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TRANSIENT ANALYSIS OF A 420KV THREE-PHASE SHUTDOWN REACTOR DURING SWITCHING

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Abstract:

In the operation of power system, in order to balance the reactive power and voltage control, shunt compensation is preferred. The switching transients are simulated during switching of shunt reactor. These transients have considerable effect on insulation of the system.

In this paper, a realistic model of a three- phase shunt reactor taking into account the asymmetrical couplings of the magnetic circuit . A realistic model of circuit breaker based on the well known Cassie & Mayr modified arc equation has been used. The Transient over voltages due to fixed reactor is considered.

During switching of 420kv circuit breaker the arc voltages, arc currents, arc resistance and transient voltages occur at 420kv line have been estimated and conclusions are given.

1. Introduction

1.1 Transients in power system:

Contemporary linked electricity networks exhibit complex and nonlinear behaviour. The unique nonlinearity of the power system makes transients possible in the event of abrupt changes. The system will become unstable if the changes during transients are substantial enough. By adjusting the power flows from the generators to the load via the switching parameter banks of the system, it is feasible to maintain stability and sufficient damping during transients. While lightning overvoltages were much higher, internal system overvoltages were mostly negligible at somewhat lower transmission voltages of about 220 kV. Later on, when transmission voltages reached 400 kV and greater, the system's overvoltages were comparable to, if not higher than, lightning overvoltages. Second, the system is more likely to experience harmful overvoltages due to their extended duration. Because they are proportional to the system voltage, switching over voltages grow in size as the voltage rises.

A transient happens in an electrical system whenever the stability of the network fluctuates between two stable states. This may happen, for example, if lightning strikes a substation. Switching action may be triggered by most power system transients. The dependability of the electrical grid is greatly affected by transients, which may cause important equipment to fail or be damaged.

1.2 Shunt reactor:

Shunt reactors are essential components of power networks because they allow for the management of reactive power and the voltage profile on transmission lines. Shunt reactors grounded via neutral reactors may only be used in systems that are designated as extra high voltage (EHV), meaning the voltage level is more than 345 kV. It is possible that these technologies may make line-to-ground fault reclosing a more practical operation by improving single-pole fault clearing. Such reactor designs include features of both ungrounded and directly grounded reactor scenarios into their switching mechanism.
Voltage regulation is only one of many uses for shunt reactors in power systems. They might be linked to the transmission line, the station busbar, or the tertiary winding of the power transformer. In the second and third scenarios, reactors with an iron core submerged in liquid were common. The linked system and circuit breaker are subjected to a distinct and demanding strain when a shunt reactor is turned on. Securingly grounded shunt reactors are significantly less dangerous than switching shunt reactors that are grounded via a neutral reactor. Interrupting these currents may cause substantial overvoltages, even though they are typically less than 300A.
Shunt reactors are often installed in substations as a cost-effective method to mitigate voltage spikes during periods of low demand. A voltage spike occurs when the load on a transmission line is smaller than its surge impedance load (SIL) because the line's inherent shunt capacitance draws charging current via its series inductance. The use of shunt reactors mitigates this impact.

2. SF6 Circuit Breaker:

Gaseous SF6 has exceptional dielectric and arc extinguishing properties; it is heavy, chemically inert, non-toxic, and non-combustible. The dielectric strength of SF6 increases with increasing pressure in a vacuum. In addition, SF6 has a higher dielectric strength than oil. Nowadays, SF6 gas is used by a myriad of electrical components, including high voltage switchgear that is metal-clad, capacitors, bushings, circuit breakers, voltage cables that are metal-enclosed, and countless more. A material's liquefaction temperature is exactly proportional to its pressure at which it undergoes the transformation into a liquid.

When dealing with high voltage circuit breakers, it is advised to utilise a fire extinguisher with SF6 rating. Notable features of SF6 breakers include extended electrical durability, dependability, availability, and silent operation, in addition to remarkable dielectric qualities. For applications that need the greatest short circuit powers—up to 550 kV and 63 kA per interrupter—the SF6 puffer type circuit breaker is the way to go.

