Controlled Switching of High Voltage SF6 Circuit breaker

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Abstract— In controlled switching technology, an effective way to reduce transients produced by switching action, equipment failure preventions, and to inhance power quality, that is, already defined controlled strategies are to close and/or open each independent circuit breaker pole. Controlled switching of high voltage AC gas circuit breaker (GCB) and explains the controlled switching methods that are existing now a days is presented in this paper. Also the paper discusses the merits of controlled switching technology with an application. The accurate prediction of the operating time, subject to the various affecting parameters at that instant. Consistency of CB open and closing time is decides the success of CSS and reliability of CSW device to operate in high voltage environment system. The work presented in the paper focuses on suitability check of the circuit breaker for controlled switching application from mechanical scatter point of view and finds the mechanical scatter window. The allowed circuit breaker scatter for various controlled switching application is discussed in the paper.

Keywords— Gas Circuit Breaker, transients, mechanical scatter, suitability for controlled switching

INTRODUCTION

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs. This is the reason electrical power system network is expanding day by day to serve the increasing energy demand of the nation. Electrical power system comprises of generation, transmission and distribution of electrical energy. Power system should meet following fundamental requirements, System must be able to meet the continually changing load demand of active and reactive power Quality of power supply should meet certain standards in terms of constant frequency, constant voltage and reliability.Generator, power transformer, circuit breaker, surge arrestors, current transformers and voltage transformers are the vital power system equipments. A circuit breaker is protective switching device and hence, it plays a very important role in the power system at the time of abnormal conditions. Circuit breaker is required for the normal switching operation as well. In the EHV and UHV transmission system SF6 gas circuit breakers are used. To maintain the adequate reactive power for voltage control, frequent switching of capacitors and reactors is required through circuit breaker. These are the two applications where transient conditions can occur frequently, which results into electrical and mechanical stresses and sometimes may lead to equipment failure. High current transients associated with uncontrolled energization of capacitors can cause voltage sags, swells on the primary system, which may create problems with power system equipment and customer processes.

Any electrical circuit has got resistance, inductance and capacitance parameters. Under steady state condition the energy stored in inductances and capacitances is being transferred cyclically between the L and C of the circuit. When there is sudden change in circuit conditions *i.e.* switching, redistribution of the energy takes place to meet new condition. This period of redistribution of energy is nothing but the transient. Transients are associated with the excessive currents or voltages. Though the transient period is very short, the circuit components get overstressed during this period and it can lead to an equipment failure, protection mal operation, plant shut down *etc.* Following are the alternatives for mitigation of electrical transients [4].

Modification of the primary system to reduce the transients eliminating the transients requires that the source of switching transients be addressed. Conventional solutions include. Closing resistors on EHV circuit breakers to control the voltage transient associated with energizing (particularly re–closing) long lines. Circuit breaker pre-insertion resistors for reactor and capacitor switching. Circuit breaker opening resistors for shunt reactor switching. Selecting a specific type of circuit breaker. Surge arresters for limiting the voltage transients.

In principle, all primary side solutions incur significant costs and may reduce the overall primary system reliability. The design and mounting arrangements of these systems is very complicated. With the use of pre insertion resistors and reactors, initial transients and bypass transients has to be faced by the power system. Strengthen the primary system to withstand the transients withstanding the imposed stresses requires that system components susceptible to damage or mal operation be configured for greater strength. The

conventional approach is to design the system components, such as capacitor banks, transformers, and circuit breakers, to withstand the voltage and current transients associated with frequent occurrence of worst case switching phenomena.This is a new method which is becoming popular day by day for the switching transient mitigation. Controlled switching is nothing but switching the load at the optimum point on voltage or current wave so that the transients will be minimum possible. This method Controlled switching has become an economical substitute for a closing resistor and is commonly used to reduce switching surges. The number of installations using controlled switching has increased rapidly due to satisfactory service performance since the late 1990s. Currently, it is often specified for shunt capacitor and shunt reactor banks because it can provide several economic benefits such as elimination of closing resistors and extension of a maintenance interval for nozzle and contact. It also provides various technical benefits such as improved power quality and suppression of transients in transmission and distribution systems. The aim of point on wave switching is to minimize switching transients, over voltages and current surges, thereby reducing the stress on equipment insulation. Controlled switching is the economical method as compared to other conventional methods discussed above. The installation part of controlled switching system is not so complicated as compared to pre-insertion resistors, pre insertion reactors, surge arrestors *etc.* Controlled switching system comprises of circuit breaker, controller and other auxiliary components like sensors, cables *etc.* The circuit breaker is one of the vital equipment responsible for the success of controlled switching success. The circuit breaker behaviour in all respect should be known thoroughly, and then only one can feed the information in the controller.

