Improvements in Transmission Switching Reliability using SF_6 Interrupter Technology

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***Abstract*—The use of load break switches and sectionalizers to perform switching operations is common in the distribution circuits of electrical power systems. The functional need to isolate local regions of the transmission grid is expanding and, as a result, a class of cost effective and reliable switching devices is needed. This paper discusses some applications where the capabilities of a transmission class switching device are employed. The proposed interrupter solves transmission class switching reliability concerns by utilizing a single break SF_6 interrupter for voltages of 72.5kV through 242kV. The reviewed design configuration increases the ampacity ratings available in cost effective transmission class switching devices. Several application descriptions and cost comparisons are included in the paper.**

I. INTRODUCTION

The modern electric utility, faced with increased reliability demands and pressure to reduce operating costs, must respond by employing lower cost switching equipment designed for a specific switching duty.

Transmission lines are becoming more like distribution feeders in their operation. As system loads have grown and the installation of additional lines has been restricted it has become necessary to confine outages to smaller sections of the system. Distributed Energy Resources (DERs) have also contributed to the complexity and frequency of switching that must be accomplished. Significant savings can be achieved by employing load switching devices rather than circuit breakers for switching, sectionalizing and isolating portions of the transmission system.

A class of load break and line switching equipment is now available that uses SF_6 technology to provide the switching capabilities of a breaker or circuit switcher at a lower cost. Low operating costs and high reliability are important factors in the success of a modern utility company. The transmission class switching equipment described below enhances both objectives.

II. TRADITIONAL TECHNOLOGIES

Four distinct technologies have been employed, over the years, to meet the need for reliable transmission switching devices. Each technology has its own benefits and difficulties.

A. Air Break Disconnect Switch

A disconnect switch with no attachment is often called a no load disconnect switch. However, this is not strictly true. Despite the slow operation, the plain air break switch does have some inherent capability to make and break current. Many utilities have successfully used disconnect switches as interrupters for small currents. Typical applications include

- De-energizing or energizing unloaded transformer banks from the high side
- De-energizing or energizing short sections of unloaded transmission line
- De-energizing or energizing short loops where the voltage imposed across the switch will be very low Examples include
  - Bypass loop around a closed breaker
  - Bus loops within a substation
  - Bypass loops around a regulator (in neutral position)

B. Quick-Break Device (Whips)

The addition of a high-speed air break interrupter (whip) increases the interrupting capability of a disconnect switch. However, due to the nature of a free arc in air, expressing this capability by means of theoretical analysis is not possible. Several factors are normally considered with the application of any load break switch, including circuit current, system voltage, and transient recovery voltage. However, with an air break interrupter, conditions such as phase spacing, wind, rain, humidity, and atmospheric pollution also effect the interrupting capability. So, the limits expressed in Table 1 may be conservative estimates of the maximum capabilities, but the information is offered to allow the safe application of different designs under varied conditions.

Even when a whip functions properly and interrupts the current, there may still be concerns for the utility, which limit use of these switching devices:

- **Operator safety**, particularly for manually operated switches, is a concern for any equipment producing a free burning arc in air. (see fig. 1)
- **Restrikes** may produce voltage multiplication that may break down the system insulation, resulting in a system fault.

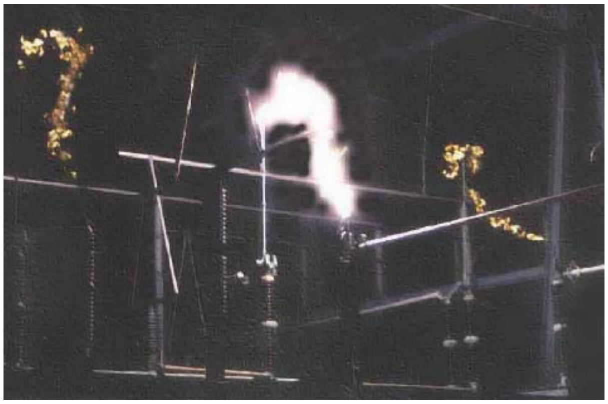

Fig. 1. A vertical break 169 kV switch with whips attempting to open seven miles of transmission line.

C. Vacuum Interrupter

The vacuum interrupter attachment has hermetically sealed arc resistant contacts that part within a high-dielectric vacuum to interrupt current. The device is inserted in the circuit only briefly during the opening sequence. Therefore, when the switch is in the fully open or fully closed position, the attachment has no effect on the disconnect switch ratings. Vacuum switch attachments share a common set of characteristics. For transmission class voltages, several gaps are required in series to develop the required voltage capability. (See fig. 2) The interrupter is essentially a stack of "bottles." The result of this multi-gap arrangement is that additional components are required to grade the potential across the series gaps. If no effort were made to distribute the potential, most of the voltage would be imposed on the first bottle resulting in dielectric failure. This would continue down the stack until the entire device flashed over.

