

Analysis of Metal Enclosed Gas Insulated Switchgear Tank for Deflection

R. T. Rikame¹ and H. A. Chavan²

¹P.G.Student, Dept. of Mechanical Engg., MET's BKC IOE, Nashik-03, India. , Email: ravirikame@gmail.com

²Assistant Professor, Dept. of Mechanical Engg., MET's BKC IOE, Nashik-03, India.

Abstract: Making pressure vessels has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. We will be optimizing the pressure vessel to suit our application i.e. using it for Gas Insulated Switchgear. We also intend to take in to consideration, the aspect of Design for Manufacturing (DFM). During designing, numerous parameters/ variables are to be considered. Hence we need to use a tool that can represent us the effects of various parameters on our requirements (output). We will manufacture the pressure vessel as per the output of our experiment. Then we will compare the output of Computer generated Simulation and actual physical manufactured vessel. Faced with challenge of delivering new product in short time, using the trial and error approach to determine the optimum parameters is no longer good enough. We therefore use advanced tools like Taguchi Method and Virtual Prototyping to reduce our lead time for development.

Keywords: Design and Development of Medium Voltage Gas Insulated Switchgear, Pressure Vessel, Taguchi Method DOE, Virtual Prototype, Analysis.

INTRODUCTION

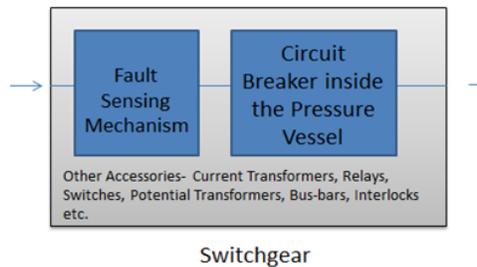
Designing pressure vessels depending on application has been a challenging task for researchers. It is mainly because of the various parameters which are to be considered to deliver a specific output. In this instance we have to optimize a design of a pressure vessel for a Gas Insulated Switchgear. The output is deflection of pressure vessel. The deflection should not be more than 5mm for a rated pressure of 1.2 bar (Absolute).

Switchgear- In an electric power system, switchgear is the combination of electrical disconnects switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply. Switchgear is a large switch used to turn on or cut off the power in various parts of an electricity distribution network. We use switchgear to isolate a fault in the network to minimize the effects of interruptions. Once a fault has been repaired, the switchgear is operated to turn the power back on.

Types:

- A. By voltage class:
 - Low voltage (less than 1kV)
 - Medium Voltage (11kV to 52kV)
 - High voltage (more than 52kV)
- B. By insulating medium:
 - Air
 - Gas (SF₆ or mixtures)
 - Oil
 - Vacuum
- C. By construction type:
 - Indoor (further classified by IP (Ingress Protection) class or NEMA enclosure type)
 - Outdoor

Construction and Working:



Switchgear is the combination of electrical disconnects switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switchgear is used both to de-energize equipment to allow work to be done and to clear faults downstream. This type of equipment is important because it is directly linked to the reliability of the electricity supply.

The very earliest central power stations used simple open knife switches, mounted on insulating panels of marble or asbestos. Power levels and voltages rapidly escalated, making opening manually operated switches too dangerous for anything other than isolation of a de-energized circuit. Oil-filled equipment allowed arc energy to be contained and safely controlled. Switchgear line-up would be a metal-enclosed structure with electrically operated switching elements, using oil circuit breakers. Today, oil-filled equipment has largely been replaced by air-blast, vacuum, or SF6 equipment, allowing large currents and power levels to be safely controlled by automatic equipment incorporating digital controls, protection, metering and communications.

Typically, the switchgear in substations is located on both the high voltage and the low voltage side of large power transformers. The switchgear on the low voltage side of the transformers may be located in a building, with medium-voltage circuit breakers for distribution circuits, along with metering, control, and protection equipment. For industrial applications, a transformer and switchgear line-up may be combined in one housing, called a unitized substation or USS.

The power distribution grid delivers electricity from a power plant. The electric charge moves in a large circuit, which is composed of many smaller circuits. One end of the circuit, the hot wire, leads to the power plant. The other end, called the neutral wire, leads to ground. Because the hot wire connects to a high energy source, and the neutral wire connects to an electrically neutral source (the earth), there is a voltage across the circuit -- charge moves whenever the circuit is closed. The current is said to be alternating current, because it rapidly changes direction.