2.1. SF6 ARC MODEL:

Circuit breakers designed for high, extra-high, or ultra-high voltages sometimes make use of SF6 as an extinction medium. No other material can compare to SF6 in terms of its extinction and insulating properties. When contrasted with plasma created by gas arcs, its properties are peculiar. It changes from a conducting arc to an insulating substance in a flash and has a high extinction capacity. The modified Cassie-Mayr equation, a synthesis of the comments made by Cassie and Mayr on their models, is used to characterise the SF6 arc in this study. According to the updated Cassie-Mayr model, the arc's nonlinear conductance behaviour manifests as follows:

$$\frac{1}{g}\frac{dg}{dt} = \frac{1}{t}\left(\frac{ui}{p} - 1\right) = \frac{1}{t_0 g^{\beta}}\left(\frac{ui}{p_0 g^{\alpha}} - 1\right)$$

Where

As a Siemens number, G represents the arc's conductance.
u is the voltage drop (in volts) across the arc.
i is the ampere-meter reading of the arc's current.
Here, t stands for the arc's time constant in seconds.
P stands for the Watts of power lost as a result of the arc's interaction with the surrounding gas.
When determining P's conductance dependence, the parameter A is important.
The conductance dependence oft is affected by the parameter ß.
The experimental constant parameters α and ß are identical.

2.2. Modeling of SF6 Breaker:

When we say that a model describes the statistical features of various occurrences occurring throughout the breaker opening process, we imply that this model is defined by parameters that have been empirically observed.

2.2.1. Cassie model:

Cassie put out an arc model in 1939 based on the premise that an arc channel is a cylinder filled with highly ionised gas at a constant temperature T but with a diameter that may be varied. Additionally, he assumed that both the heat content and the conductance per unit volume would be constant. When investigating the arc conductance's behaviour throughout the high current time period, the Cassie model works well.

2.2.2. Mayr model:

The Mayr arc model was first shown in 1943. Thermal conduction and the temperature-dependent arc conductance are the culprits behind power losses, as proposed by Mayr. For almost zero currents, the Mayr arc model works. In 1971, Schwarz finally made an improvement to the Mayr arc model. In this model, the arc conductance determines the cooling power and the time constant. The new Mayr arc model accounts for cooling power as a function of current. Black box models, also known as traditional arc models, are the ones that have been mentioned thus far. In order to illustrate the process of circuit breaking, they often imitate the impact of the switching arc on the circuit. The switching arc is different from the fault arc in a number of important ways. An updated model with a constant time parameter was used in his research; it is current dependent. Input electrical power determines the arc interruption. Arc chamber modelling allows one to find E0, the arc current, and the load current. The model uses the non-linear modified Mayr's equation until the arc conductance ga reaches a minimal value gmin, after which it begins to expand, after which it reaches the linearised solution value g0 =. The variables ϋ, I, E0, and θ in this formula represent the angular frequency of the supply voltage, root mean square (rms) value of the interrupted current in amperes, almost constant arc voltage right before it starts to suddenly decline as the current approaches zero, and arc time constant, respectively. Since the electrical arc is what really affects the circuit, the arc model is the most important part of the circuit breaker model.

2.3. Cassie-Mayr model:

The Mayr equation, when coupled with the Cassie model, may be used to explain electric arc events at low current levels (around the zero crossing) and hence increase the accuracy of calculations even more. The electric arc conductance may be determined using constant parameters that are specific to the circuit breaker design using the Mayr method, which is comparable to the Cassie model. The following is a differential equation representation of the Mayr equation that describes arc conductance.

$$\frac{dg_m}{dt} = \frac{1}{\tau_m} \cdot \left(\frac{i_a^{\,2}}{P_0} - g_m \right)$$

Where

g_m – the arc conductance [s]

τ_m – the time constant of the arc[s]

P_0 – the steady state cooling power of the arc[W]

Under circumstances of high current, the majority of the arc voltage is due to Cassie's contribution. The behaviour of the arc is better described by Mayr's part when the current is almost zero. While

Cassie's part goes to zero, the arc voltage associated with the Mayr part rises right before the current zero crossing and becomes the transient recovery voltage after the current interruption. Therefore, the arc conductance provided by the two differential models operating concurrently may be used as a representation of the total process. As a result, the whole arc resistance is calculated by

$$r_{arc} = \frac{1}{g_{arc}} . \left(\frac{1}{g_c} + \frac{1}{g_m} \right)$$

Where

g_c – The arc conductance calculated according to the Cassie equation.

g_m – The arc conductance calculated according to the Mayr equation.

