Indian Journal of Science and Technology Vol. 5 No. 5 (May 2012) ISSN: 0974- 6846

A new method to recognize the status of sic surge arresters in substations

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Abstract

SiC lightning arresters are a kind of lightning arresters that nowadays are substituted with new type such as ZnO lightning arrester. Nonetheless, many SiC lightning arresters in Iran's electricity networks are operating. For instance, all the medium voltage network lightning arresters of Bakhtar Regional Electrical Company (BREC) are SiC type. The company wants to exchange these lightning arresters, but due to high cost and numbers of these lightning arresters, it is decided to put them in suitable ranks up to a due time. Since all suggested tests for recognition of lightning arresters deficiency are laboratory tests and must be done in lab, it isn't possible for the company to transfer all lightning arresters from substation to lab. Therefore, it has been decided to carry out that in the substation. Accordingly, a project has been suggested and carried out by the writers of this paper and the present paper is the result of this project. Different theories in this paper are surveyed. DC test is introduced as a suitable way for correct recognition deficiency of lightning arresters. The acquired results of DC test on some samples of lightning arresters are in coordination with the standard tests that have been carried out in Pars High Voltage Lab. Finally, three groups of arresters are defined according to their operating condition which includes acting good, delayed acting and not operating arresters. According to this classification, BREC is capable to exchange the arresters with respect to condition of the related arrester and with an appropriate priority which is obtained from its condition.

Keywords: SiC Lightning arrester, Electricity network

Introduction

Lightning arresters are one of the most important protective equipments of networks. They are in charge of protecting transformers against different over voltages resulted from climate conditions or transient situations such as switching or short circuit (Singh & Singh, 2002). There are two main groups of lightning arresters which include non-linear resistance of Silicon Carbide (SiC) and linear resistance of Zinc Oxide (ZnO).

Since lightning arresters are always exposed to electrical shocks and different devastating environmental factors, they may face deficiency. Existence of defective lightning arresters and cause some problems such as short circuit (for ZnO lightning arresters), open circuit (for SiC lightning arresters) and damaging of expensive equipments. Hence, it is necessary to regularly check and service the lightning arresters of the networks and replace defective ones.

Nowadays, electrical companies exchange their SiC lightning arresters with ZnO type (Kanashiro *et al.,*2010), but there are a lot of SiC lightning arresters in some networks in Iran like Bakhtar Regional Electrical Company (BREC). This company wants to change them in some stages. At first, lightning arresters need to be rank according to their performance. Accordingly, it is necessary to evaluate the performance of lightning arresters with validate tests. Generally the defined standard tests for SiC lightning arresters are laboratory test which is not feasible for in service arresters. This was a problem that BREC had with SiC lightning arresters. Since, this company couldn't change lightning arresters all together and on the other hand it couldn't transfer lightning arresters to lab. BREC decided to define a project and it has done by researcher of this paper to identify a priority for replacing the lightening arresters according to the performance and the operation condition of the arresters.

Nowadays most of the studies about arrester are done in ZnO field. It's because ZnO surge arrester are more advanced than SiC and Electrical Companies are interested in using them.

Grzybowski & Gao (1999) have evaluated some gapped SiC arresters rated from 15 kV to 420 kV after being in service for 25 years. Lenk (2010) provided the utility with a quantifiable summary of potential energy savings that can be achieved by upgrading from gapped SiC to ZnO arresters across their high voltage system. Extensive Australian studies in the 1960's had revealed that internal degradation resulting from inadequate seals was the predominant cause of failure of gapped silicon carbide arresters and the results of those studies are in (Darveniza *et al.,*1996). Woodworth (2010) clarifies the difference between silicon carbide (SiC) arresters and the externally gapped line arrester (EGLA). Burk (1991) illustrated a condition where the substitution of a ZnO arrester instead of a gapped silicon carbide arrester of similar rating is inappropriate. This study proved that under conditions of high steady state over voltages which occures during faults conditions, a gapped arrester might be more appropriate and optimal. Earlier workers (IEEE Working Group,1992; Pinceti & Giannettoni,1999; Fernandez, 2001) elaborated some models to simulate the dynamic behaviors of ZnO surge arrester. The models include: IEEE model in (IEEE Working Group. 1992), Pinceti & Giannettoni,1999 model (Pinceti & Giannettoni,1999) and Fernandez model (Fernandez, 2001). The results of performance and behaviors of arresters, which are installed in polluted environment, were also analyzed (Chrzan, 2004).

