Quest Journals
Journal of Research in Mechanical Engineering
Volume 9 ~ Issue 5 (2023) pp: 01-10
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

Implementing DMAIC Lean Six Sigma Tool in Reducing Power Consumption in 132kV Substations.

Khalifa Alshaiba

R**eceived 25 Apr., 2023; **R**evised 03 May, 2023; **A**ccepted 05 May, 2023 © The author(s) 2023. **P**ublished with open access at **www.questjournals.org

Abstract
The power consumption of the HVAC (heating, ventilation and air conditioning) system is a key factor in the operation of Dubai's 132 kV substation. This summary examines various factors that contribute to the energy consumption of HVAC systems, including Cooling load, equipment efficiency and operating time. The study also looks at strategies for reducing power consumption and increasing energy efficiency, such as upgrading equipment, optimizing system controls, and using renewable energy sources. This summary aims to provide insights on how to improve energy efficiency in substation operations by analyzing power consumption of HVAC equipment at 132 kV substations in Dubai. This report will illustrate and represent how to implement DMAIC Process into a potential case study.
Data are not actual but was estimated due to the confidential data and aim of the report to represent how to implement DMAIC process.

*Corresponding Author: Charles Chikwendu Okpala

I. Introduction

DEWA stands for Dubai Power and Water Authority. Government agency and Dubai's only provider of electricity, water and sewerage. The Vision and mission of DEWA is to be a globally leading sustainable innovative corporation committed to achieving Net-Zero by 2050 relying totally on renewable energy sources. In this project we will be studying the 132kV transmission power substations thoroughly. It's an electrical substation that is related to transmission division, it connects the generation power plant to distribution substation from January 2022 to January 2023, A report has been generated by the higher management in transmission power division showing that 10 substations are consuming more power than usual.

There are several methods to improve the energy efficiency of the 132kV substation by decreasing the power consumption of the equipment's installed in the substation such as Transformers (IDt's and ET's) , Switchgear, GIS, HVAC components and LSP system(lighting and small power).To stream down our project and make it more specific we will focus on reducing the power consumption of the HVAC system in the substations which is the main customer requirement and consumes around 80% of the substation power. In our project we will implement the DMAIC leans six sigma method to deliver the project and tackle all its parameters.

Fig1.1: 132kV Transmission Power Substation

DMAIC is a problem-solving methodology that is driven by data and is commonly used in Six Sigma. It is a methodical, iterative approach that leads teams through the process of recognizing and remedying process-related issues. DMAIC stands for Define, Measure, Analyze, Improve, and Control. DMAIC is a valuable resource for organizations seeking to reduce defects and variability in their processes.

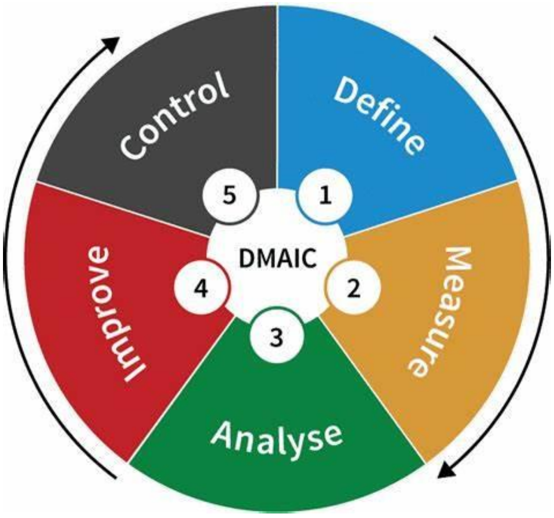

Fig.1: 132kV Transmission Power Substation

Quality in LSS Projects

A product, process, or service's degree of excellence of meeting the needs and expectations of customers is referred to as quality in the context of Lean Six Sigma. It is essential to projects like ours, which examines the power usage of HVAC equipment at 132 kV substations in Dubai in order to increase energy efficiency in substation operations.

