Торайғыров университетінің хабаршысы
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Торайғыров университетінің ХАБАРШЫСЫ

Физика, математика және компьютерлік ғылымдар сериясы

1997 жылдан бастап шығады

TORAIGHYROV UNIVERSITY

ВЕСТНИК Торайгыров университета

Серия: Физика, математика и компьютерные науки

Издается с 1997 года

ISSN 2959-068X

№ 1 (2024)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Серия: Физика, математика и компьютерные науки
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агентства и сетевого издания
№ KZ91VPY00046988
выдано
Министерством информации и общественного развития
Республики Казахстан

Тематическая направленность
публикация материалов в области физики, математики,
механики и информатики

Подписной индекс – 76208

https://doi.org/10.48081/NLWQ4802

Бас редакторы – главный редактор
Тлеукенов С. К., *д.ф-м.н., профессор*

Заместитель главного редактора	Испулов Н. А., *к.ф-м.н., профессор*
Ответственный секретарь	Жумабеков А. Ж., *PhD доктор*

Редакция алқасы – Редакционная коллегия

Esref Adali,	*PhD доктор, профессор (Турция);*
Abdul Qadir Rahimoon,	*PhD доктор, профессор (Пакистан);*
Донбаев К. М.,	*д.ф-м.н., профессор;*
Демкин В. П.,	*д.ф-м.н., профессор (Российская Федерация);*
Жумадиллаева А. К.,	*к.т.н., профессор;*
Ибраев Н. Х.,	*д.ф-м.н., профессор;*
Косов В. Н.,	*д.ф-м.н., профессор;*
Сеитова С. М.,	*д.пед.н., профессор;*
Шоканов А. К.,	*д.ф-м.н., профессор*
Омарова А. Р.,	*технический редактор*

За достоверность материалов и рекламы ответственность несут авторы и рекламодатели
Редакция оставляет за собой право на отклонение материалов
При использовании материалов журнала ссылка на «Вестник Торайгыров университета» обязательна

© Торайгыров университет

Торайғыров университетінің Хабаршысы, ISSN 2959-068X
Физика, математика және компьютерлік ғылымдар сериясы № 1, 2024

СЕКЦИЯ «ТЕОРЕТИЧЕСКАЯ И ЭКСПЕРИМЕНТАЛЬНАЯ ФИЗИКА»

SRNTI 29.03.35, 44.41.35

https://doi.org/10.48081/XNQE4237

Muhammad Faizan Shaikh, *Rehan Ali Rahimoon,
Fizza Shaikh, Abdul Saboor Gul, Mujtaba Abid Hussain
NED University of Engineering and Technology, Karachi, Pakistan
*e-mail : aqadir@iba-suk.edu.pk

TESTING OF NEW SIMPLE-STRUCTURED AC SOLID-STATE CIRCUIT BREAKER

It is time for us to move past traditional electromechanical circuit breakers. Traditional EM models have been a part of our routine since they were first invented and provide invaluable service as a back up measure for an ever changing world, but there is simply no replacement for newer high tech options available today. From new ways of electricity transmission and distribution, such as DC microgrids, to advances in electronics materials such as semi-conductors, today's advancements in the world of electrical engineering demand that we reexamine how we handle power use – especially when it comes to its most basic element: interruptions. Currently, this process involves using some kind of auxiliary mechanical device while waiting for the breaker to close; however, with newer proposed AC SSCB you will be able to perform quick operations without any need whatsoever for additional machinery. In this paper, the performance features of the proposed ac SSCB are first demonstrated by design and simulated results of Single-Phase SSCB then Three-Phase model and outcomes are carried out. To make things easier, a flowchart for the design of the circuitry is also provided.

Keywords: Circuit Breaker, Solid-State Circuit Breaker, Over-Current Protection, Overload Protection, Operating Duty.

Introduction

Solid-state circuit breakers are known for their many benefits; faster response times than traditional models, no moving parts to wear out, and a lower chance of failure. But perhaps the best thing about them is how well they work with other systems to provide more protection for you. Their quick response times give them an edge over traditional models when it comes to saving important files from damage or shutting down equipment before fires can get too big, while also providing us with greater insight into any problems we might encounter so that we know what to do next. The most attractive aspect of these new technologies – especially one this advanced – may just be their ability to work alongside others so seamlessly. Moreover, semi-conductor-based circuit breakers provide safety features that are absent in mechanical circuit breakers because they are smaller and contain no moving parts. They also last longer, which means less maintenance costs over time. Furthermore, semiconductors make no noise during operation, which makes them perfect for industrial settings where loud noises might damage the operator’s hearing or disrupt other production equipment.