This paper is the results of the research, which is carried out in BREC and proposes a solution to identify the correct SiC lightning arresters from defective ones using DC test. Comparing to other test which are carried out on lightening arresters, the proposed method has many advantages such as, low cost and the ability of doing it in the substations. The Similarity between suggested lab tests in standard and the acquired results of the test, which are carried out in BREC, proves the authenticity and the accuracy of the proposed method. Considering the DC test as a solution for determining correct lightning arresters and defective types, three different classes are suggested for lightening arresters according to their operating conditions which includes acting good, delayed acting and not operating arresters. With this classification the BREC will be able to change SiC lightning arresters according to their operation condition.

SiC lightning arrester

These kinds of lightning arresters are made in modulator type. In other word the main element of lightning arresters which are determined, assembled and placed in a protected case according to the required voltages and the related discharge current. The main elements of these lightning arresters are: Multiple series of gaps utilized to improve the gap reliability versus a single gap. In addition, the SiC resistive element, known as the non-linear resistive valve element, is a crucial part to decide the protection properties of the arrester (Grzybowski & Gao,1999). The general scheme of these lightning arrester types are shown in Fig. 1.

The performance of this kind is in this way that exceed voltage distribute to lightning arrester in air gaps and then arc in defined voltage be put in non-linear resistance. After the creation of arc and current discharge in lightning arrester, the wave current through its protected case and phase conductors goes into the earth. After electrical lightning discharge, resulting of overvoltage and changing wave current to sinusoidal, the arc path has been long and its resistance has been increased so the necessary condition is prepared for arc smother by non- linear resistances.

The SiC materials have a non-linear resistance and the value of their resistance changes with current. This property keeps the voltage of two ends of lightening arresters low in high current impulses and hence the protected equipments will not damage. In addition, the air gap is placed to prevent the flowing of current from lightening arresters. When the impulse wave reaches the arrester, the air gap turns into a conductor and conducts electrical charge to earth. The most important point about performance of the lightning arrester is that after overvoltage, the spark is not removed in the length of air gap and is continued up to end of the half cycle of voltage. The Fig. 2 and Fig. 3 show the performance of lightning arrester.

Fig.1. General scheme of SiC lightning arrester

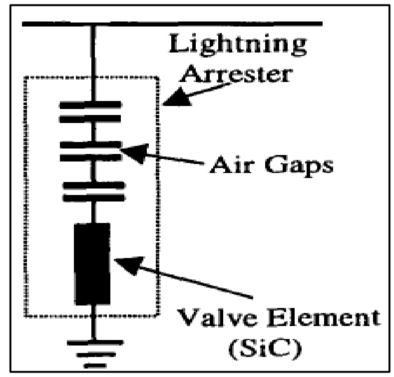
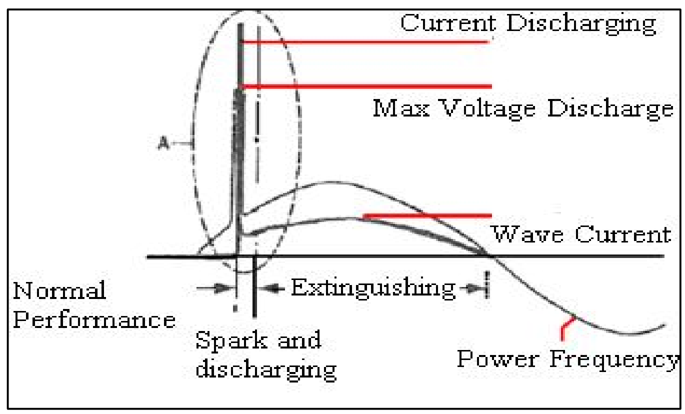