LITERATURE REVIEW

A paper on "Controlled Switching of HVAC Circuit Breakers: Application Examples and Benefits" by Dan Goldsworthy and Tom Roseburg have detected and investigated Controlled switching technology that is predefined controlled strategies for closing and/or opening each independent circuit breaker pole, is an effective way to reduce switching transients, prevent equipment failures, and improve power quality. The paper presents a tutorial on controlled switching of high voltage ac (HVAC) circuit breakers and describes the controlled switching theory and technology that is in use today. The paper discusses the benefits of controlled switching and shares one utility's applications and experiences with the controlled switching of shunt capacitors, shunt reactors, transformers using modern protective relays and control devices. The paper also discusses how to select the optimum controlled switching times to reduce switching transients**.** [1].

A paper on "Identification of Capacitor Switching Transients With Consideration of Uncertain System and Component Parameters" by H. Y. Zhu and Chen, this paper described and improved methods for identifying the capacitor switching transient. Capacitor switching transient is one of the most commonly countered power quality distributions. Measuring and identifying these transient remains challenge as the characteristics depend on the system parameter. systematic approach to design and automated system for identifying capacitor switching transients also capable of identifying transients caused by switching of both isolated and back to back capacitors. The proposed method combines the techniques of wavelet transform, rank correlation and fuzzy logic to account for the uncertainties [2].

John Brunke and Klaus Frohlich, suggested a "Method for Potentially Eliminate Inrush Current Transient By Effectively Transformer Controlled Switching". This paper explored the theoretical consideration of core flux transient Transformer inrush currents are high magnitude, harmonic rich currents generated when transformer cores are driven into saturation during energization. These currents have undesirable effects, including potential damage or loss of life to the transformer, protective relay misoperation, andreduced power quality on the system. Controlled transformer switching can potentially eliminate these transients if residual core and core flux transients are taken into account in the closing algorithm. Based on these studies algorithms were developed which allow controlled energization of most transformers without inrush current and concluded it is possible to use residual flux measurements and controlled closing to eliminate transformer inrush transient [3].

"Overall Benefits of Controlled Switching" by Victor F. Hermosillo, proposed a general overview of the benefits offered by the use controlled switching of switchgear HV and EHV electric power system was presented. The benefits of applying controlled switching are technical and economical. Technical benefits include the reduction of the severity of switching transients and their effect on equipment and system life cycle and performance. Economic benefit assessment may be qualitative or quantitative. Controlled switching offers an effective means of transient controlled and an attractive alternative to others traditional means of achieving this purposed. It may be applied as the sole solution or may be combined with other means, such as surge arrestors, to increase reliability [4].

Michel Stanek and his colleagues, studied Experience with "Improving power quality by controlled switching". The practical examples presented in this paper demonstrate the effectiveness of controlled switching as a means to reduce the effects switching

operation in various applications, for energization of capacitor banks, reactor and transformer. Switching operations in power networks are a common cause of transient disturbances. Depending on the network configuration and the characteristics of the switching condition, these transients can cause undesirable effects, not only on the switched load, but also on the entire network. As a consequence, the power supply can be drastically affected, as for example by nuisance protection operation due to high inrush currents, or under voltage due to transformer energization. Such disturbances can in turn provoke interruption of power supply to certain loads or parts of the network. Also, sensitive industrial processes can be severely impacted even if no power supply interruption occurs. Therefore, it is desirable to eliminate these potentially dangerous switching transients as far as possible [5].

Controlled switching technology is predefine methodology an effective way to reduce switching transients, prevent equipment failures, and improves power quality. Applications and benefits of CSW for capacitor, inductor and transformer switching investigated. But for this purpose, GCB is also plays an important role to successful operation of CSW device. Hence it is necessary to check the consistency of GCB for CSW application. Consistency is related with the mechanical scatter of circuit breaker. Consistency and mechanical scatter of CB operating time are the main problems to affect the successful operation of Cntrolled switching [5].

CONTROLLED SWITCHING METHODOLOGY

Controlled switching is a method for eliminating harmful transients by time instant controlled switching operation. Making and breaking commands to the circuit breaker are delayed in such a way that making or contact separation will occur at the optimum time instant related to the phase angle. By means of CSW it can be possible both energizing and de-energizing operations can be controlled with regard to the point on wave, and no harmful transients will be generated. This is a new method which is becoming popular day by day for the electrical transient minimisation. Controlled switching is nothing but switching the load at the optimum point on voltage or current wave so that the transients will be minimum possible.

