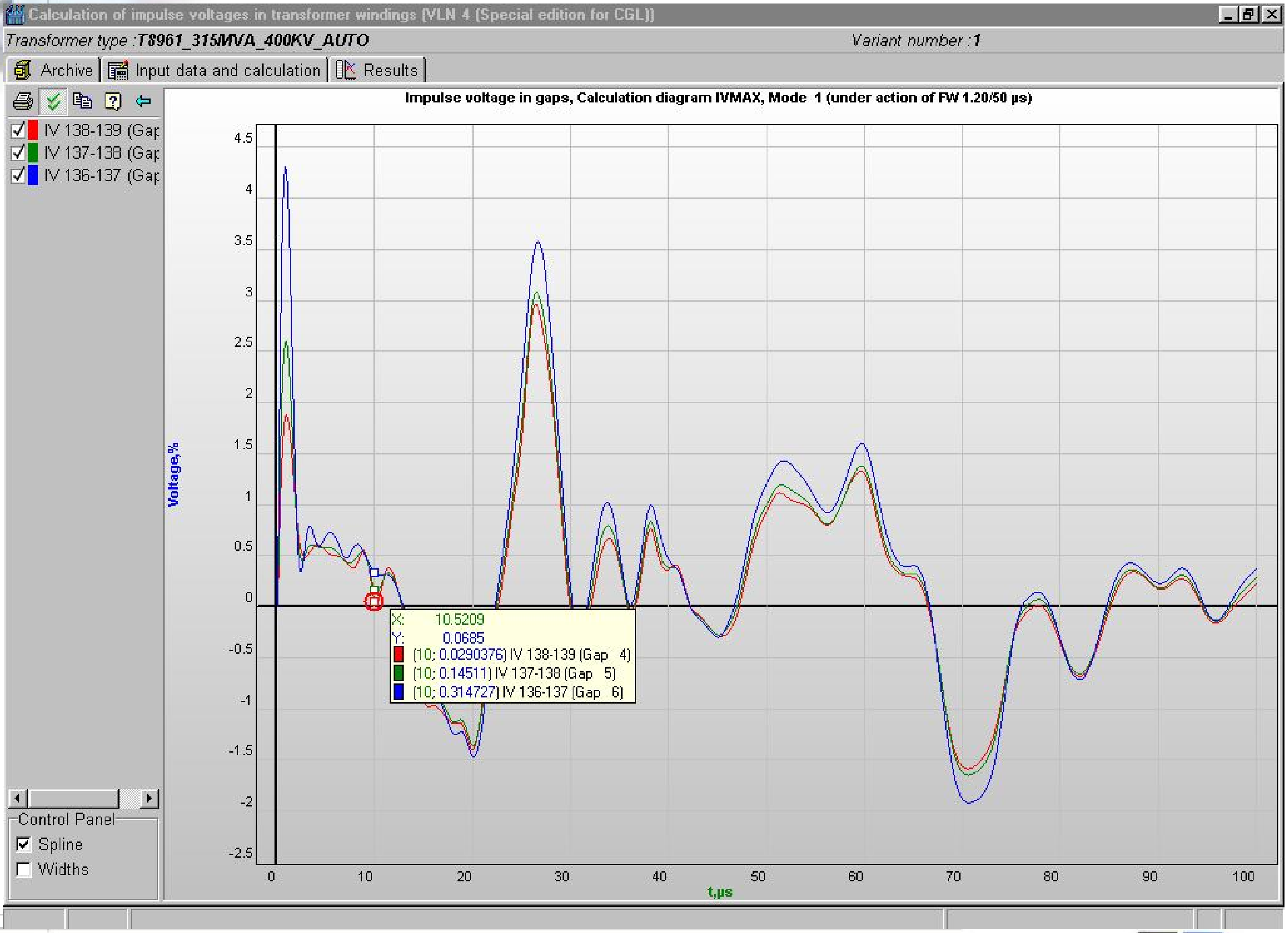
- SOFTWARE TO ANALYSE VOLTAGE STRESSES AND DIELECTRIC STRENGTH
  - ✓ 'V STRESS' (IN-HOUSE DEVELOPMENT)
  - ✓ 'ELECTRO' (IES)
  - ✓ VERIFICATION BY RSG

IMPULSE DISTRIBUTION - WINDING DIAGRAM



TEST SET UP FOR IV IMPULSING FOR CHECKINC ACROSS RANGE VOLTAGE OF TAP

IMPULSE VOLTAGES BETWEEN DISCS 136-137, 137-138, 138-139 AS FUNCTION OF TIME



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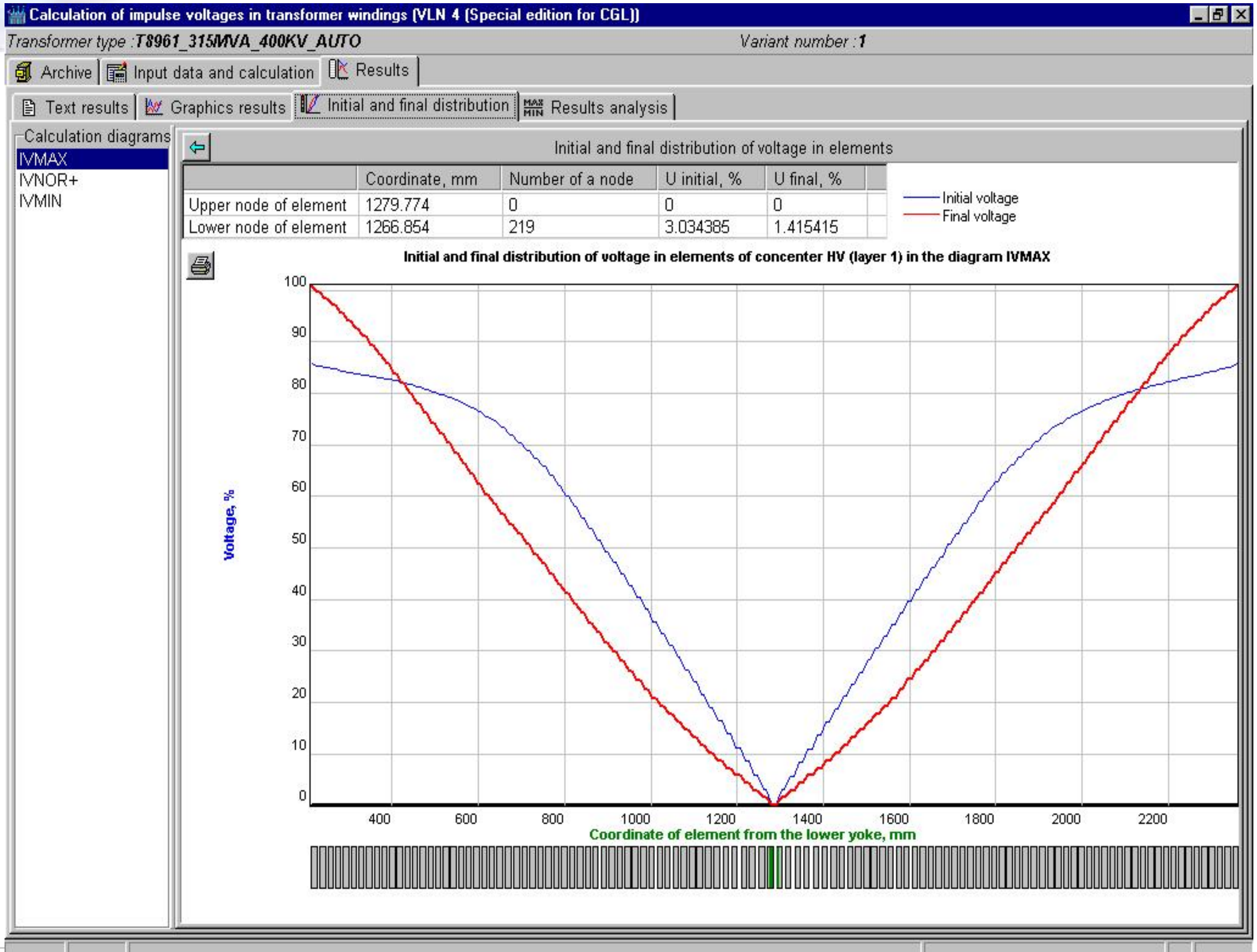
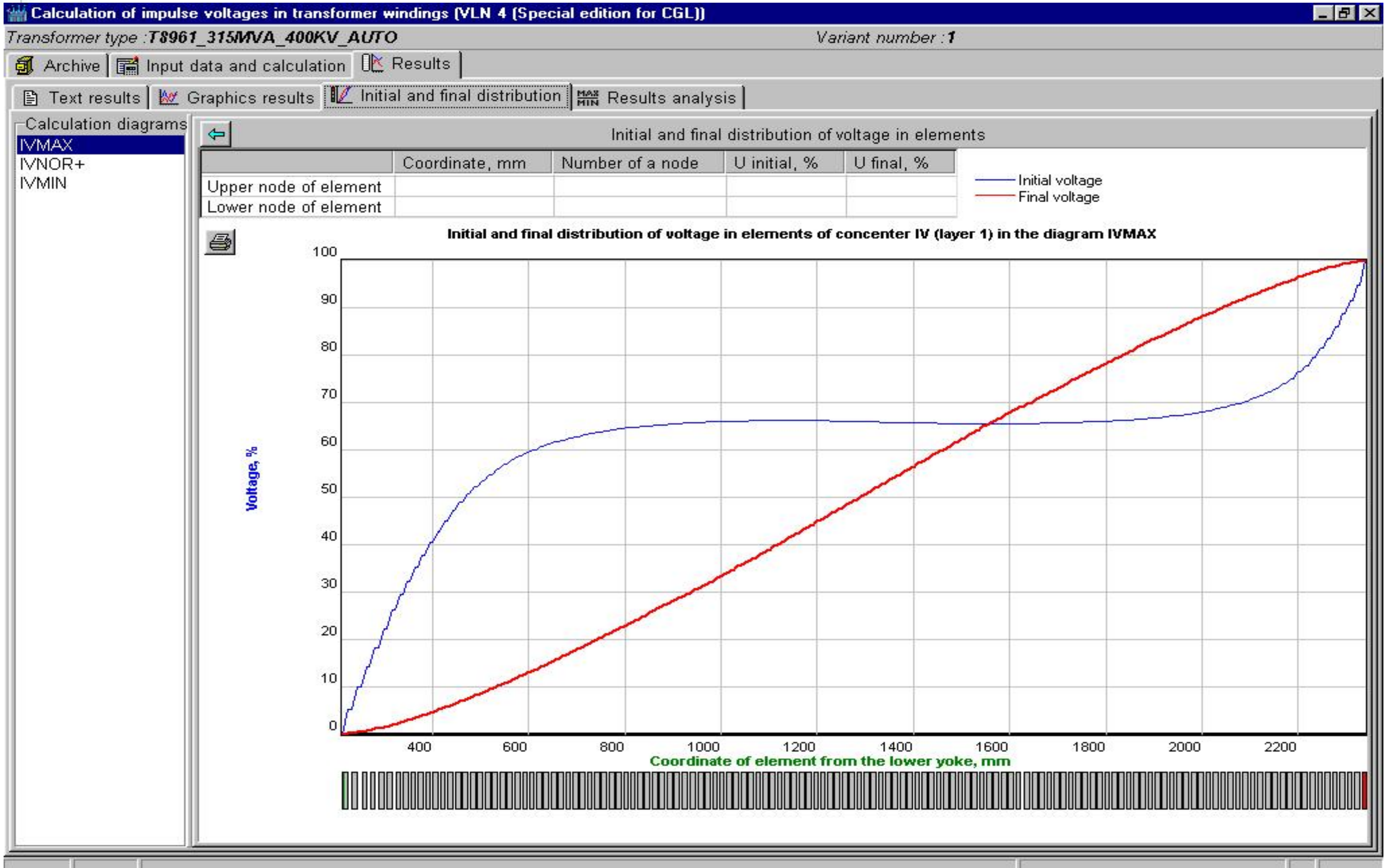
INITIAL AND FINAL VOLTAGE DISTRIBUTION IN HV WINDING