The power distribution grid delivers electricity at a consistent voltage. All of the different light bulbs and electrical appliances offer a certain amount of resistance, also described as the load. This resistance is what makes the appliance work. A light bulb, for example, has a filament inside that is very resistant to flowing charge. The charge has to work hard to move along, which heats up the filament, causing it to glow.

In building wiring, the hot wire and the neutral wire never touch directly. The charge running through the circuit always passes through an appliance, which acts as a resistor. In this way, the electrical resistance in appliances limits how much charge can flow through a circuit (with a constant voltage and a constant resistance, the current must also be constant). Appliances are designed to keep current at a relatively low level for safety purposes. Too much charge flowing through a circuit at a particular time would heat the appliance's wires and the building's wiring to unsafe levels, possibly causing a fire.

This keeps the electrical system running smoothly most of the time. But occasionally, something will connect the hot wire directly to the neutral wire or something else leading to ground. For example, a fan motor might overheat and melt, fusing the hot and neutral wires together. Or someone might drive a nail into the wall, accidentally puncturing one of the power lines. When the hot wire is connected directly to ground, there is minimal resistance in the circuit, so the voltage pushes a huge amount of charge through the wire. If this continues, the wires can overheat and start a fire.

The circuit breaker's job is to cut off the circuit whenever the current jumps above a safe level. In the following sections, we'll find out how it does this.

Applications:

- Nuclear power plants
- Thermal power plants
- Hydraulic power plants
- Transformer stations and substations
- Mining industry
- Shipbuilding industry
- Petroleum industry
- Chemical industry
- Steel Industry

II. NEED AND SCOPE

As seen from the introduction, the Tank is a very critical component in the sound working of the Gas Insulated Switchgear. The evolution of Gas Insulated Switchgear has come out of the purpose of shrinking space requirements. The per capita power consumption is on the increasing. Hence there is an ongoing increment in power generation and hence distribution. With population growing, especially in the cities, the area of cities is to be utilized effectively and in a better manner for all the activities including power distribution. In order to perform the same function in lesser space, GIS is being developed. Another aspect of evolution of GIS technology is the reduced maintenance costs. It has become increasingly necessary that power distribution be done in least operational costs. The operational costs are directly proportional to maintenance costs. Hence making switchgear more compact and keeping at least some parts isolated in hermetically sealed vessel may serve the purpose. Hence it is a challenge to design the same.

In order to reduce space and maintenance there are other options available in switchgear that can be worked upon. However our scope is to take up one of the most prominent component of Gas Insulated Switchgear – Tank/ Pressure Vessel.

We also restrict ourselves to the mechanical aspects of the design. The electrical aspects have suggested only about the material that should be used for tank. The material to be used for tank is Stainless Steel. It is however important to note that it is in our scope to select the grade of the Stainless Steel to be used.

III. PROBLEM STATEMENT

Current practice of designing of pressure vessel requires experience and knowledge. With increase in number of input factors/ variables it becomes more challenging to design a pressure vessel due to many combinations. One person cannot work with all the options practically. Hence the help of advanced tools for optimization like Taguchi Method (DOE) has been considered. Also considering the fact that this is a real life problem in an industry, the product development has to be faster in order to save time, cost of development and gain a strategic advantage amongst competitors. In order to meet the above said criteria we take the help of software.

Hence the title of our Project is ‘Analysis of metal enclosed Gas Insulated Switchgear for deflection’.

IV. LITERATURE SURVEY

Evolution of Switchgear-

The main application of switchgear is in the protection of circuits against damage caused by faults and the restoration or preservation of supplies to as large a part of the system as possible following a fault. In this function they must add reliability to the system rather than contribute to system problems.

Summary of 1960's Switchgear

- Oil and air interrupting technologies dominate LV and MV switchgear
- Interrupting devices require contact maintenance/oil change after a number of interruptions
- Powerful solenoid operating mechanisms with delicate trip latches required settings, adjustment and maintenance
- Withdraw able circuit breakers, added complexity and increased depth of switchboard
- Large and heavy switchgear, also large, heavy battery supply for high power solenoid mechanisms

Summary of 1970's switchgear

- Vacuum and rotating arc SF6 interrupters enable low energy, maintenance free interrupting devices
- Reduced energy solenoid operating mechanisms designs still require settings, adjustment and maintenance
- Fixed vacuum designs introduced but did not catch on due to lack of service experience with vacuum interrupters

Summary of 1980's switchgear

- Oil and air circuit breakers go out of production, vast majority of new switchgear put into service are vacuum or SF6
- Emphasis on production engineering to produce cost reduced designs
- Motor-wound spring mechanisms and withdraw able designs become the order of the day

Summary of 1990's switchgear

Vacuum circuit breakers have emerged during this decade as by far the most preferred technology for primary substation medium voltage switchgear as field service experience shows almost zero failure rate of vacuum interrupters and interrupter prices fall.

