International Journal of Power System Operation and Energy Management

Volume 3 | Issue 2 Article 2

April 2014

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POST INSULATOR DESIGN OPTIMIZATION IN MEDIUM VOLTAGE SWITCHGEAR

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Abstract- There has been constant development in the energy sector. As the trend of SMART grid is increasing, modern power systems require smarter and reliable switchgear. In this view, the optimum design of switchgear and components acquired prime importance. This can be achieved using various optimization techniques. In this paper, novel optimum design of post insulator is proposed and carried out. The design gives a standard value of capacitance for the indicating system and also solves problem of partial discharge in Indian system. The design is first carried out using 3D MAXWELL software tool for 33kv post insulator which gives drawing in AUTOCAD. The output design parameters obtained in 3D MAXWELL are used for optimization in MATLAB.

Index Terms- *Medium Voltage Switchgear, Finite Element Analysis (FEA), Partial Discharge, Optimization techniques, Voltage Indicating System.*

I. INTRODUCTION

A. Energy Scenario in India

In recent years, the rate of development in energy sector is tremendous in world. The availability and demand of power has been increased throughout the world. Per capita consumption of energy in India is quite low as compared to developed countries in the world.

India consumed 540 kgoe in 2008 compared to 1803 kgoe by world. India's energy use efficiency for generating GDP product in Purchasing Power Parity is better than many countries [1].

1) Generation Sector: The total installed capacity in India is 185497MW, whereas for Maharashtra it is 24182 MW [2].The Planning Commission of India has set a target of adding more than 78000MW in five year plan beginning 2007.Strategies to meet India's energy requirement are limited by it's energy sources and import possibilities. Over 55% of energy need is supplied by coal itself. Whereas the remaining is supplied by hydro, nuclear and renewable energy sources.

2) Transmission and Distribution Sector: The electricity consumption per capita for India is 566 kWh and is far below most other countries in the world. Even though 85% of villages are considered electrified, around 57% of the rural households and 12% of urban house-holds, i.e.84 million households in the country, do not have access to electricity.

Power capacity has risen at a rate of 5.87% per annum over last 25 years. The total supply of electricity has risen at a rate of 7.2% per annum over same period. Following table shows the development of transmission sector in India:-

At the end of	400 KV Transmission line ckm	220 KV Transmission line ckm	765 KV Transmission line ckm	+/- 500 KV HVDC Converter ckm
6th Plan (1980-1985)	6029	46005		
7th Plan (1985-1990)	19824	59631		
8th Plan (1992-1997)	36142	79600		
9th Plan (1997-2002)	49378	96993		
10th Plan (2002-2007)	75722	114629		
11th Plan up to 1.2.2011 (2007-2012)	104798	133787	4423	8924

(Source: Central Electricity Authority, Government of India)

Fig. 1. Development of Transmission Sector in India

B. Necessity of switchgear in power system

As we know that, electrical power system works on various voltage levels, so for protection of person as well as for safety of equipment the protection system should be reliable and accurate one. Nowadays there is recent trend about the use of switchgear in 'Smart Grid'. For such kind of functions the switchgears should be:-

1) More Reliable
2) More Accurate
3) Intelligent

Switchgears can be classified as:-

On the basis of Voltage Level:-

– Low Voltage Switchgear-upto 11kV
– Medium Voltage Switchgear-11kV to 33kV
– High Voltage Switchgear-Above 33kV

On the basis of type of terminals used in Circuit Breaker [3]

– Fixed Switchgear

– Withdrawable Switchgear

On the basis of application

– Indoor Switchgear
– Outdoor Switchgear

While inspecting the components of Medium

Voltage switchgear[4] it is found that it consists of:-

1) LV compartment
2) Withdrawable Trolley
3) Potential Transformer
4) Explosion Vent
5) Current Transformer
6) Surge Arrester
7) Earth Bus
8) Power pack

In LV compartment, there are many parts like Numerical Relay, Load manager, Voltmeter, Annunciator, Hooter etc.One of the key component in LV compartment is Voltage Indicating System. The voltage indicator system used in MV switchgear consists of voltage indicator and an electronic unit. Out of these, voltage indicator plays a role of epoxy post insulator with in-built capacitive voltage divider.