Because all of the series gaps are necessary for the interrupter to withstand the voltage, all of the bottles must open at the same time. Hence, great care must be taken to synchronize the stack for the interrupter to function properly. Should an individual bottle leak, that segment would not hold its share of the voltage. So, determining the condition of the dielectric media prior to operation is desirable to insure safe interruption of the circuit. However, this is not possible with vacuum interrupter bottles, because the only method available requires that the equipment be taken out of service and be high potential tested to check the integrity of the vacuum bottles.

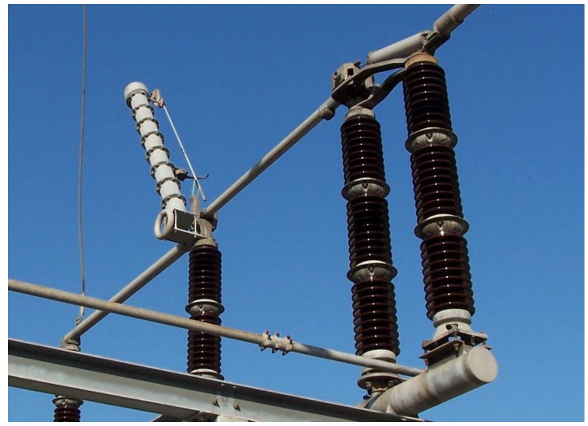

Fig. 2. Typical 145 kV Vacuum interrupter, requiring six individual bottles in series.

D. In-Series SF_6 Interrupters

The use of SF_6 in the interrupting chamber with penetrating contacts, results in a far more robust switching device. Previously, the only other products employing this superior technology, for load break switch applications, were circuit switchers. Circuit switchers and devices within this family (see fig. 3) are in series with the disconnect switch and therefore, always in the current path. Consequently, the interrupter contact structure must be far more massive to carry the full rated continuous current. This has the effect of limiting the current ratings of these devices as well as increasing the mass, complexity, and cost.

Fig. 3. 121kV Circuit Switcher (In-series) interrupter.

Some older designs employ multiple gaps in series similar to vacuum interrupters. This requires grading components to evenly distribute the voltage across the gaps and a high degree of synchronization between the gaps. These additional components are inherently less reliable than a single break device. The technology exists to make single break interrupters and all recently designed devices use the single- gap design.

III. APPLICATIONS

A. Line/Cable Switching

Perhaps the most common application for this class of device is dropping unloaded transmission line. This poses some of the most difficult challenges for disconnect switches since they have very limited interrupting capacity (See table 1). Additionally, multiple restrikes always occur with air interrupters when switching capacitive current, even though they are well within their rated capacity. Despite the fact that the current involved may be quite small; the voltage imposed on the equipment can be significantly above the nominal operating voltage.

Some attachment devices are specialized in that they can drop longer lines than a disconnect switch but are not able to split a loop or drop a load. Hence, specific switching sequences are required to achieve the process of taking a line out of service. Other users prefer to have one device that will do all functions and hence eliminate the concern that the correct switching sequence is performed.

A restrike-free operation is shown in figure 4 using a single-break SF_6 interrupter.

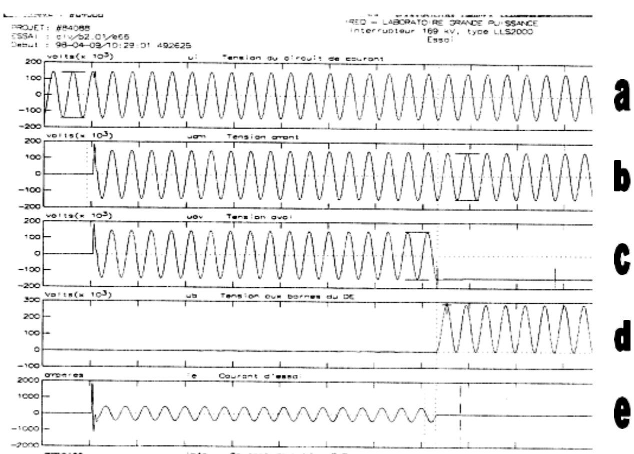

Fig. 4. 169 kV Line Switching Test Record.

a. System Voltage
b. Voltage on Test Equipment
c. Voltage on Line
d. Voltage Across Test Equipment
e. Line Current

B. Loop Splitting

Due to reduced voltage requirements loop switching may be accomplished with a much less expensive device than would be required for load or line switching. Often a single-bottle vacuum attachment can perform this function. The use of a reduced voltage device places critical operating limitations on the utility. This switch must be prevented from operating when system characteristics would impose too high a voltage across the contacts when switched. A complete analysis and careful planning is required to allow this to be done safely. As the utility grows and conditions change, this switch would need to be routinely evaluated to insure safe operating conditions.