In our project, quality is crucial for a number of reasons:

- Satisfying customers: Achieving satisfied clients is the main objective of Lean Six Sigma. You may guarantee that the power consumption is maximized, leading to greater energy efficiency, by raising the ability of substation operations and HVAC equipment. As a result, there may be an increase in customer satisfaction since final consumers will receive consistent and effective energy supply.
- Waste reduction: Lean Six Sigma strives to cut down on waste and process flaws. You can find areas of inefficiency and waste, such as energy leaks, needless usage, or defective equipment, by examining the power consumption of HVAC equipment. The effectiveness of these procedures may be increased while reducing waste.
- Process Enhancement: Quality is a major force behind process enhancement. Lean Six Sigma approaches may be used to remove process variances, standardize processes, and increase performance by monitoring the power consumption of HVAC equipment and identifying opportunities for improvement. This may lead to better production, lower costs, and enhanced energy efficiency.
- Data-Driven Decision Making: Lean Six Sigma places a strong emphasis on the use of data-driven decision making. In order to find patterns, trends, and the main reasons for inefficiencies, you may acquire objective, quantitative information by examining the power consumption statistics of HVAC equipment. This can direct your efforts toward development and assist you in making defensible judgments based on information rather than conjecture.
- Continuous Improvement: Lean Six Sigma encourages the development of an improvement-oriented culture. You may build a systematic method to continually detect and remove defects, minimize variation, and enhance performance by concentrating on quality and utilizing Lean Six Sigma tools and processes. Over time, this may result in sustained increases in the energy efficiency of substation operations.

In conclusion, Lean Six Sigma places a strong emphasis on quality, which is essential to our effort to increase energy efficiency in substation operations. It raises a culture of continuous improvement, drives process improvement, ensures customer happiness, lowers waste, and supports data-driven decision making.

Waste In 132kV Substations Related to HVAC System

Waste is any action or process that does not improve the end good or service in the context of Lean Six Sigma. Lean Six Sigma places a strong emphasis on finding and eliminating waste since it makes operations more efficient, lowers costs, and boosts overall effectiveness. Finding and treating different forms of waste might be essential for reaching our goals in our project, which focuses on enhancing energy efficiency in substation operations by examining the power consumption of HVAC equipment at 132 kV substations in Dubai.

The 9 Wastes in Lean Six Sigma, which are various waste kinds, include:

- Over-Production waste: Producing more than is necessary or producing too soon is referred to as overproduction waste. If HVAC equipment is operated or maintained inefficiently, extra energy consumption will result in wasteful overproduction in our project.
- Delay/Waiting waste: Wasted time due to waiting or delays in procedures is referred to as delay. In our project, waiting waste may happen if data or information essential for monitoring power consumption is delayed, or if maintenance or repair tasks that impact the operation of HVAC equipment are delayed.
- Excess Inventory/Overstock waste: Holding more inventory than necessary is referred to as excess inventory or overstock waste. If there are too many HVAC components or spare parts stocked up in our project, it might lead to excess inventory waste, which would raise expenses, storage space requirements, and the risk of obsolescence.
- Defects/repair waste: Errors or faults that call for rework or repair are referred to as defects/repair waste. If there are mistakes in the power consumption study, the results might be wrong, or the analysis could need to be redone, wasting time and resources.
- Human potential/skills waste and behavior waste: Underutilization of staff skills or unproductive conduct that reduces production are referred to as "human potential/skills waste" and "behavior waste," respectively. If there are knowledge or skill gaps among team members, or if there are behaviors that impede effective energy management techniques, human potential/skills waste and behavior waste may take place in our project.

In conclusion, our project's performance may be increased, expenditures can be decreased, and energy efficiency in substation operations can be optimized by identifying and resolving these sources of waste. For a more effective and efficient project execution, we may simplify processes, remove waste, and drive continuous improvement by using Lean Six Sigma principles and technologies.

DMAIC Stages

Define

Problem statement and goals

Problem Statement:
Over the past 12 months DEWA transmission 132 kV substation has witnessed an increase of 50% of power consumption. This is above the allowable limit of consumption. Failure to meet this requirement will result in power waste, higher cost and decrease equipment life.
Goal statement:
Reduce the average power consumption of transmission power substations by 10% by the end of 2nd quarter of 2023 and implement usage of one renewable energy source. The team has been formed based on several expertise from different backgrounds. It is important to form the team wisely because it will help aid in achieving the goals of the project.