INITIAL AND FINAL VOLTAGE DISTRIBUTION IN IV WINDING



INITIAL AND FINAL VOLTAGE DISTRIBUTION IN LV WINDING

Calculation of impulse voltages in transformer windings (VLN 4 (Special edition for CGL))

Transformer type : ***T8961_315MVA_400KV_AUTO*** *Variant number :* ***1***

Archive | Input data and calculation | Results

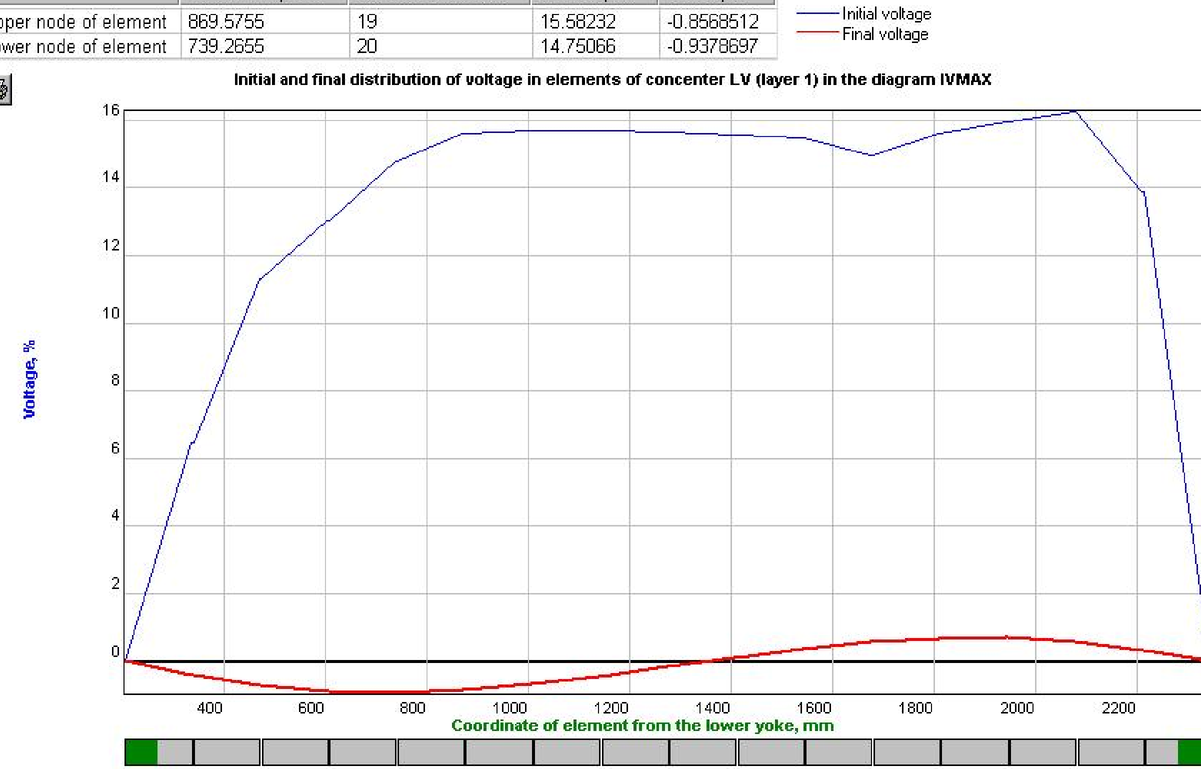
Text results | Graphics results | Initial and final distribution | Results analysis

Calculation diagrams
- IVMAX
- IVNOR+
- IVMIN

Initial and final distribution of voltage in elements

	Coordinate, mm	Number of a node	U initial, %	U final, %
Upper node of element	869.5755	19	15.58232	-0.8568512
Lower node of element	739.2655	20	14.75066	-0.9378697

Initial and final distribution of voltage in elements of concenter LV (layer 1) in the diagram IVMAX



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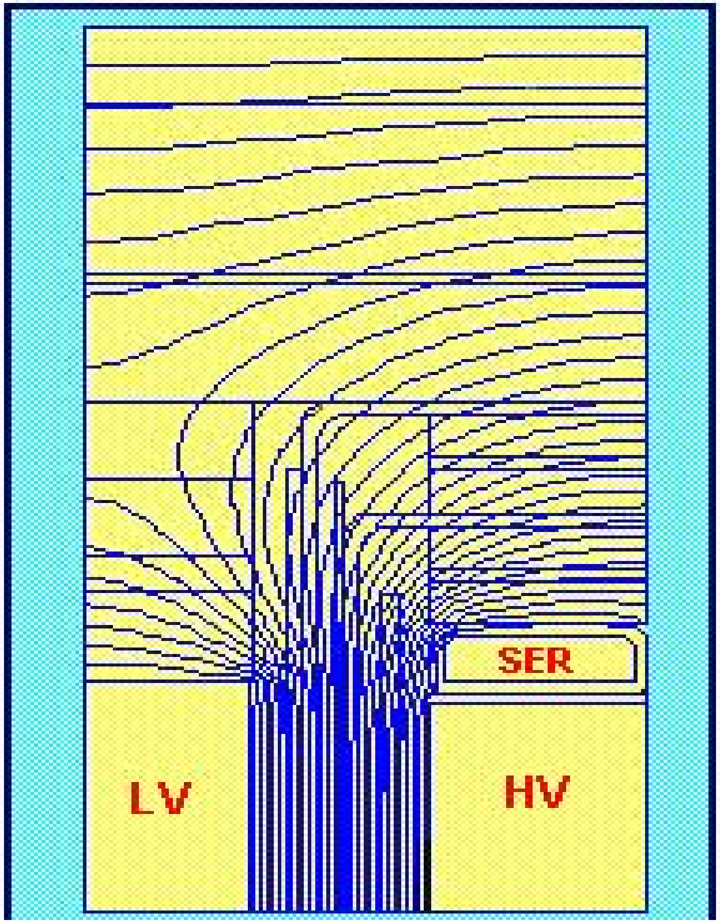
1. WITHSTAND AGAINST SYSTEM OVER VOLTAGES AND TEST OVER VOLTAGES (CONTD.)

ANALYTICAL TOOLS AVAILABLE (CONTD)

B. POWER FREQUENCY

- ASSESSMENT OF STRESS LEVELS AT VARIOUS CRITICAL LOCATIONS BY ELABORATE FEM ANALYSIS BY
  - 'ANSYS' SOFTWARE
  - 'ELECTRO' SOFTWARE

FEM ANALYSIS FOR END INSULATION EQUIPOTENTIAL PLOT



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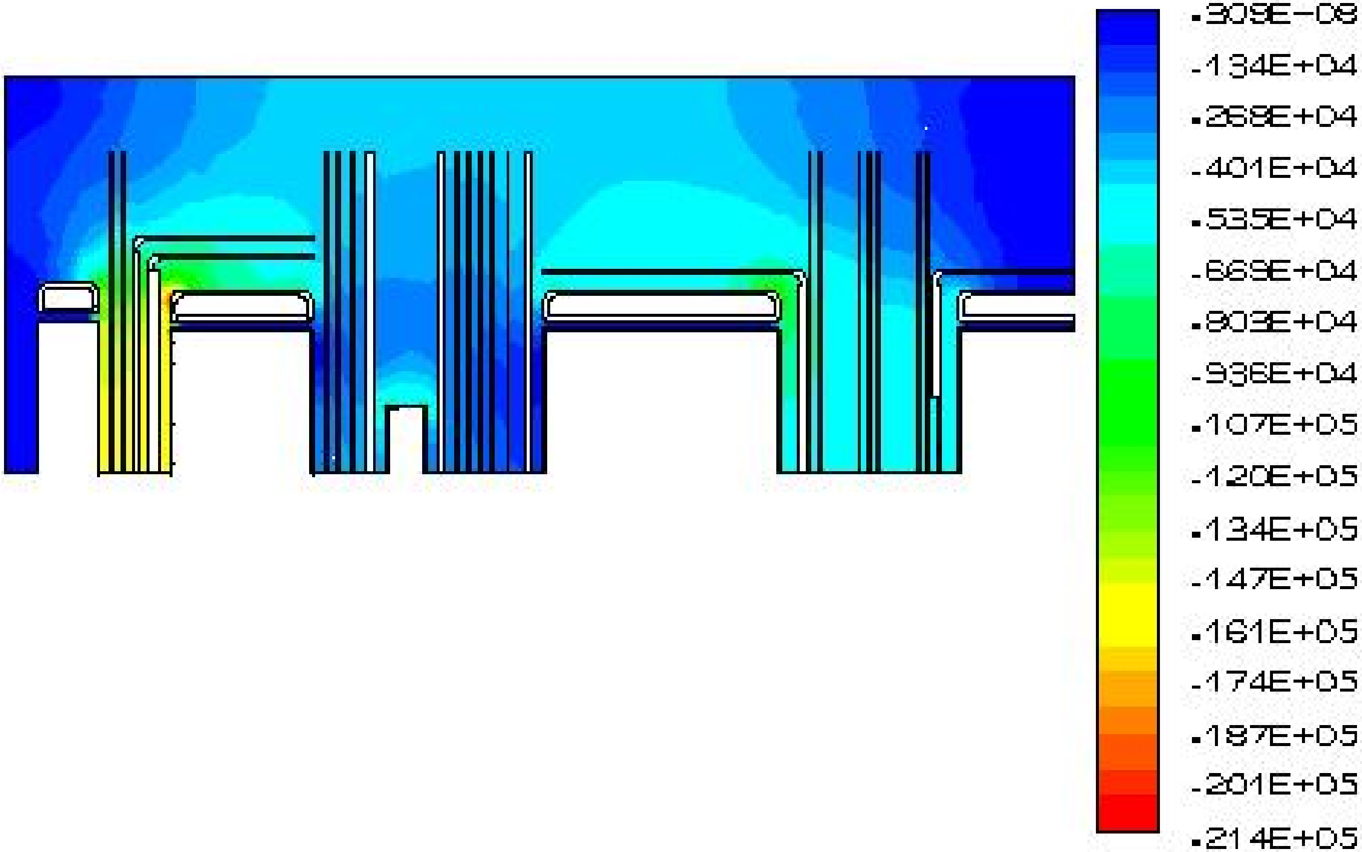
FEM ANALYSIS FOR END INSULATION ELECTRIC STRESS DISTRIBUTION



1. WITHSTAND AGAINST SYSTEM OVER VOLTAGES AND TEST OVER VOLTAGES (CONTD.)

CG-PAUWEL DESIGN PHILOSOPHY

- DIL CONCEPT
- PD INCEPTION FREE STRESS LEVELS USING SUB-DIVIDED OIL DUCTS.
- USE OF SPECIAL INSULATING COMPONENTS, STRESS RELIEVING SHIELDS, SNOUTS
- DIELECTRIC STRENGTH OF INSULATION
- DISTANCE FROM LEADS BASED ON STRESSED VOLUME CONCEPT