Table.2.1. Exemplary values of constants for Cassie and Mayr equations

Circuit breaker type	Cassie equation		Mayr equation	
	time constant of the arc (τ_c)	steady state arc voltage (u_s)	time constant of the arc (τ_m)	steady-state cooling power of the arc (P_0)
	[µs]	[kV]	[µs]	[kW]
Air	0.8	2.60	0.124	3.45
SF_6	0.8	2.35	0.22	8.8

2.4. Schwarz-Avdonin model:

The Cassie-Mayr model has been adapted in several ways; one of them is the Schwarz-Avdonin model. The following equation forms the basis of this approach:

$$\frac{dg}{dt} = \frac{1}{\tau_g} . \left(\frac{i^2}{p_g} - g \right)$$

Where

g – Arc conductance [S]
i – Interrupting current [A]
P (g)–arc cooling power dependent on the electric arc conductance [W]
τ(g)–arc thermal time constant dependent on the electric arc conductance [s].

The Schwarz-Avdonin formula, which is fundamentally similar to the Cassie-Mayr formula, describes arc behaviour. Both the cooling power P and the thermal time constant τ are conductance dependent variables in the Schwarz-Avdonin approach; P(g) stands for the former and τ(g) for the latter. Like the Cassie-Mayr technique, the constant parameters in formula are affected by a number of factors, such as temperature, the kind of circuit breaker used, and the quenching medium (5). The following relationships, expressed as functions of conductance f (g), characterise the cooling power and thermal time constant:

$$P = P_0 . g^{\beta}$$

$$\tau = \tau_0 . g^{\alpha}$$

Where

g – arc conductance [S]

α – free parameter $[S]^{-1}$

β – free parameter $[S]^{-1}$

P0 – the arc cooling power constant [W]

τ(g) – the arc thermal time constant [S].

In Table.2.2, you can see the values of the constants that were used in the example HV circuit breaker design using air and SF6 quenching medium. A change in arc temperature and conductivity may be expected as a function of the power input-to-cooling thermal power ratio.

Table.2.2. Values of parameters for HV circuit breakers in Schwarz-Avdonin model

Circuit breaker type	Arc cooling power P	Time constant of the arc τ_{np}	α coefficient	β coefficient
	[MW]	[µs]	[–]	[–]
SF_6	4	1.5	0.17	0.68
Air	16	6	0.20	0.50

The three-phase 420kV shunt reactor transients induced by controlled and uncontrolled switching are described in this study. Using the EMTP-RV program, we built a model to analyse transients induced by reactor switching. A dynamic electric arc in an SF6 circuit breaker and a model of the equipment at a substation are both included.
According to the Schwarz-Avdonin electric arc model, a two-chamber SF6 circuit breaker with 500 pF grading capacitors linked in parallel with the chambers may be imagined. Equipment, the SF6 circuit breaker, the main bus bars, and the comparable 420 kV network make up the EMTP-RV model.
The three-phase SF6 double-break circuit breaker is responsible for switching the reactor's three phases. Below Fig.3.1, you can see the simulation model.The simulation takes into account the transients at the three-phase reactor as well as the different arc voltages, arc currents, and arc resistances at the SF6 double-break circuit breaker.