When short-term outages occur because of weather related issues or temporary malfunctions, the power grid must be able to supply enough electricity for current demands using quick breaking action from the initial fault state. For this reason, the SSCB should always be closed again after being broken apart – any other approach will result in long duration outages without an open SSCB which can result in significant economic damages and losses [1]. To ensure safety, IEEE requirements C37.09 requires circuit breakers to be able to perform multiple reclosing and rebreaking operations consecutively [2]. Modern society requires power quality even in today’s fast paced world. It is needed specifically in microgrids and smart grids to have a breaker capable of rapid breaking, which could carry out its duties without fault [3; 4]. However, current SSCBs lack the ability to perform efficiently; so there is an urgent need for new ones that can keep up with today’s standards.

Since the load energy is constantly supplied directly via the SSCB, an SCR might be most appropriate for implementing an SSCB because of its comparatively lower conduction loss compared to other switching devices [5; 6].

A three-phase SSCB with a three-step reset for rapid breaking was proposed in [6]. However, this type of device is limited because it can't perform reclosing and rebreaking operations during sustained load side faults. Without charging the commutation capacitors after an impulse, attempts at performing these tasks are futile due to heavy arcing or other power transformer problems.

It is important to have the ability to break the loop of power when a fault is detected. Previously, it was possible to do this with an automatic switch circuit breaker (ac SSCB). This type of breaker had an essential circuit topology which utilized unidirectional commutation capacitors – these would be charged as long as they were turned on through one alternating current (ac) source [7]. These sources also did not allow for faults in the grounded side of connections, but allowed for faults in either a live or neutral point. Of course this system does come with limitations – namely that it required complex thyristors that could charge the power supplies and one line going towards ground was affected by a fault [8; 9; 10; 11].

Materials and methods

In order to fix the problems discussed above, this paper proposes a New Solid-State Circuit Breaker that can close quickly and break again when needed (ac SCCB). This will allow it to carry out its operating duty – or in other words, it will provide for the closing and breaking operations. It will also be able to do so regardless of whether or not there is an ungrounded system as long as there are three phases. In addition, even if there is a short circuit fault on either side of the load or there is an overload condition – which would cause one phase's voltage to exceed a preset level – the new SCCB could charge up the commutation capacitor before shutting off all of them again. The prototype of this device is rated at 46 kW with a line voltage of 380 V. After testing its function under different circumstances, the performance features proved that it would work as well with single-phase and three- phase sources.

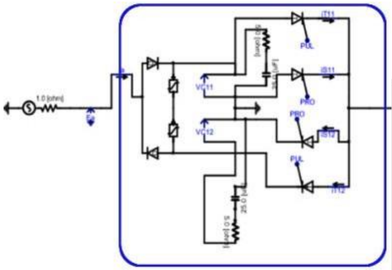


Figure 1 – New ac SSCB with single-phase source

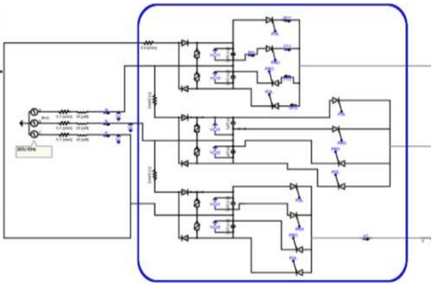


Figure 2 – New ac SSCB with three-phase source

New AC solid-state circuit breaker. Fig.1 shows the circuit diagram of proposed Solid State Circuit Breaker with a single-phase source. For implementing it in real world, we have tested the performance of new SSCB in short-circuit and overload fault condition. This will not only determine the potential of the Circuit Breaker also it will depict its real-world application. Fig. 2 illustrates the circuit diagram of the new ac SSCB circuit with a three-phase source. Despite the sustained short fault at the load side or Overload conditions, the new SSCB can charge the commutation capacitor. In brief, because the commutation capacitor is viable to charge regardless of whether it continued the fault state on the load side, the new ac SSCB can well carry out the operating duty regulated inside the circuit breaker requirements [2].