Project Milestones:

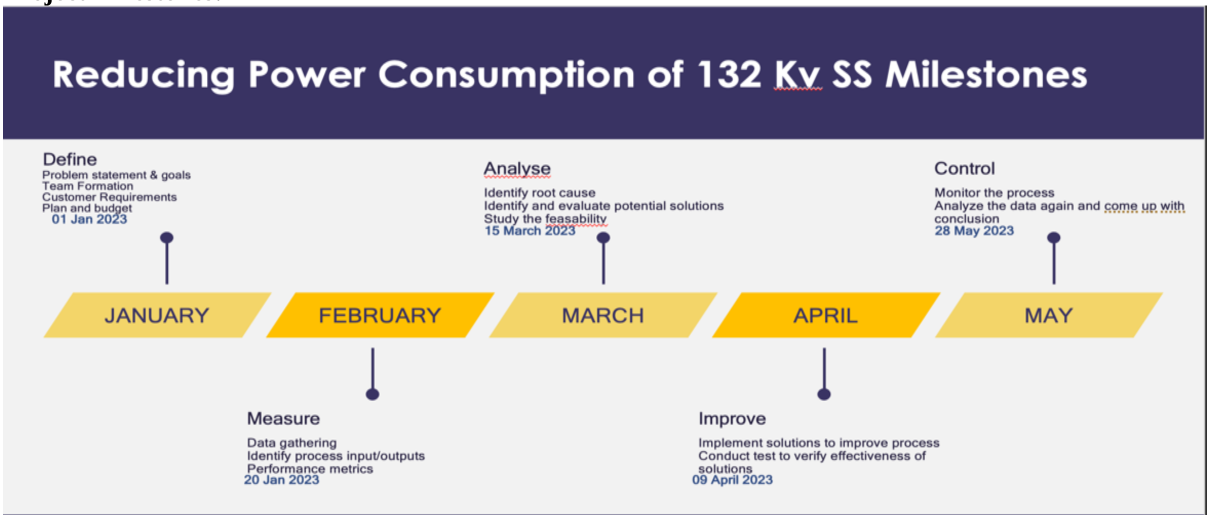

fig1.3: Project Milestone

Customer Requirements
In our project our targeted customers are two types:

1- Internal Customers
2- External Customers

Internal Customers are the customers involved within the organization and are considered as Dubai Water and Electricity Authority departments, employees, management, staff and operation teams who are involved the planning, execution and monitoring of power consumptions improvement initiatives. They are the internal customers because reducing the power consumption will generate benefits and savings in terms of power and cost to the whole company. However, the external customer is Dubai government, and they will benefit from this project and has several requirements that form the base on achieving the goals of the project and it should be aligned.
Internal customer Requirements:

1- Root cause analysis to reduce the power consumption of transmission power substation
2- Reliable healthy equipment's in the transmission power substation
3- Healthy communication relationship between stakeholders and supply chain
4- Achieve DEWA vision of Net-Zero 2050 by the transition of renewable energy sources.

5- Continuous improvement and progress in power consumption

Voice of Customer
In this part we constructed the voice of customer which represents the customer expectations and needs.