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- CONCLUSION

2. EDDY AND STRAY LOSS CONTROL REQUIREMENTS

A RELIABLE DESIGN TO ADDRESS

- AXIAL & RADIAL EDDY LOSSES CONTROL IN THE CONDUCTORS

- STRAY LOSSES CONTROL IN TANK, CORE CLAMPING STRUCTURES AND LEAD TERMINATIONS

- HOT-SPOTS IN METALLIC PARTS TO PREVENT GASSIFICATION OF OIL

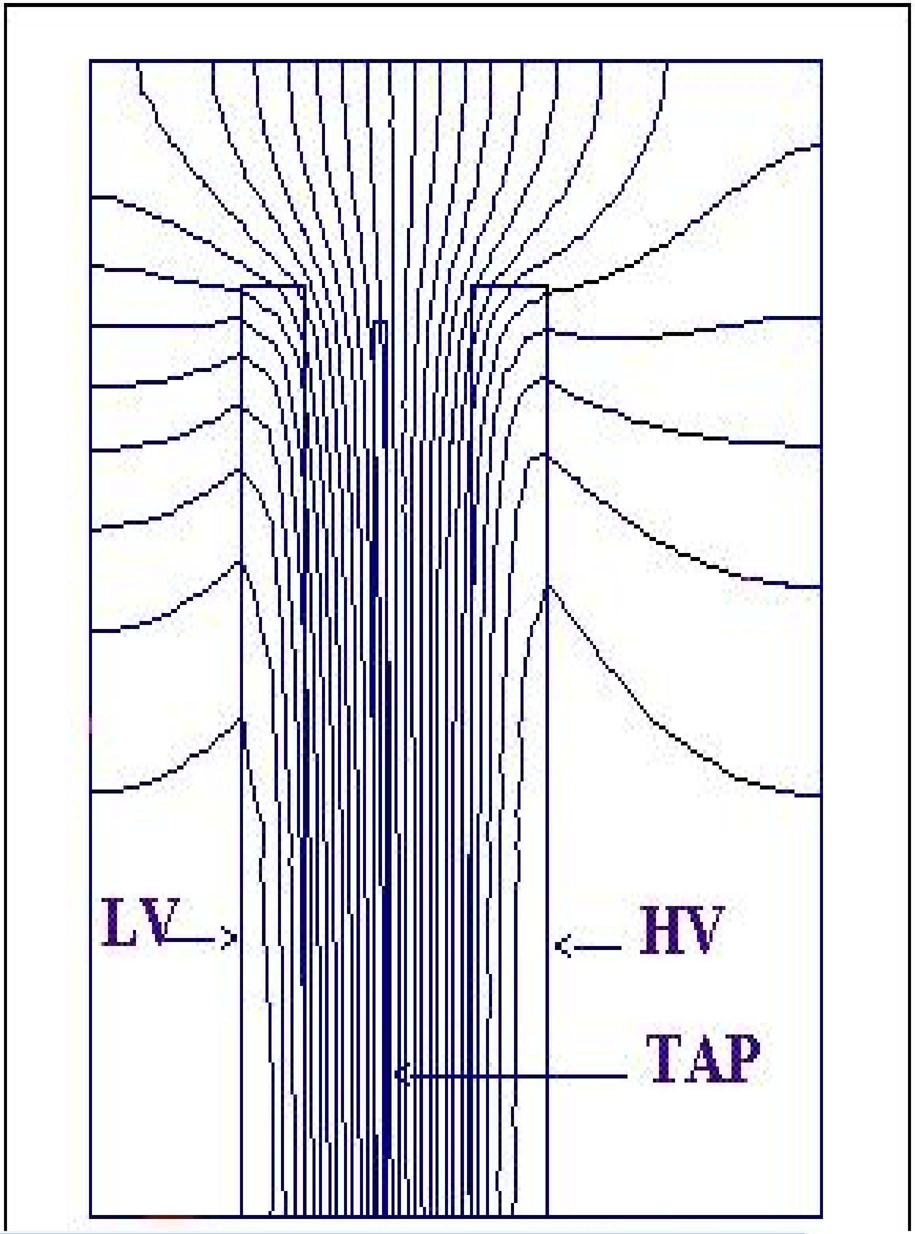
2. EDDY AND STRAY LOSS CONTROL (CONTD.)

ANALYTICAL TOOLS & DESIGN PHILOSOPHY

A. EDDY LOSS

- PROGRAM EDMAG-3D (VIT) TO CALCULATE WINDING EDDY LOSS - RADIAL / AXIAL
- FEM ANALYSIS FOR CIRCULATING CURRENT OR PROGRAM TOK (VIT)
- PROGRAM “MAGNAXi”
- CHOICE OF PROPER WIDTH & THICKNESS OF CONDUCTOR TO MINIMIZE EDDY LOSS
- USE OF CTC FOR HIGHER MVA TRANSFORMERS

FEM ANALYSIS FOR WINDING EDDY LOSS



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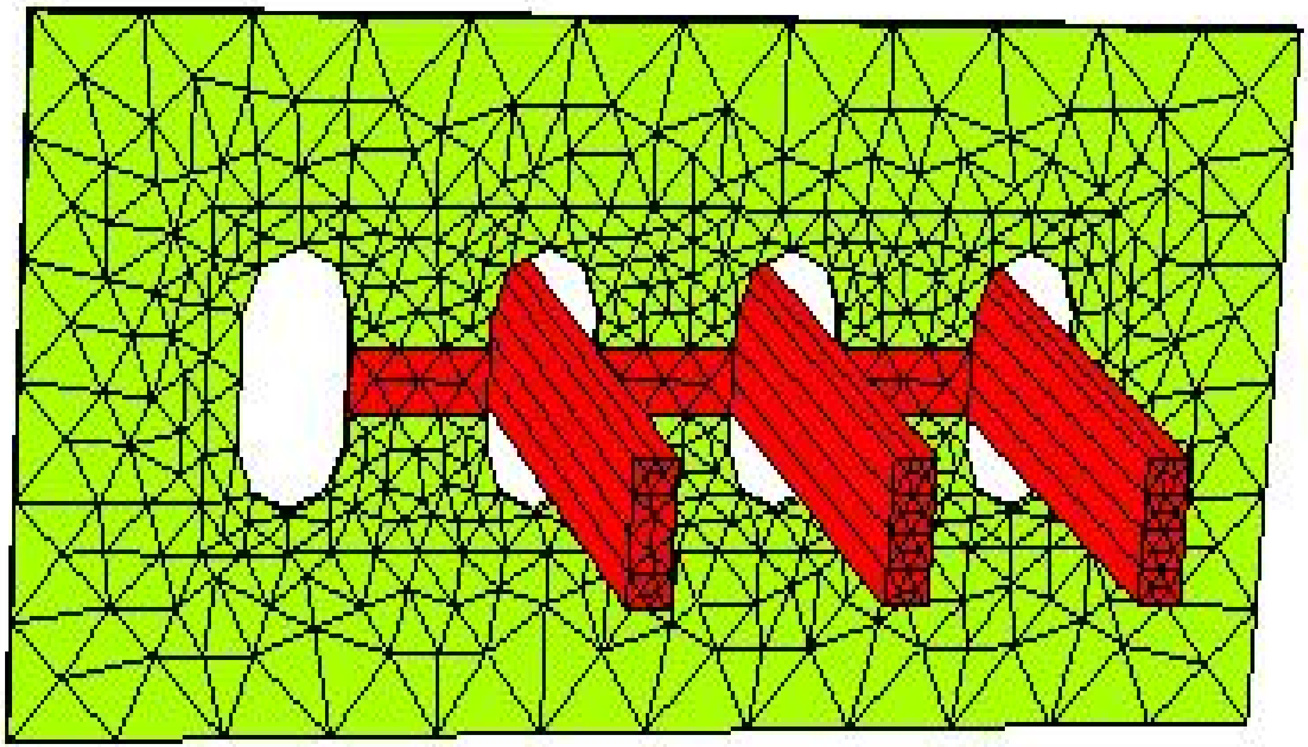
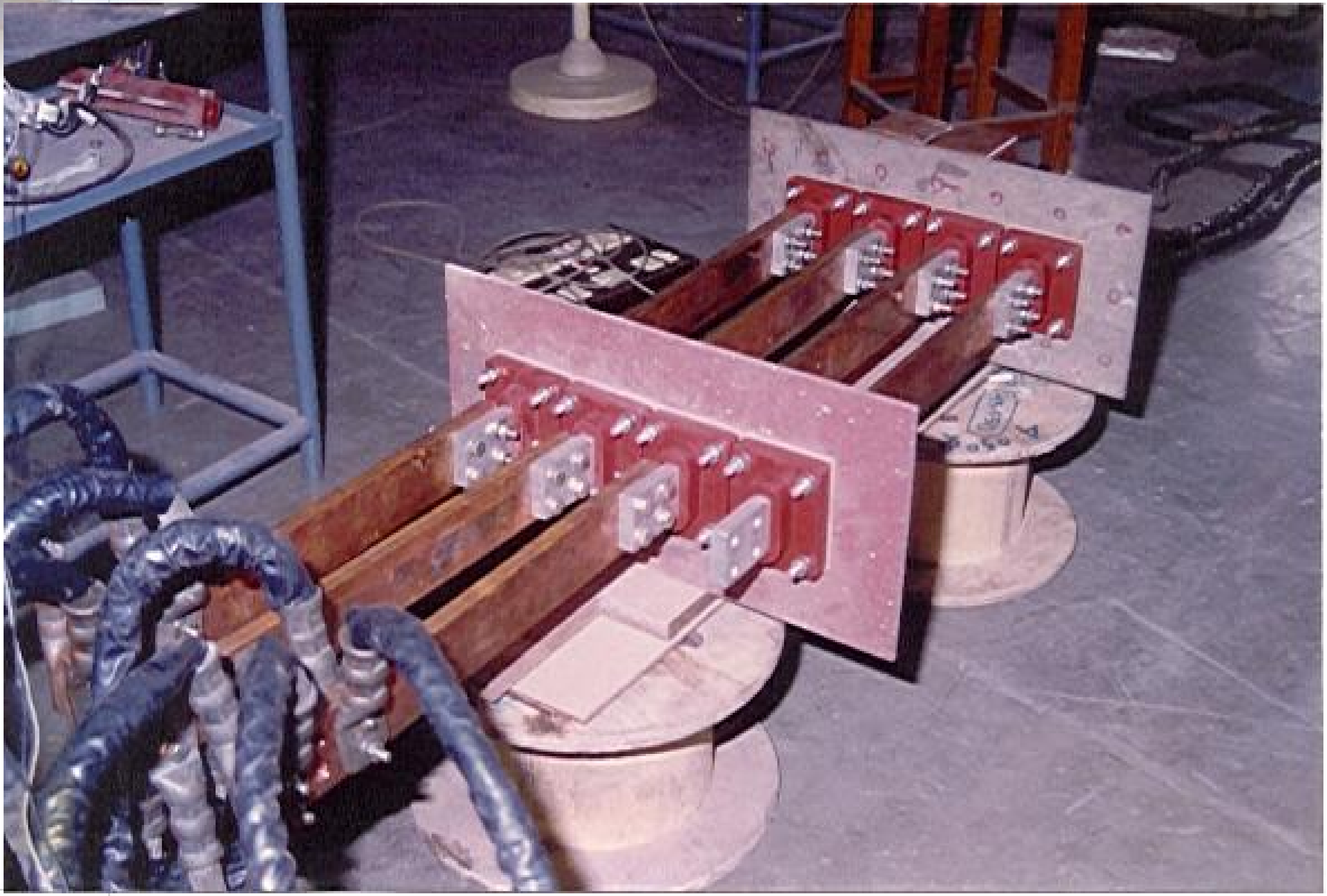
EDDY LOSS ANALYSIS IN BUSHING MOUNTING PLATE BY 3D FEM ANALYSIS



