Point on wave switching / controlled switching

Dr. Klaus Böhme / Stefan Werben, Siemens AG / Christopher Pritchard, OMICRON

Abstract

Controlled switching is a way of opening and closing breakers while causing less stress to the equipment. It is now also available with SIPROTEC 5 devices. The ability to use it together with a protection/control unit opens up new opportunities and savings in the wiring overheads. The seminar examines its implementation and explains how the device was tested.

Introduction/problem summary

Controlled switching, or point on wave switching (**P**oint **o**n **W**ave PoW), reduces the amount of stress imposed on the equipment and switch during switching operations, and minimizes disturbance to the system. This increases the service life of equipment and reduces aging. There are fewer system faults (for example, re-strikes on capacitors), which in turn increases availability. The switching operation (a make and/or break operation, depending on the application) is carried out phase selectively at pre-determined switching angles. Specialist devices are available from certain manufacturers.

As protection/control units are specifically designed or optimized for a different type of application in which the precise closing angle is not a major consideration (rapid 1- or 3-pole opening), the required switching accuracies cannot normally be achieved using the existing binary outputs (relays). The SIPROTEC 5 platform satisfies all the requirements in terms of protection and controlled switching. Controlled switching demands new testing methods which are described below.

The energizing of a capacitor bank/capacitive load is used as an example to explain the principle behind controlled switching. The same principle applies to other equipment/loads using different switching angles.

Effect of different closing angles

The effects of different closing angles can be verified very easily by means of a simulation, for example, RelaySimTest. The observations for a MSCDN system (Mechanical Switched Capacitor with Damping Network) are described in [1]. This MSCDN system would generate the inrush currents shown in Figure 1. As can clearly be seen, the current amplitude at an unfavorable closing angle (Phi=90°) is significantly higher, imposing greater stress on the system, switch and MSCDN system.

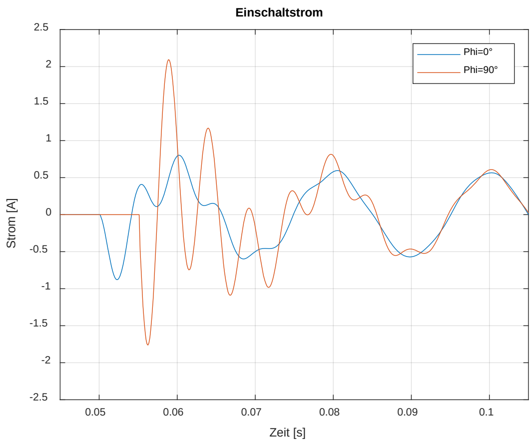

Figure 1: Inrush current at favorable and unfavorable closing angles in a MSCDN system

Figure 2 illustrates the maximum current of all three phases for a 3-pole closing operation above the closing angle. In this case, it is impossible to find any angle that would reduce the stress during the closing operation. The breaker poles need to be energized separately to avoid high inrush currents. This is shown in the same way in Figure 3. The inrush currents for the closing angles L1:0°, L2:120°, L3:60° (for the closing of capacitive equipment) can be significantly reduced. Figure 3 shows the offset to these optimum angles.

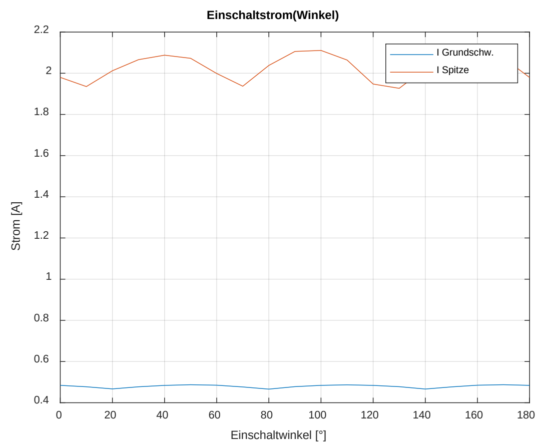

Figure 2: Maximum current as a function of the closing angle during 3-pole closing