PRINCIPLE OF CONTROLLED SWITCHING

Controlled switching is a technique that uses an intelligent electronic device, *i.e.* a modern numerical relay or a controller as shown in the figure 3.2, to control the timing of closing and opening of independent pole breakers with respect to the phase angle of an electrical reference voltage or current. The desired accuracy and repeatability of current conduction at a specific point on the waveform is ±1 msec. or less, and requires that the CB be constructed so that it provides this consistency under all operating and ambient conditions. Alternatively, the controller issuing the breaker close commands for the point on wave operations must be able to measure the operational variables such as CD control voltage, ambient temperature, and idle time, and remove the effect of these variations by compensating the breaker control Signal timing.
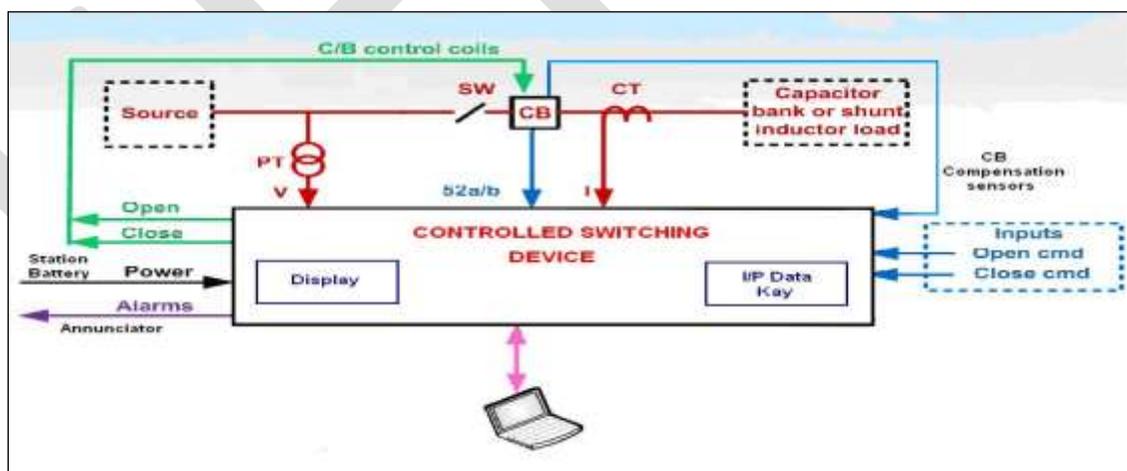

Fig. 1. Block diagram of controlled switching

CONTROLLED CLOSING

Controlled closing refers to controlling the point of conduction of each pole of the breaker with respect to the phase angle of the voltage. Breakers used in these applications must be constructed to provide the consistency to successfully repeat the controlled closing operations. The controller monitors the source voltage for a controlled closing operation. The closing command is issued

randomly with respect to the phase angle of the reference signal at some instant, as shown in Figure 3.3 [1]. The example sequence shown in Figure 3.3 relates to closing of capacitive load, where the optimum closing instant is at a voltage zero assuming that the prestrike time is less than one half cycle. The controller delays the randomly received closing command by some time, Total time, which is the sum of mechanical closing time (Tc) of the circuit breaker and an intentional synchronizing time delay (waiting time interval).
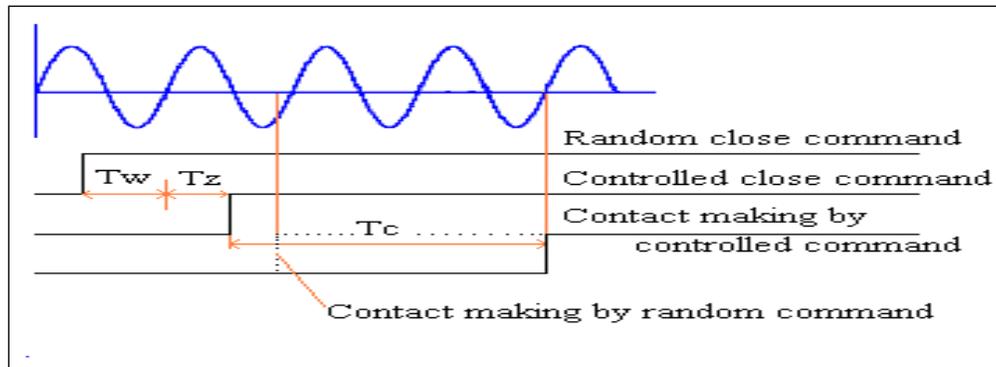

Fig 2. Controlled closing sequence

Total time   = Tw + Tz +Tc

Where,

Tw   = Total wait time

Tz   = time with respect to relevant zero crossing

Tc   = Total closing time of circuit breaker

The controller introduces delay with respect to a relevant zero crossing that is calculated by assuming circuit breaker closing time. The current starts to flow at time and the corresponding interval, is defined with respect to the following zero crossing. The closing time is the time from circuit breaker closing coil energisation to when the mechanical contacts touch.