The fixed switchgear concept has made a comeback with SF6 insulated vacuum switchgear and air insulated SF6 switchgear with conventional mechanisms in the low voltage compartment driving the interrupters through linkages.

2000's Switchgear

New designs of switchgear has evolved, designed from scratch with every component as simple and reliable as possible to capitalize on the potential of the magnetic actuator mechanism to be as trouble free as the latest interrupter technology. This concept should has been applied to low voltage switchgear, finally replacing the old technology air circuit breakers at this voltage and later to EHV switchgear.

Gas Insulated Switchgear-

Although the first prototypes of Gas insulated Switchgears were made in late 1980's, the technology has evolved from early 1990's in Europe and the USA. However the technology of Gas Insulated Switchgear in Medium Voltage Segment is very new in India. Pressure Vessel Design optimization has evolved through the years and abundant literature is available. Various optimization techniques and software (like ANSYS, Mixed integer optimization using the quasi-chaotic optimization, Hybrid algorithm for ant colony optimization etc.) have been put in to practice to optimize pressure vessel depending on the applications. However, there has not been any major literature on optimization of Pressure Vessel for the application in Gas Insulated Switchgear.

V. SELECTION OF RESEARCH METHODOLOGY

Taguchi Method

Taguchi's philosophy is an efficient tool for the design of high quality manufacturing system. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provides much-reduced variance for the experiment with optimum setting of process control parameters. Thus the integration of design of experiments (DOE) with parametric optimization of process to obtain desired results is achieved in the Taguchi method.

Classical experimental design methods are time consuming. Many experiments must be performed when the number of control factors is high. Taguchi methods use a special design of orthogonal arrays to study the entire factor space with only a small number of experiments. In general usage, design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled experiments. Formal planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components, and materials. Other types of study, and their design, are discussed in the articles on opinion polls and statistical surveys (which are types of observational study), natural experiments and quasi-experiments (for example, quasi-experimental design).

In the design of experiments, the experimenter is often interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"), which may be people, parts of people, groups of people, plants, animals, etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering. There are mainly three principals of Design of Experiments (DOE) methods in practice today. They are the Classical or Traditional methods, Taguchi methods, and Shainin methods. Sir Ronald Fisher, who applied DOE to agricultural problem in 1930, applied the traditional method to his work. Dr. Taguchi of Japan refined the technique with the aim of achieving robust product design against sources of variation. The Shainin method was designed and developed by consultants. Dorian Shainin used a variety of techniques with major emphasis on problem solving for characterizing product development. Experimental design techniques are a powerful approach in product and process development, and they have an extensive application in the engineering areas. Potential applications include product design optimization, process design development, process optimization, material selection, and many others. There are many benefits gained by many researchers and experimenters, from the application of experimental techniques.

In our project, DOE can be applied in identifying the parameters that have significant influence in the deflection of pressure vessel/ Tank i.e. output. The easiest way to do find the parameters and their effect is to use the designers/ researcher's experience, or trial and error method. This trial and error method is unacceptable because it is time consuming and not cost effective. The objective of this seminar/paper is to obtain the optimal method of performing this experiment using Taguchi Method (DOE).

Virtual Prototyping:

To verify system concepts, to optimize the design or just to present the system in an extensive way, virtual prototyping can be used. Virtual prototype is a computer simulation of the system containing a 3D-model. It should provide human-product interaction and ways to test the product properties and behavior in different perspectives. Wang (Wang, 2002) has studied and compared different definitions of virtual prototyping (VP) and summarizes VP as follows:

"Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP)." Virtual prototyping is a technique in the process of product development. It involves using computer-aided design (CAD) and computer-aided engineering (CAE) software to validate a design before committing to making a physical prototype. This is done by creating (usually 3D) computer generated geometrical

shapes (parts) and either combining them into an "assembly" and testing different mechanical motions, fit and function or just aesthetic appeal. The assembly or individual parts could be opened in CAE software to simulate the behavior of the product in the real world.

Software Selection:

For our experiment we will be using the AutoDesk Inventor Software. Autodesk Inventor, developed by U.S.-based software company Autodesk, is 3D mechanical solid modeling design software for creating 3D digital prototypes used in the design, visualization and simulation of products. Autodesk Inventor competes directly with SolidWorks and SolidEdge.