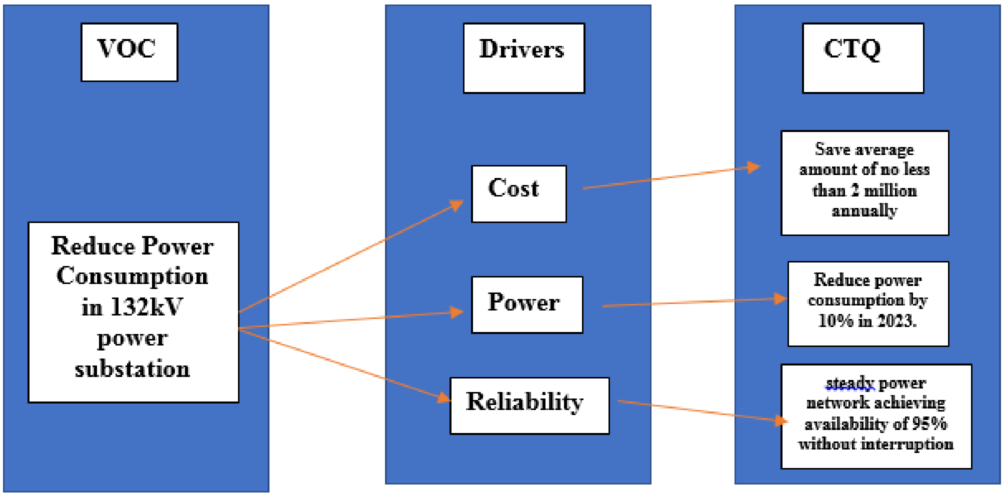

Fig1.4: Voice Of Customer and CTQ's

SIPOC Diagram

In this part, we will use SIPOC diagram which is process mapping tool that represents Suppliers, Inputs, Process, Outputs, and Customers to identify improvement opportunities.

Supplier	Input	Process	Output	Customer
Power girds from power supplies	HVAC equipment such as chillers, air handling units, and fans	HVAC equipment operation to maintain desired temperature and humidity levels	Conditioned air at desired temperature and humidity levels for maintaining the substation environment	Substation operators and personnel who require a comfortable and safe work environment.
Transmission maintenance department	High power consumption at listed substation	Generated report from higher management of DEWA	List of substations with high power consumptions	Higher management of DEWA
Maintenance team	HVAC equipment's	Define root cause analysis (RCA)	List of root cause analysis found	Transmission management team
DEWA higher management	Substation after implementation of root cause analysis	Implement root causes analysis	Substation with lower power consumption by 10% till 3nd quarter of 2023	Dubai executive council

Table1.2: SIPOC Diagram

Measure

Data collection
As shown in the figure below this project will examine the most 10 Substation with high power consumption around Dubai taking into consideration the two main seasonality's (summer, winter) and the table portrays the initial power consumption of 2022 and minimizing it would yield into huge savings in terms of cost and power.

Sr	Substation	Average Power Consumption(Jan-June2022) Total (kWh)	Average Power Consumption(July-Dec 2022)Total (kWh)
1	**Substation 1**	116,157.41	174,236.12
2	**Substation 2**	123,143.70	184,715.55
3	**Substation 3**	288,309.44	432,464.16
4	**Substation 4**	340,082.87	510,124.31

5	**Substation 5**	346,788.16	520,182.24
6	**Substation 6**	371,371.99	557,057.99
7	**Substation 7**	373,320.24	559,980.36
8	**Substation 8**	390,792.94	586,189.41
9	**Substation 9**	432,239.91	648,359.87
10	**Substation 10**	432,344.98	648,517.47

Table2: Transmission Power Substaion Power Consumption

Statistical Sampling

Statistical sampling is a statistical approach that is frequently employed for reaching conclusions and judgements about a population by using a smaller set of data or sample of that population. As shown in the figure at the right of the page a sample of 10 transmission power substations from a total of 323 were taken at random from DEWA statistics.

Statistical sampling has various benefits and includes it is cost effective, time efficient, feasible and precise.

297	INDS	116,157.4
298	HAMR	340,082.9
299	JABL	520,028.7
300	KSWG	823,601.2
301	MUSH	954,734.0
302	QUOZ	831,465.2
303	EMRT	820,631.1
304	JIND	803,418.2
305	LSTA	1,686,949.0
306	CMC	503,369.5
307	SATW	740,842.2
308	RGBN	703,920.4
309	HDQNSHBA	699,460.1
310	ESTA	953,297.4
311	UMRAMOOL	123,143.7
312	SRSBM	373,320.2
313	FORSAN	573,504.6
314	FURJAN	543,424.5
315	QANAT	601,219.7
316	BNYSSQUR	511,699.0
317	WAHADLND	448,040.0
318	CIRCLEX	471,401.6
319	TUNISRD	477,168.0
320	MDNASEHA	497,479.7
321	SATELITE	548,515.0
322	SCHOOLS	371,372.0
323	FAYROAD	288,309.4

