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An Approach to Reduce the Variation in the Continuous Operating Voltages across Lightening Arrester Assemblies

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Abstract

Lightening arresters made of zinc oxide (ZnO) blocks are used to protect electrical equipments against lightening and switching surges. The continuous operating voltage (COV) is an important characteristic of the lightening arrestor, which is the sum of the continuous operating voltages of the individual zinc oxide blocks used in the lightening arrester. An Indian electrical equipment manufacturing company was facing great difficulty in getting the correct combination of ZnO blocks for assembling lightening arresters. The major reason is the variation in COV between ZnO blocks. In this paper, the author discusses presents a solution to the aforementioned problem by providing a new approach for the selection of the ZnO blocks. The suggested approach significantly reduces the variation in COVs across arresters as well as the variation in number of ZnO blocks used across arresters. It also minimizes the usage of the total number of ZnO blocks under the given constraints and reduces the time taken to generate the required number of assemblies.

Keywords: Lightening Arrester, Zinc Oxide Blocks, Continuous Operating Voltage, Optimisation, Integer Linear Programming Problem, Lindo software

Introduction

The electrical equipments often get damaged due to over-voltage. Lightening is one of the serious causes of over-voltage. If the power equipment, especially at outdoor substation is not protected, the over voltage will cause burning of insulations [1]. Lightening arrester is a device used to protect all electrical equipments and installations, especially transformers, against lightening and switching surges in substations. The lightening arresters exhibit an extremely high resistance during normal operations and a very low resistance during transient over voltages [2]. Nowadays, the use of zinc oxide (ZnO) arresters, as a means of electrical equipment protection against over voltages due to lightening strikes, has been spread all over the world.

The ZnO lightening arrestors consist of zinc oxide blocks assembled in a porcelain housing and hermetically sealed. The section view of ZnO arresters is given in figure 1. ZnO blocks are highly purified, closely grained metal oxide powders, mixed; spray dried and then pressed to form discs & sintered at high temperatures. This process result in a dense polycrystalline discs. The basic molecular structure of the disc is a matrix of highly conductive zinc oxide and surrounded by highly resistive inter granular layer of other oxides. Under steady state conditions these barriers withstand the applied power frequency voltages, however under over voltage conditions they break instantly turning into conduction mode and divert surges to earth. The continuous operating voltage (COV) is an important characteristic of the lightening arrestor, which is the sum of the continuous operating voltages of the individual zinc oxide blocks used in the lightening arrester.