While designing of MV switchgear processes were done on the basis of engineer's experience. This is also known as 'cut and try approach'. The disadvantage of such method was it was time consuming and also limited by engineer's knowledge of the problem. To overcome such kind of problem optimization approach is more convenient and more analytical. It gives more accurate results also.

For such kind of optimization, it is necessary to do Finite Element Analysis (FEA) of insulation element i.e. the post insulator for detailed analysis. Till now, there is use of non standardized post insulators for Voltage Indication purpose in MV Switchgears .As a result, rate of failure of such post insulator is more. There are many reasons behind such failure and those are:
1. Partial Discharge
2. Switchgear Enclosure and surrounding area
3. Thermo graphic Inspections

Partial Discharge is a leading indicator of an insulation problem. For detection of such kind of problem, Coupling capacitor PD sensors are mostly used. Due to advantages of good sensitivity to high frequency signals, compact volume, etc. 80pF capacitance sensor is more popular [5]. In this example, we are going to embed this capacitance in the support insulator of switchgear panel itself. It will serve as PD sensor as well as can be used in Voltage Indication System.

Here two quantities were optimized in the described example of switchgear design. They are the capacitance of the voltage divider, which is part of the insulator, and size of insulator. Capacitance of the voltage divider is defined in accordance with IEC standard 61243-5, which requires capacitance in a range between 74 and 88 pF. The distribution of electric field strength depends on the position of the capacitive voltage dividers elements and on the insulators external shape. The modeling of a post insulator with a pre-defined external shape is described in [6].

II. WORKING PRINCIPLE

The voltage indication system consists essentially of a capacitive voltage divider between a conductor L and earth. Moreover, the system includes an indicator for the detection of voltage and a surge arrester for protection purposes.

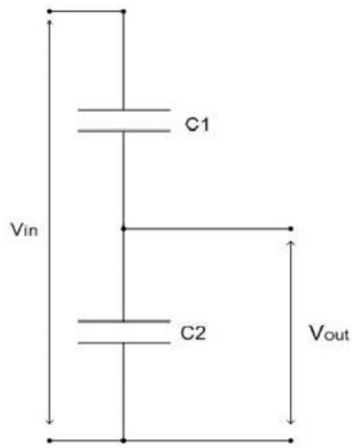

Fig. 2. Schematic diagram of Capacitive Post Insulator.

Voltage division occurs due to the capacitive values of C1 and C2. According to IEC 61243-5 the indication should start in between 10% of the read voltage of the system. For that reason, the capacitance values are adjusted in accordance within this range so that the indication starts. Up to 10% of the rated voltage, there shall be no indication. Under any circumstance above 45% of the rated voltage the indication shall be "ON".

The presence of voltage is indicated separately and independently for each phase conductor. The system operates without a battery or auxiliary supply. The energy required for the system is being drawn from the high voltage system.

III. MODEL

The metal fitting of the insulator (upper connection) for fastening to the conductive part of the upper side, is elongated with a special electrode of the divider, which has the potential of the conductive part i.e. 33kV in this example. The metal fitting for fastening the insulator to the earthed part (lower connection) is situated at the bottom of the insulator.

A cylindrical metal mesh with a potential of 0 V is mounted around this metal connection, which represents the other electrode of the divider.

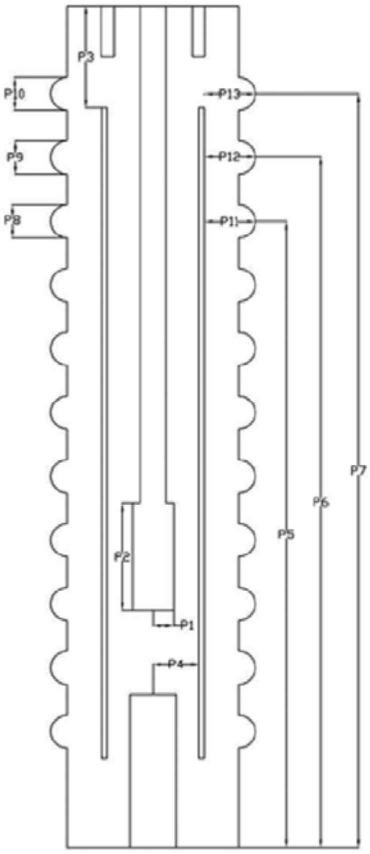

Fig. 3. Schematic diagram of Post Insulator.