In this work use of the latest version of the same. It is called 'Autodesk Inventor 2013'.

VI. USE OF TAGUCHI METHOD

Design consideration for a pressure vessel to be used in switchgear.

The pressure vessel is to be designed in such a way that it complies with the guidelines laid by International Electro technical Commission (IEC) - IEC 60694. Accordingly, all active medium voltage components, including the busbar system, are enclosed in a hermetically sealed, gas insulated, metal compartment and should thus be insensitive to humidity, corrosive atmosphere, dust, insects etc. The value of Pressure in Pressure Vessel/ Tank is 1.2 bar (Absolute), There are various input parameters that can be used to for designing the Pressure Vessel.

The Taguchi method attempts to optimize a process or product design and is based upon three stages, as follows:

1. Concept Design or System Design
2. Parameter Design
3. Tolerance Design

The concept design is considered to be the first phase of the design strategy. This phase gathers the technical knowledge and experiences to help the designer to select the most suitable one for the intended product. In parameter design, the best setting of the control factors is determined. This is perhaps the important step, as it does not affect the unit manufacturing cost of the product. The third step is performed only after completion of the parameter design step and is exercised when further improvements are required for the optimized design. This phase focuses on the trade-off between quality and cost. However, designers in this stage consider only tightening tolerances, upgrading material standards and components, if any, having a significant impact on quality through parameter design experiments. The Taguchi method uses the signal-to-noise (S/N) ratio instead of the average to convert the trial result data into a value for the characteristic in the optimum setting analysis. The S/N ratio reflects both the average and the variation of the quality characteristic. The standard S/N ratios generally used are as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio. Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation, but have criticized the inefficiency of some of Taguchi's proposals. Taguchi's work includes three principal contributions to statistics:

A specific loss function i.e. Taguchi loss function;

The philosophy of off-line quality control; and Innovations in the design of experiments.

We will now identify and develop the methodology for performing this experiment.

The input parameters are

Design of Tank/ Pressure Vessel (3 levels)

Material (3 levels)

Tank/ Pressure Vessel thickness (3 levels)

Stiffener Thickness (3 levels)

Weldment Length (3 levels)

The output is Deflection.

After studying the above input-output relationship we can conclude that we need to use the Taguchi DOE method having 5 Factor- 3 Level experiments.

The orthogonal Array generated using the software of Minitab is as follows.

Table no.6.2 Orthogonal Array generated using the software of Minitab

Sr. No.	Tank Thickness (mm)	Stiffener Thickness (mm)	Design Layout (Number)	Material	Weldment Length (%)
1	2	2	1	J4	10
2	2	2	1	J4	20
3	2	2	1	J4	30
4	2	3	2	SS304	10
5	2	3	2	SS304	20
6	2	3	2	SS304	30
7	2	4	3	SS316	10
8	2	4	3	SS316	20
9	2	4	3	SS316	30
10	3	2	2	SS316	10
11	3	2	2	SS316	20
12	3	2	2	SS316	30
13	3	3	3	J4	10
14	3	3	3	J4	20
15	3	3	3	J4	30
16	3	4	1	SS304	10
17	3	4	1	SS304	20
18	3	4	1	SS304	30
19	4	2	3	SS304	10
20	4	2	3	SS304	20
21	4	2	3	SS304	30
22	4	3	1	SS316	10
23	4	3	1	SS316	20
24	4	3	1	SS316	30
25	4	4	2	J4	10
26	4	4	2	J4	20
27	4	4	2	J4	30

VII. VIRTUAL PROTOTYPING

Virtual prototyping is a technique in the process of product development. It involves using computer-aided design (CAD), computer-automated design (CAutoD) and computer-aided engineering (CAE) software to validate a design before committing to making a physical prototype. This is done by creating (usually 3D) computer generated geometrical shapes (parts) and either combining them into an "assembly" and testing different mechanical motions, fit and function or just aesthetic appeal. The assembly or individual parts could be opened in CAE software to simulate the behavior of the product in the real world.

The product design and development process used to rely primarily on engineers' experience and judgment in producing an initial concept design. A physical prototype was then constructed and tested in order to evaluate its performance. Without any way to evaluate its performance in advance, the initial prototype was highly unlikely to meet expectations. Engineers usually had to re-design the initial concept multiple times to address weaknesses that were revealed in physical testing.

Today, manufacturers are under pressure to reduce time to market and optimize products to higher levels of performance and reliability. A much higher number of products are being developed in the form of virtual prototypes in which engineering simulation software are used to predict performance prior to constructing physical prototyping. Engineers can quickly explore the performance of thousands of design alternatives without investing the time and money required to build physical prototypes. The ability to explore a wide range of design alternatives leads to improvements in performance and design quality. Yet the time required to bring the product to market is usually reduced substantially because virtual prototypes can be produced much faster than physical prototypes.