C. Load Switching

Shedding load from the system at transmission voltages is an uncommon event. The need to perform this function will likely increase as the operating environment for utilities continues to change. (See table 1 for load switching capabilities of various devices.) As transmission systems become automated, the potential for dropping a load as a result of a switching error will increase.

D. Switching Unloaded Transformers

It may be generally assumed that any device capable of full load current interruption and switching capacitive current will switch out an unloaded transformer. A full rated load break device may not be required. The magnetizing currents involved are on the order of 1% of the full rated current of the transformer. High voltage appears across the contacts very quickly after interruption. This rapid transient recovery voltage gives rise to multiple reignitions when using an air interrupter. These multiple reignitions can cause damage to the transformer and result in a shorter transformer life.

Line Switching
(Capacitive Current - amperes)

System Voltage	72.5 kV	121 kV	145 kV	169 kV	242 kV
Plain Disconnect Switch (Requiring Horn Gap Phase Spacing)	2.7	2.2	2.3	2.2	1.7
Quick-Break Dev ices (Whips)	10	8	6	4	NR
Vacuum Interrupters	350	350	350	350	100
New Single-Gap SF6 Attachment	300	300	300	300	300
In-Series SF6 Interrupter (permanently inserted in the circuit)	150	150	150	150	150

Load Switching
(70% P.F. - amperes)

System Voltage	72.5 kV	121 kV	145 kV	169 kV	242 kV
Vacuum Interrupters	2000 (50)	2001 (50)	2002 (50)	2003 (50)	2004 (50)
New Single-Gap SF6 Attachment	3000 (2000)	3000 (2000)	3000 (2000)	3000 (2000)	3000 (2000)
In-Series SF6 Interrupter (permanently inserted in the circuit)	1200 (5000) *	1200 (5000) *	1200 (5000) *	1200 (5000) *	1200 (5000) *

NR - Not Recommended for this application
(####) - Rated number of full current operations
* - If device is used to interrupt maximum load currents, inspection is required ev ery 50 operations to insure continued performance.

Table 1. Current Interrupting Capability of Switching Devices

IV. LOAD BREAK SWITCH DEVELOPMENT

Load break switches are now available that have been developed specifically for the above applications. These devices use penetrating contacts within an SF_6 filled chamber to achieve superior interrupting capability. In terms of the internal interrupter parts, the device functions the same as a circuit switcher. Therefore, the rated load interrupting capability (3000 A) does not tax the contact structure and may be accomplished at least 2000 times.

Fig. 5. 145 kV 2000A SF_6 Load Break Switch.

The principal difference between the new device and the circuit switcher is how the device is used in the circuit. The new device is an attachment. It is inserted only briefly during the opening stroke, much like a vacuum interrupter. Therefore, in the fully open or fully closed positions, the attachment has no effect on the disconnect switch ratings. This allows the contacts within the interrupter to be smaller, lighter, and more easily accelerated with a less complex mechanism.

This SF_6 attachment uses a single-gap interrupter to further reduce the complexity and component count. No synchronization of multiple gaps is required. No voltage grading components are needed. A simple toggle mechanism directly drives the female contact.

Fig. 6. 72.5 kV SF_6 single-gap attachment.

By using SF_6 as the interrupting media, the dielectric withstand capability of the interrupter may be easily verified visually by use of the pressure gauge. The sealing methods employed are derived from those used for years on larger SF_6 devices. The overall system leak rate for each interrupter is measured and verified to be below 0.5% per year. Should a leak occur for any reason, gas may be added in the field to allow safe operation until the unit can be replaced. However, at the maximum acceptable leak rate, it would take 45 years before the pressure fell below the minimum safe operating threshold.

Because the new interrupter is an attachment, it may use existing switch structures for upgrading performance. It is not subject to the same application restrictions as a circuit switcher. It may be applied to line switches in remote locations.
(See fig. 7).

Fig. 7. 145 kV Load Break Switch on tall Wood Poles.

Further development has extended this single-gap attachment to 242kV. The design uses a voltage limiting device across the single break to limit the transient recovery voltage (TRV) to a level within the capabilities of the interrupter. This allows the application of a common interrupter assembly for voltages of 72.5 kV through 242kV. The weight and cost savings are substantial since the fully rated device would have been much larger and heavier.

Metal Oxide arresters are very effective at reducing overvoltages. However, when permanently inserted into the circuit, the clipping voltage must be set at about 1.7 times the line to ground voltage. This is done to insure that the arrester does not carry currents that would send the unit into thermal runaway.

