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Research Article

Enhancing Transformer Reliability : Implementing Lean Six Sigma Tools To Reduce Failure Rate From 0.75% PPM To 0.35% PPM

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ARTICLE INFO | **ABSTRACT**

In today's global business environment, quality cannot be under estimated or overlooked by any firm, whether it is a manufacturing firm or a service firm, regardless of its size or assets. The challenge for business today is to produce quality products efficiently and in a cost effective manner.

Quality management is concerned with the understanding of the principles of total quality that allows the organization to become more effective and competitive in its performance characteristics viz; cost efficiency, quality, dependability and flexibility.

Firm promotes a positive attitude by adopting or approaching to cultivate supplies and customers and to stay close to firm for total benefit. It has become a global approach for restructuring business processes and seeking continuous business improvements. The customers have gained renewed focus and unprecedented competitive processes have become the norm.

Total quality management is essentially about the development of an ideology, a philosophy, method of actions that are designed to satisfy customers completely, through continuous improvement.

The total quality philosophy is an approach that focuses all of the resources of an organization or the continues and simultaneous improvement of both quality and productivity. The purpose of total quality approach is to continually improve the organization's performance and in turn competitiveness.

To support develop and adhere a process of continuous improvement it is needless for and organization to use a selection of tools and techniques. Some of the tools and techniques are simple while some are more complex.

The tools and techniques, along with management practices and the organizational infrastructure are fundamental components of total quality management. However, one should not view quality management only from tool based perspective and fail to see the management practices and infrastructure required to make use of these tools successfully. when used properly, these tools and techniques are powerful and effective in helping organization to design products and processes and to identify and solve quality problems that will ultimately lead to better customer value and operational performance.

Top management have a vital role to play in implementing total quality management for overall global welfare . well developed tools and approaches are available . They have to deploy tools effectively with a knowledge involvement and commitment.

Key words: DMAIC, Six Sigma, CTQ, VOC

2. Introduction:

Sigma is a statistical concept that represents the amount of variation present in a process relative to customer requirements or specifications. When a process operates at six sigma level the variation is so small that the resulting products and services are 99.9997% defect free. In addition to being a statistical measure of variation, the term six sigma also refers to a business philosophy of focusing on continuous improvement by understanding customer needs, analyzing business processes and instituting proper measurement methods. To increase organization's process-sigma level it must decrease the amount of variation that occurs. Less variation gives following benefits:

- Greater predictability in the process.
- Less waste and rework,
- Products and services that perform better and last longer.
- Happier customers who value the organization.

Critical To Quality (CTQ) Characteristic: A key feature by which customers evaluate the quality of product or service and that can be used as measures for project.

The DMAIC method has five steps: Define, Measure, Analyze, Improve and Control. It is used to improve the current capabilities of an existing process. This method defines CTQs first. The improvement team then studies ach one intensively to understand the key drivers that influence successful process performance. Improvement in key drivers can then be made, and the process can attain the required six sigma level and thereby meet the CTQs. The five steps of the DMAIC method are outlined below:

1.**Define the project**.

- Define the project's purpose and scope.
- Collect background information on the process and your customer's needs and requirements.

2. Measure the current situation.

- Gather information on the current situation to provide clearer focus for improvement effort.

3. Analyze to identify causes.

- Identify the root causes of defects.
- Confirm them with data.

4. Improve

- Develop, try out and implement solutions that address the root causes.
- Use data to evaluate results for the solutions and the plans used to carry them out.

5. Control

- Maintain the gains achieved by standardizing work methods or processes.
- Anticipate future improvements and make plans to preserve the lessons learned from this improvement effort.

3. Literature review:

In order to be competitive and successful on the marketplace and satisfy customers, companies should continuously improve their production processes and product quality. The features of reliable and stable production processes: less scrap, less rework, less consumption of additional recourses, time and money.

From the literature review of the various sources that describe the scientific achievements made in the field of FMEA and Six Sigma, it can be summarized that the main goal of these methods is continuous improvement of business processes. Initially, researchers used these methods independently in order to achieve their goals. However, later, researchers started to combine these methods in order to achieve results that are more efficient.

Initially the Six Sigma methodology was developed for elimination of variability, and lean manufacturing for elimination of wastes in business processes (Womack *et al.,* 1990; Womack & Jones, 1994). Later, these methodologies have been combined with DMAIC method for structural approach of problem solving. This combination later became known as Lean Six Sigma (Aon Management Consulting, 2003; Brook, 2010). There are many different tools that are used in Lean Six Sigma, such as FMEA, Value Stream Mapping, Cause & Effect, Design of Experiments (DOE), SIPOC/COPIS, QFD/House of Quality and others (Brook, 2010). These methods are developed for various purposes, such as, measurement, analysis and improvement of business processes. But the most suitable Lean Six Sigma tool that is intended to improve the reliability of business processes is FMEA (MacDermott *et al.,* 1996). There are large amount of research papers where discussed common application of FMEA and Six Sigma for attainment of specific goals (Mekki, 2006; Krishna & Dangayach, 2007; Sarkar, 2007; Yang *et al.,* 2010; Bhanumurthy, 2012; Chiarini, 2012). Based on comprehensive literature review results, it is possible to discover what achievements have not yet been done by combining these methodologies together:

- Calculate Sigma performance level that shows the level of process or product quality based on the data from FMEA.
- Calculate the financial impact of failure, in the process, on the final product cost using the data from FMEA.

Weerahandi (1993)[1] introduced the concept of the generalized pivotal quantity (GPQ) and the generalized confidence interval (GCI), and demonstrated how to use them to derive confidence interval procedures for situations when exact frequents intervals are unavailable or difficult to apply.

Tsui and Weerahandi (1989)[2] introduced the concept of the generalized p-value, which is in the same spirit as the idea of GCI. **Iyer and Patterson (2002)[3]** provided a general recipe for the construction of generalized test variables and GPQs. Recently, **Hannig et al. (2006)[4]** proposed a subclass of GPQs, called fiducially generalized pivotal quantities (FGPQs), and showed that, under fairly mild conditions, fiducially generalized confidence intervals (FGCIs) constructed using FGPQs have correct frequents coverage, at least asymptotically. In addition**, Hannig et al. (2006) [4]** described three general approaches for constructing FGPQs and demonstrated their usefulness by deriving some previously unknown GPQs and GCIs. Connections between GPQs and fiducially inference are also discussed.

4. Need of the study:

This research paper develops the framework for continuous improvement of reliability of production processes that allows improving KPIs – product Quality and Cost. This framework should integrate various quality improvement tools and methodologies. The new framework will be applied in rigorous Six Sigma DMAIC methodology that enables to define, measure, analyses improve and control problematic production process. This framework helps engineers to find problematic operations and eliminate root causes of problems quickly and with less effort. The framework would play the role of a "dashboard" like in a cockpit, which allows monitoring the specified indicators such as Process/Product Sigma Performance Level (PSPL) and Cost Weighted Factor for RPN (*CWFRPN*). These subsequently influence Quality KPI and Cost KPI in an up-to-date way due to the constantly renewed data from production floor, for example, data from Enterprise Resource Planning (ERP) system **(Umble *et al.*, 2003)[5]**. The framework is oriented towards the improvement of production processes in production floor, it is suitable for SMEs and can be applied in big enterprises, which have Batch production.

5. Statement of the problem:

Expectations from the research

Zero Rejection:

No Customer complaints of UPS noise due transformers.

Customer Satisfaction:

An unreliable product will negatively affect customer satisfaction severely. Thus high reliability is a mandatory requirement for customer satisfaction.

Warranty Costs :

If a product fails to perform its function within the warranty period, the replacement and repair costs will negatively affect profits, as well as gain unwanted negative attention.

Repeat Business :

A concentrated effort towards improved reliability shows existing customers that a manufacturer is committed to customer satisfaction.

Cost Analysis:

The initial cost of a product might be higher, the overall lifetime cost is lower because product requires fewer repairs or less maintenance.

Customer Requirements:

Customers demand that their suppliers have an effective reliability program.

6. Key Concepts Applied in the Research

This section provides the background of basic concepts and definitions that have been used in this research. Key Performance Indicators (KPIs). KPI is a measure of performance; it is very useful for evaluating the current status of a company and for foreseeing the possible benefits of adopting an innovation in the system. KPIs are quantifiable measurements and depend on the particular company, which would evaluate those **(Barchetti *et al.*, 2011)[6].** Performance measurement is a fundamental principle of management and it is important because it identifies the gaps between current and desired performance, also provides indication of progress towards closing the gaps. Carefully selected KPIs identify precisely where to take action to improve performance **(Weber *et al.*, 2005)[7].** *Production Route (PR) card*. It is a card that gives the detail of an operation to be performed in a production line. It is used to instruct the production people to take up the production work. The content and formats of the PR card can vary from a company to company. In general, it contains: an item and the number of quantities to be produced; production time; dimensions; any additional information that may be required by the production worker. PR card traces the route to be taken by a job during a production process (PR card 09.2013).