EXPERIMENTAL VERIFICATION OF EDDY LOSS CALCULATION IN BUSHING MOUNTING PLATE



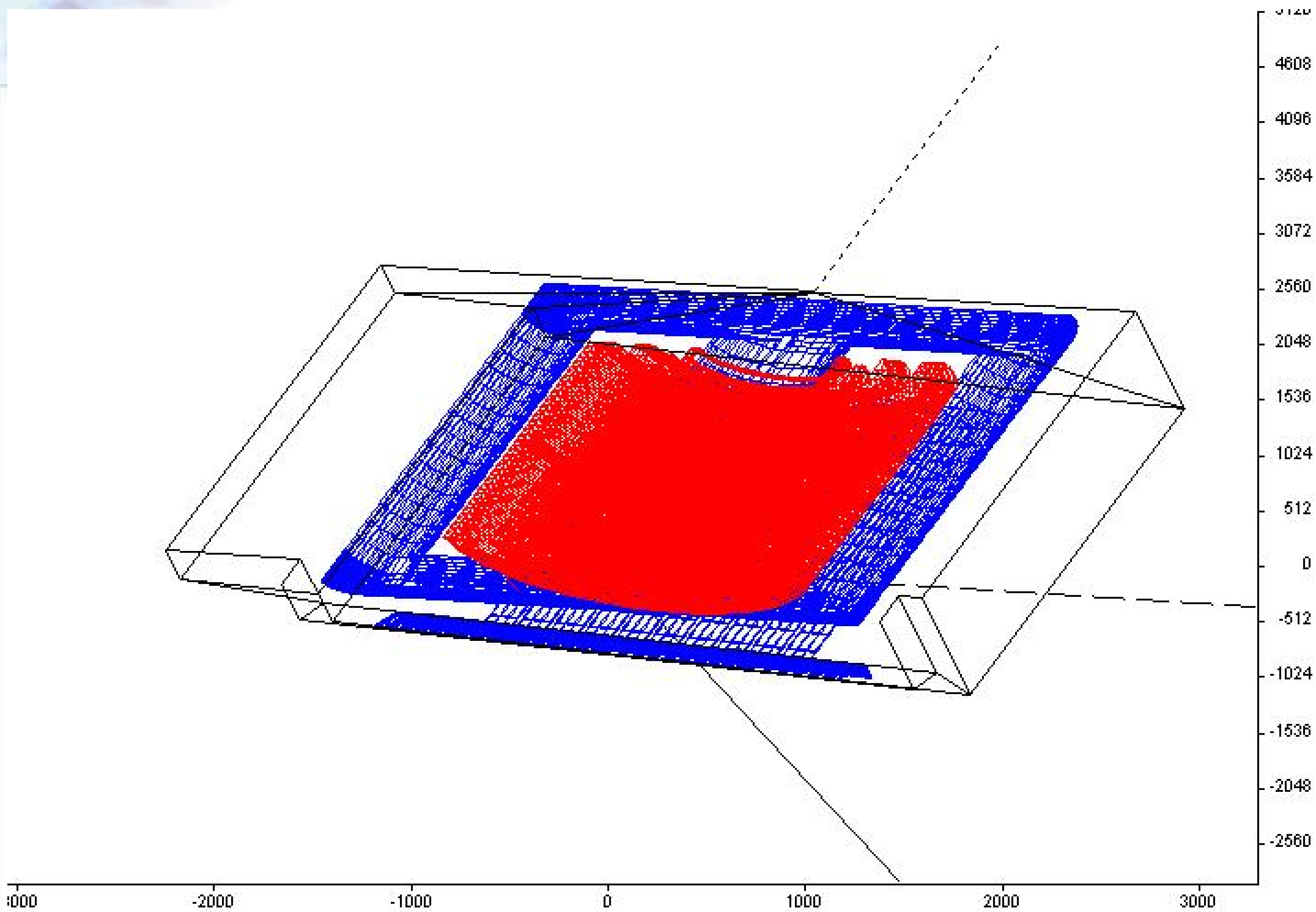
2. EDDY AND STRAY LOSS CONTROL (CONTD.)

ANALYTICAL TOOLS & DESIGN PHILOSOPHY

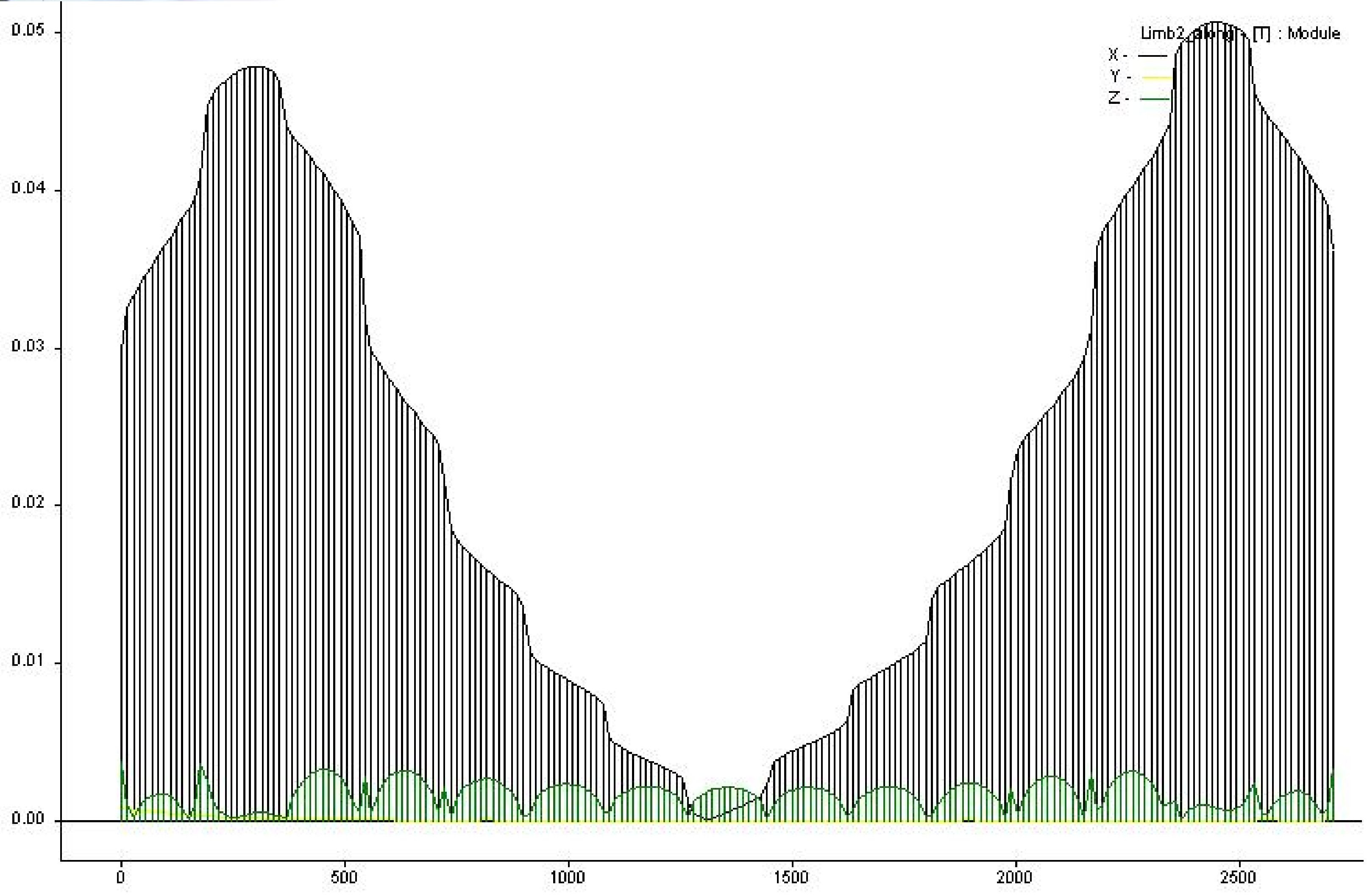
B. STRAY LOSS

- "EDMAG-3D" AND "MAGNAXI" SOFTWARE FOR ESTIMATION OF STRAY LOSS & HEATING IN TANK AND CORE CLAMPING STRUCTURAL ELEMENTS
- FEM (3D) SIMULATION FOR STRAY LOSS CONTROL IN HIGH CURRENT TERMINATIONS OR BY PROGRAM EDMAG-3D
- PROPER CHOICE OF FLITCH PLATE MATERIAL (MS / SS / LAMINATED) AND TYPE (WITH SLOTS / WITHOUT SLOTS) (ALSO TIE-ROD ARRANGEMENT WITHOUT FLITCH PLATE)
- JUDICIOUS USE OF MAGNETIC / NONMAGNETIC SHIELDING

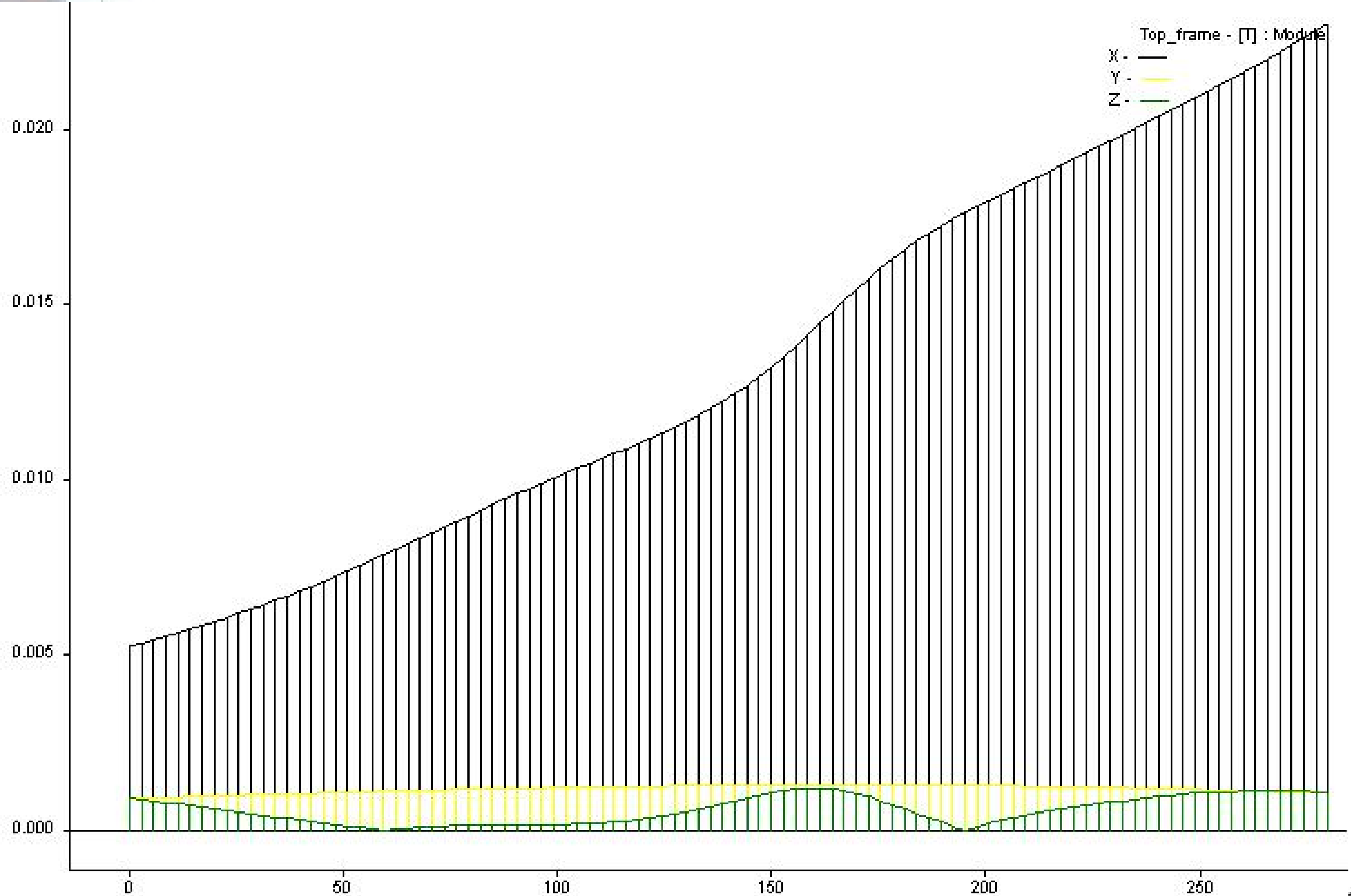
EDMAG MODEL OF 66.67 MVA AUTO TRANSFORMER