Table2.1: ALL High-Power Consumed SS

Analyze

Cause and effects diagram

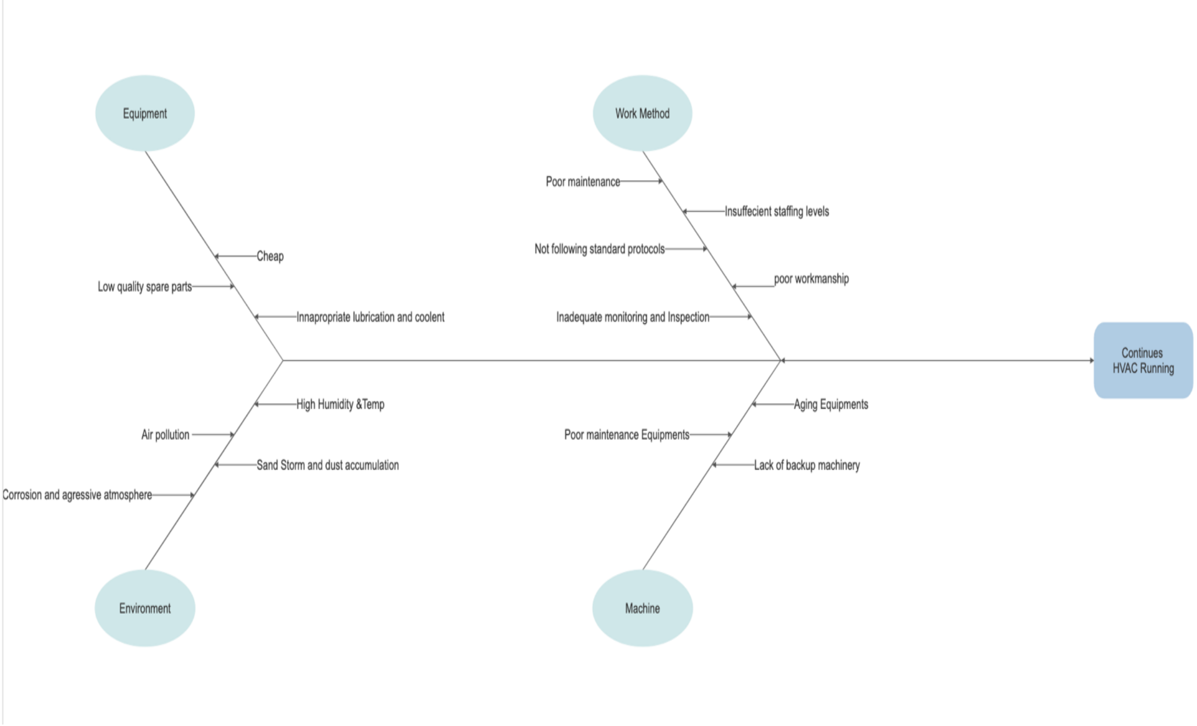

Fig 2.1: Fish Bone Diagram

The cause-and-effect diagram, commonly referred to as the fishbone diagram, is a useful tool for problem-solving and process improvement in Lean Six Sigma initiatives. It bears the name of Dr. Kaoru Ishikawa, a Japanese quality control specialist who made use of it widely known in the 1960s. The fishbone diagram is a graphic depiction that aids in locating and organizing the sources of an issue or impact, making it a useful tool for doing root cause analysis and locating areas for improvement.

Using a fishbone diagram in Lean Six Sigma initiatives has various advantages such as: Logical and structured approach, a comprehensive examination and analysis, visual illustration, team participation, putting root causes first and making decisions based on data. Due to its systematic methodology, thorough analysis, visual depiction, team engagement, emphasis on underlying causes, and data-driven decision making, the fishbone diagram is a useful tool in Lean Six Sigma initiatives. It supports teams in locating and addressing the underlying causes of issues or outcomes, resulting in efficient and long-lasting process changes.

5 Whys

In this part of the project, we used the 5 WHY's tool that will help use to pin point the root causes of the dilemma we are facing by asking several why questions related to the problem statement and finally target the root causes.

