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Hybrid Circuit Breaker – A Case Study

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----------Abstract----------
High Voltage Circuit Breaker (CB) is important electrical equipment used in the power system network to isolate the faulty section from the healthy network and thus ensure safe operation of the electrical system. Vacuum Circuit Breakers and SF_6 Circuit Breakers are widely used depending upon the power rating of the transmission line. The merits and demerits of the two are reviewed and the need for hybrid model is analyzed.

Keywords-*Vacuum Circuit Breaker, SF_6 Circuit Breaker, Hybrid model*

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I. INTRODUCTION

The main aim of the paper is to explore ongoing research in the field of high voltage engineering. The paper intends to present a contrast between the Vacuum interrupter and SF_6 interrupter, thus highlighting the need of the hybrid circuit breaker.A circuit breaker is an electrical switch designed to detect fault condition and interrupt the circulation of current in the faulty section of the circuit. It is an automatic switch that responds to the fault, through the excitation of relay assembly incorporated in the transmission line.The relay senses the fault and sends a tripping signal to the circuit breaker initiating the interruption process of the current. As the movable contacts begin to separate, the area between them reduces thereby increasing the current density and as a result an arc is produced.

This arc needs to be extinguished, in order to retain the breaking capacity of the circuit breakers.SF_6 circuit breakers stretch the arc and use the dielectric strength of the sulfur hexafluoride (SF_6) to quench the stretched arc. In a vacuum interrupter, the electrical contacts are enclosed in a vacuum out of which one is fixed and the other is movable. During a fault, the movable contacts pulls away from the fixed contacts and minimal arcing is produced. The SF_6 and vacuum interrupters both have their advantages as well as disadvantages. The advantages of SF_6 interrupter and the characteristics of vacuum interrupter are employed together to model the hybrid circuit breaker. It comprises of SF_6 circuit breaker and vacuum circuit breaker connected in series.

II. COMPARISION BETWEEN SF_6 AND VACCUUM CBS

Due to high dielectric strength and high thermal conductivity of SF_6, these circuit breakers are used for providing protection against high voltage levels. On the other hand, vacuum CBs are employed in medium voltage levels (5-38kV).With the use of SF_6, compact electrical equipment occupying less space for installation, can be manufactured. Yet SF_6 gas contributes to greenhouse effect and poses threat to the environment as it is highly toxic at high temperatures.In contrast, vacuum CBs are environment friendly. Recyclable materials such as glass container and metallic components are used for its construction. They have a long operation life, compact size and are light in weight but possess poor insulation characteristics in long vacuum gap. Due to the high cost of vacuum CBs, SF_6 CBs are the most commonly used CBs.

The operating energy requirements of SF_6 CBs are high because it has to supply the energy needed to compress the gas. On the other hand, in vacuum CBs, the operating energy requirements are low since it has to move relatively small masses at moderate speed over very short distance. In SF6 CBs, the no. of short-circuit operation ranges from 10 to 50, while in vacuum CBs, it lies between 30 and 100.

Only small values of high frequency transient currents are interrupted in case of SF_6 CBs. In case of vacuum interrupter, extremely rapid deionization ensures the interruption of all currents irrespective of whether they are large or small.With respect to maintenance, in SF_6 interrupters, the labor cost is high while the material cost is low, while in vacuum interrupters, it is vice versa.

III. NEED OF HYBRID CIRCUIT BREAKER

The ongoing research in the field of High Voltage Engineering focuses on the modeling of Hybrid circuit breakers, which in the future have the potential to take over SF_6 circuit breakers. The vacuum interrupters have the ability to recover the dielectric strength across the interrupting gap at the time of current zero. In case of vacuum arc mode, the dielectric recovery is the fastest. Figure 1 indicates the comparison of dielectric strength recovery speed between SF_6 interrupter and vacuum interrupter when the gap is 6.35mm breaking current 1600A, 180A vapor pressure. The rate of rise of vacuum recovery voltage is 20kV/us which is faster than SF_6. This type of CB has the following shortcomings:

[1] Random dielectric breakdown across the open contacts of the CB can occur under continuous voltage stress which can lead to energizing the system to be isolated. This breakdown occurs for about one cycle of the system frequency.
[2] The butt contacts of the CBs, may bounce or close. Due to the multiple make and break operations occurring in the circuit, the voltage produced may reach above the insulation level of the system and the equipment.
[3] Vacuum interrupters have the tendency to chop the current as it reaches zero during circuit interruption .High voltages comparable to the system voltage but less than the insulation level are generated due to chopping .
[4] The interrupting gap in SF_6 CBs has high dielectric recovery capability along with thermal recovery and high dielectrics withstand capability under continuous voltage stress. This characteristic helps to prevent the random breakdown of the gap by isolating the vacuum CB from the system. SF_6 has wiping contacts of tulip and bayonet type. SF_6 arc resistance is higher than that of vacuum arc resistance. Thus in the hybrid model SF_6 CB bears the main voltage drop and works in conjunction with vacuum CB to complete current interruption. These contacts make the circuit without any bounce and thus no multiple system energisations will occur.