DPMO (To find existing Quality Std Level)

$$DPMO = \frac{\text{Qty. Rejected} \times 1000000}{\text{Qty. Supplied} \times \text{No. of Opportunities}}$$

Failure Mode and Effect Analysis (FMEA). It is a systematic method of identifying and preventing product and process problems before they occurred. In recent years, companies are using FMEA to enhance the reliability and quality of their products and processes **(Johnson 1998)[8]**. The risk of a failure and its effects in FMEA are determined by three factors:
Severity (S) – the consequence of a failure that might occur during process.
Occurrence (O) – the probability or frequency of that failure occurring.
Detection (D) – failure being detected before the impact of the effect realized.
Every potential failure mode and cause is rated in these three factors on a scale ranging from 1 to 10. By multiplying these rating, a Risk Priority Number (RPN) is generated. This RPN is used to determine the effect of a failure.
RPN = S × O × D (1)
The RPN ranges from 1 to 1000 for each failure mode. It is used to rank the need for corrective actions to eliminate or reduce the potential cause of failures **(MacDermott et al., 1996)[9].** All FMEAs are team based and the purpose of FMEA team is to bring a variety of perspectives and experience to the project **(Stamatis, 2003)[10]**.
Failure Classifier (FC). Reliability engineering deals with an analysis of the causes of the faults in factories. In this paper a Failure Classifier (FC) is developed based on DOE-NE-STD-1004-92 standard. There are seven major cause categories, and each has its subcategories. The basic goal of using this standard is to define the problems or causes that might occur for each operation during production process, in order to further correct them (DOE-NE-STD-1004-92, 09.2013). This standard was adapted and modified for the machinery enterprises **(Karaulova et al., 2012)[11].**

7. Objectives of the study:

1- To study effect of current density on Burning of Transformer.
2- To evaluate effect of creepage distance on Burning of Transformer.
3- To identify whether VPI Process is superior to current Varnishing method.

8. Hypothesis:

H_{01}- Burning of transformer is independent on current density.
H_{a1}- Burning of Transformer is dependent on current density.

H_{02}- Burning of transformer is independent on creepage distance
H_{a2}- Burning of Transformer is dependent on creepage distance.

H_{03}- Both VPI & Varnishing are having same effect.
H_{a3}- VPI is better than Varnishing

9. Research Methodology:

1- Period of study:

2- Tools used:

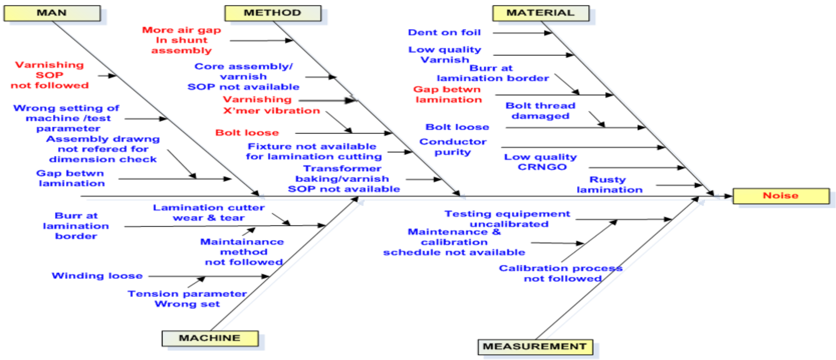
SIPOC

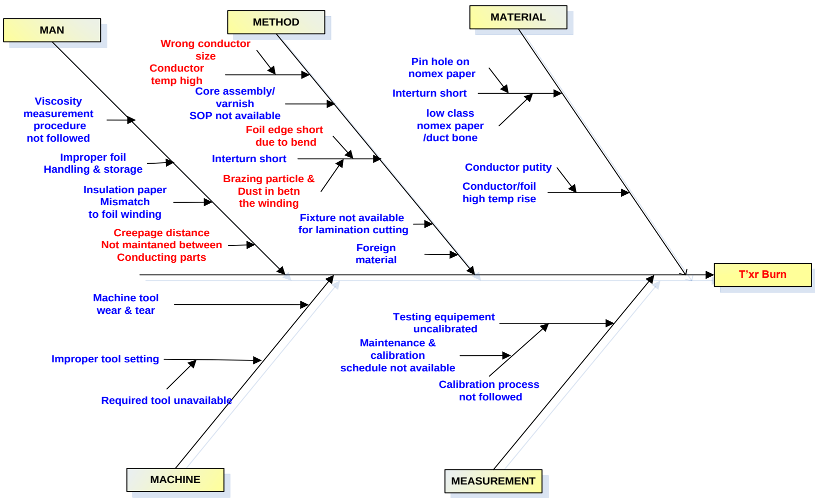
Supplier	Inputs	Process	Outputs	Customers
Production Planning and Control Store	1. Production Plan 2. Raw Mate. PO 3. Dispatch Details 4. Test Procedure 5. Ref. Standard 6. QAP 7. Drawing 8. Raw Material 9. Oprators	**Transformer Manufacturing** Incoming Insp. → Cutting Core Assy. → Winding Assy. Brazing Joints Lug Crimping → Transformer Assy. → Testing Pre Heating (Varnish Baking) → Final Testing (HV, Megger)	1. Final Test Reports 2. Finished Goods 3. Packing details 4. Dispatch Schedule	Packing And dispatch Section
	Input Metrics	**Process Metrics**	**Output Metrics**	
1. Testing Instruments 2. Varnish 3. Defined Test Procedure 4. Raw Material	# Inadequte Testing Facility # Varnishing Method # Accurate Test Procedure # Stacking System	# Detoriation after few interval # Inconsistancy # Safty	# Defective Goods # Process Variation	Quality

WASTE WALK

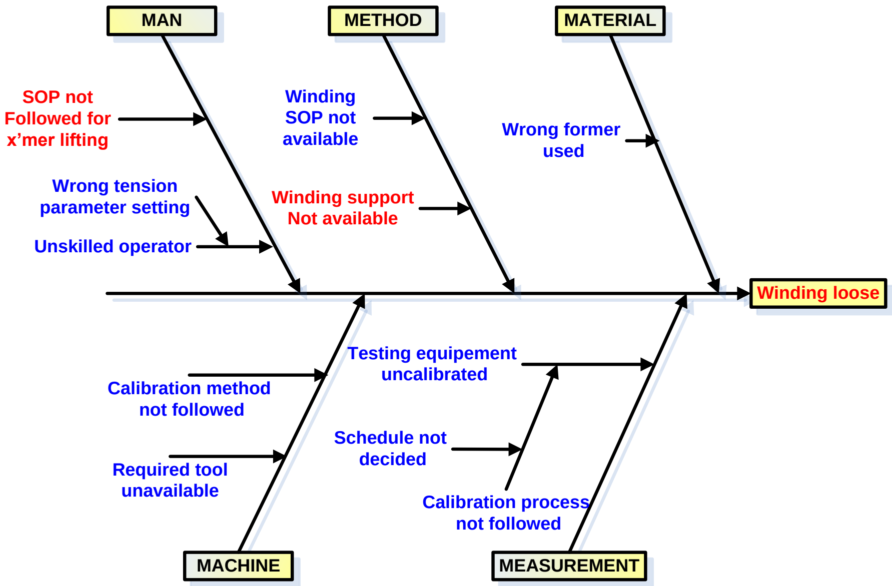
- Wrong lamination fixture setting
- Gap between lamination
- Improper foin roll storage
- Insufficient grip in bolt and nut to sustain vibration
- No support for top side winding
- Less creepage distance between two live parts

FISH BONE DIAGRAM

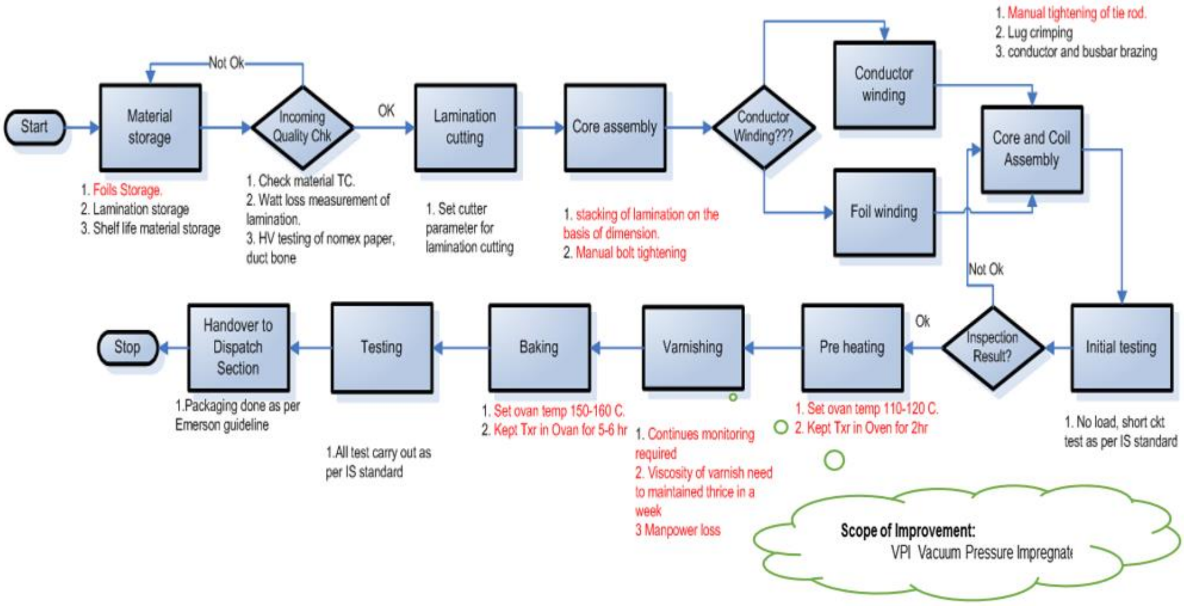




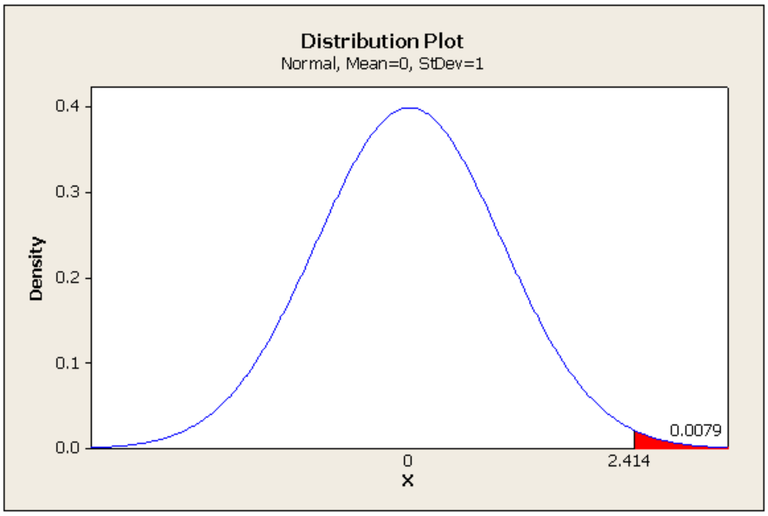
FISH BONE DIAGRAM FOR WINDING LOOSE ISSUE