Problem Statement	Over the past 12 months DEWA transmission 132kV substations has witnessed an increase of 50% of power consumption. This is above the allowable limit of consumption. Failure to meet this requirement will result in power waste, higher expenses and decrease equipment life. Failure to do so will affect the reliability of Dubai grid system.
Why?→	The continues running of the HVAC system in the substations
Why?→	High temperature in the rooms of the substations
Why?→	Not meeting the cooling capacity for the rooms
Why?→	Faulty Sensor and Leakage in the duct
Why?→	Inefficient Preventive and corrective maintenance
Root Causes	1- Faulty return air sensor resulting in inaccurate reading. 2- Air leakage in the duct resulting in high temperature. 3- Poor preventive and corrective maintenance resulting in lower equipment life time

Table2.2: 5 WHY's Diagram and Root Causes

After analyzing the data and doing the root cause analysis we found out that the return air sensor is not placed in the accurate location in the duct and most of them are placed near to the fresh air intake which gives inaccurate reading resulting in the continues work of compressor during the day.
Moreover, we found deficiencies in the duct system resulting in air leakage which result into high power consumption.

Improve

Introduction of Solutions

The solutions that were implemented to achieve the project goal are:

1- Use better technology of the return air sensor that takes an average reading of all points in the duct which will give a more accurate and precise reading.
2- Better placement of the return air sensor which avoid mixture of ambient air that can result in wrong readings that corresponds to continue running of HVAC system.
3- Redesign the defected ducts by using a more reliable and strong cladding to withstand Dubai harsh weather conditions.
4- Redo the air balancing test for the duct and ensure the correct values of airflow in comparison with the design and capacity of the unit.
5- Refurbishment of HVAC inner components
6- Implement preventive and corrective maintenance based on the standard protocols to achieve healthy life of the units.
7- Reduce the reliability of the traditional energy sources and support it by introducing renewable energy as a second source of power such as Solar panels on the roof connected to the HVAC system.

Fig 3.1: Air Leakage In Duct

Fig 3.2: Return Air Sensor Near Fresh Air Intake

II. Findings

In the improve stage after implementing the proposed solutions the below data was generated.
Column 3 represents the average power consumption for the periods Jan-June 2022 which is the average power consumption of the ten substations before facing the dilemma.
Column 4 represents the average power consumption for the periods July-Dec2022 which had an increment of 50% compared to the last 6 months.
Column 5 is the average power consumption for the periods Jan-June2023 after implementing the proposed solutions which is 10% reduction in the power consumption.
Column 6 is how much power was saved after implementing the solutions per year.
Column 7 is the cost savings generated from implementing the solutions per year.

Sr **(1)**	Substation **(2)**	Average Power Consumption (Jan-June2022) Total (kWh) **(3)**	Pre-Average Power Consumption (July-Dec 2022) Total (kWh) **(4)**	Post Average Power Consumption (Jan-June2023) Total (kWh) **(5)**	Average Power Consumption (3-2 Total) (kWh) **(6)**	Average Power Consumption (AED 3-2) Tariff 1000kw/h=0.34F **(7)**
1	**Substation 1**	116,157.41	174,236.12	156,812.51	17,423.61	AED 79,451.67
2	**Substation 2**	123,143.70	184,715.55	166,244	18,471.56	AED 84,230.29
3	**Substation 3**	288,309.44	432,464.16	389,217.74	43,246.42	AED 197,203.66
4	**Substation 4**	340,082.87	510,124.31	459,111.88	51,012.43	AED 232,616.69
5	**Substation 5**	346,788.16	520,182.24	468,164.02	52,018.22	AED 237,203.10
6	**Substation 6**	371,371.99	557,057.99	501,352.19	55,705.80	AED 254,018.44
7	**Substation 7**	373,320.24	559,980.36	503,982.32	55,998.04	AED 255,351.04
8	**Substation 8**	390,792.94	586,189.41	527,570.47	58,618.94	AED 267,302.37
9	**Substation 9**	432,239.91	648,359.87	583,523.88	64,835.99	AED 295,652.10
10	**Substation 10**	432,344.98	648,517.47	583,665.72	64,851.75	AED 295,723.97

Total cost Saving = AED 2,198,753.33 (based on the local Tariff)

Statistical Tool- Improve Stage

Going further in improving this project our team gathered valuable information from DEWA engineering and design department that would aid in improving the Duct design and knowing whether it has an effect on the air leakage which is considered as a major issue in this project.