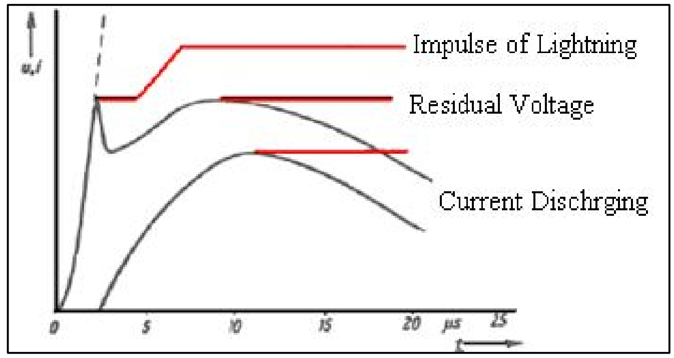
Fig. 2.Changing in current and voltage for SiC surge arrester



Factors causing deficiency in Lightning arresters of BREC

Lightning arresters are damaged because of many factors in the networks. if the cause of deficiency wasn't inappropriate selection of lightning arresters and with assumption that the lightning arresters of different locations were in coordination with nominal voltage and discharge current, according to the standards of IEC6009-1 and IEC60099-4 the exploitation problems

Fig. 3. Details of A in Fig. 1



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should be discussed and taken into consideration (IEC Standard 60099-1. 1999; IEC Standard 60099-4. 2004). The main factors causing these operating problems are: environmental factors (moisture, air contaminants and etc), electrical shocks and mechanical impacts. According to the carried out research, the main factors of the malefaction of BREC arresters are working for too long time and the excessive number of operations.

Environment factors: Environmental factors and the permeation of the moisture into the lightning arresters are the most common deficiency factor in SiC lightning arresters (American standard ANSI/IEEE, 1967; Lat. 1981;*Darveniza et al.,1996*). Investigating the defective SiC lightning arresters of BREC, it was identified that the air gap was damaged in most of them. Damaging of air gapes usually causes the decrease in the discharge current level in them. This exposes lightning arresters to high thermal pressure. Damaging of the air gap is usually caused by the permeation of dust and moisture into the lightning arresters. When an impulse wave become large enough to cause a spark in each air gap, a spark is created and accordingly the total discharge level of lightning arresters is reduced.

Electrical shocks: Electrical shocks play an important role in decreasing the lifetime of lightning arresters. The multiple impulses of lightning can damage the resistance blocks. In addition, sometimes the created energy of electrical shocks is more than the tolerance of lightning arresters. In this condition, the transferring of thermal energy increases the conductance of inside gas pressure and causes the outside coverage's lightning arresters to break or explode. The explosion of the coverage may be dangerous and have a high risk for personnel's company and others. The mentioned case has been observed in BREC sometimes.

Working longer than the suggested time by producer: One of the most common problems which was observed in lightning arresters of BREC is that these arresters were installed in the network for a long time. Although the researches have shown that after 13 years of installing lightning arresters, their performance decreases significantly and should be replaced (Darveniza *et al.,*1996), it was observed that the lightning arresters were operating in the network for 25-30 years in BREC**.**

Operating more than limited operation times: Producers claimed 50 performances for the number of performances in overvoltage condition for SiC lightning arresters in medium pressure networks of BREC. Since the most of the counters of the lightning arresters are defected and personals have not considered this problem seriously, it is expected that the lightning arresters have operated more than suggested numbers by producer with regard to long time of their existence in the network and the high amount of the lightening of the area. In the other hand, the arresters with the correct counters also prove the excessive operation of these arresters.

Standard tests for lightning arresters

According to American standards (American standard ANSI/IEEE, 1967) and IEC international standards (IEC Standard 60099-1, 1999), there are some tests introduced to evaluate the performance of SiC lightning arresters. Some of these tests include; power-frequency spark over voltage, maximum 12/50 µs lightning impulse spark over Voltage, front-of-wave impulse spark over voltage and determining of residual voltage test. Most of this these tests are laboratory tests and should be carried out in lab.