The application of the arrester in parallel with the interrupter, and inserted in the circuit only during the opening stroke, allows the clipping voltage to be set much closer to the system voltage. This approach reduces the maximum possible ervoltage to 1.2 P.U. even if a restrike should occur.

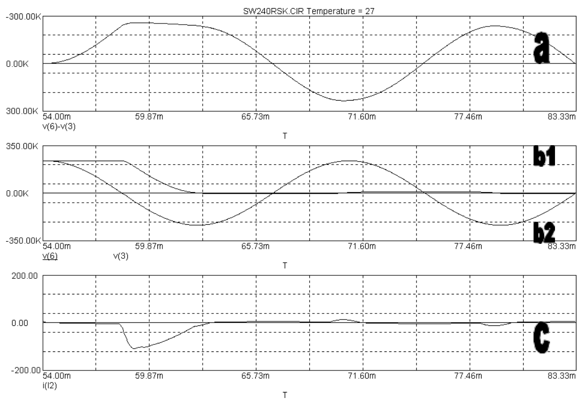

Fig. 9. Simulation of TRV for Line Dropping at 242 kV with arrester in Parallel with Interrupter.

a. Voltage across Interrupter
b1. Voltage of Line
b2. Voltage of Power System
c. Current through Arrester

By using a proven interrupter design and a commercially available arrester, the development time and cost have been significantly reduced. The common parts result in savings associated with increased volume. The result is an inexpensive, robust load break switching device well suited for use at 242kV.

V. Cost

The relative cost differences between load break switching devices is significant. The values listed are estimates and the true costs can vary greatly even within a classification. So, each requirement for a load break switch must be individually evaluated to determine what is actually needed and which device provides the best value.

Relative cost Compared to Disconnect Switch	Type of Device
1	Bare Disconnect Switch
1.2	Switch with Air Interrupter (Whips)
2.8	Switch with Vacuum Interrupter
3.2	Switch with SF6 attachment
4.1	In-Series Interrupter

VI. Benefits

- **Reliability** has been increased by use of a single-gap SF_6 attachment.
- **Versatility** has improved because a single device may now be used for all of the load break applications with no complex switching schemes required.
- **Costs** are reduced over the comparable in-series interrupters available before.
- **Safety** has improved since there are no open arcs and a visible gauge verifies the dielectric capability.

VII. Acknowledgment

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VIII. REFERENCES

[1] IEEE Committee Report, "Results of Survey on Interrupting Ability of Air Break Switches," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-85, No. 9, Sept. 1966.

[2] *IEEE Guide to Current Interruption with Horn-Gap Air Switches*, IEE Standard C37.36b-1990.

[3] IEEE *Standard for Interrupter Switches for Alternating Current, Rated Above 1,000 Volts*, IEEE Standard C37.39 Draft 15a, April 5, 1998.

[4] F.E. Andrews, L.R. Janes, and M.A. Anderson, "Interrupting ability of Horn Gap Switches," AIEE Transaction, Vol 69, pp. 1016-1027, 1950.

[5] R.J. Denis, 'Tests to Determine the Interrupting Capabilities of 115kV Quick Break Devices," U.S. Department of Energy – Bonneville Power Administration, Rep. ELE-89-39 March 1989.

[6] L. Masson, Y. Rajotte, and G. Genest, "The Interrupting Capability of Disconnect Switches," Canadian Electrical Association Project 069 T 102, CEA Fall Meeting, October 1981.

[7] S.G. Patel, W.F. Holcombe Jr., and D.E. Parr, "Application of Air-Break Switches for De-Energizing Transmission Lines," presented at the IEEE/PES Winter meeting, New York, NY, February 1988.

[8] D.F. Peelo, "Current Interrupting Capability of Air Break Disconnect Switches," IEEE Transactions on Power Delivery, vol. PWRD-1, No. 1 pp. 212-216, 1986.

[9] David F. Peelo, "Unloaded transformers can be switched reliably with disconnect switches," Transmission and Distribution, pp. 60-40, July 1987.

[10] E.C. Rankin, W.W. Ward Jr., "Experience with Methods for Extending the Capability of High-Voltage Air Break Switches," AIEE Transactions, Feb. 1960.

IX. BIOGRAPHIES

Brian Berner received his B.M.E. degree from the Georgia Institute of Technology in 1996. He joined Southern States in 1996 as a design engineer. Since then, he has been involved in the development of SF_6 switching equipment. He is presently the VP General Manager of the Southern States Power Switching Division.

Joe Rostron received his B.S. in Mechanical Engineering from Washington State University in 1970 and his MBA from the University of Pittsburgh in 1984. He joined Southern States in 1998 as Vice President of Market and Product Development. Prior to that, he had over twenty-five years experience in designing and developing switching products with Westinghouse, ABB, and Siemens.