3. Simulation Model and Results:

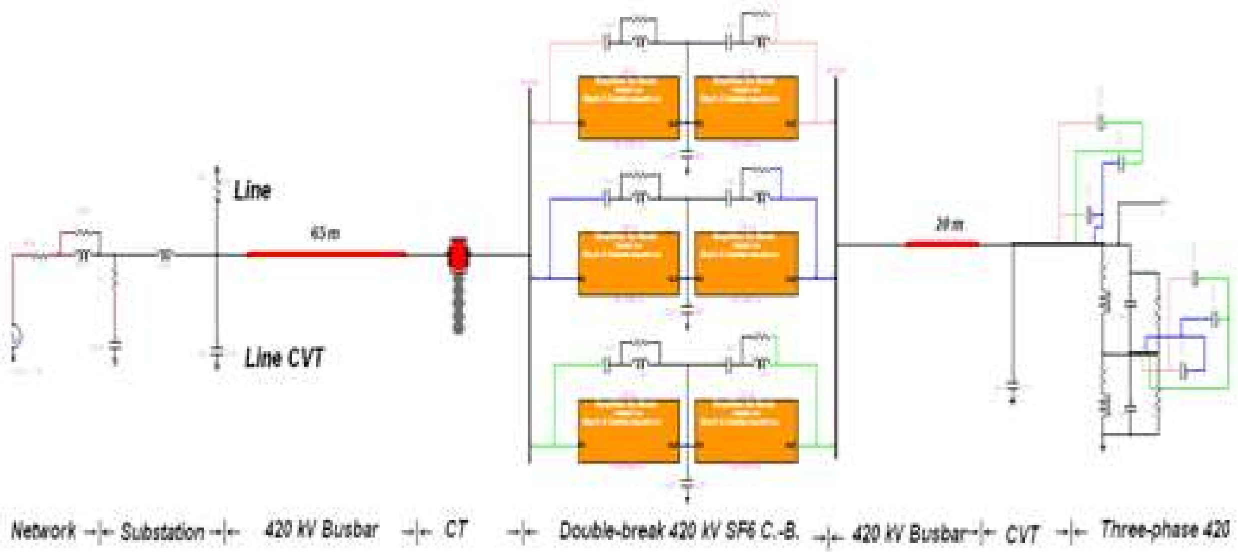

Fig.3.1 Simulation model of 420kV three phase shunt reactor in EMTP-RV

Table.3.1 Voltage, Frequency, Phase Angle, Start and Stop time values

Parameter	Phase A	Phase B	Phase C	Unit
V_m	405	405	405	KV RMSLL
F	50	50	50	HZ
θ	-30	-150	90	degree
T_{start}	-1	-1	-1	Second
T_{stop}	1	1	1	Second

Table.3.2 Resistor values (Line resistances in each phase)

Phase A	R	0.8Ω
Phase B	R	0.8Ω
Phase C	R	0.8Ω

Table.3.3 RL Coupled branch Values

R	1	2	3
1	3	0	0
2	0	3	0
3	0	0	3
L	1	2	3
1	870.5	42	27
2	21	875	21
3	27	42	870.5

3.1 Simulation Results:

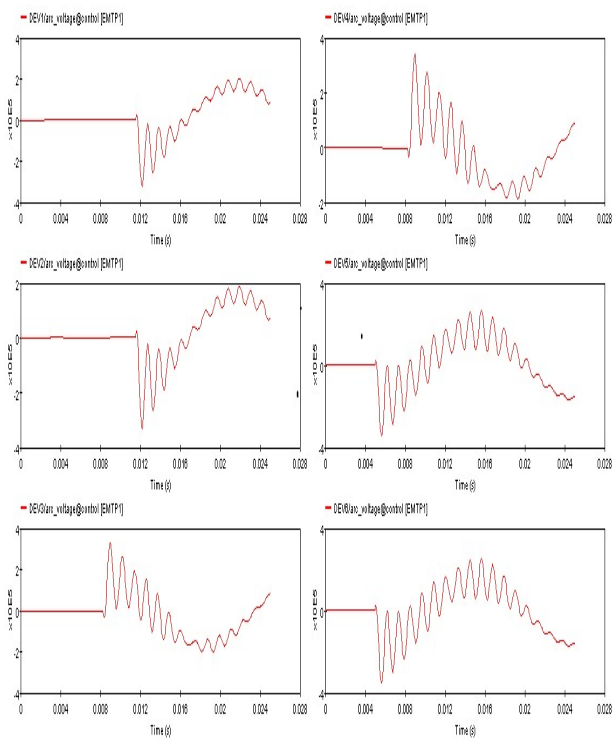

Fig.3.2 output wave forms of arc voltage of double break 420kv SF6 circuit breaker

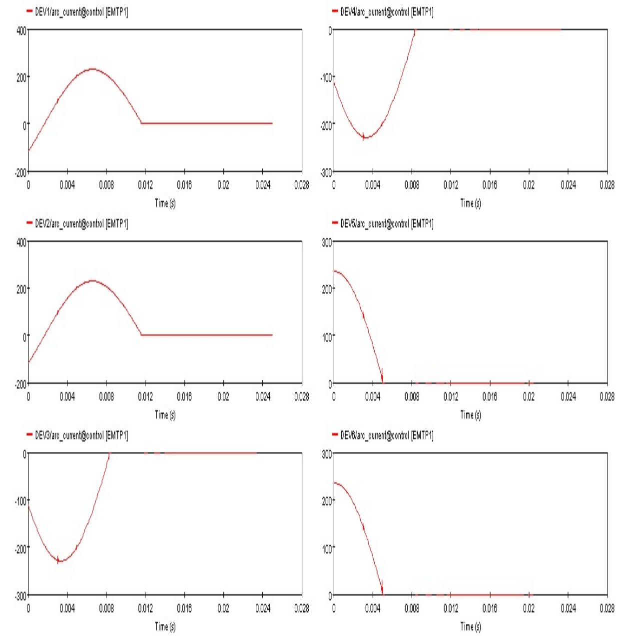

Fig.3.3 output wave forms of arc current of double break 420kv SF6 circuit breaker