The controller takes into account variations of circuit breaker operating times and prestrike characteristics as required by specific applications. Operating times and their dependency on environmental and operating conditions as well as the prestrike behavior are particular to every type of circuit breaker.

CONTROLLED OPENING

    Controlled opening refers to controlling the contact separation of each circuit breaker pole with respect to the phase angle of the current. Controlling the point of contact separation determines the arcing time of the contacts to help prevent breaker and circuit switcher failures and to minimize stress and disturbances to the power system. The implementation of controlled opening is approximately the same regardless of the equipment being switched. The control is straightforward once timing data for a breaker is available, particularly the time from energizing the trip coil to contact separation. Although controlled opening is best done using the current through the breaker, the bus voltage can be used if the voltage current phase relationship is always known, such as for shunt reactor and shunt capacitor switching. The breaker is controlled so that its contacts will part just after a current zero. As the contacts continue to open they draw out an arc that will extinguish less than a half cycle later at the next current zero. When the arc does extinguish, the contacts have been separated as far apart as practical, which provides the maximum dielectric strength available for the circumstances. This gives the breaker its best chance of successfully withstanding the recovery voltage and not having a re-ignition or a re-strike. Re-ignition is a dielectric breakdown that reestablishes current within 90 electrical degrees of interruption. Re-strike is a dielectric breakdown after 90 degrees. Figure 3.4 shows the timing sequence for controlled opening [1]. The control command is issued randomly with respect to the phase angle of the reference signal at an instant. The randomly received opening command is delayed by the controller by some time, Total time, which is the sum of mechanical opening time of circuit breaker and an intentional

synchronizing time delay (waiting time), synchronizing time is calculated with respect to a relevant zero crossing which is a function of the opening time (Tz) and waiting time (Tw), The mechanical opening time, is the time interval from energization of the breaker trip coil to the start of breaker contact separation, shown in Fig
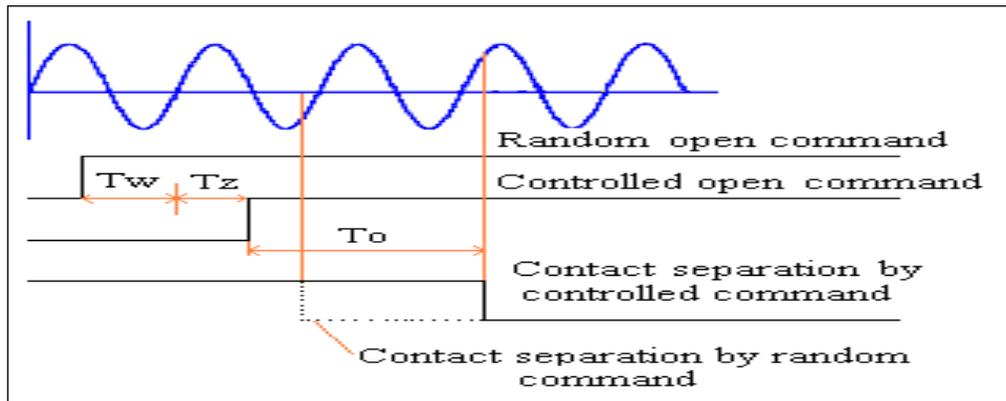

Fig.3. Controlled opening sequence

Ttotal   = Tw + Tz + To

Where,

Tw   = total wait time

Tz   = Calculated time with respect to a relevant zero crossing which is a

                    function of the opening time.

To   = Mechanical opening time of contacts of   circuit breaker

CONTROLLED SWITCHING UNIT

The purpose of the Circuit Breaker Synchronous Control (Controller unit) system is to provide controlled (synchronous) switching commands to the open and close coils of the circuit breaker. Successful controlled switching reduces the mechanical and electromagnetic stresses endured during normal switching operations by reducing the inrush currents upon closing and re-ignition currents during opening. A further benefit is that the insertion resistors, as commonly found in air blast breakers, can be done away with as well as their costly recurring maintenance requirements. Given the well documented effect of fluctuations in operating variables (temperature, pressure, auxiliary voltage *etc.*) on the operating time of the breaker, compensation is built into the calculation algorithm, ensuring optimum performance over a wide range. Due to differences in operating times between phases, Controller unit is designed to compute and send phase segregated switching commands to the breaker. Monitoring of inrush and re-ignition currents confirms successful synchronous switching of the breaker. The operating principles use the zero crossings of a sinusoidal signal; a voltage signal will be used as reference prior to closing and a current or voltage signal can be used prior to opening. When the breaker characteristics are identical for each phase, then a constant time delay (T/6) exists between synchronous commands in each phase, for example in the "A,C,B" sequence (1/3 of a cycle overall). For ungrounded capacitor bank switching, simultaneous switching of the two leading phases is followed by a quarter cycle delay in the switching of the third phase.