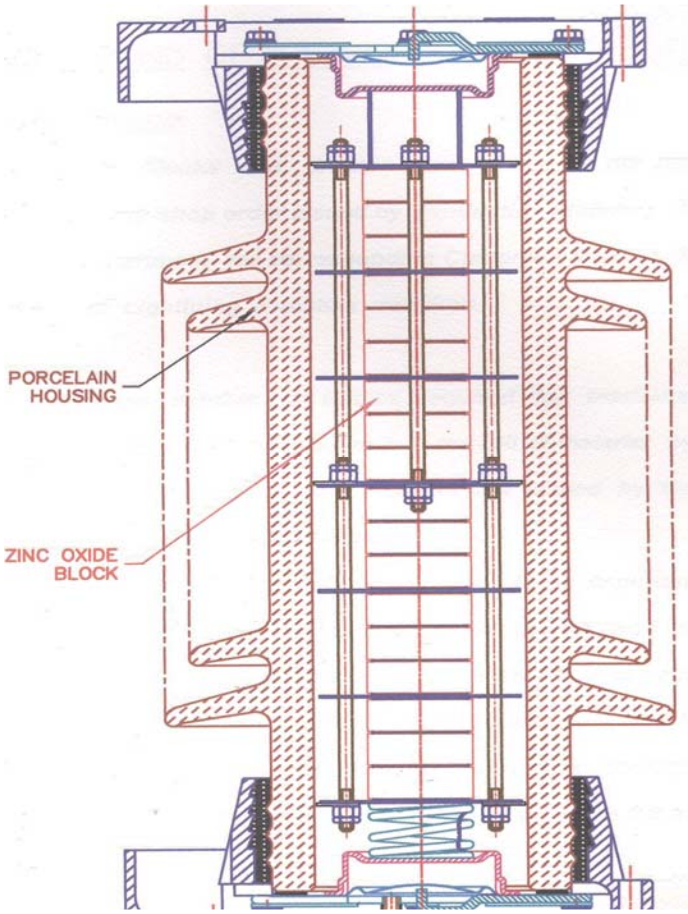

Figure 1: Session of View Lightening Arrester

An Indian electrical equipment manufacturing company with a product range of insulators, bushings, transformers, wave traps, lightening arrestors, grading capacitors, surge capacitors, etc was facing great difficulty in getting the correct combination of ZnO blocks for assembling lightening arresters. The major reason was the variation in COV between ZnO blocks. The observed variation in COV was from 1.8 kilovolts (kV) to 2.8 kV across ZnO blocks. This, in turn, resulted in large variation in the number of blocks as well as in the COV between lightening arresters. For example, to full fill an order of 19 arresters with a COV of 303kV from the electricity supply and distribution board of a north-western state of India, the company used 130 to 145 ZnO blocks in different arresters and the COV varied from 303 kV to 307.8 kV between arresters as shown in table 1. Moreover the company used to spent two man-hours per day on segregation and selection of zinc oxide blocks for lightening arrester assembly, which amounts to Indian Rupees (Rs.) 72,000 annually. Hence this study was undertaken to minimize the variation in the COVs across lightening arrester assemblies as well as the variation in the number of ZnO blocks used across arresters.

Table 1: Lightning Arrester Assemblies generated using existing method

Assembly Number	Number of ZnO blocks with different COVs used in the assembly									Total Blocks	COV
	2.4	**2.35**	**2.3**	**2.25**	**2.2**	**2.15**	**2.1**	**2.05**	**2**		
1	0	2	0	0	0	51	77	14	0	144	304.75
2	0	0	0	0	0	0	125	10	10	145	303
3	0	0	5	1	61	67	7	0	0	141	306.7
4	0	0	76	52	1	0	0	5	0	134	304.25
5	0	45	80	2	1	0	0	2	3	133	306.55
6	1	0	44	84	5	1	0	1	0	136	307.8
7	0	3	0	0	0	95	41	2	2	143	305.5
8	0	0	0	88	40	7	1	1	0	137	305.2
9	1	3	89	38	3	0	0	0	0	134	306.25
10	0	0	6	124	6	0	0	0	0	136	306
11	0	0	0	80	47	6	2	0	2	137	304.5
12	0	0	0	0	0	72	60	11	0	143	303.35
13	0	0	49	81	4	0	0	1	0	135	305.8
14	0	0	0	71	56	8	0	1	1	137	304.2
15	0	1	0	81	51	4	0	0	0	137	305.4
16	1	0	48	81	4	0	0	0	1	135	305.85
17	0	49	81	1	0	0	1	0	0	132	305.8
18	0	93	36	1	0	1	0	0	0	131	305.75
19	8	122	0	0	0	0	0	0	0	130	305.9
Total	**11**	**318**	**514**	**785**	**279**	**312**	**314**	**48**	**19**	**2600**	

The remaining part of this paper is arranged as follows: the details of the existing assembly process and the suggested approach are given in section 2. The formulation of the problem is given in section 3. The validation of the suggested approach is presented in section 4 and the conclusion is given in 5.