Since the purpose of this paper is finding a method for recognizing correct and defective SiC lightning arresters in substations, none of the mentioned test is appropriate and feasible method for this aim. On the other hand, these tests should be carried out on the arresters to evaluate the performance of them. The first test which was carried out on the arresters was residual voltage test. In this test, 8/20 µs lightening current wave is applied to the lightning arresters with an amplitude depending on nominal voltage. If the arrester operates in the expected voltage, it can be concluded that the arrester is correct and if it does not operate, it is defective. The voltage in which the lightning arresters should act is called residual voltage and according to standard is defined as the voltage that indicates the protection offered by the arrester due to its voltage clamping action (Miller *et al.,*1991). To do this test, some lightning arresters shown in Table 1, were transferred to Pars Lightning Arresters Company (PLAC) and were tested in high voltage lab of this company. It should be mentioned that the performance of them were not clear before tests. The lightening current generator and its circuit are shown in Fig. 4 and Fig. 5.

Table 1. Arrester samples for residual voltage measurement test

Sample no.	Design rated voltage(kV)	Design residual voltage (kV)	Manufacture	Type of arrester
TS1	11	33	PARAFOUDRE	SIC
TS2	11	33	PARAFOUDRE	SIC
TS3	11	33	PARAFOUDRE	SIC
TS4	63	172	TRIDELTA	SIC

Residual Voltage Test. Sample No.TS1

The performance of the TS1 after applying the lightening wave was as follows:

As shown in the Fig. 6 and Fig. 7 applying the impulse wave, the TS1 arrester operated in 23 KV and with the operation of it 348 A current is grounded. But according to table 1, this arrester should have operated 33 KV. Hence the operation point of the arrester is changed and this fact proves the defection of this arrester that lightning arrester is out of order. Furthermore, the depicted oscillations at the beginning of the figure is due

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Fig. 4.The circuit of impact current producer equipment

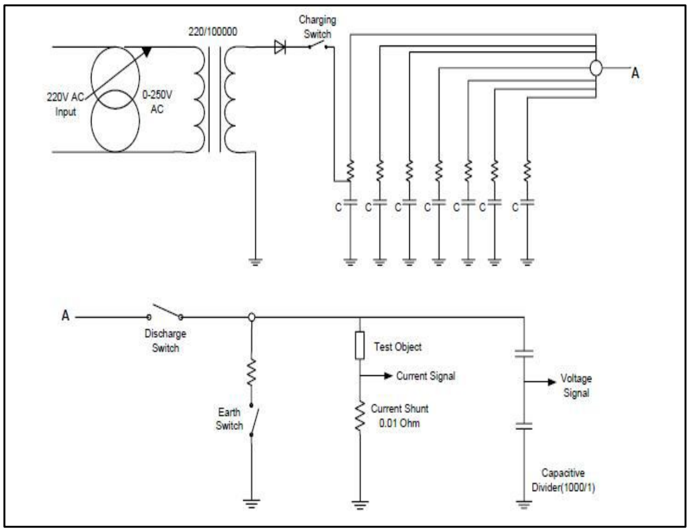

Fig. 5. The lightening current generator of the PLAC

Fig. 6.TS1 arrester while test

Fig. 7. The graph of the remained voltage for TS1 arrester

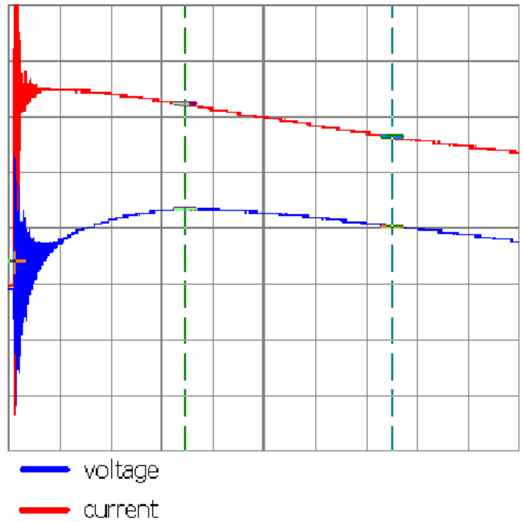

Fig. No. : 1
Subject: Min. Ures Measurement
Sample No. : TS1
Current Peak : 348 A
Voltage Peak: 23 kV
Volt/Div: 20 kV/Div
Amp/Div: 100 A/Div