As soon as a close command is received, Controller unit is blocked and a time delay is initiated, awaiting the first zero crossing of voltage. Should no zero crossing be detected within the preset time delay, synchronous switching is aborted and a 3-phase random close is executed. Should a zero crossing occur within the preset delay and no further failures are detected, synchronous close commands to each phase are issued after the computed time delays. The computed time delays are measured from the reference zero crossing and compensated for variable effects and variations in the breaker characteristics of each phase. Sequencing of individual phase is monitored to insure proper sequencing at the breaker coils.

Sequencing of individual phase commands is monitored. Output control circuits are monitored for timing analysis, if a sequence error is detected, synchronous control is aborted and a 3-phase random control switching is executed. The functional design of the open operation is the same as that for close with the variation that a current or a voltage zero crossing can be used as the reference signal and that re-ignition currents are monitored

Technical Specifications of CB Controller unit

CB Controller unit is designed to meet the requirements of **SF6** based Circuit Breakers for EHV applications and has the followings technical and functional specifications.
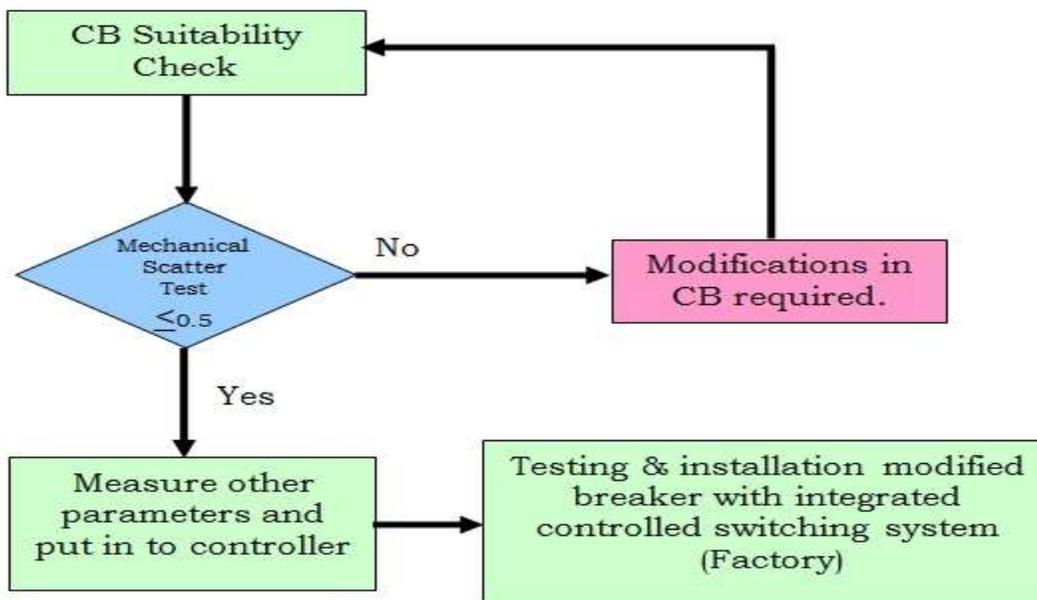
- *Mechanical scatter*

It is a random statistical variation of the mechanical operating time of a circuit breaker excluding the influence of external variables and the effect of long term wear and/or drift. Circuit breaker main contacts and auxiliary contacts which are used for position feedback in a controlled switching system should be tested to prove their accuracy and repeatability. Auxiliary contact repeatability plays a very vital role in success of control switching system. When the breaker is connected to line the auxiliary contact should act as a replica of main contact to give circuit breaker operating time information to the controller. It has two type mechanical scatter closing and opening mechanical scatter It is a random statistical variation of the opening time of a circuit breaker excluding the influence of external variables and the effect of long term wear and/or drift. Closing mechanical scatter.

SYSTEM MODIFICATION

One of the challenges in controlled switching application lies in the accurate prediction of the operating time, subject to the various affecting parameters at that instant. The success of controlled switching system depends on the consistency of circuit breaker operating time and reliability of controller to operate in high voltage environment and other is to know, whether the circuit breaker is suitable for the required controlled making application or not. If the circuit breaker is not suitable for the same then, one can change the conditions like closing velocity, SF6 gas pressure, Mechanical play in the joints and check that whether it can become suitable or not. Then the change in condition can be implemented in the actual circuit breaker. For this purpose I developed a circuit breaker suitability check flow chart.