Approach

Through discussion with engineers, the step-by-step details of existing lightening arrester assembly process are identified as follows:

Step 1 Draw ZnO blocks from store
Step 2 Segregate and select blocks for assembly
Step 3 Calculate the COV and count the number of blocks required
Step 4 Check whether the number of blocks is less than or equal to the maximum specified number
If yes, proceed to next step
Else, go back to step 2

Step 5 Check whether the COV is greater than or equal to required COV
If yes, proceed to next step
Else, go back to step 2
Step 6 Check whether the ZnO blocks of different COVs is less than or equal to the number available
If yes, proceed to next step
Else, go back to step 1
Step 7 Do stack assembly
Step 8 Do Module Assembly
Step 9 Leak and Electrical testing

It has been seen that there are 3 major loops (steps 4, 5 & 6) in the assembly process. The engineers pointed out that assembly process often enter into one or more of these loops and in many times lot of iterations are required to exit the loop, especially when the customer orders a batch of arresters with the same COV.

Based on the discussions and process details, the author felt that the selection of ZnO blocks for lightening arrester assembly is an optimization problem. Formulating and solving it as an optimization problem may yield a better result than the current practice of trial and error method for selecting ZnO blocks for assembly. A detailed literature survey [3 – 14] revealed that nobody has formulated the selection of ZnO blocks for lightening arrester assembly as an optimization problem. The company professionals are also unaware of any organization using optimization methods to arrive at the best combination of ZnO blocks for lightening arrester assembly. Hence it is decided to try this novel approach. The formulation of the problem is given in the next section.

Problem Formulation

The selection of ZnO blocks for assembling a batch of lightening arresters of a given COV is formulated as follows:

Let $i = 1,2, - -, n$ be the number of lightening arresters to be assembled. Let the required minimum COV for every arrester be V and the variation in COV across arresters be V to $V + \delta$.

Let k be the maximum number of ZnO blocks allowed in a single assembly and the variation in the number of ZnO blocks between arresters be $k - \nabla$ to k.

Let $j = 1,2, - - -, m$ be the different ZnO blocks with COVs of $y_1, y_2, - - -, y_m$ and let A_j be the number of j^{th} ($j = 1,2, - - -, m$) ZnO block available in the store.

L et $x_{ij,}$ $i = 1,2, - - , n; j = 1,2,- - -, m$ be the number of j (with COV y_j) ZnO blocks used in i^{th} assembly.

Then the problem is to minimize the total number of blocks used for assembling the entire batch of arresters

i.e. Minimize z = $\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}$ (1)

subject to the constraints

1 The number of ZnO blocks in each and every arrester should be between $k - \Delta$ and k

i.e. $k - \nabla \le \sum_{j=1}^{m} x_{ij} \le k$, for $i = 1,2, - - -, n$ (2)

2 The COV of each and every arrester should be between V and $V + \delta$

i.e. $V \le \sum_{j=1}^{m} x_{ij} y_j \le V + \delta$, for $i = 1,2, - - -, n$ (3)

3 The number of times the *jth* ZnO block (with COV y_j, $j = 1,2, - - -, m$) used in assembling the entire batch of arresters should not exceed the number of the same available in the store

i.e $\sum_{i=1}^{n} x_{ij} \le A_j$, for $j = 1,2, - - -, m$ (4)

4 The number of ZnO blocks, $x_{ij,}$ $i = 1,2, - - , n; j = 1,2,- - -, m,$ used should be integer and non negative

i.e. $x_{ij} \ge 0,$ for $i = 1,2, - - , n; j = 1,2,- - -, m$ (5)

i.e. $x_{ij} = \text{integer};$ for $i = 1,2, - - , n; j = 1,2,- - -, m$ (6)

The aforementioned problem is an integer linear programming problem (ILP). ILPs [15-16] are linear programming programs with some or all variables are restricted to integer (discrete) values. This problem can be solved using any operations research packages like Lindo [17].

Validation and Implementation

The new approach is tested with the same order of 19 arresters with a required COV of 303kV from the electricity supply and distribution board of a northwestern state of India. The result obtained is given in table 2. The comparison of table 1 & 2 revealed that the new approach used only 2579 blocks instead 2600 (reduction of 21 blocks). The variation in the number of blocks across the assemblies is also reduced (131 to 138 in new approach against 130 to 145 in old approach). Similarly the variation in COV across arresters also reduced (303kV to 304.65kV in new approach against 303kV to 307.8kV in old approach). Also the time taken to generate assemblies is also reduced to less than 5 minutes. Hence it is concluded that the new approach is superior to existing method of ZnO block selection for lightening arrester assembly.