We are trying to study whether the outer body of the duct will have an effect on the air leakage during the unit life. The following data was obtained from DEWA team studying the 10 units with different duct material used and their corresponding CFM:

Duct Material	**Observations (CFM)**				
Galvanized Steel	**30,767**	**31,887**	**32,267**	**30,512**	**12,388**
Aluminum	**17,000**	**16,566**	**17,112**	**15,665**	**14,887**
Flexible Ducting(plastic)	**15,115**	**13,887**	**13,998**	**12,564**	**35,887**

Table 3.2: Duct Material &CFM

We are experimenting the Duct material effect on air leakage of HVAC units in DEWA Transmission Power Substations. The Single-Phase ANOVA statistical tool will be implemented and it will be generated through EXCEL.

First of all, assumptions are set including the null hypothesis and the alternative hypothesis where the "μ" indicates the duct material.

Assumptions:

Hypothesis Test

H_0: $\mu1=\mu2=\mu3=\mu4$ (Null Hypothesis)

H_1: At least one $\mu \neq$ zero (Alternative Hypothesis)

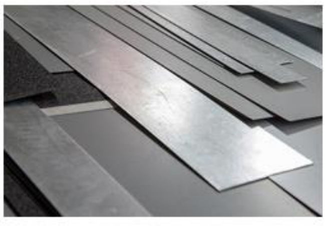

Fig 3.4: Galvanized Steel

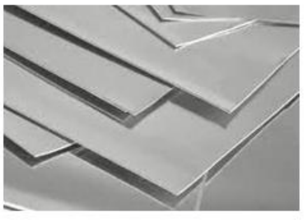

Fig 3.5: Aluminum

Fig 3.6: Plastic

RF Power (W)	1	2	3	4	5	$\bar{y}_{i.}$	$\bar{y}_{i.} - \bar{y}_{..}$	$(\bar{y}_{i.} - \bar{y}_{..})^2$
Galvanzied Steel	15,115	13,887	13,998	12,564	12,388	13590.4	-7109.733333	50548308.07
Aluminum	17,000	16,566	17,112	15,665	14,887	16246	-4454.133333	19839303.75
Flexible Ducting(plastic)	30,767	31,887	32,267	30,512	35,887	32264	11563.86667	133723012.3
$\bar{y}_{..}$	20700.13333						$\sum_{i=1}^{a} (\bar{y}_{i.} - \bar{y}_{..})^2$	204110624.1
$y_{ij} - \bar{y}_{..}$	-5585.13333	-6813.13	-6702.13	-8136.13	-8312.13		$\sum_{i=1}^{a} (\bar{y}_{i.} - \bar{y}_{..})^2$	1020553121
	-3700.13333	-4134.13	-3588.13	-5035.13	-5813.13			
	10066.86667	11186.9	11566.9	9811.87	15186.9			
	-20700.1333	-20700.1	-20700.1	-20700.1	-20700.1			
$\sum_{i=1}^{a} \sum_{j=1}^{n} (y_{ij} - \bar{y}_{..})^2$	3190292592							

ANOVA

Source of Variation	*SS*	*df*	*MS*	*Fo*	*F crit*
SSTreatment	1020553121	2	510276560.3	2.82214	2.81
SSE	2169739471	12	180811622.6		
SST	3190292592	14			

a	3
n	4
N	12

Fig 3.7: Excel Data & Solution

As observed, we can see that F_0 = **2.82**, and we find the Fc (0.05**, 2,12)** from the F table
Fc= 2.81
So since F_0 =**2.82** > Fc= 2.81 we reject the null hypothesis and conclude that there is statistical difference in the mean and we observe that the duct material has an effect on the Air leakage and reduction of CFM indicates that the material will not withstand the substation life cycle and be more exposed to air leakage.