To affirm the overall features of the proposed SSCB, this paper explains all the above-mentioned important operations of the ac SSCB by illustrating the single-phase and 3-phase short-circuit fault with the largest fault current value compared to all other faults. After which the SSCB is tested in Overload conditions.

Results and discussion

Short-circuit fault. Short-Circuit Faults are the most common hazardous condition for electrical power systems. These types of faults result in heavy-current flow through the transmission system making the system over-heated, over-loaded, and prone to alternator and transformer damage. In this condition, the voltage is not affected as much as the current does. Little or no voltage drop occurs in practical and ideal case.

As the SLG fault and 3-phase fault doesn't show a big difference in the simulated results hence single-phase short circuit fault and 3-phase fault in 3-phase systems experiments are done.

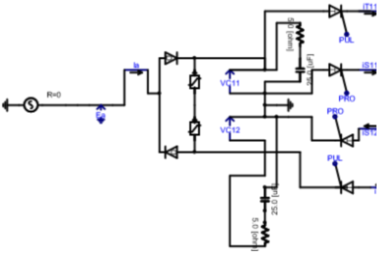


Figure 3 (a) – Single Phase Short-Circuit Fault Model

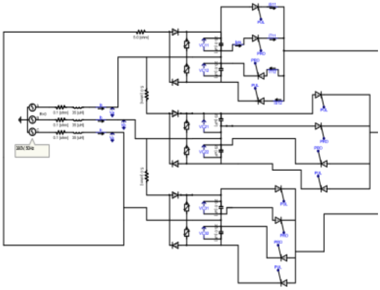


Figure 3 (b) – Charging Mode ($t_0 \leq t < t_5$)

In charging mode, it is important to make sure that all of the commutation capacitors are fully charged before you switch into Normal Mode because if a fault occurs, the SSCB can only stop it by discharging those capacitors which have been precharged. By switching on power while using a Line Voltage and Varistor, you can set up Charging Mode where the Commutation Capacitor is charged up to a certain Voltage Level.

At t0, as the line switch is turned ON, the charging of the commutation capacitors begins. At time t0 – t1 in Fig. 4, the capacitors C11, C12 are charged fully in single phase medium while all capacitors are charged according to three phases if their corresponding lines do not coincide; depending on which phase the system has first received in order to charge.

The proposed AC solid-state circuit breaker (SSCB) charges commutation capacitors using a series resistor, diode, and capacitor configuration. This configuration doesn't require the current to be either switched or interrupted with an SCR, so there is no requirement for extra switching operations when it comes time to charge up these capacitors – making it both fast and easy-to-use. The SSCB can even break/rebreak the power supply across load side faults – which makes this design highly functional in all conditions.

In our case, $t_0 = 0$ sec and $t_5 = 0.2$ sec.