FLOW CHART FOR SUITABILITY CHECK OF GCB FOR CONTROLLED SWITCHING APPLICATION

A simple Flow chart is developed for suitability check of circuit breaker to controlled switching as shown in the figure 4.2. Find mechanical scatter and if it is more than 0.5 then it needs some modifications in the breaker to minimize the scatter

After modification again find mechanical scatter of CB operating time. When it is less than 0.5 then goes for next parameter measurement which is required and put all these parameters in to the controller setting with help of HMI.

- *EXPERIMENTAL ARRANGEMENT*

Testing arrangement for suitability check of breaker controlled switching *i.e.* speed time measurement of circuit breaker arrangement shown in the figure 4.3, for this arrangement needs circuit breaker, speed time measurement instrument, power supply, mechanism rotary transducer and spare wires for connection. Connect the required apparatus to the CB as shown in the figure 4.3. CB operating command is   send to CB with help of speed time measuring instrument and display the results in the form of graphical representation as shown in the figure 4.4 and 4.5

- *SPEED TIME MEASUREMENT INSTRUMENT*

This instrument is digital software based instrument manufacture by Scope Electrical Instruments Ltd. It use to raise the closing and open command to circuit breaker and displays the closing and opening speed, Main and auxiliary contact opening and closing timing, Travel of mechanism movements.
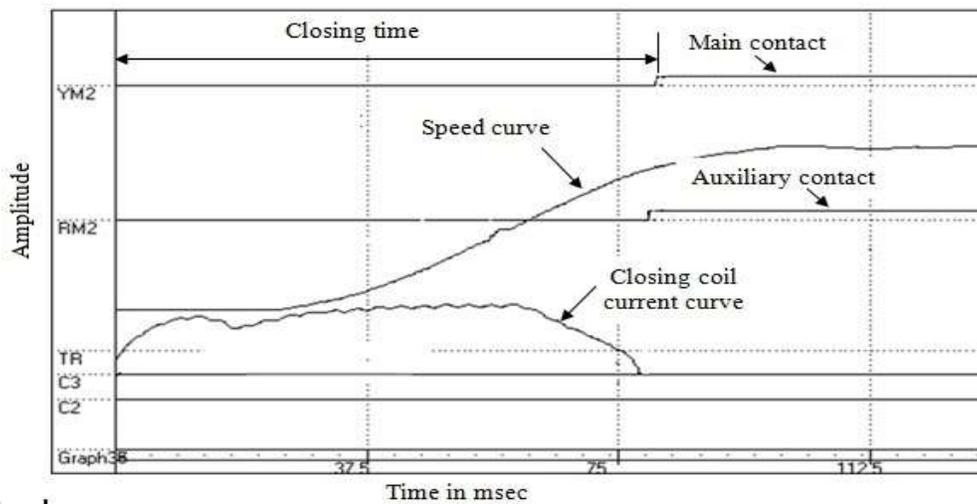
Graph.1. Speed time graph for closing
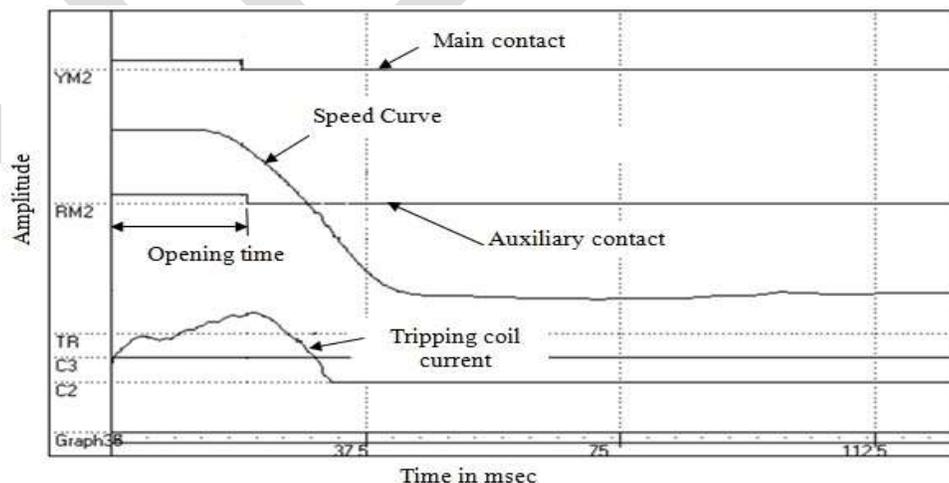
Graph 2. Speed time graph for opening

INITIAL MECHANICAL SCATTER MEASUREMENT

Initial 50 operations are carried out on circuit breaker (table 4.2) and calculate the mechanical scatter (table 4.3). It is found that mechanical scatter is 1.1 at closing time of circuit breaker as shown in the observations table 4.3.