10. Analysis:
PROCESS FLOW ANALYSIS
Transformer manufacturing process:



$$\text{DPMO} = \frac{69 \times 1000000}{2882 \times 3} = 7980$$



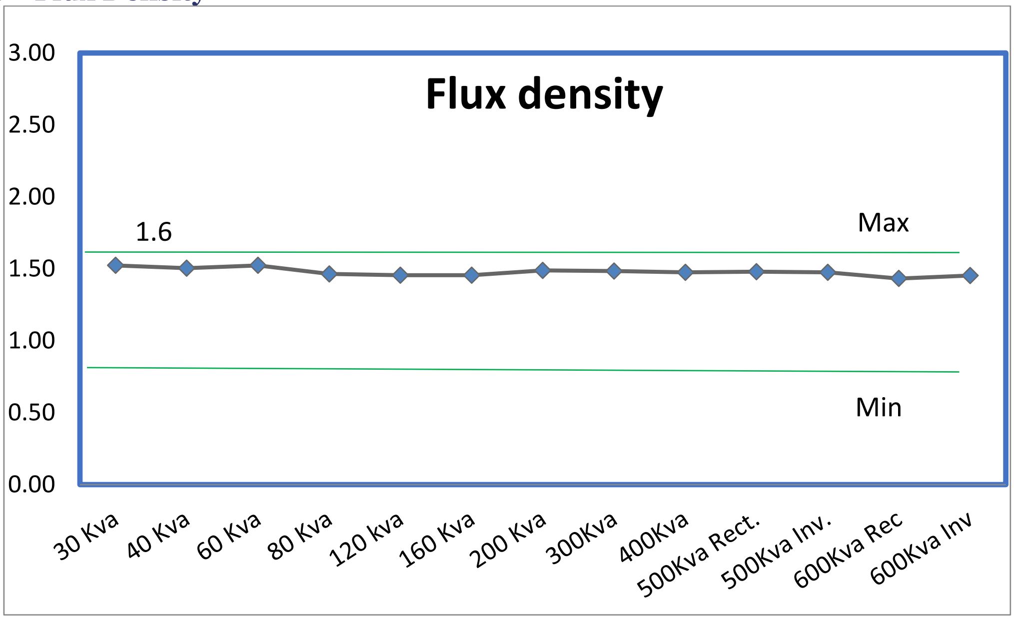
Z–LT = 2.414
Z-ST = 2.414 + 1.5
Z-ST = 3.91

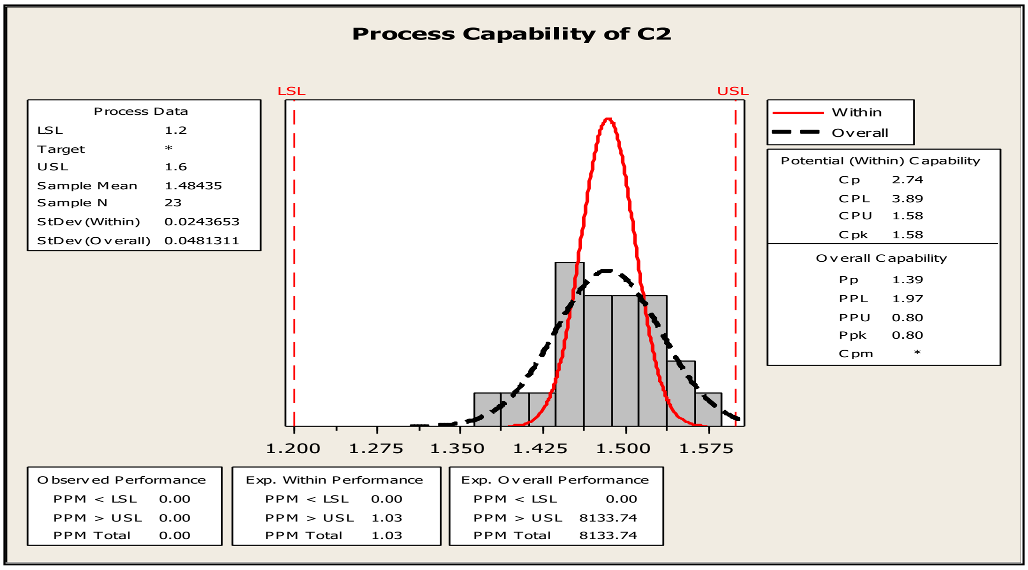
Current & Flux Density measurement

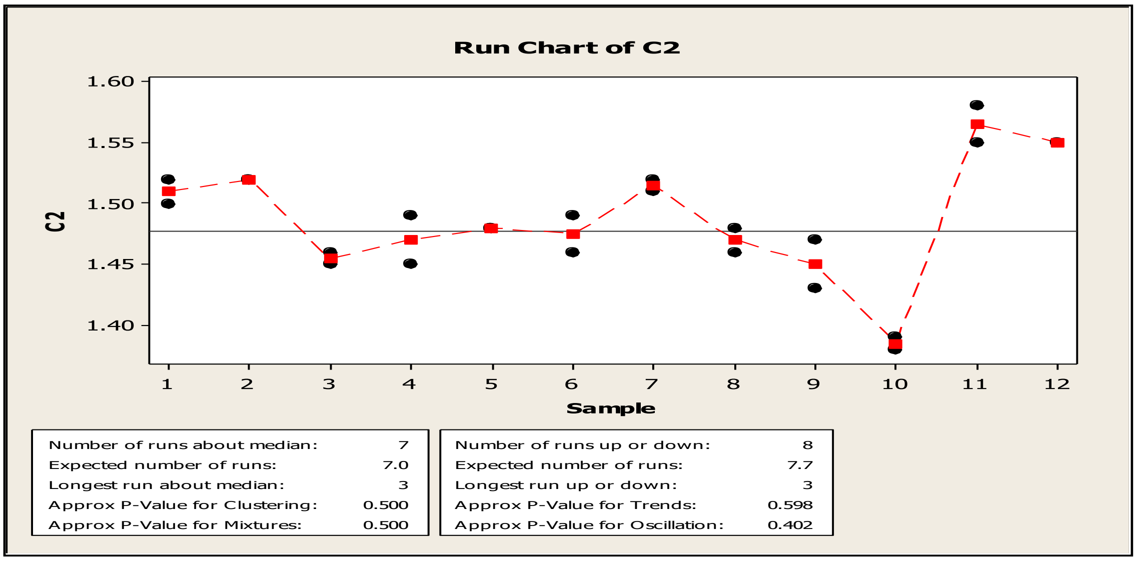
Kva rating	Conductor size	Conductor area	Current	Current density	Voltage	Turns	Core dimension	Core dimension2	Area of iron	Area of iron* Factor	Flux density (prim)
30 Kva	(6*3)*2 (Pri)	36	46.8	1.3	200	88	140	50	7000	0.00672	1.52
	6*3 (Sec)	18	39	2.2							
40 Kva	10*2.5)*2 (Pri)	50	62.4	1.2	200	65	160	60	9600	0.00922	1.50
	10*2.5 (Sec)	25	52	2.1							
60 Kva	8*2)*4 (Pri)	64	93.6	1.5	200	44	200	70	14000	0.01344	1.52
	8*2)*2 (Sec)	32	78	2.4							
80 Kva	10*3*3 (Pri)	90	124	1.4	200	46	170	82	13940	0.01338	1.46
	10*2.5*2 (Sec)	50	104	2.1							
120 kva	200*0.7 (Pri)	140	180.13	1.3	200	30	215	100	21500	0.02064	1.45
	200*0.7 (Sec)	140	156	1.1							
160 Kva	250*0.8 (Pri)	200	240	1.2	200	30	215	100	21500	0.02064	1.45
	250*0.8 (Sec)	200	207.85	1.0							
200 Kva	310*0.7 (Pri)	217	300.22	1.4	200	21	240	125	30000	0.02880	1.49
	310*0.7 (Sec)	217	260	1.2							
300Kva	430*0.75(Pri)	323	405.88	1.3	222	27	260	100	26000	0.02496	1.48
	430*0.75(Sec)	323	390	1.2	133						
400Kva	500*0.8(Pri)	400	508	1.3	236	30	250	100	25000	0.02400	1.48