Control

As we have seen in the results of the improve stage, the material plays a role in the air leakage of the duct systems. Therefore, we have to use the material with the least amount of air leakage in the duct and we have to aim for a zero loss of air, or try to minimize this leakage as much as possible.
Our aim and goal are to control and maintain the results that we have acquired and always strive to improve on them once they become the usual norms.

Proposed Solutions to implement in control phase:

1- Regular inspections: by implementing the preventive maintenance and routine maintenance that will be followed using a standardized procedure and checklist to ensure that the maintenance team will inspect all causes of high power consumption in the substation.
2- Airflow Meters and energy management software: Implementation of new innovations and enhanced technologies that will give real time data and alarms of current status of the unit operating and health condition.
3- Data Analysis Tools: Using the data obtained to analyze all patterns and trends that interpret the air leakage or faulty sensors in the duct. This can enhance the system operation and performance which will result in reduction in power consumption.

Finally building the control chart is a very effective way in this phase of enhancement process which also will provide valuable insights into the performance and identify the areas of improvement. However due to lack of data and time we are not able to build the control charts, but proposed solution are given above.

III. Discussion & Concluding Remarks

Dubai, a fast-expanding metropolis with a desert environment, struggles to control its energy usage, especially in areas with vital infrastructure like 132 KV substations. High power consumption may be a result of the HVAC (Heating, Ventilation, and Air Conditioning) systems utilized in these substations. Thus, it is essential to investigate techniques and innovations that might subtly cut down on energy use without lowering the quality of the conversation.

Optimizing HVAC system functioning and design is one useful tactic. Detailed energy audits might reveal areas that need to be improved, such as old equipment, inadequate insulation, or air leaks. Energy may be saved significantly by switching to more energy-efficient parts, such high-efficiency chillers, motors, and fans. Additionally, you may improve energy efficiency and HVAC system performance by properly sealing the building envelope, increasing insulation, and putting in place effective controls, including variable frequency drives (VFDs) for motor speed regulation.

Integrating renewable energy sources into the HVAC systems is an additional practical strategy. Dubai has made significant investments in clean energy, including solar energy. Using solar panels or other renewable energy sources helps balance out grid electricity use and cut down on total power demand. Batteries and other energy storage technologies may also store extra solar energy and supply electricity during times of high demand, decreasing dependency on the grid.

Modern automation and control technologies can be extremely important for raising energy efficiency. HVAC systems may be adjusted for effective operation using real-time monitoring, predictive maintenance, and automated control techniques using Building Management Systems (BMS) and sophisticated algorithms. For instance, temperature sensors, occupancy sensors, and weather information may be utilized to modify ventilation rates, temperature set-points, and other parameters in response to real demand, resulting in more accurate and energy-efficient HVAC operations.

Reducing power usage requires regular maintenance and system improvement. HVAC components like air filters, coils, and fans may all benefit from regular cleaning and maintenance to function at their best and save energy. Implementing a thorough preventative maintenance program that include routine HVAC equipment calibration, tuning, and inspections will help find and address any problems that can affect energy efficiency.

Increasing awareness and encouraging energy-conscious behaviour among stakeholders are crucial in addition to technology solutions. A culture of energy efficiency in the operation and management of HVAC systems can be established by educating facility managers, operators, and end users about energy conservation techniques like optimizing temperature set-points, avoiding unnecessary heating or cooling, and using controls effectively.

Conclusion:

By optimizing system design and operation, incorporating renewable energy sources, putting advanced control and automation technologies into practice, performing routine maintenance, and encouraging energy-conscious behaviour among stakeholders, it is possible to improve the energy efficiency of HVAC systems in Dubai's 132 KV substations. These covert actions can help vital infrastructure operate more sustainably and effectively, supporting Dubai's objectives for energy saving and reducing its environmental impact.

Reference:

[1]. Reports or studies published by Dubai Electricity and Water Authority (DEWA) or other relevant government agencies in Dubai.
[2]. Reference:
[3]. The Lean Six Sigma Pocket Toolbook" by Michael L. George, John Maxey, David T. Rowlands, and Mark Price.The Six Sigma Handbook" by Thomas Pyzdek and Paul Keller.