The easiest way of obtaining the required model geometry is the use of parameterization, which is the basis for automatic generation of the mesh and for optimization. From among the parameters, P1, P2, P3 and P4 influence both the capacitance as well as electrical field strength, while remaining parameters influence the electrical field strength only.

TABLE I
INSULATOR PARAMETERS.

Sr.No.	Parameters	Initial Value(in mm)
1	P1	8
2	P2	42
3	P3	40
4	P4	20
5	P5	246
6	P6	270
7	P7	296
8	P8	13
9	P9	13
10	P10	13
11	P11	20
12	P12	20
13	P13	20

Fig.3. shows MAXWELL computer simulation results obtained for above insulator. In this, for analysis purpose the insulator is taken in R-Z plane. Also Balloon boundary conditions have been applied to such design [7].

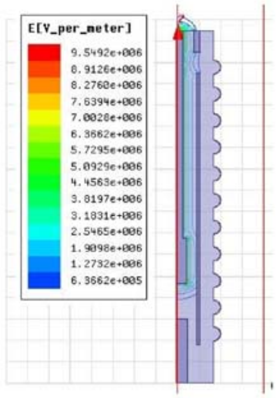

Fig. 4. MAXWELL results of Practical Post Insulator.

From above results the capacitance can be obtained as [8]: The energy stored in the electric field can be calculated by:

$$W_e = \int D.E dV \quad (1)$$

The capacitance can be calculated by using following key equations:

$$W_e = \frac{1}{2} CV^2 \quad (2)$$

whereas,

We is energy stored in the electric field in Joules. C is capacitance in the Farad.
V is voltage across the dielectric in volts.

IV. RESULTS

A. Cut and try approach

The design process was traditionally accompanied by greater number of prototypes elaboration. Later the use of numerical analyses decreased the number of needed prototypes, but the major design decisions were still dictated by engineers' experiences. This kind of design process is often referred as 'cut and try' approach. In this procedure the models modifications were determined by technical directives and our experiences in the field of modeling of similar devices [9].

The proposed Post insulator design is obtained by this method:

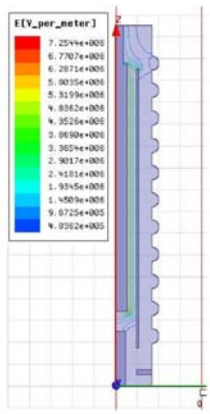

Fig. 5. Maxwell result of Proposed Post Insulator.

Here the diameter of special electrode is increased in such a way that it gives 80pF.Also the position of terminal for voltage indication has been changed. But the main constraint in such kind of design is, the space in between special electrode and the metal mesh around it, is quite much less. So practically, there might be possibility of flashover in between these two part internally itself.

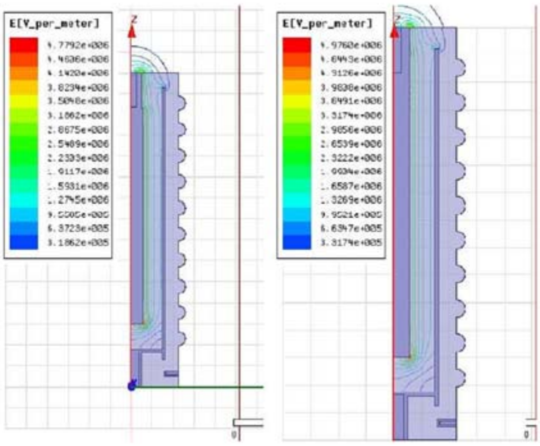

Fig. 6. Step by step development of Post Insulator designs.

So to overcome such kind of constraints, the overall diameter (OD) has been increased so the diameter of metal mesh. Also the height of such insulator has been reduced. It's design is as below:

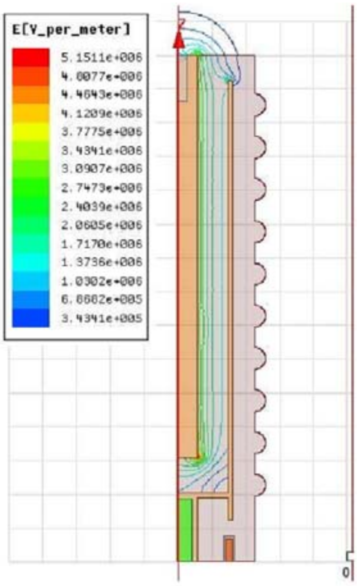

Fig. 7. Prototype design of Proposed Post Insulator.