End-to-end prototyping accounts fully for how a product or a component is manufactured and assembled and links the consequences of those processes to performance. Early availability of such physically realistic virtual prototypes allows testing and performance confirmation to take place as design decisions are made; enabling the acceleration of the design activity and providing more insight on the relationship between manufacturing and performance than can be achieved by building and testing physical prototypes. The benefits include reduced costs in both design and manufacturing as physical prototyping and testing is dramatically reduced/eliminated and lean but robust manufacturing processes are selected.

The research firm Aberdeen Group reports that best-in-class manufacturers that make extensive use of simulation early in the design process hit revenue, cost, and launch date and quality targets for 86% or more of their products. Best-in-class manufacturers of the

most complex products get to market 158 days earlier with \$1.9 million lower costs than all other manufacturers. Best-in-class manufacturers of the simplest products get to market 21 days earlier with \$21,000 fewer product development costs.

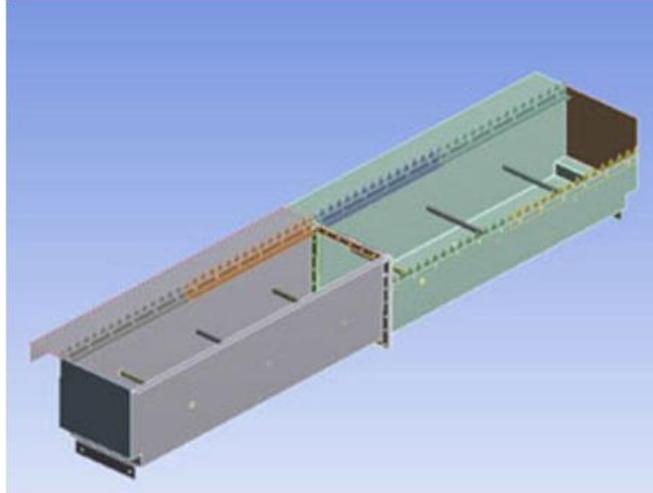


Fig: 3D modeling of tank.

The similarly 3D models are developed with all results of taguchi method and then proceed for simulation.

VIII. COMPUTER ANALYSIS

A computer model refers to the algorithms and equations used to capture the behavior of the system being modeled. By contrast, a computer simulation refers to the actual running of the program that contains these equations or algorithms. Simulation, therefore, refers to the result of running a model. In other words, you would not "build a simulation". You would "build a model", and then either "run a model" or "run a simulation".

Computer simulation developed hand-in-hand with the rapid growth of the computer, following its first large-scale deployment during the Manhattan Project in World War II to model the process of nuclear detonation. It was a simulation of 12 hard spheres using a Monte Carlo algorithm. Computer simulation is often used as an adjunct to, or substitute for, modeling systems for which simple closed form analytic solutions are not possible. There are many types of computer simulations; their common feature is the attempt to generate a sample of representative scenarios for a model in which a complete enumeration of all possible states of the model would be prohibitive or impossible.

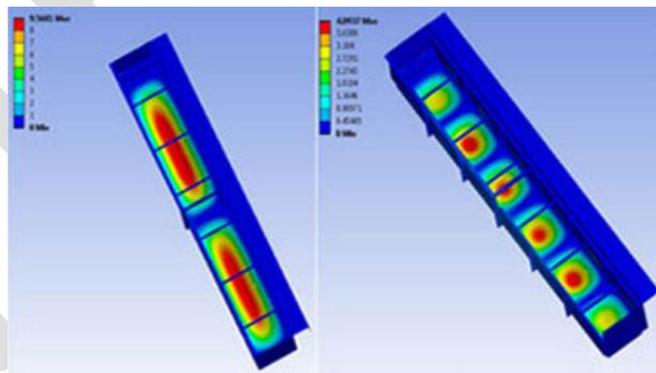


Fig: Result of analysis.

Similarly, simulation of all models for displacement is in process to optimize the solution for minimum deflection of gas insulated switchgear tank.

CONCLUSION

- After performing the simulation, we get the optimum combination of the 5 variables/ factors for the required output of deflection.
- According to the results of our experiment physical prototype made and found 2mm deflection.
- Physical prototype is matching result 80% that to our experiment.
- New product Development cycle time reduced by 70%
- New product Development cost reduce by 75%

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