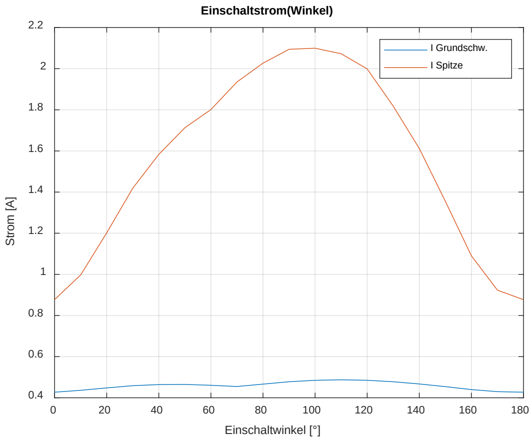

Figure 3: Maximum current as a function of the closing angle during 1-pole closing (L1:0°/L2:120°/L3:60°)

Controlled switching

The switching angle is dictated by the device being switched. In the case of a capacitive load or capacitor bank, the voltage zero crossing of the respective phase is the best option. Using the zero crossing (Phi=0°) of a measured reference value, the breaker data, and the specified closing angle, a calculation is carried out to determine the instant at which the device contact would have to be energized to ensure the breaker meets the requirements. Given a reference voltage U_{L1}, a closing sequence L1:0°/L2:120°/L3:60° relative to the zero crossing of the reference voltage is required to switch a capacitive load. To compute the instant at which the contact that energizes the breaker has to be actuated, we need to know the mechanical and electrical switching times (closing time and make time respectively). These vary according to the pre-arcing time at which the arc in the breaker makes the electrical contact. The closing time/opening time will also depend on the following:

- Control voltage of the open/close circuit
- Temperature
- Breaker pressure

If required, these can all be taken into account during the switching periods through measurements using isolation amplifier inputs. This can take place with linear or specific characteristics. These variables are used in the calculation of the switching instant.

Figure 4 illustrates the principle behind the closing operation.

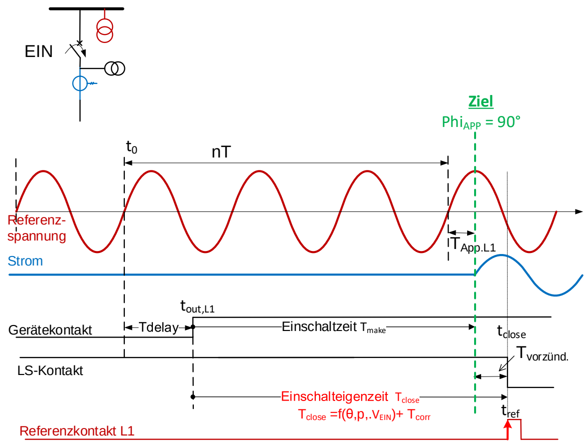

Figure 4: Principle of controlled switching

A low level of scatter in the device closing time is required in order to achieve good switching results. The closing time scatter of normal mechanical binary outputs (relays) is 1 to 2 ms. A time scatter of 1 ms produces, in a 50 Hz system, a closing angle error of 18°. This results in an increase in the peak current of around 30% (see Figure 3). With respect to the device closing time, an accuracy of <100 µs, which equates to 1.8°, is required. The contacts being used should have as low a closing time scatter as possible. Mechanical contacts are not suitable in this instance. The constant systematic components of the closing time can be taken into account in the calculation of the closing instant.

The SIPROTEC 5 system features "semiconductor relays" which, as well as very short trip delays, also have a very low closing time scatter. This produces device closing accuracies as low as <50 µs.

Testing method

The closing time reference point is the zero crossing of a defined voltage, for example, U_{L1}. All closing times relate to this zero crossing point. The switch times are used to calculate the time at which the relay in the device has to be activated to achieve the desired closing target. The source used for the test has to exhibit a high degree of time stability, which the CMC 256/356 devices, for example, guarantee. The switching sequence can be output using the State Sequencer, while the measurement of the making of the contact compared with the reference voltage is performed using an oscilloscope. The measurement setup and measurement principle are shown in Figure 5.

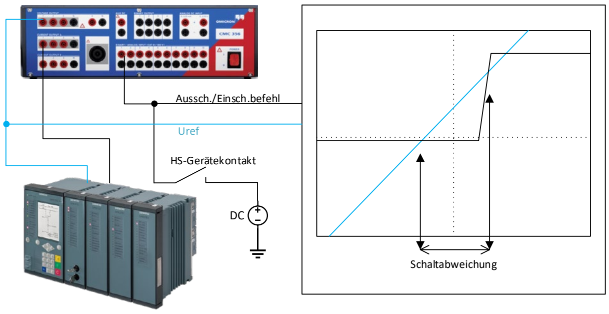

Figure 5 Measurement setup/principle

The deviation in closing time between the zero crossing of the reference voltage and the operation of the device contact is measured. This shows a closing time deviation of the device contact of <30 µs (<0.18°). More significant in this instance is the low time scatter of the results. The systematic inaccuracies can be compensated for in the settings. The sample measurement in Figure 6 resulted in a closing time deviation between the zero crossing of the reference voltage and operation of the contact of 3.0 µs (0.054°).