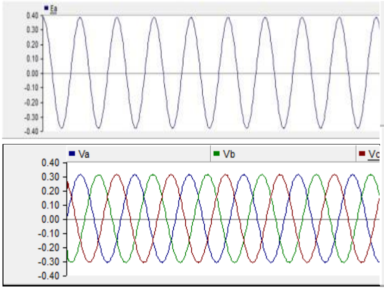


Figure 4 (a) – Single and 3-phase voltage source

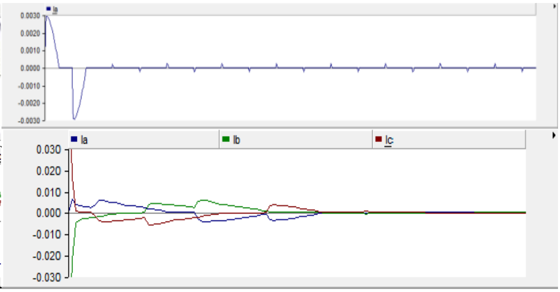


Figure 5 (b) – Single and 3-phase current source

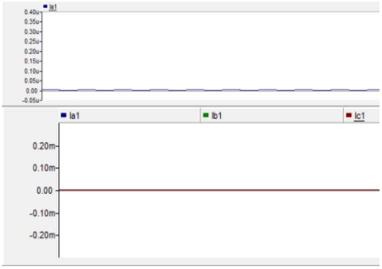


Figure 4 (c) – Single and 3-phase load currents

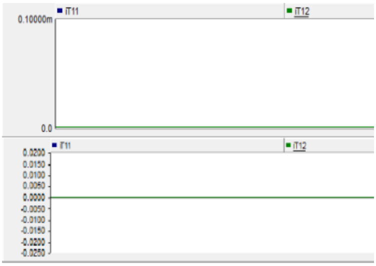
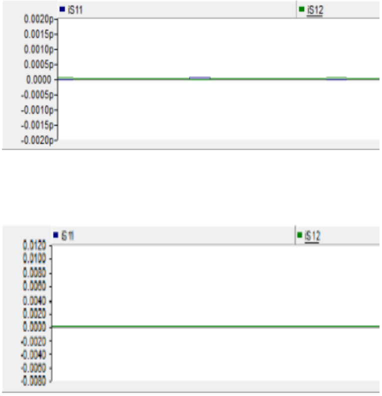


Figure 4 (d) – Main SCR currents



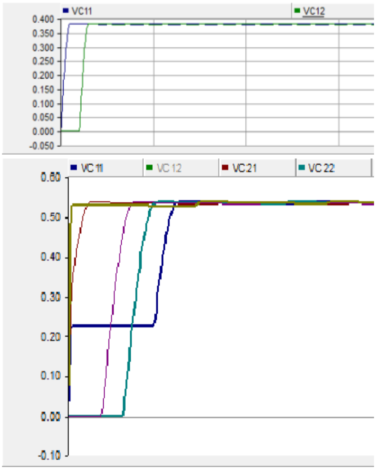


Figure 4 (e) – Auxiliary SCR currents

Figure 4 (f) – Commutation Capacitor Voltages

Normal Mode ($t_5 \leq t < t_6$). This is the optimal operational mode needed to efficiently supply electrical power. To do so, all of the SCR Tall (T11, T12, T21, T22, T31, and T32) are turned ON to maintain a constant flow through the circuit. When enabled in this manner during normal operation mode; SSCB can monitor faults within the system such as overcurrent and sags which could easily be detected by monitoring currents or voltage levels while continuously compensating when needed. In Normal Mode, Source Voltage(s), Aux Thyristors Currents and Capacitor Voltages (Charged) will remain same as in the Charging Mode. In our case, $t_6 = 0.4$sec.

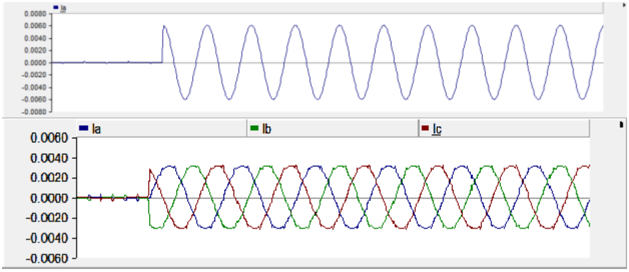


Figure 5 – (a). Single and 3-phase current source

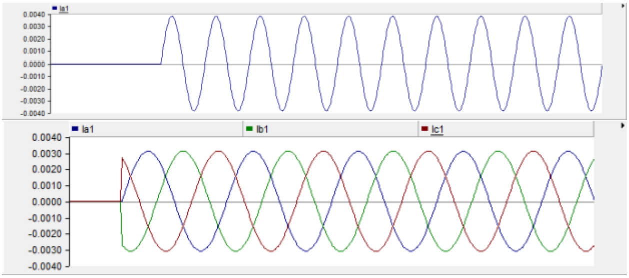


Figure 5 – (b). Single and 3-phase load currents

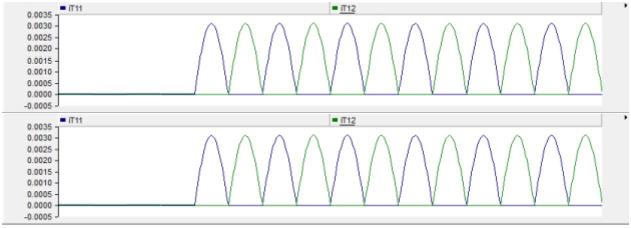


Figure 5 – (c). Main SCR currents

Normal Mode (Short-Circuit Fault: t6 ≤ t < t7). In this Normal mode, the fault current will rise very quickly due to a single phase or three-phase short circuit event at t6. If it is first initialized with an minor short fault that has already taken place, the proposed ac SSCB will operate in normal mode until it reaches the predetermined set point (to define a short circuit) which causes it to switch modes and interrupt the short circuit at t7. In our case, $t_7 = 0.4001$sec.