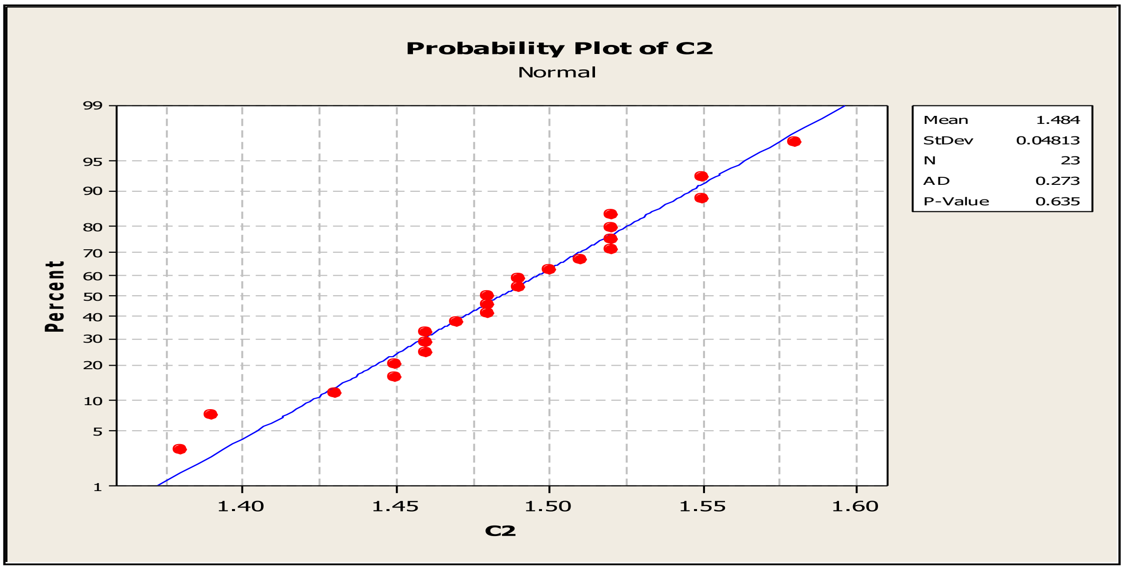
	500*0.8(Sec)	400	520	1.3	133						
500Kva Rect.	370*0.45(pri)	167	220	1.3	485	42	305	120	36600	0.03514	1.48
	370*(0.75+0.45)(Sec1)	444	543	1.2	230						
	370*(0.75)(Sec2)	278	381	1.4	49						
500Kva Inv.	370*(0.75+0.45) (Pri)	444	525	1.2	286	28	260	125	32500	0.03120	1.47
	330*(0.75*2)(Sec)	495	650	1.3	133						
600Kva Rec	500*0.5(Pri)	250	324	1.3	400	39	210	160	33600	0.03226	1.43
	500*0.95(Sec)	475	562	1.2	230						
600Kva Inv	500*(0.85+0.45)(Pri)	650	762	1.2	236	23	265	125	33125	0.03180	1.45
	500*(0.85+0.45)(Sec)	650	780	1.2	133						