Fig. 8.The graph of the remained voltage for TS2 arrester

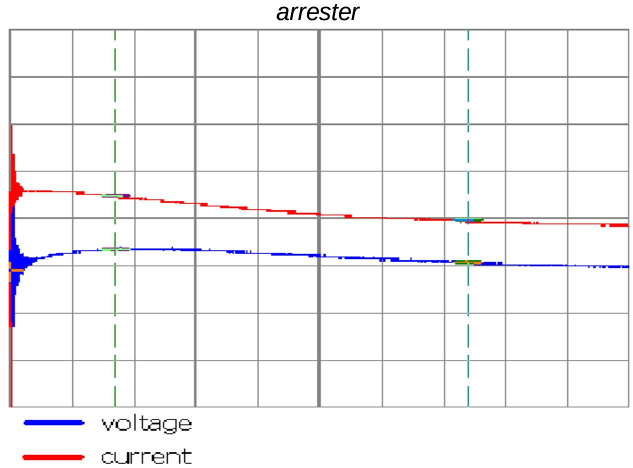

Fig. No. : 2
Subject: Min. Ures Measurement
Sample No. : TS2
Current Peak: 320 A
Voltage Peak : 8 kV
Volt/Div: 50 kV/Div
Amp/Div: 200 A/Div

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Fig. 9. The graph of the remained voltage for TS3 arrester

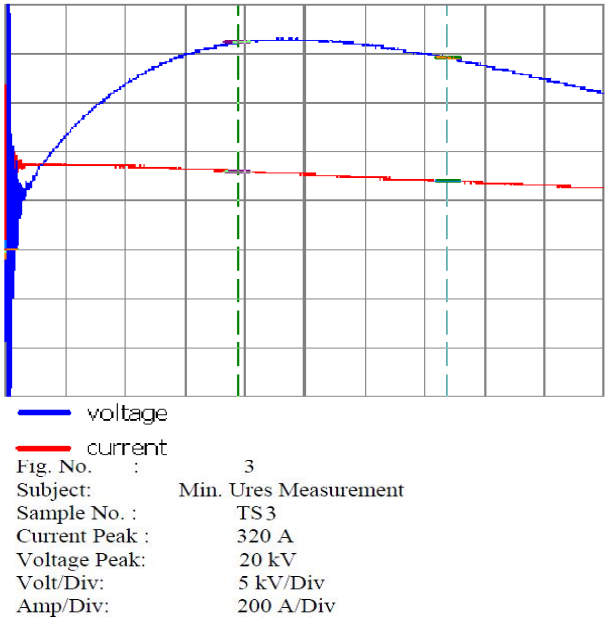


Fig.10. a. Inside of defected lightning arrester
b. Inside of correct lightning arrester

Fig. 11. A section of TS4 lightning arrester while test

Fig. 12. Graph of the residual voltage of one section of TS4 arrester

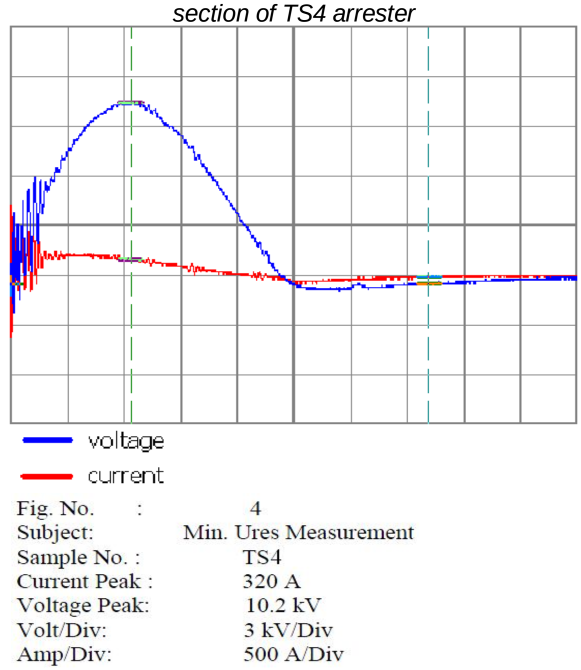
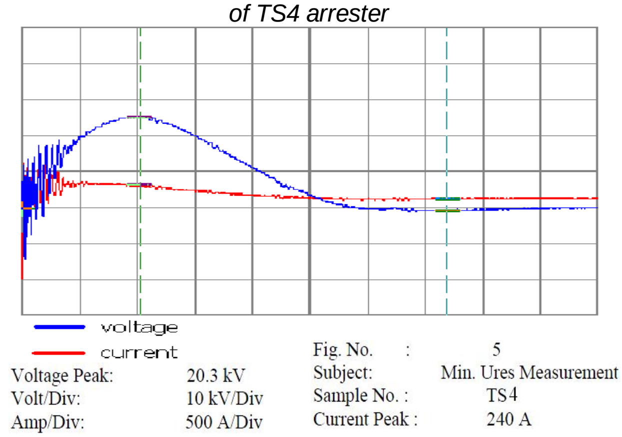