STRAY FLUX DISTRIBUTION IN FLITCH PLATE OF 66.67 MVA AUTO TRANSFORMER



STRAY FLUX DISTRIBUTION IN TOP YOKE FRAME OF 66.67 MVA AUTO TRANSFORMER



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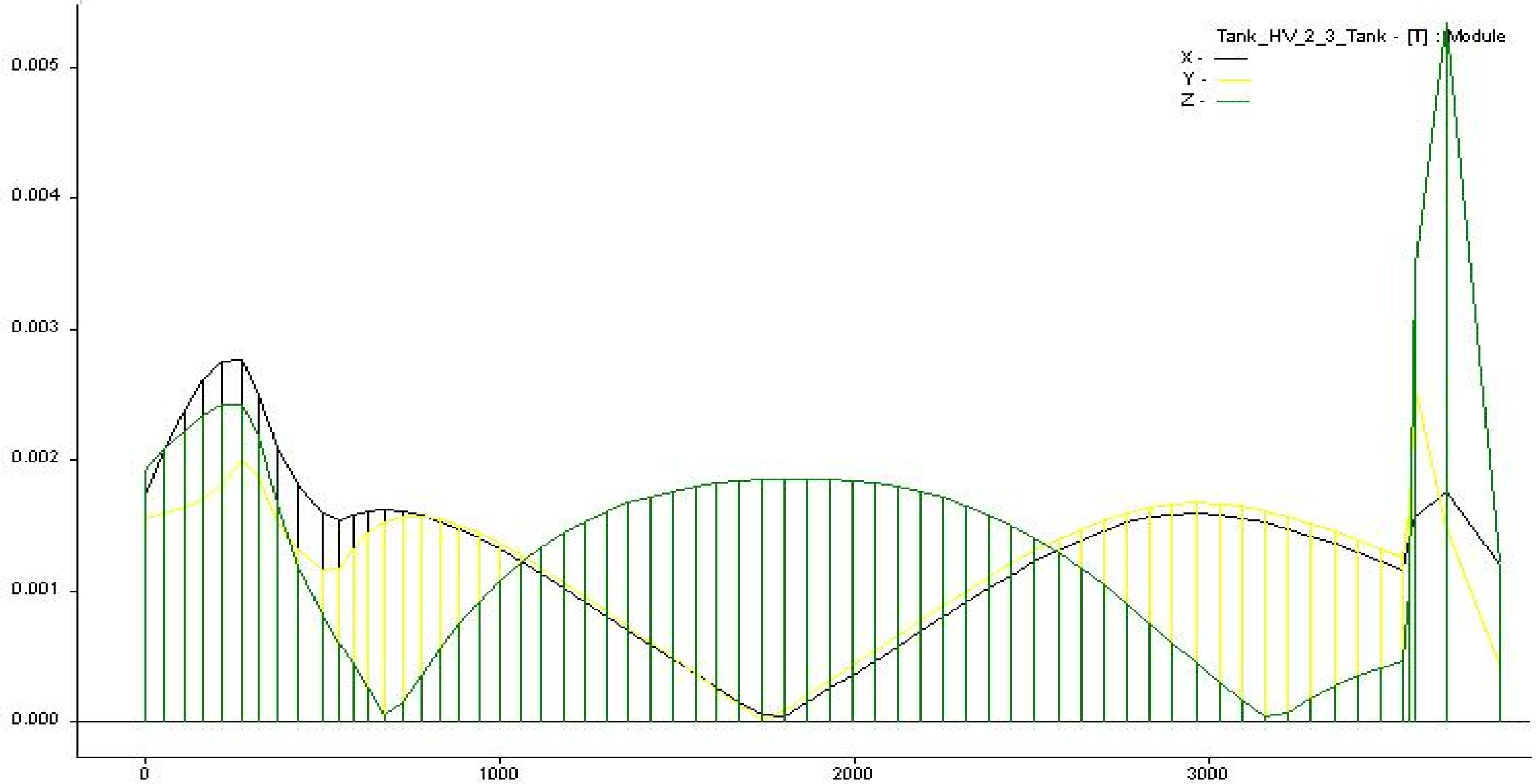
STRAY FLUX DISTRIBUTION IN TANK OF 66.67 MVA AUTO TRANSFORMER



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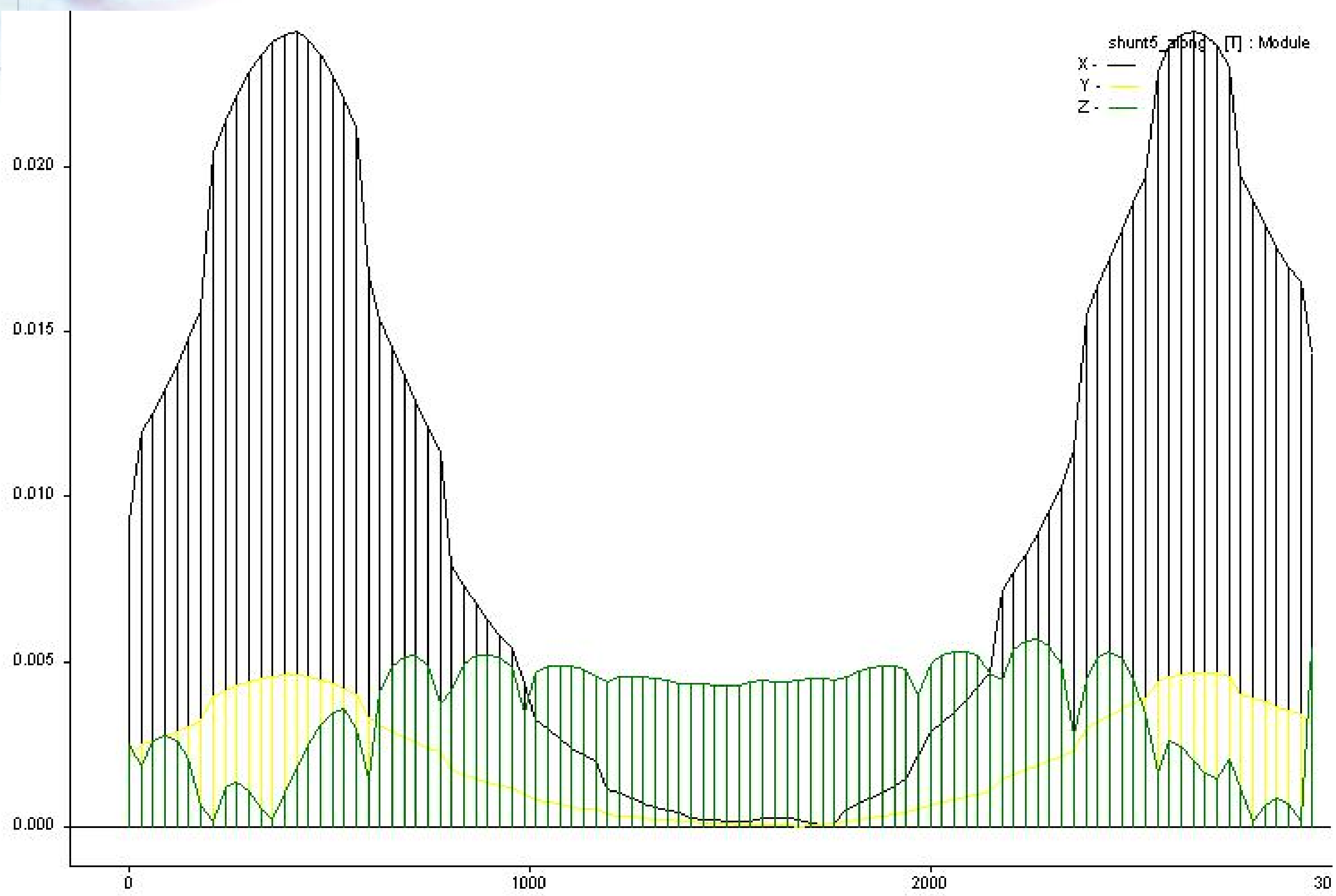
STRAY FLUX DISTRIBUTION IN WALL SHUNTS OF 66.67 MVA AUTO TRANSFORMER



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- CONCLUSION

3. WITHSTAND AGAINST SHORT CIRCUIT FORCES

A RELIABLE DESIGN TO ADDRESS

- WINDING STRENGTH, RIGIDITY AND STABILITY UNDER THE ACTION OF RADIAL FORCES
- WINDING STRENGTH, RIGIDITY AND STABILITY UNDER THE ACTION OF AXIAL FORCES
- CONDUCTORS TILTING STRENGTH
- STRENGTH OF CORE FRAME, FLITCH PLATE, PRESS RINGS AND CLAMPING STRUCTURE

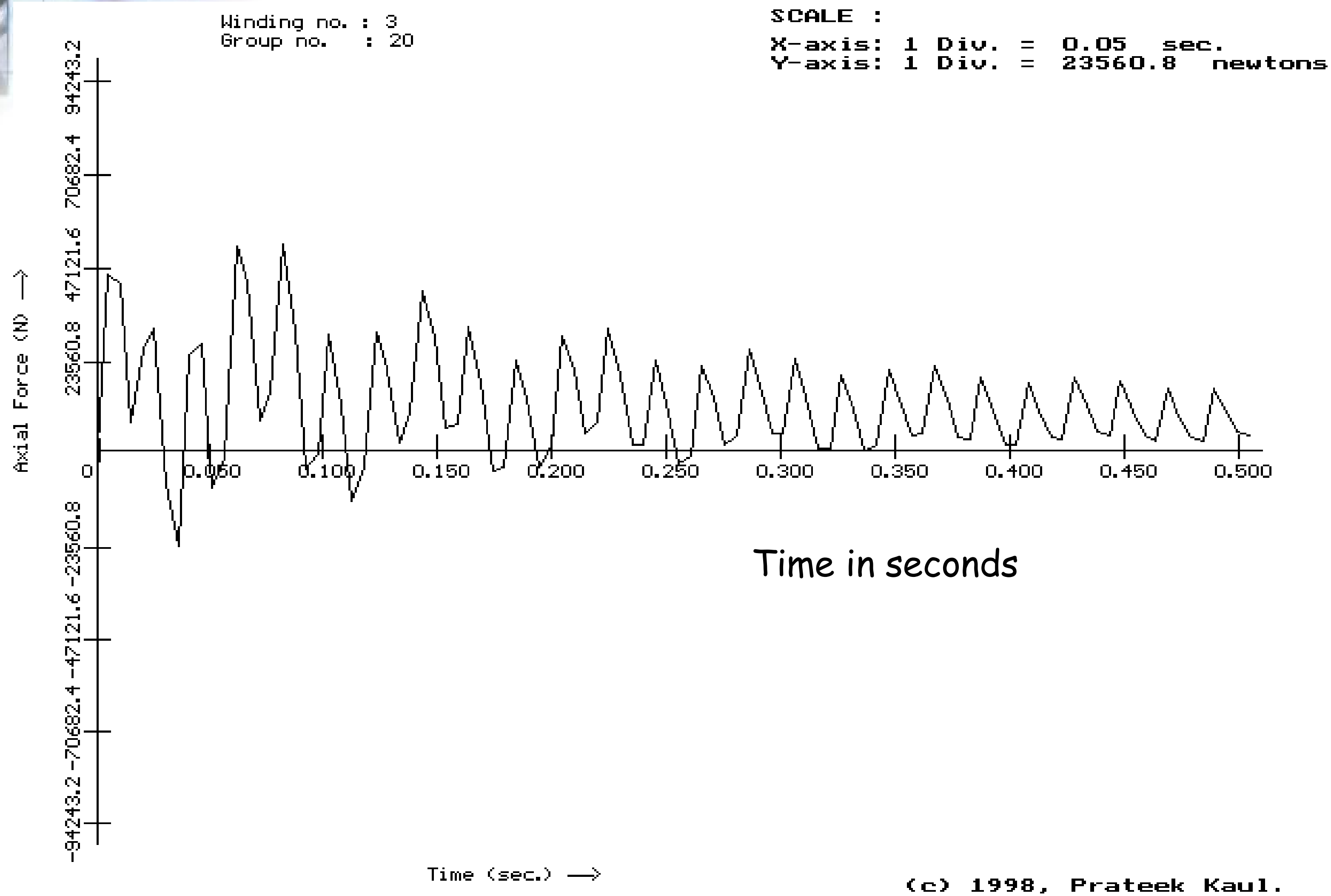
3. WITHSTAND AGAINST SHORT CIRCUIT FORCES (CONTD)