Run chart – Flux Density

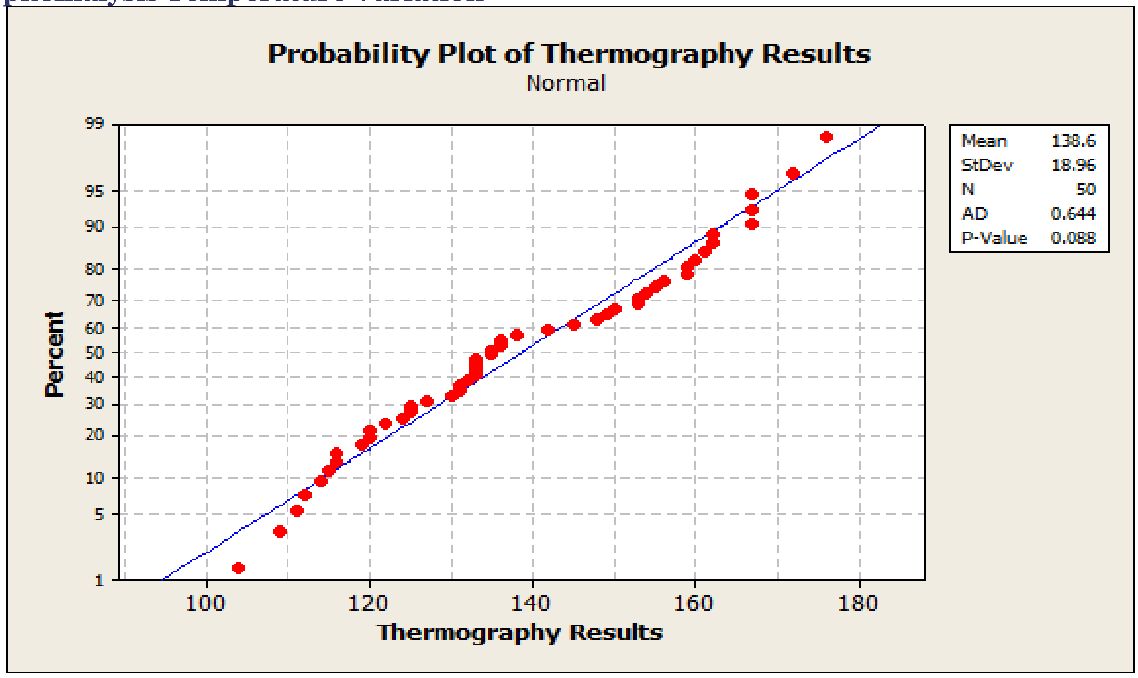






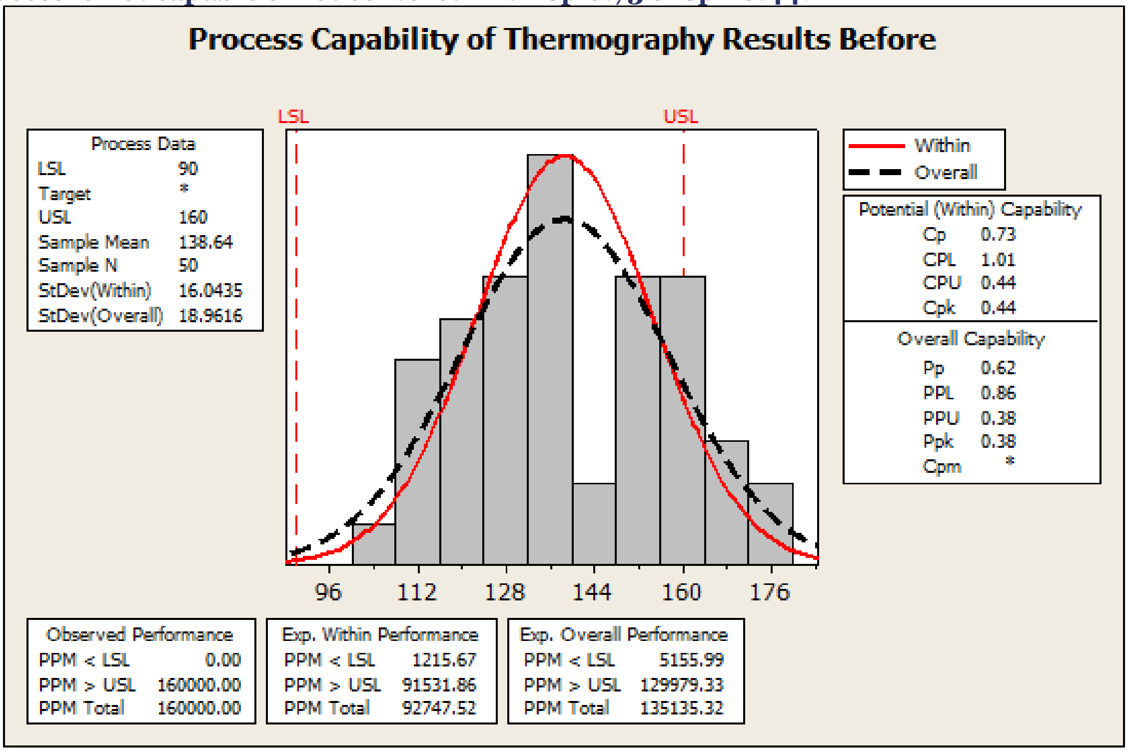


Cp /Cpk Analysis Temperature Variation

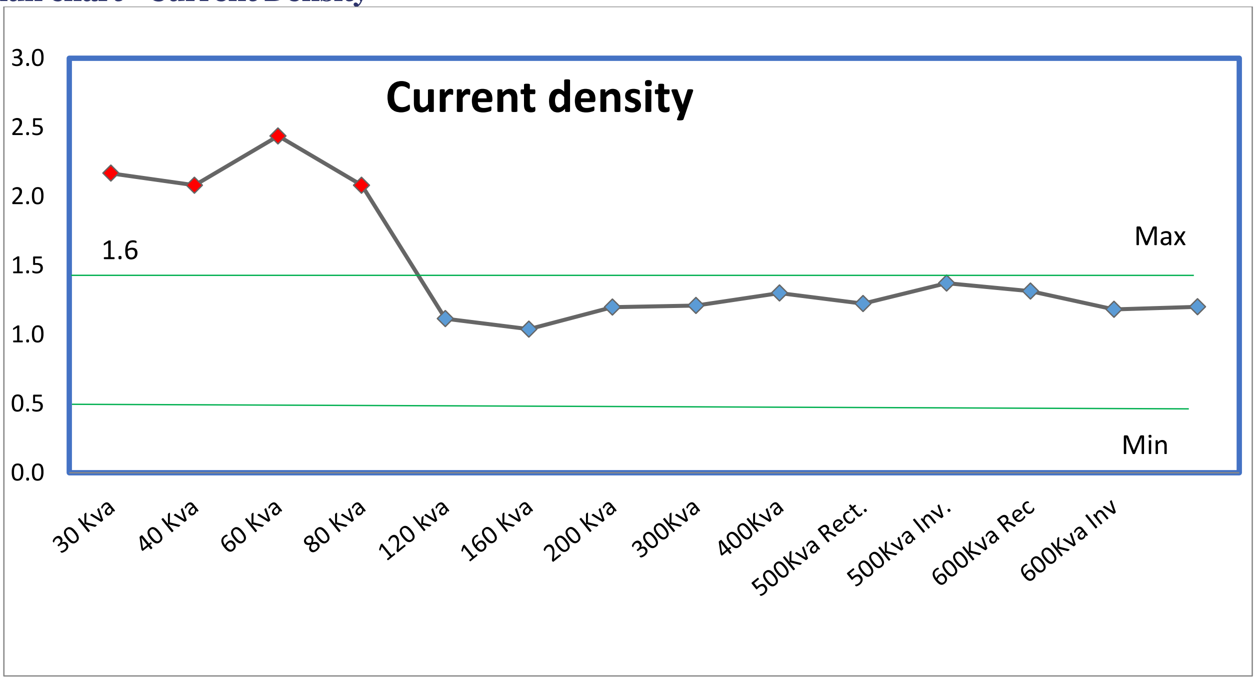


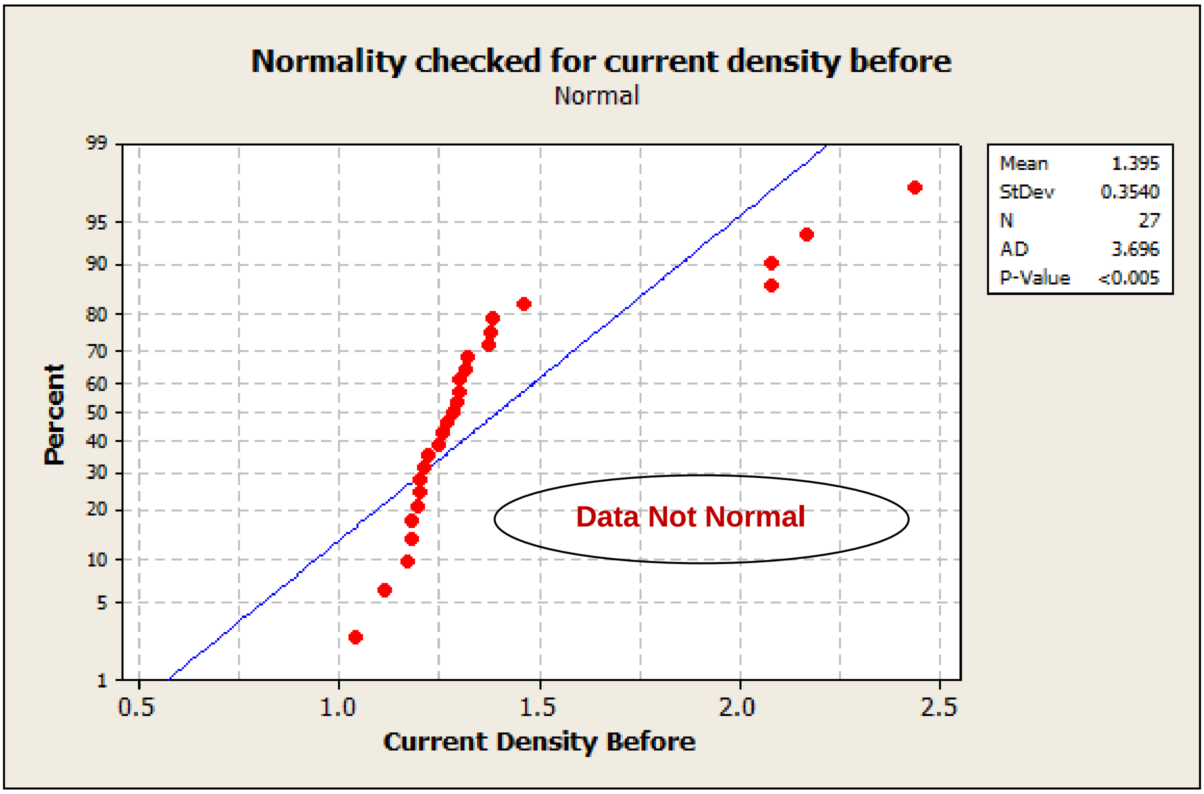
Temperature Variation:

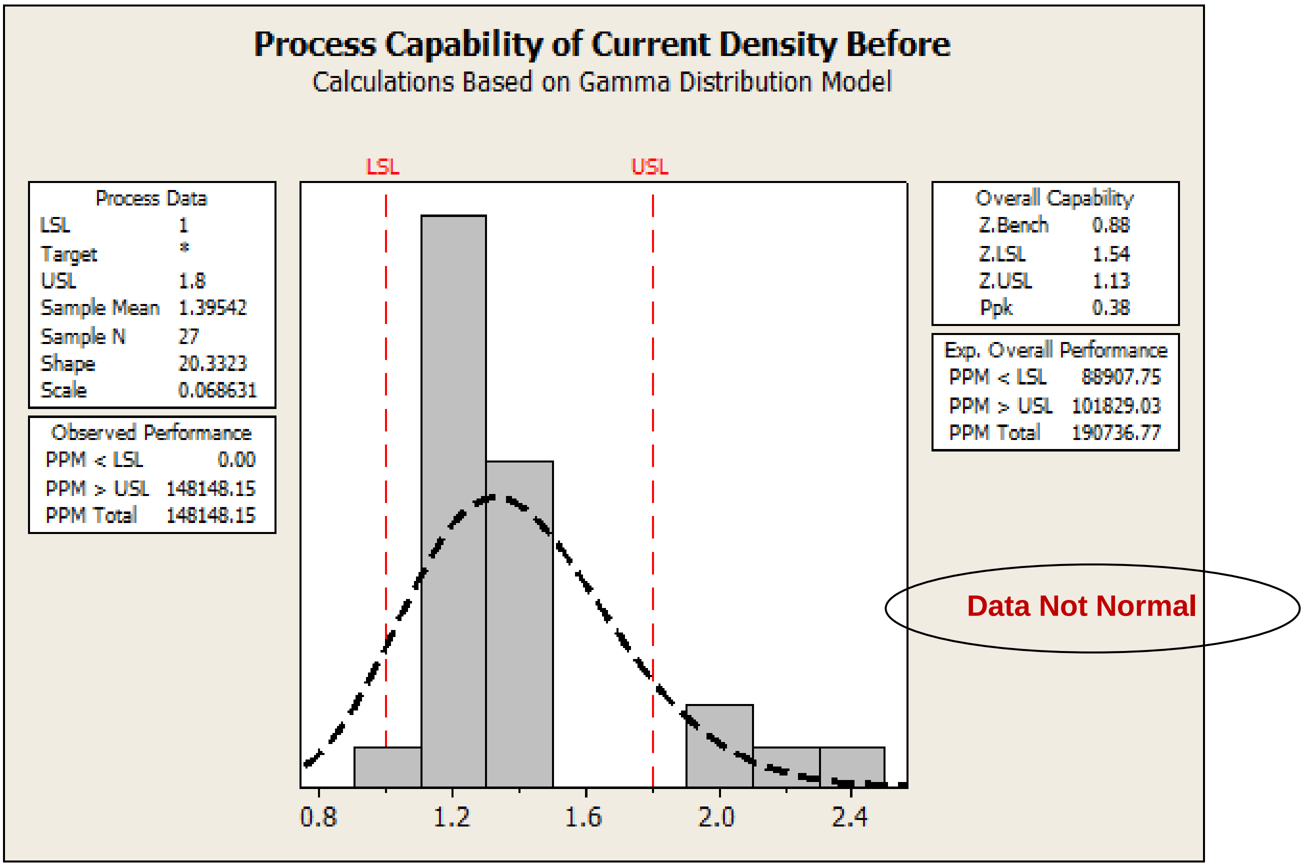
- **Observed Temperature is on & above USL.**
- **Process is not capable & not centered with Cp 0.73 & Cpk 0.44.**