In the construction of post insulator the potential on cylindrical metal mesh is 0V, so to position such kind of cylindrical metal mesh is quite much difficult from manufacturing point of view.i.e.encapsulation of metal mesh around the special electrode. So in this new design, the additional disk is welded to metal mesh so that it will give support and will also increase the capacitance of overall insulator. By doing this, the safety of insulator has been in-creased. The drawing of proposed design has been done on AUTOCAD software. In this design, all the constraints are taken into consideration. The prototype design has been sanctioned by the manufacturer. By simulation in MAXWELL, it gives 60pF capacitance.

The typical parameters have been set to get 60 pF capacitance and they are:

TABLE II
SYSTEM PARAMETERS.

Sr.No.	Parameters	Value
1	Nominal line voltage (V_L)	33kV
2	System frequency (f)	50Hz
3	Potential of Earth	0V

B. Finite Element Method

It is the technique for computer solution of complex problems. It is the powerful tool for approximate solution of differential equations describing differential physical process [10].

1) The formulation of problem in variational form.
2) Finite Element discretization of this formation
3) Effective solution of resulting finite element

Analysis and design of electrical equipment is difficult task as:-
1) Complex geometry
2) Mixed set of materials involved
3) Dynamic aspect

FEM can be used not only in Electrical Engg. but in Aerospace industry, Structural Engg.,High Voltage production and manufacturing industry also[11].

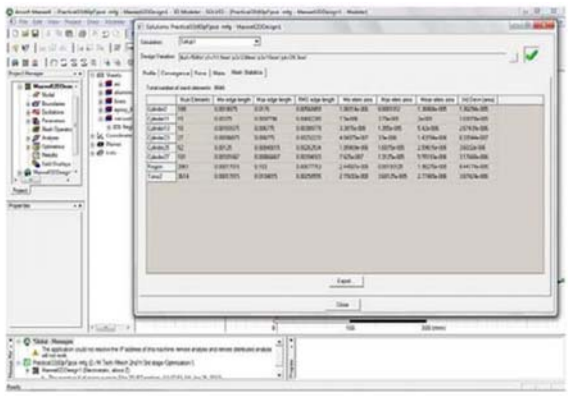

Fig. 8. Snapshot of Maxwell FEM analysis.

C. Optimization Algorithm

The main algorithm for designing of medium-voltageswitchgear insulation elements by means of FEM analysis consists of the following four basic modules: a parametrically described insulators model, mesh generator, solver of the MAXWELL program package, and an evolutional optimization algorithm. A parametrical description of the insulators geometry in connection with the newly developed mesh generator is necessary, since it enables larger possible changes in geometry that require new meshing of the model to finite elements. The algorithm for optimization is as below [12]:

Begin
Initial parametric model of insulator
For N=1 to MAX GENERATION Do
Meshing of geometry
Preparation of the model in the pre-processor
FEM solver of MAXWELL software

Calculation of capacitance and electrical field strength Evaluate the objective function f(x)
If (f(x) < of required condition) Then
Optimal insulator's geometry
Else
Use Optimization algorithm
End if

End
End

D. Determination of objective function

In our case, the goal of optimization is to achieve adequate standard capacitance of voltage divider at lowest size of insulator, it is necessary to consider the effect of parameter variation on the capacitance value. For determination of such relation, the graph of electrical field density (D) Vs. Parameters has been plotted with the help of MATLAB software.

From the graph, the equation of such graphs has been found out by 'optimization toolbox' available in MAT-LAB.

V. CONCLUSION

In this report, the performance of proposed Post insulator is investigated for the values of capacitance within range of 74-88pF. Simulation results also show that the it is the optimized version of the original practical post insulator. It provides safe insulation as support insulator.

As compared to other support insulator for same rating, the total volume is much more less. So there is 13% saving of material. Also the weight of such kind of insulator is 2.9 kg. and is more than proposed insulator (2.5kg) [13]. Some other post insulator works on resistive voltage division and it requires much more space than proposed one[14]. So ultimately by this design optimization, there is optimization of space, material and cost also.

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