ANALYTICAL TOOLS AVAILABLE

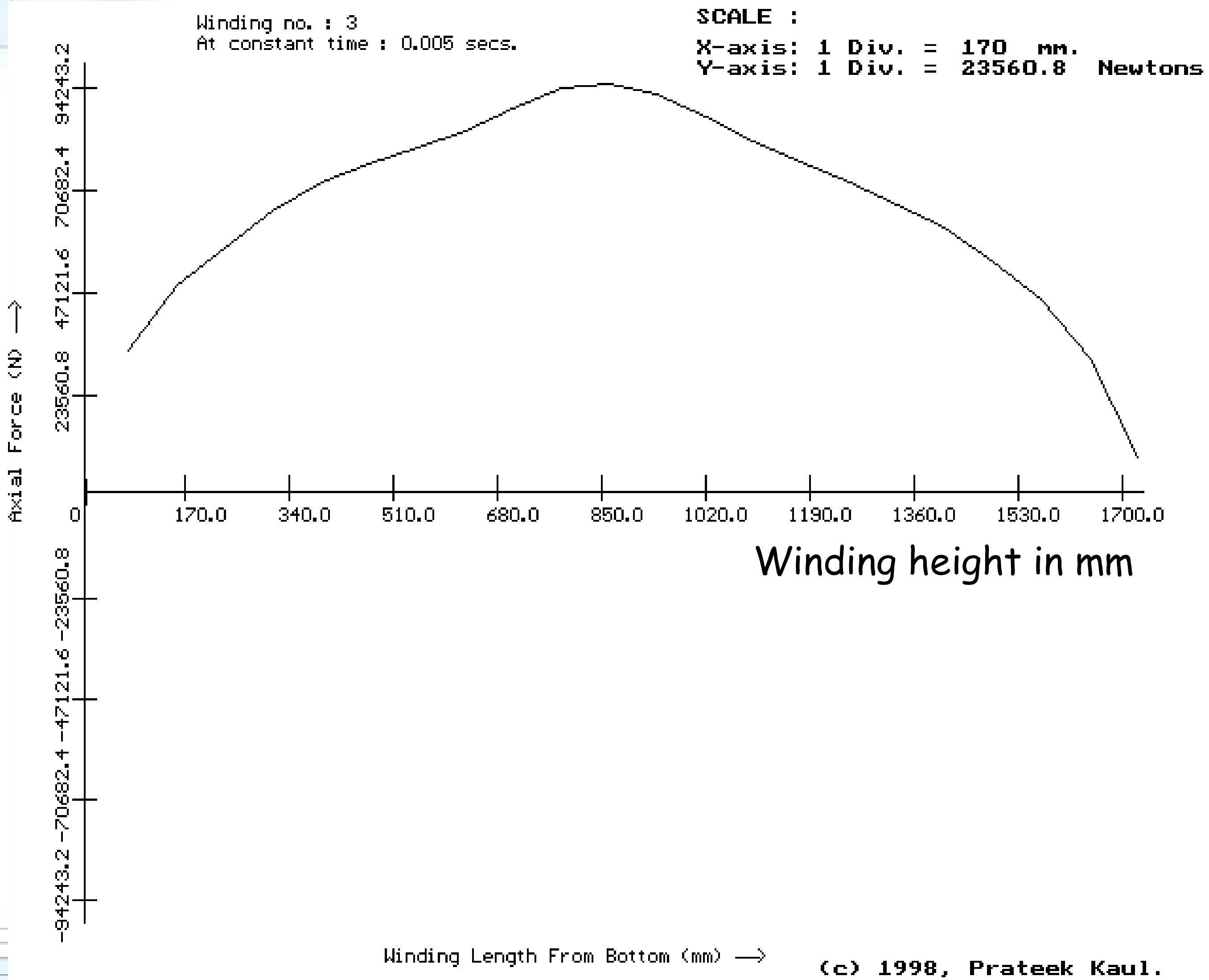
- “ELDINST’ (VIT) SOFTWARE USED TO ANALYSE DYNAMIC STABILITY OF COILS UNDER SHORT CIRCUIT CONDITIONS.

- “MAGNAXI” AND “FORCE” PROGRAMS USED TO CALCULATE STRESSES & STRENGTH (RADIAL/AXIAL, BENDING, TILTING,CLAMPING RING)

FORCE PATTERN AT A LOCATION



FORCE ALONG WINDING AT A TIME INSTANT



3. WITHSTAND AGAINST SHORT CIRCUIT FORCES (CONTD)

CG-PAUWELS DESIGN PHILOSOPHY

- USE OF WORK HARDENED CONDUCTOR
- USE OF GLUED CTC CONDUCTORS FOR HIGH CURRENT COILS
- AMPERE-TURN BALANCE
- PRESTABILISATION OF COILS
- PRE-DEFINED CLAMPING PRESSURE ON COILS.

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4. THERMAL HOT-SPOT CONTROL

A RELIABLE DESIGN TO ADDRESS

- ESTIMATION OF WINDING HOT-SPOT TEMPERATURE AND LOCATION
- CONTROL OF HOT-SPOT TEMPERATURE RISE BY EFFICIENT COOLING DESIGN
- ESTIMATION AND CONTROL OF CORE HOT SPOT TEMPERATURE

4. THERMAL AND HOT SPOT CONTROL (CONTD)

ANALYTICAL TOOLS & DESIGN PHILOSOPHY

- SOFTWARES USED

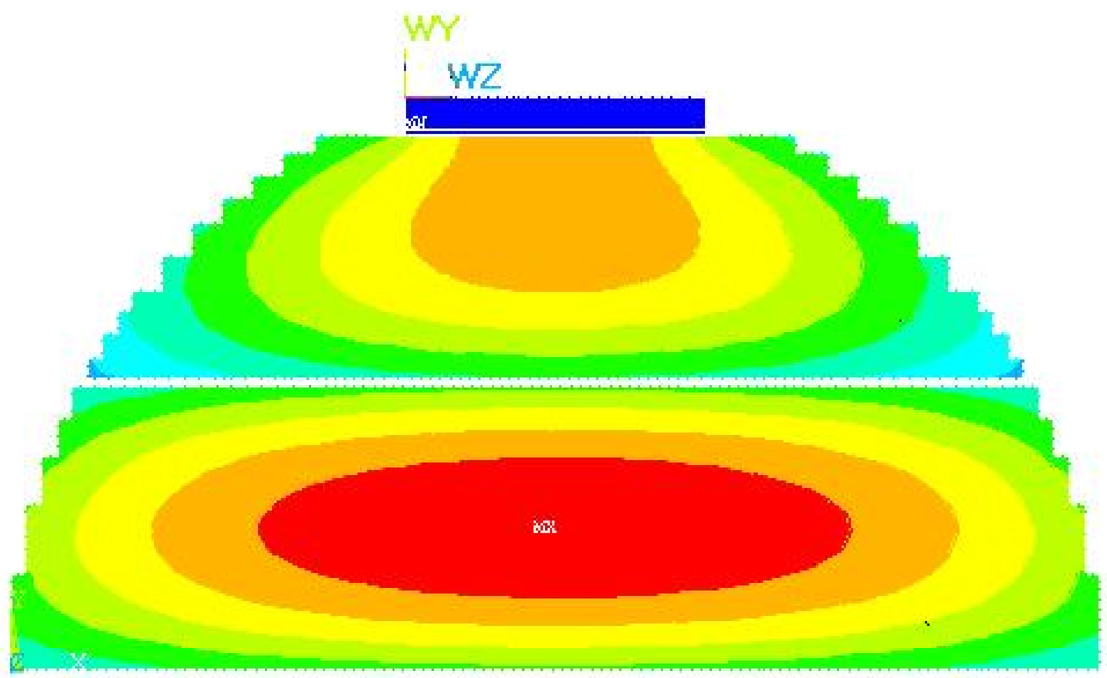
  GRAD
  RADIATOR
  ONAN POWER
  ONAF POWER
  OFAF POWER

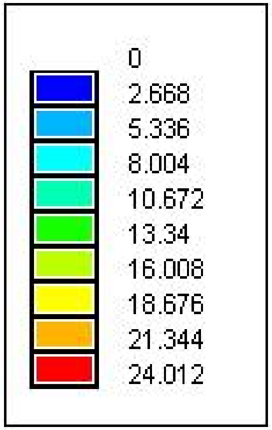
- GUIDED FLOW IN WINDING
- HIGH THERMAL HEADS
- FULLY DIRECTED OIL FLOW
- FEM ANALYSIS FOR CORE HOTSPOT
- HOT SPOT VERIFIED BY FIBRE OPTICS

3D FEM THERMAL ANALYSIS OF CORE

1

Temp. Rise Distribution in Yoke / Limb at Extreme Negative Tap





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5. STRUCTURAL DESIGN & SEISMIC WITHSTAND

A RELIABLE STRUCTURAL DESIGN TO ADDRESS

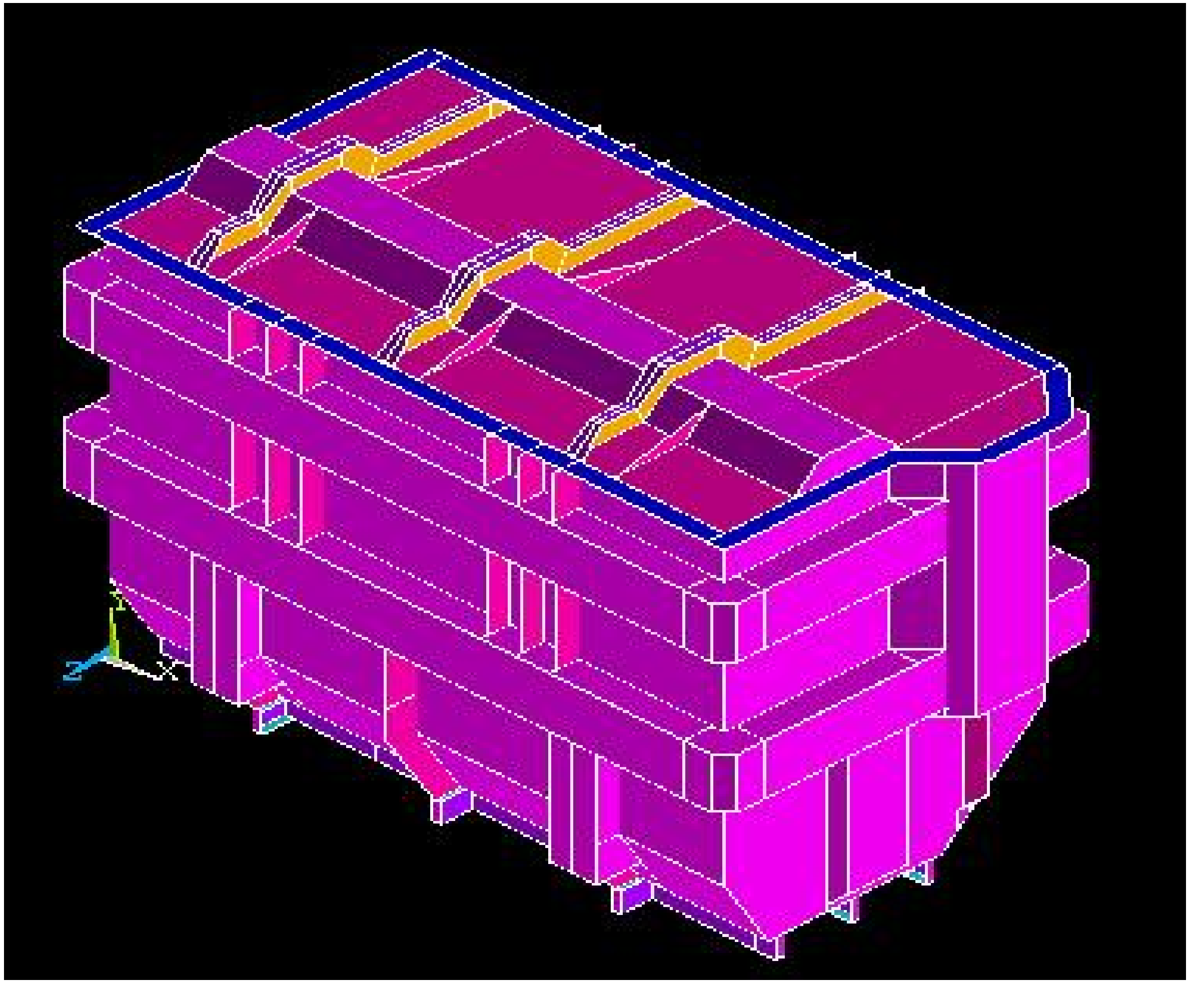
- TRANSFORMER TANK TO WITHSTAND STRESSES UNDER VACUUM PRESSURE, LIFTING & JACKING CONDITIONS
- ACTIVE PART ANCHORING TO TANK TO WITHSTAND STRESSES DURING TRANSPORT CONDITIONS
- STRUCTURAL PARTS AND SUPPORTS TO WITHSTAND STRESSES UNDER SEISMIC EARTHQUAKE CONDITIONS