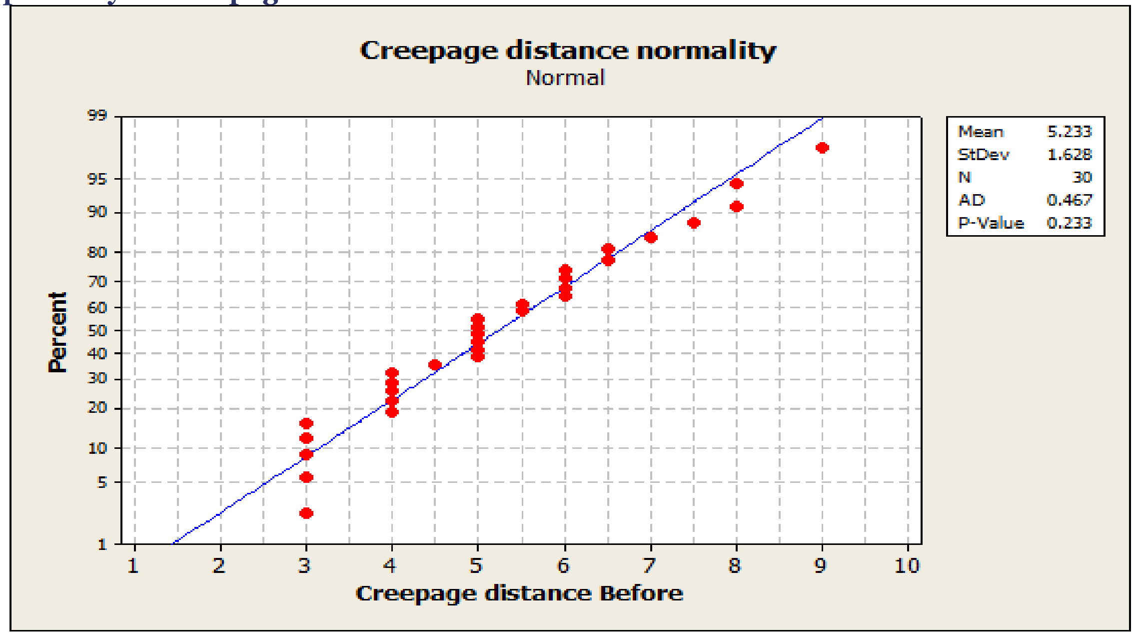
Run chart –Current Density




Normality checked for current density before
Normal
Percent
Current Density Before
Mean 1.395
StDev 0.3540
N 27
AD 3.696
P-Value <0.005
Data Not Normal

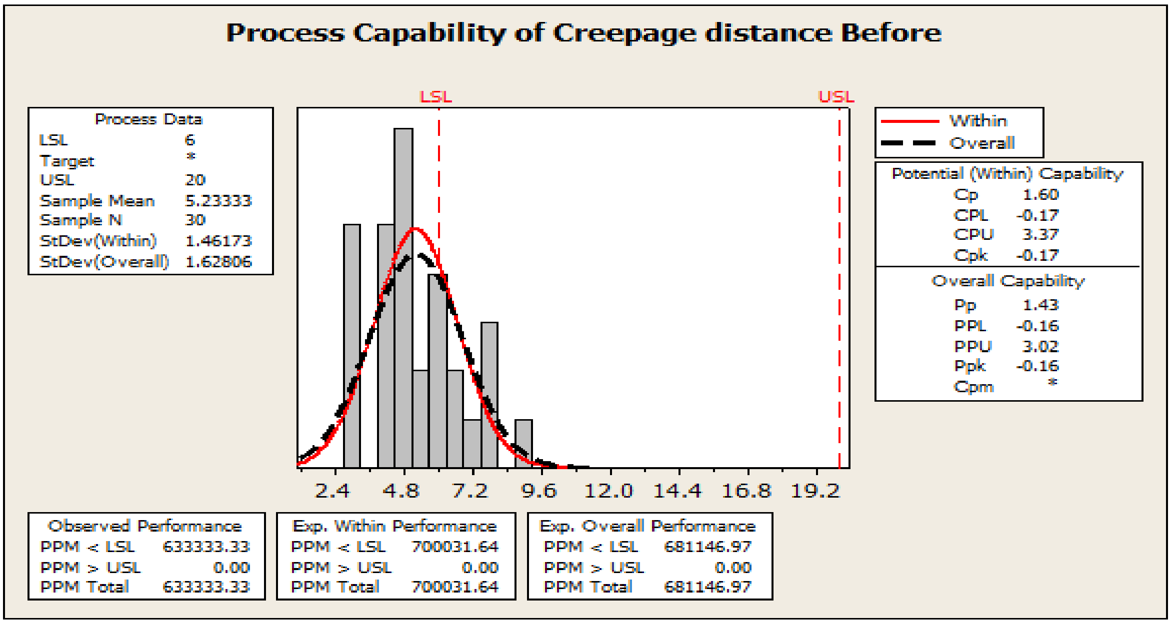

Process Capability of Current Density Before
Calculations Based on Gamma Distribution Model
LSL
USL
Process Data
LSL 1
Target *
USL 1.8
Sample Mean 1.39542
Sample N 27
Shape 20.3323
Scale 0.068631
Observed Performance
PPM < LSL 0.00
PPM > USL 148148.15
PPM Total 148148.15
Overall Capability
Z.Bench 0.88
Z.LSL 1.54
Z.USL 1.13
Ppk 0.38
Exp. Overall Performance
PPM < LSL 88907.75
PPM > USL 101829.03
PPM Total 190736.77
Data Not Normal

Cp /Cpk Analysis Creepage Distance



Creepage Distance:

- Observed creepage distance on lower side.
- Even though CP is 1.6 process is not centered causing CPK -0.17.

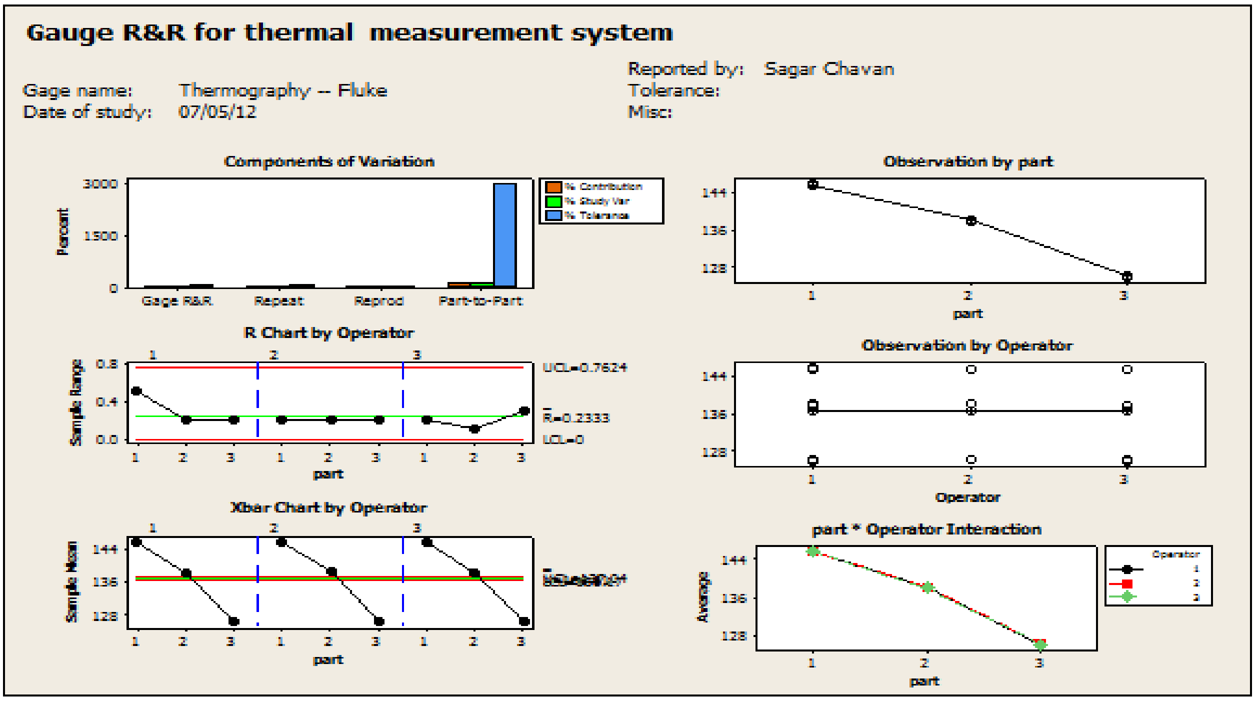


Gauge R & R

For Thermography...

PART	OPR.	OBSRN.
1	1	145.5
1	1	146.0
1	2	145.8
1	2	145.6
1	3	145.5
1	3	145.7
2	1	138.2
2	1	138.0
2	2	138.4
2	2	138.2
2	3	137.9
2	3	138.0

3	1	125.8
3	1	126.0
3	2	126.2
3	2	126.0
3	3	125.9
3	3	126.2



Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0328	0.03
Repeatability	0.0306	0.03
Reproducibility	0.0022	0.00
Operator	0.0022	0.00
Part-To-Part	98.4019	99.97
Total Variation	98.4347	100.00

Process tolerance = 2

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.18105	1.0863	1.82	54.31
Repeatability	0.17480	1.0488	1.76	52.44
Reproducibility	0.04714	0.2828	0.48	14.14
Operator	0.04714	0.2828	0.48	14.14
Part-To-Part	9.91978	59.5187	99.98	2975.93
Total Variation	9.92143	59.5286	100.00	2976.43