Fig. 13. A section of TS4 lightning arrester while test

Fig. 14.Graph of the residual voltage of two section of TS4 arrester



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to the high sampling oscilloscopes of the PLAC and do not stand for anything. The important issue about this figure is the peak value of the curve where the arrester operates.

Residual voltage test sample no.TS2 : As shown in Fig. 8, the TS2 arrester operates after 8 kV. Hence this arrester is completely defective. The cause of discharge level decrement was identified after opening this arrester. The moisture has permeated inside the arrester and the air gaps were completely destroyed due to the influence of the moisture.

Residual voltage test. sample no.TS3: As shown in the Fig. 9, the TS3 arrester operates in the voltage of 20 kV which is lower than its nominal voltage and like previous arresters it is defective.

Residual voltage test. sample no. TS4. 1 of 17 sections of arrester: Since the impulse current generator of the PLAC had some limitation for creating current big enough for the operation of the 63 kV arrester, the test was carried out on sections of this arrester and hence the lightening arresters were opened and different sections of them were separated and the test results were developed for the arrester. After opening these arresters it was observed that despite the perfect appearance of one of the arresters the sections of another was completely ruined and defected. Fig. 10 shows the open scheme of these two lightning arresters.

The correct 63(kV) lightning arrester was tasted first with a section and next time with two sections as TS4 test and the conclusions were developed for the arrester. This arrester consisted of 17 sections.

It is shown in Fig.11 and Fig. 12 that one section operated in 10.2 (kV) and grounded 320 current. Developing the result of this test for all sections of lightning arrester it gains the voltage of 173.4 kV ($10.2 \times 17 = 173.4$). As this voltage approximately equals the designed residual voltage, this lightning arrester is not defected. For ensuring the acquired result two section of this arrester is tested (Fig.13 and Fig. 14).

Residual voltage test. sample no.ts4. 2 of 17 sections of arrester: According to acquired result of testing two sections of TS4 lightning arresters, they have operated in the voltage of 20.3 (kV). Hence all of the lightning arrester operates in the voltage of 172.55 (kV). The result of two TS4 tests shows that this lightning arrester is correct and operates in expected condition.

Different theories for testing lightning arresters in service

Calculating frequency response of correct and defect lightning arrester and comparing them : The purpose of this theory is comparing the frequency response of the correct and defective arresters and identifying the defective ones. Research group wanted model the lightning arrester using series of resistance and capacitors and obtain the equivalent circuit to get the frequency response. Regarding different researches it was identified that this method is not feasible, because frequency analyzing is related to an active circuit while the lightning arrester is not an active component and pills of silicon carbide creates a non-linear resistance. On the other hand air gapes do not have any frequency response so this theory was rejected.

Sound test: This theory expressed that with sound registering of one sample of air gapes lightning arrester during operation in correct form and comparing that with other lightning arresters the operation condition become clear. The most important cause of ignoring this test is the existence of noise in substation that disturbs the registering of sound of lightning arresters in substation.

Resonance test: The air gapes are composed of two conductive with an insulator between them (like capacitors). After operating for multiple times, quality of this insulator is degraded and the conductors oxidize. The Silicon carbide pills are also changed their mass operating for multiple times and accordingly the original design of the lightning is change. With regard to this points and according to the changes that the lightning arrester encounters after operating, the research group decided to analyze the resonance response of the arresters to identify the correct and defective ones comparing the this parameter.