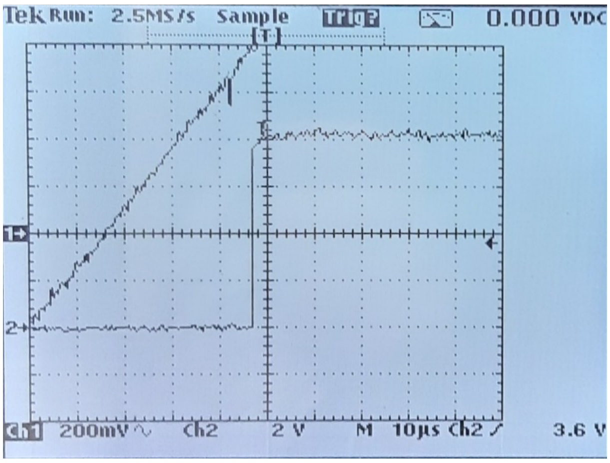

Figure 6 Measurement of closing time deviation

A simple yet similar measurement method is to use the isolating amplifier inputs. These are normally used to compensate the control voltage of the make/break circuits or to record the reference contacts (in the case of Siemens circuit breakers, the reference contact signals the mechanical making of the breaker contact), etc. An external direct voltage (<=10 V) is applied to the isolating amplifier via the contact. Evaluation of the generated fault recording (f_{sample}=8 kHz) enables the make/break to be roughly assessed in the laboratory for an exploratory test (time resolution: 125 µs).

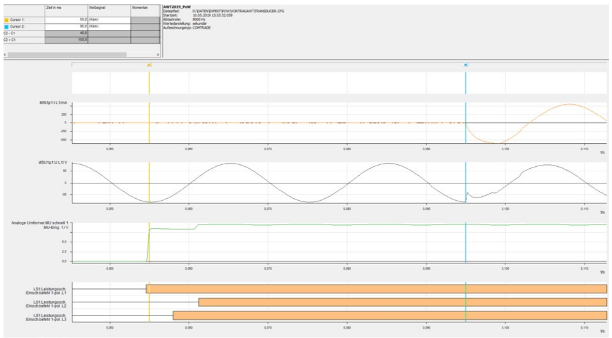

Figure 7

Using a State Sequencer also facilitates the direct measurement using a suitable CMC test set. A direct measurement via the binary inputs of the CMC356 cannot achieve the same level of accuracy as the measurement using the oscilloscope, as the binary inputs are read at a sampling rate of 10 kHz (in other words, every 100 µs). This equates to an angular deviation of 1.8° and is, therefore, acceptable for the purposes of an exploratory test of the function and/or the settings. Older CMC devices, such as the CMC156, do not achieve this sampling rate.

A closed loop simulation is required in order to see the effects of the switching on the equipment. The reactions (or actions) of the device have a direct impact on the simulation. This is complex and only achievable with expensive real-time simulators, such as the RTDS (Real Time Digital Simulator).

An easier approach is to use the iterative closed-loop simulation feature of RelaySimTest. Here, the simulation is performed several times so as to take account of the switching response. The simulation is executed as follows:

1. Output of the simulation variables, ignoring the commands. The commands are measured during the second run.
2. Output of the simulation variables, this time including the previously measured commands.
3. If there is very little variance between the first and second set of commands, the simulation is correct and is terminated; otherwise further simulation runs are necessary.

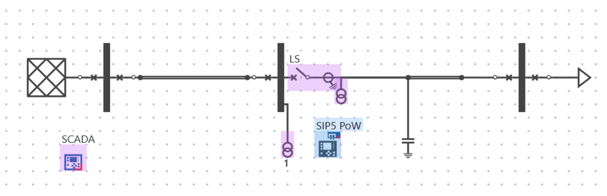

Figure 8: Simulated system (capacitive load)

For a capacitive load (or a capacitor bank), the iterative closed-loop simulation was carried out for the system depicted in Figure 8 for a favorable switching operation (Figure 9) and a switching operation with an unfavorable closing angle (Figure 10). The higher harmonic distortion is clearly evident.