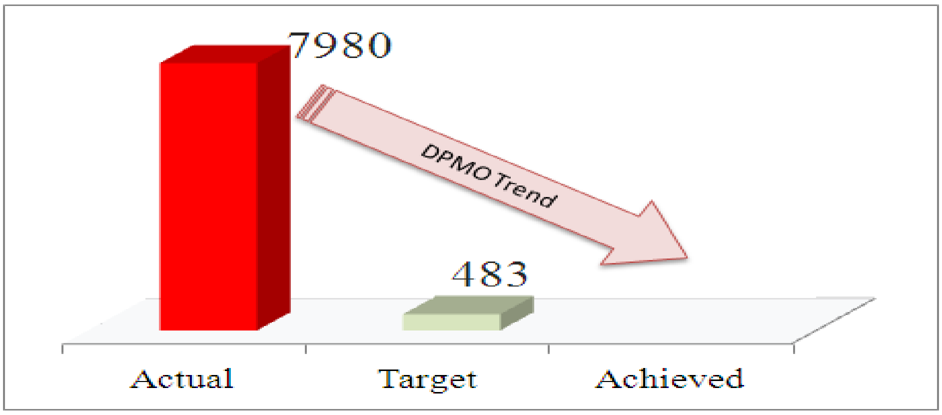
Number of Distinct Categories = 77

Gage R&R for Observation

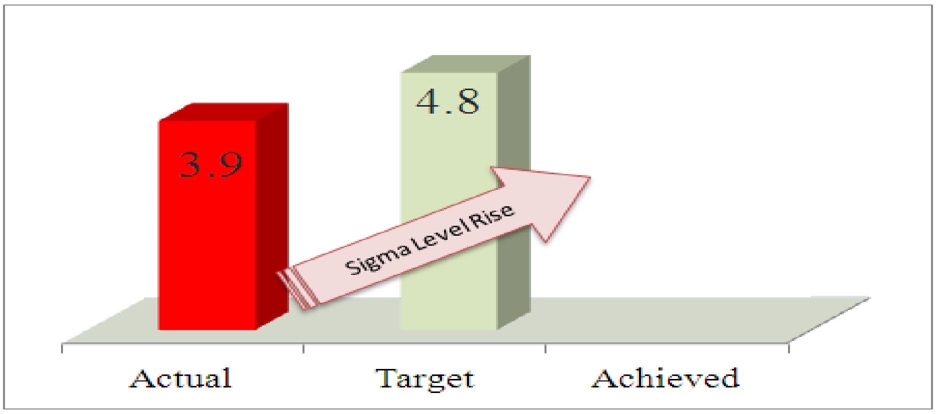
Sigma Level (To know exact process status)

Defects per 100	Defects per 10,000	Defects per 1,000,000	Success rate	Sigma Value	
2	179	17,900	98.21%	3.6	
1	139	13,900	98.61%	3.7	
1	107	10,700	98.93%	3.8	
1	82	8,200	99.18%	3.9	Existing Sigma Level
1	62	6,210	99.379%	4.0	
	47	4,660	99.534%	4.1	
	35	3,470	99.653%	4.2	
	26	2,560	99.744%	4.3	
	19	1,870	99.813%	4.4	
	14	1,350	99.865%	4.5	
	10	968	99.903%	4.6	
	7	687	99.931%	4.7	
	5	483	99.952%	4.8	Targeted Sigma Level
	3	337	99.966%	4.9	
	2	233	99.9767%	5.0	
		3.4	99.99966%	6.0	

Defective PPM



Sigma Level



Failure Mode Effect Analysis (FMEA)

FMEA NO. :	8	Team Leader:	Ramesh Pawar	DATE (ORIG.) :	8th Dec'10
Process NAME :	Transformer Manufacturing	CORE TEAM:	Sagar Chavan Jayant Khadse Jayashree Yadav Swapnil Kapse	REVISION NO. :	0
PART NO. :				REVISION DATE :	
CUSTOMER NAME :	ALL			PREPARED BY. :	Ramesh Pawar

PROCESS FUNCTIONS REQUIREMENTS	POTENTIAL FAILURE MODE	POTENTIAL EFFECT(S) OF FAILURE	S	POTENTIAL CAUSE(S) MECHANISM(S)	O	CURRENT PROCESS CONTROLS Corrective	CURRENT PROCESS CONTROLS Preventive	D	RPN	RECOMMENDED ACTION(S)	RESPONSBILITY & TARGET COMPLETION	ACTION RESULTS ACTION TAKEN
Material storage	Interturn short	Transformer burn	10	Al. Foil edge bent or dent mark	4	Vertical/random storage of foil roll	No control	5	200	Use horizonal rack for Al foil storage	Vendor	
Core assembly	Core bolt loose	Noise	7	Bolt fitting with below specification torque	6	Manual screw driver used	Tightness marking	8	336	Torque control screw driver to be used	Vendor	
	Localized heating	Noise	7	More air gap in shunt than required.	7	No control	No control	8	392	Taken up with engineering for air	Sagar Chavan	
	Uneven stack assembly	Noise	7	Operator mistake	5	No control	No control	6	210	Core assembly checked againts weight chart	Vendor	
	Loose winding	Noise	7	No support to hold winding	5	Tie two winding for support.	No control	6	210	Tie one set of winding for support	Vendor	
Final assembly	Tie rod loose	Noise	7	Tie rod material hardness below specification	4	Check Supplier TC for hardness	Tightness marking	8	224	1- Third party testing. 2- Loctite added	Vendor	
	Less creepage distance between live parts	Transformer burn	10	Operator mistake	7	No control	No control	3	210	Busbar position changed from bottom to top	Vendor	
Final assembly	Poor crimping joint	No output	7	Insufficient pressure applied for crimping	7	Manual pull out check	No control on pressure measurement	10	490	Process added to monitor temp. at lug after 15 mints of x'mer heat run	Vendor	
	Poor crimping joint	No output/Temp high at joint	7	Filler conductor not added	6	Visual inspection	No control	10	420	Process added to monitor temp. at lug after 15 mints of x'mer heat run	Vendor	
	Interturn short	Burn	7	Operator mistake	6	No control	No control	10	420	Clean particles from foil after brazing & visual checking to be added	Vendor	
Varnishing	Air gap between lamination	Noise	7	Low viscosity	7	Viscosity check with defined frequency	No control	9	441	Resin VPI process to be implement		
Baking	Air gap between lamination	Noise	7	Varnish not cure properly due to baking duration not follwed	5	No control	No control on baking duration	9	315	Resin VPI process to be implement		
	High temp of x'mer due to high current density	Burn	10	Wrong conductor size	3	No control	1st sample validation	9	270	Conductor size changed as per specifictaion for current density	Sagar Chavan	
Dispatch	Unable to mount T'xr	Mounting holes mismatch	4	Mounting channels misaligned during handling	8	No control	No control	8	256	Provid Jig (pallet) to hold t'xr while transportation Provide Nylon rope for T'xr handling.	Vendor	

QFD Analysis

KPOV → Key Process Output Variables

KPIV ↓ Key Process Input Variables

Key Process Output Variables	Transformer Noise	Transformer Burn	Winding Loose	Design	Crimping	Brazing	Transformer damage		
Weightage CPN →	10	10	7	7	5	4	4		
Key Process Input Variables	Association Table							Rank	% Rank
Varnishing	10	8	3	3	3	3	0	249	8.96
More Air Gap in shunt assembly	10	10	3	10	3	3	0	318	11.44
Insufficient grip to sustain vibration	10	10	3	3	3	3	0	269	9.68
Uneven stacking	9	7	3	5	3	3	0	243	8.74
Wrong Conductor size	3	7	5	7	5	3	0	221	7.95
No awareness for creepage distance parameters	5	10	3	5	3	5	0	241	8.67
Conductor temp high	3	7	3	7	5	5	0	215	7.73
Improper foil storage system	5	10	3	5	3	5	0	241	8.67
Brazing particals and dust in between the winding	5	7	3	3	3	10	0	217	7.81
Winding support not available	10	10	10	3	3	3	0	318	11.44
SOP not followed for Transformer lifting	8	0	10	3	5	5	8	248	8.92
	78	86	49	54	39	48	0	2780	

11. Hypothesis Testing

• **Theory :** Effect of current density on Burning of Transformer
Ho – Burning of transformer is independent on current density**.**
Ha – Burning of Transformer is dependent on current density.
Test and CI for Two Proportions : High Vs Low current density effect

Sample	X	N	Sample p
Current density greater than 1.6	4	436	0.009174
Current density less than 1.6	0	60	0.000000

Difference = p (1) - p (2)
Estimate for difference: 0.00917431
95% CI for difference: (0.000224988, 0.0181236)
Test for difference = 0 (vs not = 0): Z = 2.01 P-Value = 0.045
The Hypothesis testing is done on basis of data:
A: Burning of transformer with high current density
B: Burning of transformer with low current density.
Practical Conclusion : Burning of transformer is dependent on current density.

• **Theory :** Effect of creepage distance on Burning of Transformer
Ho – Burning of transformer is independent on creepage distance.
Ha – Burning of Transformer is dependent on creepage distance.
Test and CI for Two Proportions: Creepage distance High Vs low

Sample	X	N	Sample p
Creepage distance less than 6mm	4	113	0.035398
Creepage distance greater than 6mm	0	55	0.000000

Difference = p (1) - p (2)
Estimate for difference: 0.0353982
95% CI for difference: (0.00132811, 0.0694684)
Test for difference = 0 (vs not = 0): Z = 2.04 P-Value = 0.042
The Hypothesis testing is done on basis of data:
A: Burning of transformer with high creepage distance
B:Burning of transformer with low creepage distance.
Practical Conclusion : Burning of transformer is dependent on creepage distance

• **Theory :** VPI Process is superior than current Varnishing method.
Ho – Both VPI & Varnishing are having same effect.
Ha – VPI is better than Varnishing
Test and CI for Two Proportions

Sample	X	N	Sample p
With Varnishing	20	460	0.043478
With VPI PROCESS	0	82	0.000000

Difference = p (1) - p (2)
Estimate for difference: 0.0434783
95% CI for difference: (0.0248423, 0.0621143)
Test for difference = 0 (vs not = 0): Z = 1.92 P-Value = 0.054
The Hypothesis testing is done on basis of data:
A: Burning of transformer with high creepage distance
B:Burning of transformer with low creepage distance.
Practical Conclusion : Burning of transformer is dependent on creepage distance

Potential X's (For Improvement Actions)
Final List of Potential X :-
Noise

- Existing (Varnishing)Process Issue
(Air gaps not get removed)
- Insufficient grip to sustain vibration
- No standard ref. for Shunt Gap

Burning Issue

- Uneven stacking observed
- No awareness for Creepage distance
- High current density at secondary.