Necessity of this test was moving the arresters. After different researches, it was identified that using this test only helps to comprehend the operation condition of the insulator of the arrester and only the mechanical quality of them can be analyzed, hence this theory was rejected.

DC test: Fig. 15 shows the circuit used for generating DC voltage in high voltage laboratory.

In this circuit, the transformer transforms the 220(V) network voltage to 100 (kV) maximum voltages. The R_1 limits the current which flowing into the transformer. The resistance of R_2 is a voltage divider that is used for measuring the secondary voltage of the transformer.

The D Diodes and C capacitors are used for producing a DC voltage. The resistance of R_3 is voltage divider that is used for voltage measuring of two sides of the test object. The purpose of this test is applying DC voltage to lightning arrester and registering their performance. If the arresters operated in a voltage which equals their residual voltage it can be concluded that they are correct and otherwise they are defective.

In this test all SiC lightning arresters received from company either some that impulse test is carried out on them in PLAC or the ones that cause problems and damage to transformer because of their weak performance and it was clear that they were defective are subjected to the test. In addition, a new SiC lightning

Fig. 15. The DC voltage generator circuit

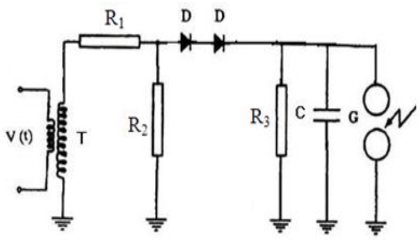

Fig.16. DC test on TS1

Fig. 17. DC test on TS2

Fig. 18.DC test on TS3

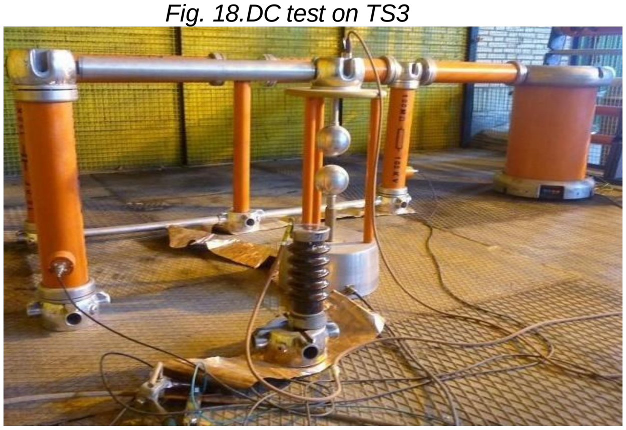

Fig. 19.DC test on TS4

Fig. 20.DC test on TS5

Fig. 21.DC test on TS6

Fig. 22. Required equipments of producing a portable DC generator

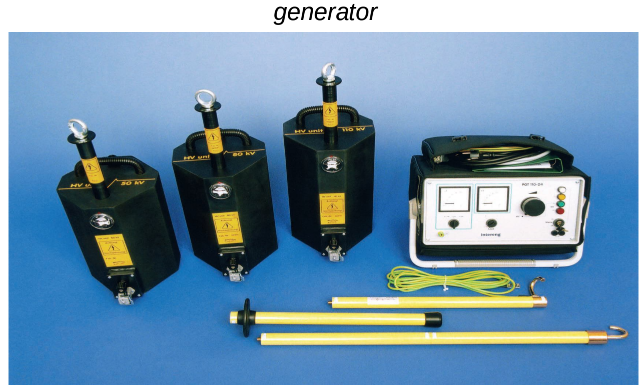

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Table 2. Test samples for DC test

Sample no.	Design rated voltage(kV)	Design residual voltage (kV)	Manufacture	Type of arrester	Diagnosis
TS1	11	33	PARAFOUDRE	SIC	Defective
TS2	11	33	PARAFOUDRE	SIC	Defective
TS3	11	33	PARAFOUDRE	SIC	Defective
TS4	24	72	Not apparent	SIC	Defective
TS5	24	72	Not apparent	SIC	Defective
TS6	24	72	Not apparent	SIC	Normal

arrester in the stock room was tested. List of tested lightning arresters are shown in Table 2.