5. STRUCTURAL DESIGN & SEISMIC WITHSTAND (CONTD)

AVAILABLE ANALYTICAL TOOLS & DESIGN PHILOSOPHY

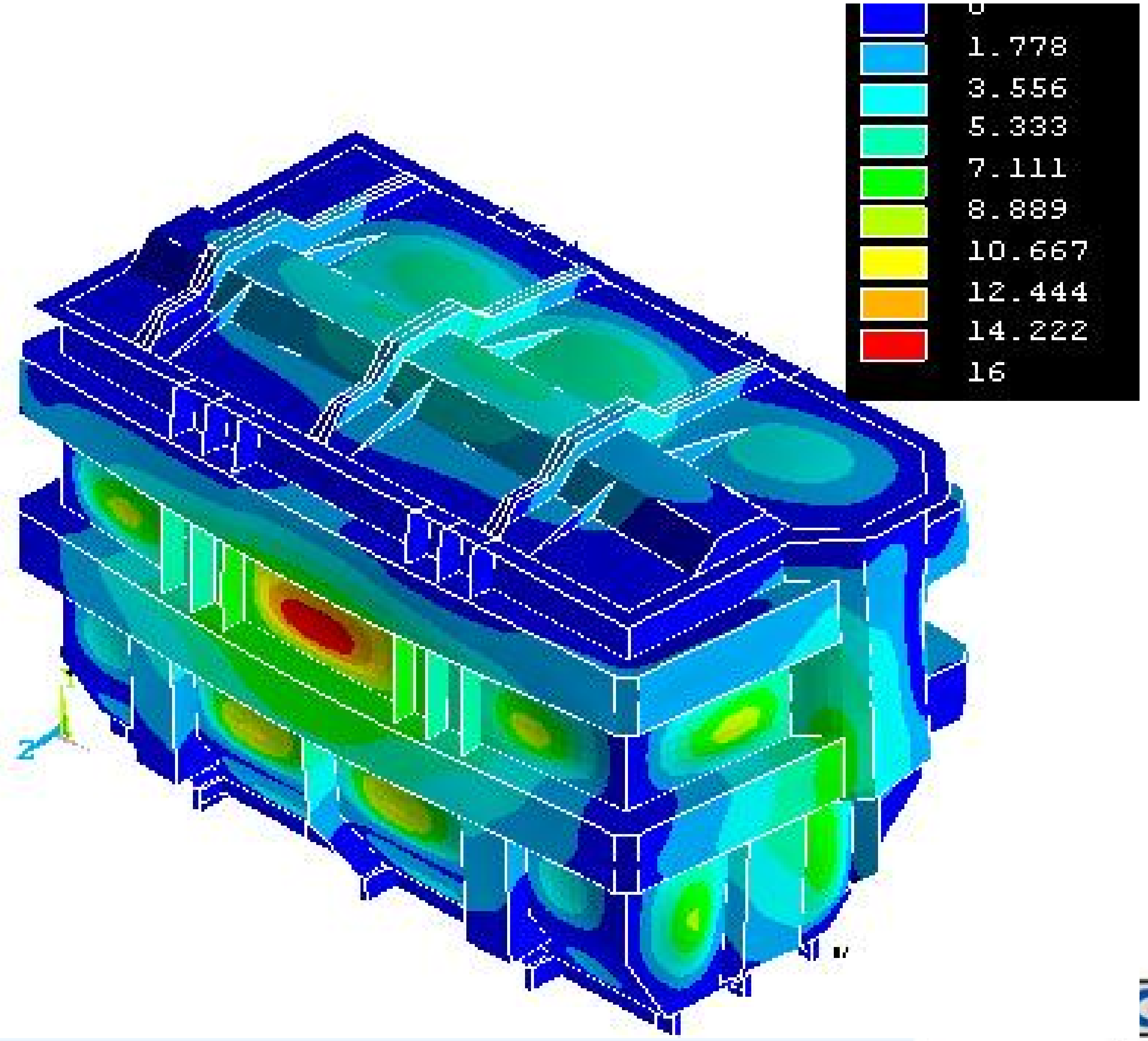
- USE OF 3D FEM TO CHECK VACUUM / PRESSURE WITHSTAND BY 'ANSYS'
- ADEQUATE STIFFENING FOR VARIOUS TYPES OF LOADS (LIFTING, JACKING, ETC.)
- VERTICAL BOX STIFFENERS
- BELL SHAPED TANKS
- WELDED TANKS

FINITE ELEMENT MODEL OF TRANSFORMER TANK

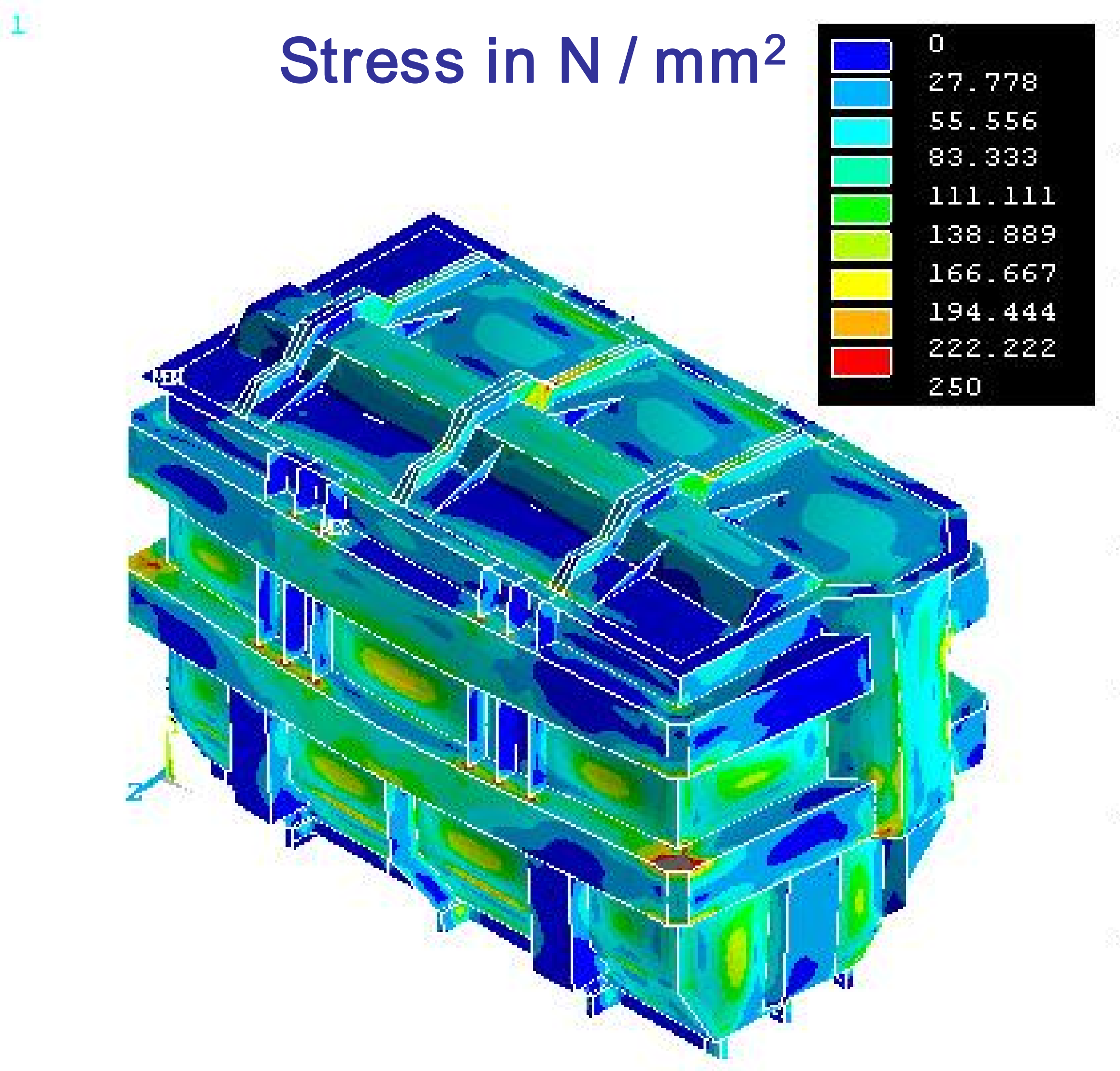


DEFLECTION PLOT UNDER PRESSURE LOADING

Deflection in mm



STRESS PLOT UNDER PRESSURE LOADING



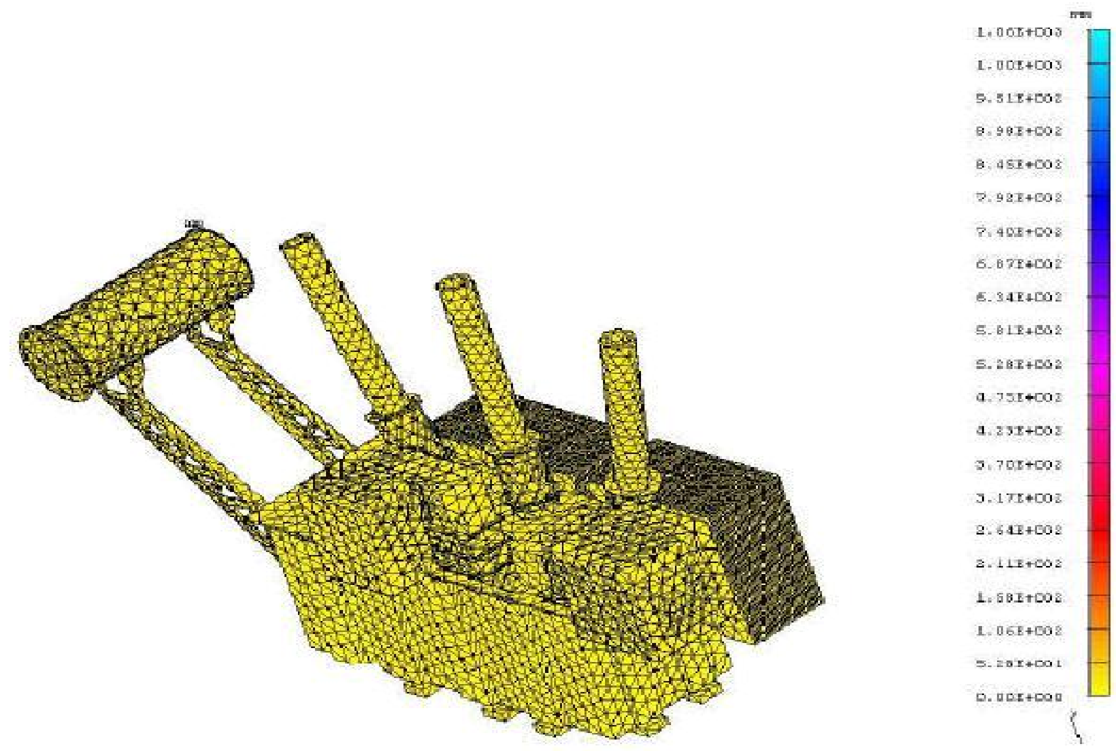
SEISMIC WITHSTAND CAPABILITY

SEISMIC DESIGN METHODS

- STATIC ANALYSIS COMPRISING CALCULATIONS OF CENTRE OF GRAVITY, NATURAL FREQUENCY, STRESS CALCULATIONS AND WITHSTAND DESIGN