Coil Loose

- ➢ No support for winding
- ➢ Improper handling while transformer lifting

12. Suggestion and Recommendation:

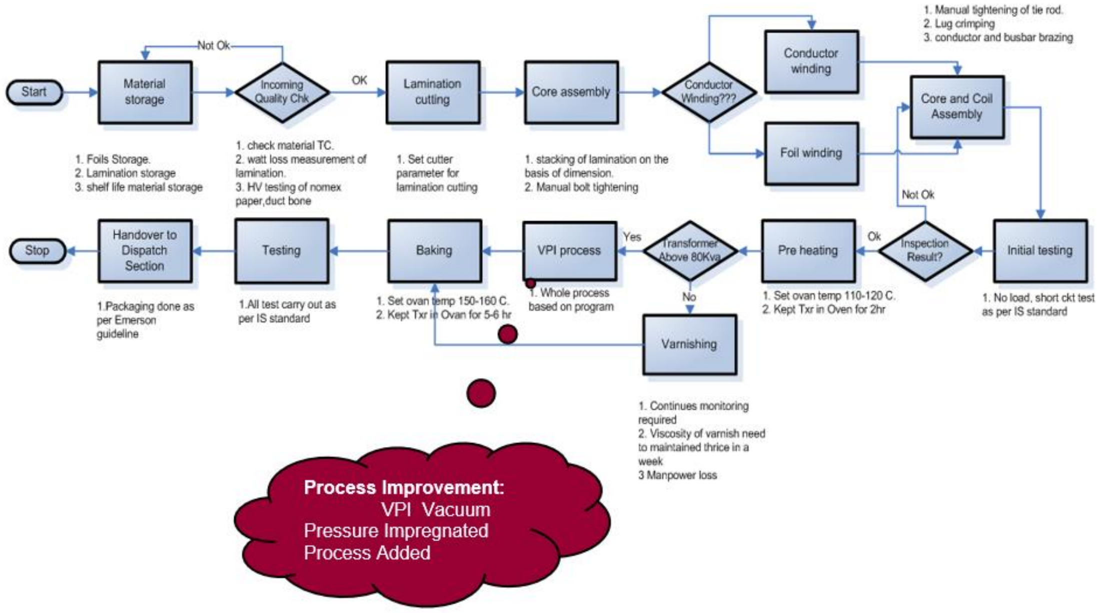
- VPI process introduced to overcome varnish process loopholes for viscosity & duration.
  - o Since this is automatic process, avoid chances of human error.
  - o No contact between varnish and air.
  - o Reduce the man power loss.
  - o Whole process happened inside the closed chamber
- Use thread locking Loctite 262 to prevent from loosening from shock & vibration
  - o Sufficient grip available due to loctite liquid.
  - o No heating of transformer.
  - o No noise from transformer
- Standardized shunt air gap (2mm- 5mm)
- Check core dimension & weight before assembly
- Use Horizontal racks for foil storage
  - o No damage to foil.
  - o No dust on foil.
  - o Increase the reliability of transformer .

13. Limitations of the study:

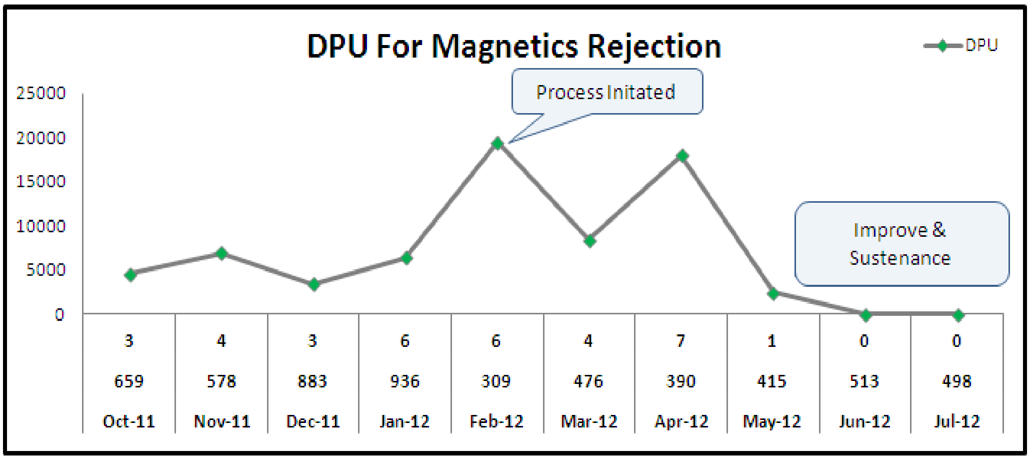
14. Conclusion:

Process Flow Analysis After Improvement

Transformer manufacturing process (As expected) :



Sustenance – DPU Monitoring Chart



Sigma Level (To know exact process status)

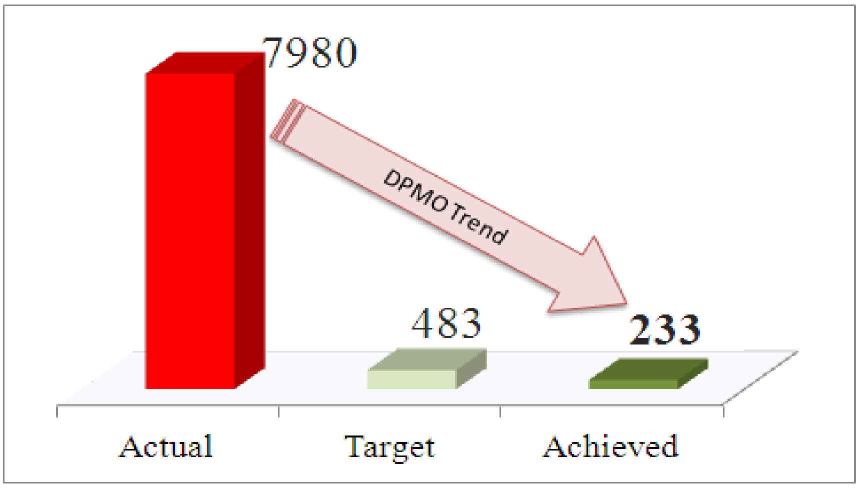
Defects per 100	Defects per 10,000	Defects per 1,000,000	Success rate	Sigma Value
2	179	17,900	98.21%	3.6
1	139	13,900	98.61%	3.7
1	107	10,700	98.93%	3.8
1	82	8,200	99.18%	3.9
1	62	6,210	99.379%	4.0
	47	4,660	99.534%	4.1
	35	3,470	99.653%	4.2
	26	2,560	99.744%	4.3
	19	1,870	99.813%	4.4
	14	1,350	99.865%	4.5
	10	968	99.903%	4.6
	7	687	99.931%	4.7
	5	483	99.952%	4.8
	3	337	99.966%	4.9
	2	233	99.9767%	5.0
		3.4	99.99966%	6.0

Existing Sigma Level (3.9)

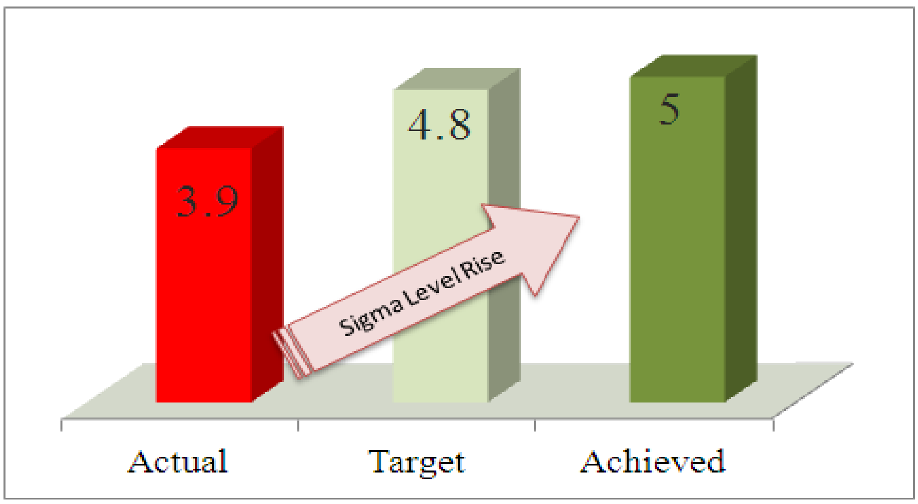
Targeted Sigma Level (4.8)

Achieved Sigma Level (5.0)

Defective PPM



Sigma Level



The detailed analysis of transformer failure expose the process issue at supplier end as well design issues, improvement actions in co-ordination with supplier helps to achieve the desired quality of the Product.

Benefits :

Parameter	Before	After Improvement
Rejection PPM	23958	700
COPQ	1885000	1296

15. Future scope:

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