According to acquired results from Table 3, the TS1, TS2 and TS3 lightning arresters that are recognized as defective in impulse test have similar result in DC test. In other hand, the 24(kV) lightening arresters of TS4 and TS5 have induced problem and were absolutely defective. Furthermore because of the two lightening arresters have no performance in lightening it was clear that either they have been transformed to insulator or they are in threshold level. By applying DC voltage, the two lightening arresters acted in voltages of 92(kV) and 95.6(kV). According to Table 2 their design residual voltage was 72(kV) and should have acted in that voltage. Hence they were defective. The TS6 has been a new 24(kV) lightening arrester that has not been installed in the network. After applying DC test the lightening arrester acted in 73(kV). Comparing the performance of this arrester and residual voltage, it was clear that they have had correct performance. The images of DC test on these lightening arresters are shown in Fig. 16-21.

Table 3. The results of DC test

Sample no.	Operation voltage in DC test	Acquired result of DC test	Acquired result of impulse test
TS1	27	Defective	Defective
TS2	15	Defective	Defective
TS3	29	Defective	Defective
TS4	92	Defective	-
TS5	95.6	Defective	-
TS6	73	Intact	-

Comparing the results of DC test and result of impulse test and by verifying the accuracy of correct lightening arresters and recognition of the defective lightening arresters it can be conclude that the DC test is a trustful test for evaluate the accuracy of the lightening arresters. Since the necessary equipment of this test is portable and can be done in substation it is feasible to use this test in place and hence moving arresters from the substation is not necessary. The necessary equipments for doing DC test in the place are depicted in the Fig. 22.

Table 4. Results of the DC test (kV)

Nominal voltage (kV)	Accurate operation (kV)	Operating late (kV)	Insulator (kV)
11	30-35	35-40	Upper than 40
24	65-75	75-85	Upper than 85
63	170-180	180-190	Upper than 190

Since the purpose of the test is the recognition of lightening arresters accuracy in their operation place to give priority for replacing them, so the research group has classified the results of DC tests. This classification is shown in Table 4.

According to this table, the BREC can replace SiC lightning arresters in high voltage substations with regard to their priority. This company can obtain the following economical and technical benefits:

Economic advantages:

- Enduring the low cost of purchasing a portable DC generator, replacing all of the lightning arresters which requires a high cost and is almost impossible for the BREC can be deferred
- Replacing correct lightning arresters can be prevented
- By replacing defective lightning arresters, enormous expense of damaging high cost equipments is prevented

Technical advantages:

- With replacing defective lightning arresters, the reliability of network in transient overvoltage is increased.
- With disposing and priority processing in replacing of lightning arresters, it can replace SiC lightning arresters with ZnO type as reach to update technology in this subject.
- It's possible to recognize correct and defective lightning arresters in substations

Conclusion

With respect to vital role of lightning arrester in electrical networks protection while overvoltage conditions, it is pivotal to ensure of equipments accuracy. Since this paper is the result of an industrial project for BREC and its purpose is to recognize the accurate and defective SiC lightning arresters in the place, the most important factors of deficiency of the lightning arresters are presented. These factors include, environmental factors, electrical shocks and the time of installing and number of operations in network.

Since every method that is designed for carrying out in the substation should be approved by standards some 11 and 63 arresters were tested in high pressure voltage lab of PLAC by residual voltage measuring test. Some theories were proposed and investigated for recognition accurate and defective SiC lightning arresters in the place and at last with carrying out frequently tests in high pressure voltage lab of BREC, the DC test was introduced as an appropriate method for recognition accurate and inaccurate SiC lightning arresters in the substation. The results of DC test have a good compatibility with impulse standard test. Finally three confines are presented according to the operation condition of these arresters and hence the BREC is capable of replace the arresters with a logical priority. Therefore, in addition to avoiding the high cost of replacing all of the lightning arresters simultaneously, the BREC can decrease the destroyer effects by identifying defective lightning arresters and furthermore improve network security by replacing them in a scheduled task.

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