From the table 4.3 it is cleared that the mechanical scatter is stay in the circuit breaker. The value of scatter should be kept as low as possible to avoid the high inrush current. From the performed some simulations on MATLAB software at 1msec. scatter (graph 4.4), inrush current increased 55.17%. To eliminate this it is necessary to make some modifications in the CB as per flow chart (figure 4.2).

Table 1. Scatter of initial operating time of CB

Max closing time	80	79.8	Max opening time	22.4	22.4
Min closing time	77.8	77.6	Min opening time	22	22
Max-Min	2.2	2.2	Max-Min	0.4	0.4
Scatter	1.1	1.1	Scatter	0.2	0.2

CB DEVELOPMENTS AND MODIFICATIONS

Scatter found 1.1 msec. in the initial closing operations and 0.2 msec. scatter in the opening operations from the table of breaker. Opening scatter within the limit hence it is not necessary to make modifications in the opening scatter side but regarding other side scatter is beyond the limit hence to make some modifications in the closing side with help of flowchart shown in the fig

Auxiliary switch is the replica of the main contact of the breaker as shown in the fig. Some mechanical play observed in the auxiliary switch during the operation of circuit breaker because of this scatter increases. Mechanical play observed in the adjusting rod which is connected between mechanism shaft and auxiliary rotating shaft as shown in fig. to avoid this mechanical play new ball and bearing arrangement as shown in fig and performed operations.

Closing speed of breaker is depends on closing spring by varying the load of spring and load of spring is increased by compressing spring as shown in the fig. Speed increases with increasing the load and load increase with compression of the spring hence closing speed is directly proportional to compression of spring. To increase speed such way that the optimum scatter produced for this purpose some operations are taken on breaker at different speed and note down closing time as shown in the table.

VERIFICATION OF GCB USING CONTROLLED SWITCHING UNIT

The aim of point on wave switching is to minimize switching transients, over voltages and current surges, thereby reducing the stress on equipment insulation. To achieve this, it requires a control device which receives a random command for circuit breaker operation, and synchronizes it with a reference waveform, such that the circuit breaker operates at a given point on wave (POW).

EXPERIMENTAL TEST SETUP

The experimental test setup to measure and verify whether the GCB is suitable controlled switching or not and also find error from the expected target on point on wave during closing and opening operation of circuit breaker with controlled switching unit. This test setup consists of voltage and current source for inject current and voltage in to circuit breaker and control voltage for breaker operation and controlled switching device and Sf6 gas circuit breaker.

RESULTS

CAPACITOR SWITCHING

Verification of CSW device and GCB is a no load test *i.e.* no capacitor is used to connect to the system and not apply rated voltage (420kV). Single phase 100V voltage is applied to the GCB through voltage current source. Connect Controlled switching device as shown in the fig. and connect laptop to the CSW device for observing the switching characteristic. After connecting all devices and