The new approach is piloted with another order for 12 lightening arresters with a required COV of 268kV from the electricity supply and distribution board of a northern state of India. The assemblies generated using the new approach is given in table 3. It has been seen that the variation in the number of blocks across the arresters is only 5 (from 100 to 105) and the variation in COVs across the arresters is only 3.25kV (from 268kV to 271.25kV). Moreover the time taken to generate the assemblies is drastically reduced.

Table 2: Lightning Arrester Assemblies generated using new method

Assembly Number	Number of ZnO blocks with different COVs used in the Assembly									Total Blocks	COV
	2.4	2.35	2.3	2.25	2.2	2.15	2.1	2.05	2		
1	0	58	52	21	0	0	0	0	0	131	303.15
2	0	27	70	35	0	0	0	0	0	132	303.2
3	0	22	69	36	0	3	3	0	0	133	304.15
4	0	0	77	37	2	9	9	0	0	134	303
5	2	0	75	37	1	10	9	0	0	134	303.15
6	0	37	9	41	15	16	17	0	0	135	303
7	0	34	10	41	15	18	18	0	0	136	304.65
8	0	28	10	43	19	18	18	0	0	136	303.85
9	0	9	11	44	22	23	23	5	1	138	303.85
10	0	14	13	45	20	21	21	3	0	137	303.45
11	0	14	13	45	20	21	21	3	0	137	303.45
12	0	14	13	45	20	21	21	3	0	137	303.45
13	0	14	13	45	20	20	21	3	1	137	303.3
14	0	14	13	45	20	21	21	3	0	137	303.45
15	3	11	13	45	20	21	21	3	0	137	303.6
16	0	14	13	45	20	21	21	3	0	137	303.45
17	3	11	13	45	20	21	21	3	0	137	303.6
18	0	14	13	45	20	21	21	3	0	137	303.45
19	0	14	13	45	20	21	21	3	0	137	303.45
Total	8	349	513	785	274	306	307	35	2	**2579**	
Available	12	356	517	797	284	317	314	51	20	**2668**	

Table 3: Pilot implementation result

Assembly Number	Number of ZnO blocks with different COVs used in the Assembly								Total Blocks	COV
	2.8	2.75	2.7	2.65	2.6	2.55	2.5	2.45		
1	0	0	1	3	0	97	4	0	105	268
2	0	0	3	14	20	67	0	0	104	268.05
3	3	1	21	60	10	6	0	0	101	268.15
4	0	0	66	15	10	10	0	0	101	269.45
5	1	21	45	15	10	8	0	0	100	268.2
6	0	18	12	15	47	10	0	0	102	269.35
7	0	53	12	15	10	10	0	0	100	269.4
8	5	48	12	15	10	10	0	0	100	269.65
9	37	16	12	15	10	10	0	0	100	271.25
10	36	16	12	15	10	10	1	0	100	270.95
11	37	16	12	15	10	10	0	0	100	271.25
12	37	16	12	15	10	10	0	0	100	271.25
Total	156	205	220	212	157	258	5	0	**1213**	
Available	156	205	220	215	159	265	175	76	**1471**	

Conclusion

In this paper, the author discusses a new approach for selecting the ZnO blocks for lightening arrester assembly. T he suggested approach is to formulate and solve the problem as an optimization problem. The validation of the approach showed that there is significant reduction in the variation in COVs across arresters as well as the number of ZnO blocks used across arresters. Moreover the new approach minimizes the usage of the total number of ZnO blocks under the given constraints. The new approach also reduces the time taken to generate the required number of assemblies. This helped the organization to save two man-hours per day resulting in a monitory saving of Indian rupees 72,000/- annually.

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