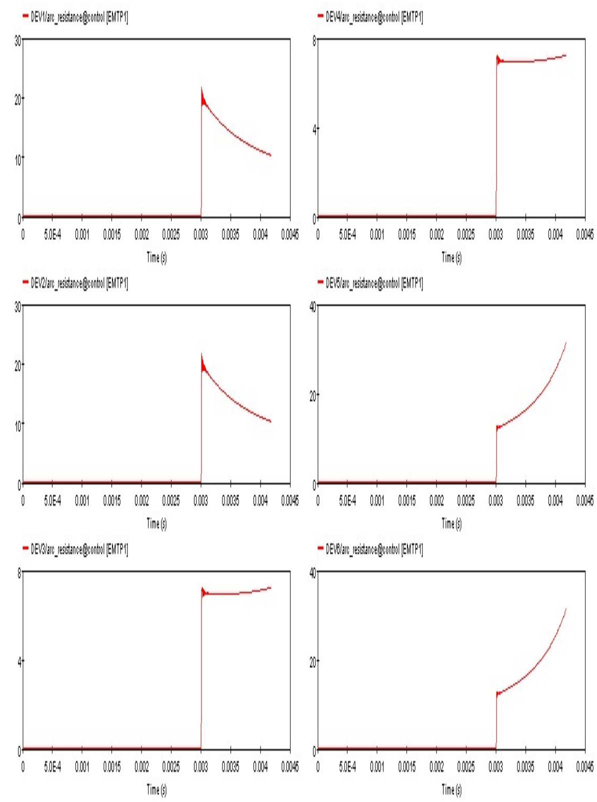

Fig.3.4 output wave forms of arc resistance of double break 420kv SF6 circuit breaker

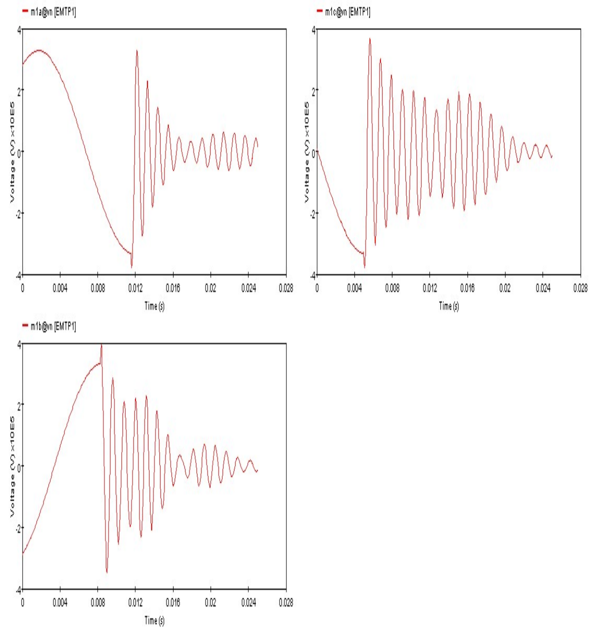

Fig.3.5 output wave forms of Transients during Fixed reactor Switching

4. CONCLUSION:

The Transient arc voltage is observed 210KV in two breaks of phase A, where as the transient arc voltage observed 320KV in phase B and 280KV in phase C respectively. The transient arc currents observed in phase A is about 180KA and quenches around 2ms time. The arc currents are observed in phase B, C are having negative slope. The arc resistances in three phases are observed that in phase A the maximum value reached first and it is gradually increased in phase B and in phase C it increases rapidly. The main transient over voltages observed during reactor switching is, first in phase A. The magnitude of 310KV is observed with high frequency components. In phase B over voltage transient is having highest frequency components and it decays after 0.024 sec time. In phase C, the transient over voltages reaches almost 400kv with high frequency transients.

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