- DYNAMIC ANALYSIS COMPRISING NATURAL FREQUENCY OF FULLY ASSEMBLED TRANSFORMER, MODAL/ RESPONSE ANALYSIS ON 3D FEM

NATURAL FREQUENCY & MODE SHAPE OF A 30 MVA ASSEMBLED TRANSFORMER AT 0.5g SEISMIC ACCELERATION



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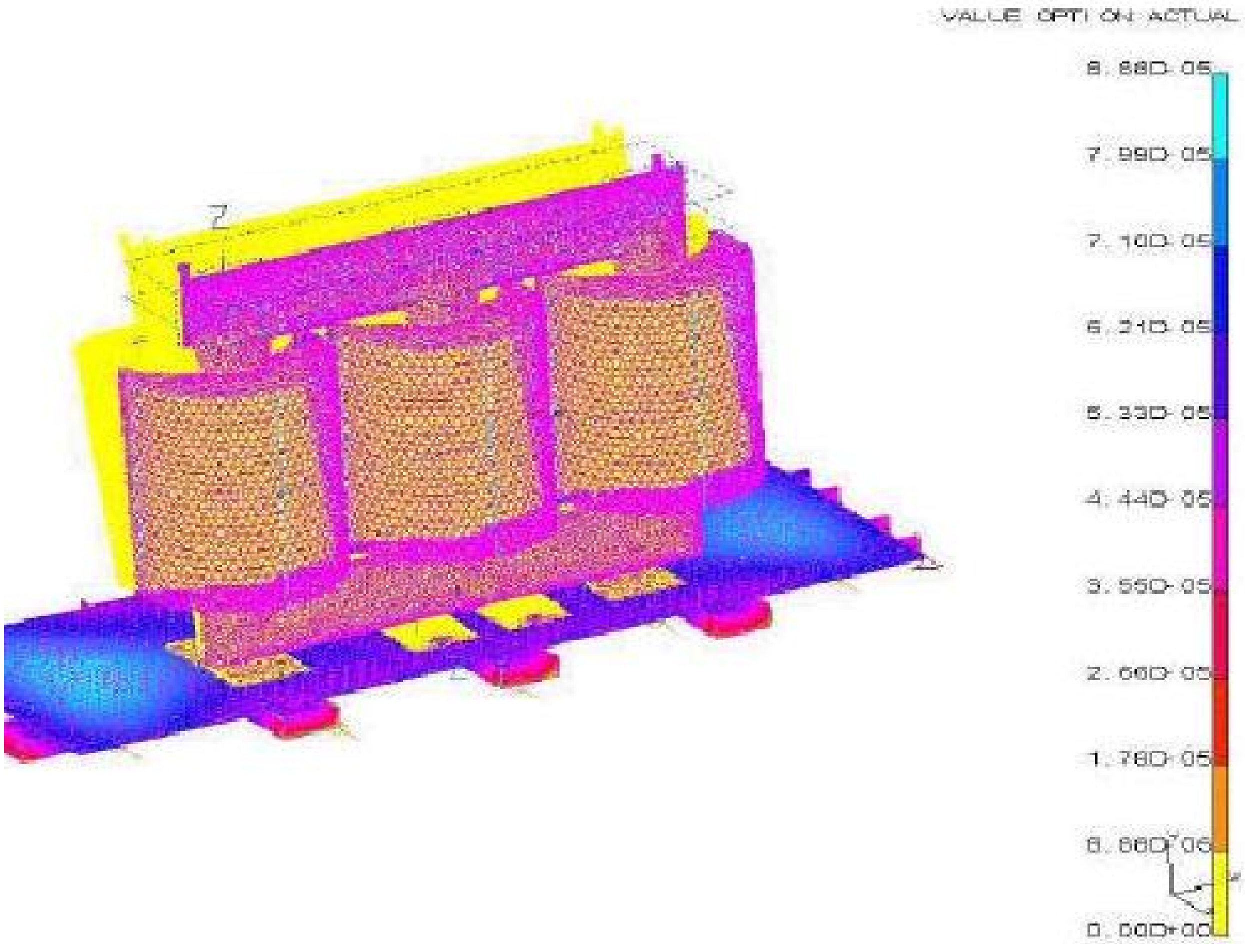
STRESS PLOT OF CORE COIL ASSEMBLY AT 0.5g SEISMIC ACCELERATION



ECO-FRIENDLY TRANSFORMERS

ECOFRIENDLY TRANSFORMERS

ECOFRIENDLY EXPECTATIONS

- LOW NOISE
- LEAK PROOFNESS
- AESTHETICS

ECOFRIENDLY TRANSFORMER (CONTD.)

LOW NOISE

EXPECTATIONS :

- 10-15 dB LOWER THAN NEMA LEVELS

- MEASURES ADOPTED FOR UPTO 10 dB REUCTION
  - REDUCTION OF FLUX DENSITY
  - USE OF HI-B MATERIAL
  - GLUING OF CORE
  - ANTI-VIBRATION MOUNTS
  - LOW NOISE FANS

- MEASURES FOR MORE THAN 10 dB REUCTION
  - SANDWICH PANELS / CONCRETE HOUSE
  - ACHIEVED 60 dB ON 90 MVA TRANSFORMER, 54 dB ON 25 MVA & 47 dB ON 16 MVA TRANSFORMERS

ECOFRIENDLY TRANSFORMERS (CONTD)

NO LEAKAGE

REQUIREMENTS OF AN UPGRADED SEALING SYSTEM

- NO / MINIMUM EXPOSURE OF GASKET
- THINNER AND MINIMUM WIDTH GASKET
- JOINTLESS GASKET TO THE EXTENT POSSIBLE
- REUSABLE TYPE OF GASKET MATERIAL
- CONSTRAINED TYPE OF SEALING SYSTEM WITH NO OVER COMPRESSION OF GASKET (GASKET IN MACHINED GROOVE OR WITHIN LIMITERS)
- GASKET COMPATIBLE WITH TEMPERATURES EXPECTED

ECOFRIENDLY TRANSFORMERS (CONTD)

NO LEAKAGE

DESIGN PHILOSOPHY

1. BASIC PHILOSOPHY IS TO PROVIDE RECTANGULR SECTION,
   NITRILE RUBBER (NBR) GASKET IN MACHINED GROOVE

2. IN THE CURB, ELLIPTICAL NBR CORD WITHIN 3 LIMITER ARRANGEMENT

ECOFRIENDLY TRANSFORMER (CONTD.)

AESTHETICS :

PACKAGING - DESIGN PHILOSOPHY

- WOOD QUALITY & TREATMENT
- STRENGTH / LOADABILITY OF BOX
- SEA WORTHY PACKING BOXES
- ITEMS COVERED IN POLYETHYLENE
- DAMAGE FREE SHIPMENT PARTICULARLY FRAGILE ITEMS LIKE PORCELAINS, INSTRUMENTS IN MODULABLE FOAM PACKAGING
- MARKINGS & SYMBOLS ON BOXES
- CO-RELATION OF ITEMS VIS-À-VIS ITEM NOS. ON CUST. DRAWINGS
- USER FRIENDLY PACKING LIST

ECOFRIENDLY TRANSFORMER (CONTD.)

PAINT & FINISH

PRE-REQUISITES OF A GOOD SURFACE FINISH

- UPGRADED SURFACE PREPARATION GUIDELINE (SA $2^1/_2$ / SSPC P6) (50 λ APPROX.)
- UPGRADED WELDING QUALITY GUIDELINES (APPROVED FABRICATORS)
- UPGRADED PAINT SPECIFICATION (APPROVED PAINT SUPPLIER)
- SAME BATCH OF PAINT FROM ONE SOURCE FOR TANK & ACCESSORIES
- UPGRADED PAINT PROCESS SPECIFICATION
- QUALITY CHECKS ON PAINT AND PROCESS
- FINAL COAT BEFORE SHIPMENT

ECOFRIENDLY TRANSFORMER (CONTD.)

PAINT & FINISH (CONTD.)

Paint system compatible with different environment zone according to degree of corrosion

Mildly Corrosive

Epoxy-Polyamide HB Zinc Phosphate Primer 50 - 60 Microns)

+

Acrylic Aliphatic Polyurethane top coat (35 - 45 Microns)

Highly Corrosive

Inorganic Zinc Silicate Primer (60 - 65 Microns)

+

Epoxy Polyamide HIB MI0 (100 - 125 Microns)

+

Acrylic Aliphatic Polyurethane top coat (35 - 45 Microns)

CONTENTS

- RELIABLE SYSTEM NEEDS A RELIABLE TRANSFORMER !
- WHAT IS A RELIABLE TRANSFORMER ?
- RELIABILITY OF DIELECTRIC DESIGN – WITHSTAND AGAINST OVER-VOLTAGES
- RELIABILITY OF ELECTROMAGNETIC DESIGN – EDDY AND STRAY LOSS CONTROL
- RELIABILITY OF ELECTRODYNAMIC DESIGN - WITHSTAND AGAINST SHORT CKT FORCES
- RELIABILITY OF THERMAL DESIGN – HOT SPOT CONTROL
- RELIABILITY OF STRUCTURAL DESIGN – VACUUM, PRESSURE, SEISMIC WITHSTAND CAPABILITY
- CONCLUSION

CONCLUSION

- TRANSFORMER RELIABILITY IS A PRE-REQUISITE OF OPERATIONAL RELIABILITY OF ELECTRICAL SYSTEM.
- TRANSFORMER RELIABILITY IS THE THEME OF SEVERAL CONFERENCES, FORA AND IS CURRENT FOCUSSED AREA OF R&D.
- RELIABILITY OF TRANSFORMER CAN BE BUILT IN THE DESIGN STAGE ITSELF

CONCLUSION (CONTD.)

DESIGN RELIABILITY CAN BE ENSURED BY

- ACCURATE PREDICTION OF TRANSIENT OVER OVER-VOLTAGE DISTRIBUTION
- MAPPING THE 3-D ELECTROMAGNETIC FIELD DISTRIBUTION FOR STRAY LOSS AND HOT SPOT CONTROL
- ADEQUATE FACTORS OF SAFETY TO WITHSTAND DYNAMIC EFFECTS OF SHORT CIRCUIT FORCES DURING SYSTEM FAULTS

CONCLUSION (CONTD.)

- ACCURATE ESTIMATION OF HOTSPOT TEMPERATURE FOR ENSURING FULL INSULATION LIFE
- LEAK-PROOF STRUCTURAL DESIGN ALSO WITHSTANDING SEISMIC FORCES AND SUDDEN PRESSURE SHOCKS

THANK YOU

Crompton Greaves
EVERYDAY SOLUTIONS