The hybrid circuit breaker has the following advantages over SF_6 and vacuum CBs:

[1] This type of breaker has the capability of switching short line faults at high voltage.
[2] High operating force is not required and the size and the cost of the breaker reduces
[3] Various standard design of this type are available which can be applied to free standing breakers and compact substation breakers.
[4] It has an excellent capability to deal with the steep-rising transient recovery voltage (TRV).
[5] A basic interrupting module can be formed which is rated at 145kV or more.

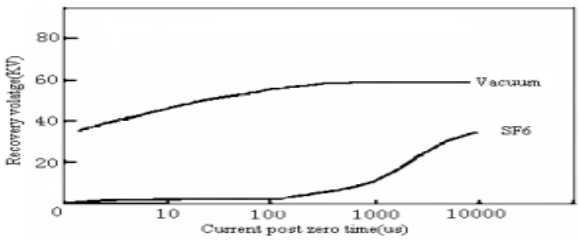

Fig.1. The comparison of dielectric recovery speed between SF6 interrupter and vacuum interrupter [7]

IV. CURRENT INTERRUPTION IN HYBRID MODEL

The minimum arc duration are shorter in a vacuum interrupter as compared to the SF_6 interrupter by several milliseconds. Hence it is preferable to open the SF_6 interrupter initially followed by the opening of vacuum interrupter with some delay of a few milliseconds. Since there are two interrupters connected together therefore the currents can be interrupted by each of the interrupters.

4.1 Interruption Initially By Vacuum Interruption

In this case, current is first interrupted by the vacuum interrupter. This mode of operation is observed at the highest current. Vacuum interrupter first transmits initial recovery voltage peak value and the latter higher peak value is shared by SF_6 interrupter as highlighted in figure 2.

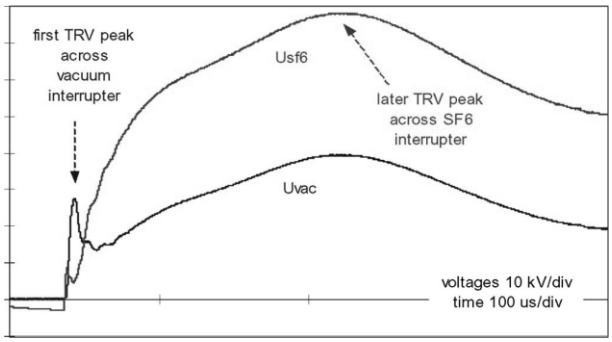

FIG 2- Transient recovery voltage of the two interrupters

As can be seen in figure 3 ,the vacuum arc extinguishes at current zero while the SF_6 arc continues to operate for the next 5usec and then after current zero 8 A post arc current flows in the vacuum interrupters.

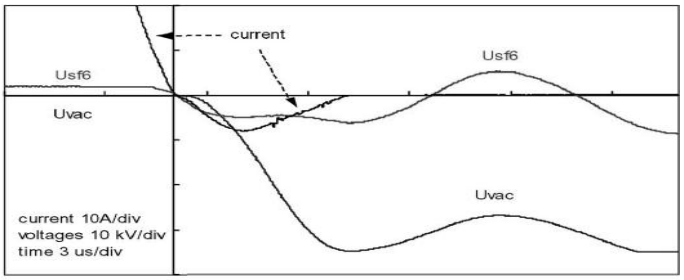

FIG 3 – Current zero region,vacuum interrupter interrupts first

When the vacuum post arc current decays to zero then only the SF_6 post arc current is forcibly chopped to zero.Due to this, the arc voltage and current do not cross zero simultaneously and the arc voltage is initially of opposite polarity.

4.2 Interruption Simutaneously By Vacuum And Sf_6 Interrupter

In this case, current is simultaneously interrupted by both vacuum and SF_6 interrupters. This mode of operation is typically observed in conditions in which current is less than maximum current. Here, the performance of SF_6 circuit breaker is reduced deliberately but it is sufficient to do the job alone.SF_6 post arc current is much smaller as compared to the vacuum CB, so the SF_6 interrupter stops the flow of vacuum arc charge. The post arc vacuum charge remains trapped. This prevents the Transient Recovery Voltage (TRV) to build up in vacuum interrupter until all the charges disappear Therefore the complete TRV is carried by SF_6 interrupter. The above operation can be easily seen in figure 4 below.