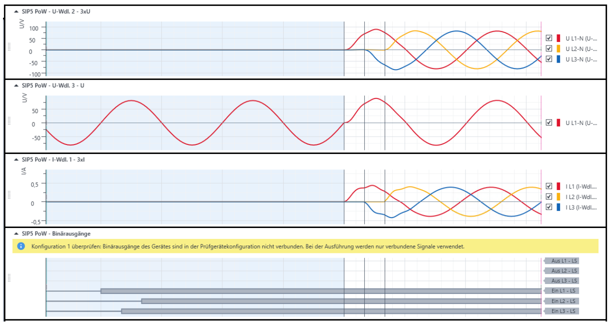

Figure 9: Favorable switching operation

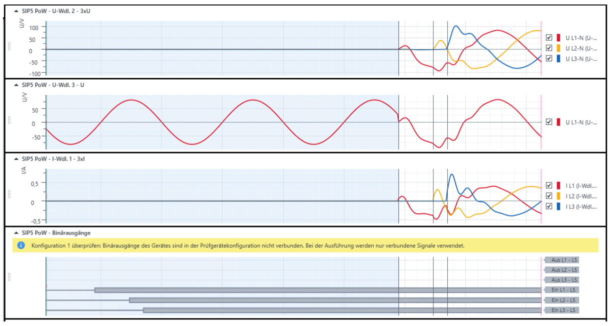

Figure 10: Unfavorable switching operation

Integration in the control function

Control of the breaker is currently performed using a combined protection/control unit. At present, a separate device is required if the breaker is also to be controlled/switched in sync with the phases. To integrate this into the control system, some additional external wiring will be necessary for coordination with the protection/control unit. A complete integration of the "Point on wave switching" function in the control function of a protection/control unit means one less device and lower engineering and installation overheads. As the control unit is integrated into the process control system, the additional overhead required for controlled switching is much lower. If "Point on wave switching" is available in the device and has been activated, every switching operation will be controlled.

The "Point on wave switching" function is included in the Circuit Breaker function group. The function also has function blocks for enabling and disabling it, so can, therefore, be customized for the specific application in question.

Figure 11a Point on wave switching in DIGSI 5 library

Figure 11b Point on wave switching parameter in Circuit Breaker function group

Summary

Controlled switching allows all equipment to be opened and closed in a way that causes less stress to the equipment. Integrating controlled switching into the control function enables automated and efficient point on wave switching to be implemented. Various testing methods are available for checking the results. The iterative closed-loop simulation with RelaySimTest enables the effects of the closing operation on the system variables to be tested directly.

References

[1] Poster: Untersuchung des dynamischen Verhaltens von Kondensatorbänken und deren Auswirkungen auf den Schutz, Schutz- und Leittechnik 2018, [Investigation into the Dynamic Response of Capacitor Banks and their Effects on Protection, Protection Technology and Process Control] Dr. Klaus Böhme, Stefan Werben, Siemens AG, Andrea Ludwig, Ulf Hoffmann, 50Hertz Transmission

[2] Handbuch, Anwenderprogramm PSD-Control 2.x Für die Geräte PSD01, PSD02 und PSD03 [Manual, PSD-Control 2.x User Program for PSD01, PSD02 and PSD03 Devices], Siemens AG 2012

About the authors

Dr. Klaus Böhme was born in Berlin in 1963. He studied electrical engineering at the Technical University of Berlin until 1989. The university awarded him a doctorate in 1994. Klaus has been employed since 1992 by Siemens AG, where he is involved in the development of digital protection devices. As a developer and project manager, he was responsible for the development of various devices, beginning with the 7UM5 V2.x before progressing to the SIPROTEC 4 and SIPROTEC 5. The focus of his work has been in the fields of generator protection, the synchronizing function and feeder protection devices. He is currently the Senior Key Expert for new applications for the SIPROTEC 5 platform.

Mr. Stefan Werben was born on June 1st, 1964 in Nijmegen, The Netherlands. He passed his school leaving examination at the Goethe Gymnasium in Einbeck, Germany in 1983. Stefan studied electrical engineering at the Technical University of Braunschweig (Brunswick, Germany) and obtained his degree in 1990. In 1991, he went to the USA for a year to study business administration at the Southern Illinois University in Carbondale. He joined Siemens AG in Berlin in 1992 as a software developer for digital protection devices. After software development and the managing of development projects, in 1998 he moved to a project management role in Nuremberg, where he has been employed since 2001 as Product Manager for protection devices.

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