setting of Controlled switching device at capacitor load, raise the closing command to the GCB. Observed the switching characteristics on laptop as shown in the graph 3. and calculate target error.
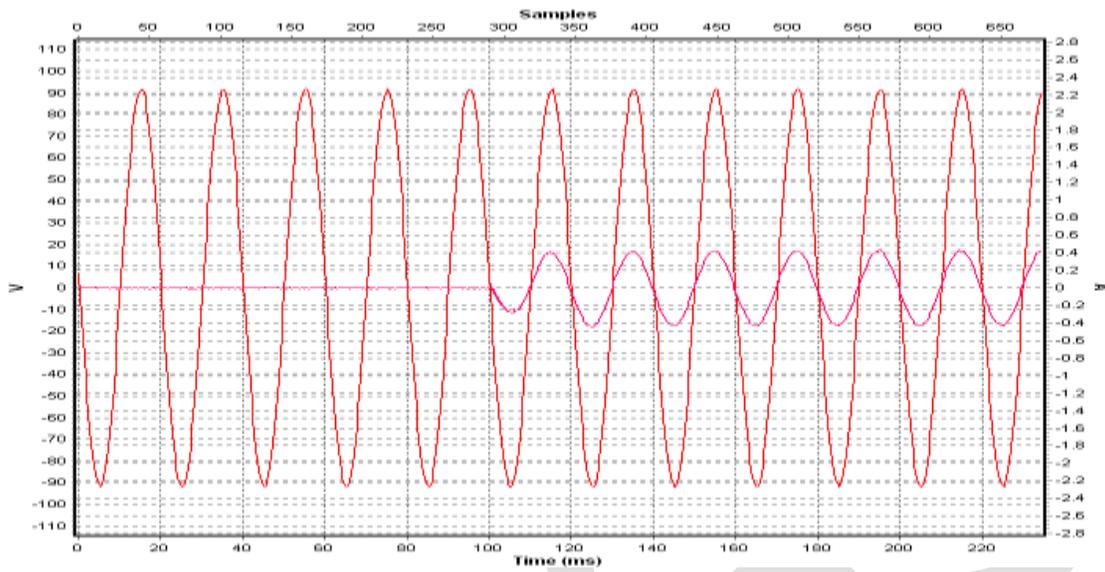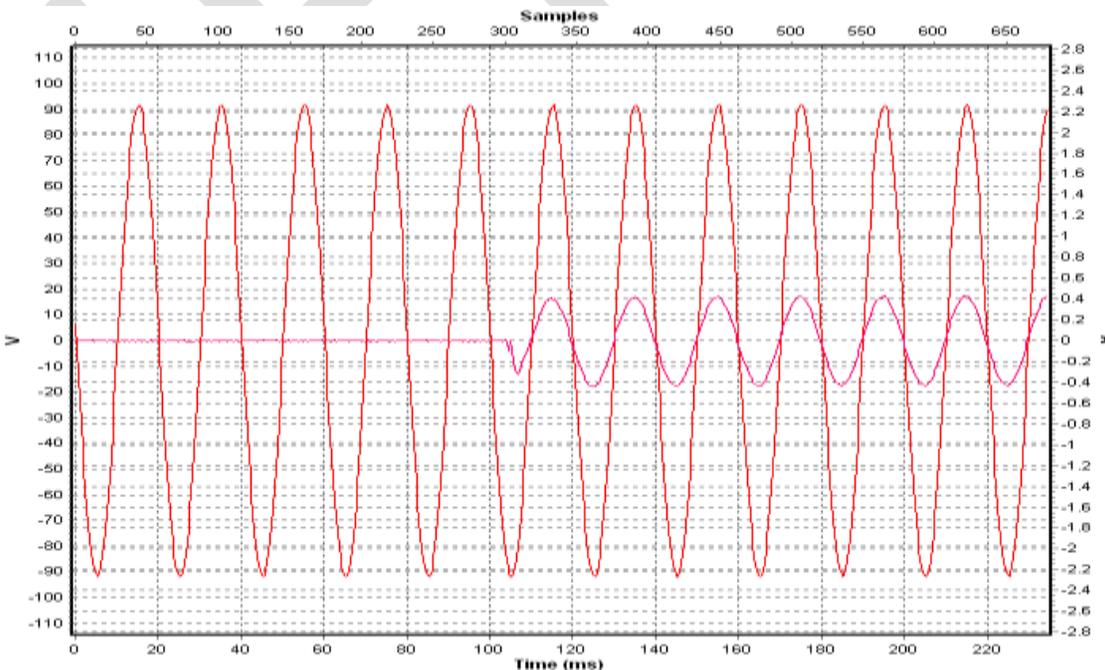

Graph 3. Capacitor switching characteristic with controlled device

Target for capacitor switching   = Voltage zero point.

Error from target of above graph   = Zero msec.

- *INDUCTOR SWITCHING*

Similarly as mentioned in the 4.6.2 section only change is set the CSW device at inductive load instead of capacitor load. Observed the switching characteristics on laptop as shown in the graph 4. and calculate target error.

Graph. 4. Inductor switching with controlled device

- Target for inductor switching   = Voltage peak point.
  Error from target of above graph   = 0.13 msec.

ADVANTAGES
- System and equipment transient reduction.
- Power quality improvement.
- Circuit breaker contact burn reduction.
- Circuit breaker enhanced performance during current interruption in the dielectric region.
- Avoidance of nuisance relay operations.
- Avoidance of re-ignition and re-strike region

CONCLUSION

Controlled switching is feasible with reasonable economical effort. It is capable of very precise breaker timing control for switching a wide variety of reactive power system loads and improves power quality also prevents switchgear and other system components from severe stresses. Effectiveness of controlled switching depends on several factors, the most important of which is the circuit breaker operating time consistency. Breakers with a deviation in operating times (*i.e.* statistical scatter of main and auxiliary contact) of less than ±0.5 ms are best suited for controlled switching applications. Accurate circuit breaker characteristics establishment for all parameters which affect operating time is also one of the important factor for the success of controlled switching system.Some modifications and test should be required to high voltage breaker suitable for controlled switching. 420kV gas circuit breaker is modified and tested and it is conclude that controlled switching error has been found ± 0.5ms for opening and closing. Experimentation is carried out for the spring-spring type circuit breakers. The mechanical scatter found is in the range of ± 0.5 ms. This can be acceptable for the total allowed making window of ± 1 ms.

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