The performance of the hybrid circuit breaker in the first mode is better than that in second mode.

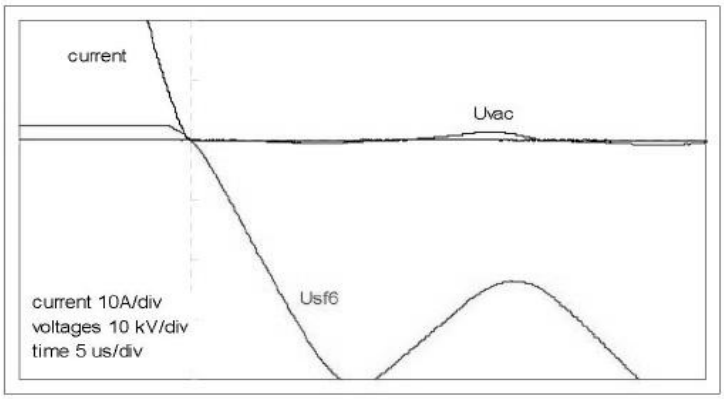

FIG 4- SF_6 and vacuum interrupt simultaneously

V. DESIGN OF HYBRID CIRCUIT BREAKER

Recent studies focus on designing a hybrid circuit breaker operation mechanism with strong contollability property and low dispersion degree. The former researchers have adopted an operation mechanism that connects the two interrupters with the help of a connection rod or a spring. This mechanism led to weak controlability property and low dispersion dergree.Figure 5 depicts a hybrid circuit breaker based on fiber control vacuum CB connected in series with SF_6 CB .

A synchronized cordinate operation control unit which adjusts the coordination movements of the two interrupters in microseconds is utilized in this scheme.The top bus terminal of vacuum circuit breaker is connected with the bus input, and the end bus terminal box is linked with top bus terminal of SF_6 circuit breaker. The end bus terminal of SF_6 circuit breaker is connected to bus output, its operation mechanism and synchronization unit are placed at low potential. The synchronization unit of hybrid circuit breaker receives system control signal and perform synchronized operation to operate the vacuum circuit breaker and SF_6 circuit breaker respectively.

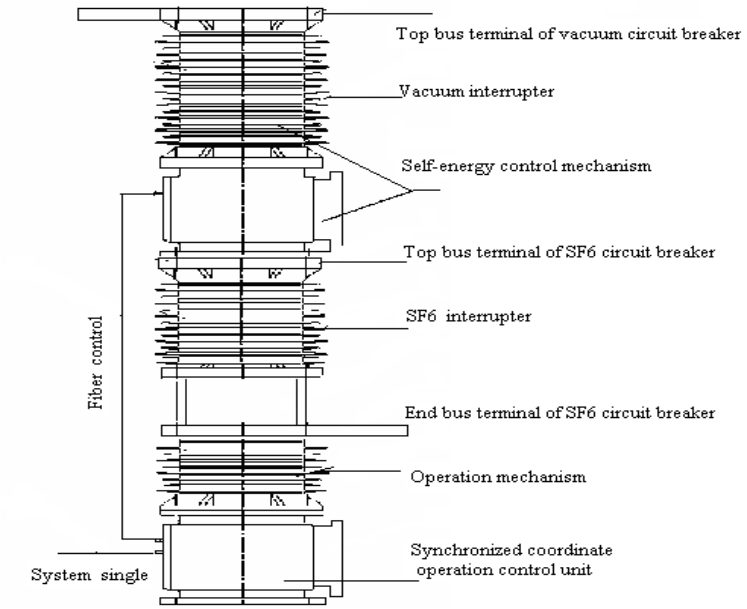

Fig.6. Structural representation of hybrid circuit breaker

VI. CONCLUSION

From the testing it is observed that the initial peak of the transient recovery voltage falls across the vacuum interrupter and the later much higher peaks are taken by the SF_6 interrupter. In this way both the SF_6 interrupter and the vacuum interrupter assist each other. The vacuum interrupter capability to withstand the steep rate of rise of recovery voltage reduces the pressure of SF_6 gas in SF_6 interrupter. Hence it can be concluded that the breaking capacity of the hybrid circuit breaker is more than that of the SF_6 circuit breaker. In the future, it can be seen as a great alternative of SF_6 circuit breaker in high voltage applications.

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