Breaking Mode ($t_7 \leq t < t_8$). In this mode, the interruption in fault current is noticed like in Fig. 6 at 0.4 sec(t_7). Turning off the corresponding main SCRs T11, T22, and T32 when there is no need for it was key to protecting the unit from possible damage. When this happens, bypasses are created where current then flows through R, L, and C before continuing on its way back up again. These bypasses maintain power in the event of a faulty or disconnected connection which ensures that sensitive parts of the machine don’t sustain any damage. In the end, the fault currents are broken. In our case, $t_8 = 0.402$sec.

Breaking Mode ($t_8 \leq t < t_9$). When the mode switches to this one, the power supply would stop flowing out of the circuit. As a result, all of the SCRs of SSCB stay turned off during this time period. For example, during t_8 - while they are in normal working condition - no sparks would be emitted from them even if there were some kind of power surge since the capacitor is still being charged up at that point in time. In our case, $t_9 = 0.403$ sec.

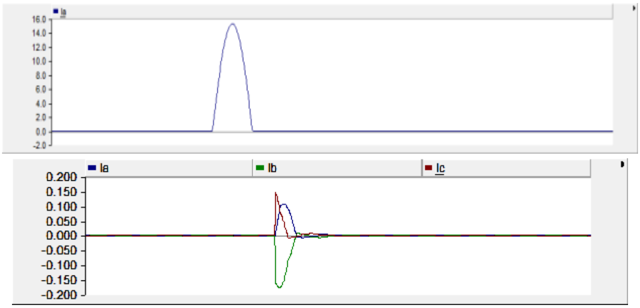


Figure 6 (a) – Single and 3-phase current source.

Figure 6 – (b). Single and 3-phase load currents

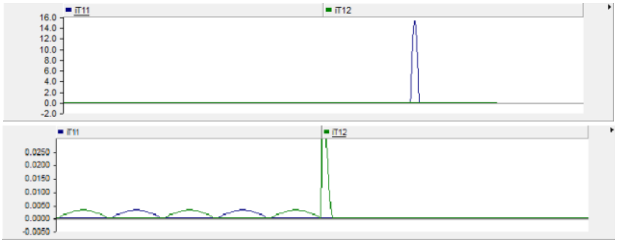
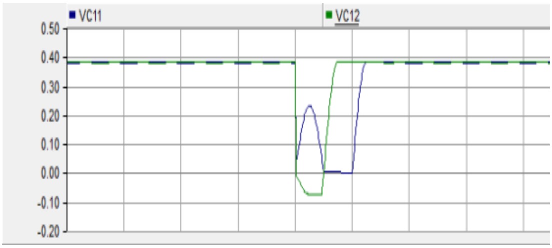


Figure 6 (c) – Main SCR currents

Recharging Mode ($t_{10} \leq t < t_{13}$). In this mode, the capacitors which discharge during the breaking mode before it start again are charged. The charging process for capacitors C11, C22, and C32 (from time 8 - 12) is performed when all of the SCRs have been switched off. This allows them to charge without having to control every single thyristor; even if there is a line-to-line fault on one side, they're still able to do so. When this process finishes, there might be a reclose operation being done by using some signals from the main SCRs since they prepare themselves for a break in case of an short circuit fault.



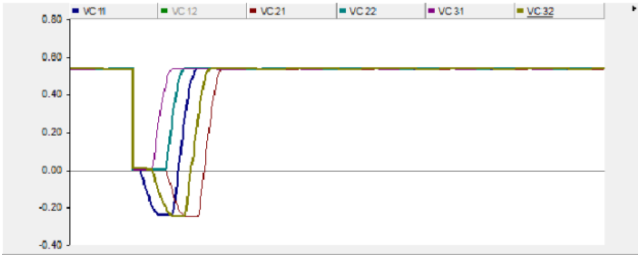


Figure 7 – Commutation Capacitor Voltages

Reclosing Mode ($t_{13} \leq t < t_{14}$*).* This mode is called reclosing mode because all the primary SCRs (T11, T12, T21, T22, T31, and T32) are turned ON and system again powers up the load. The circuit breaker needs to carry out the predetermined re-closing operation in keeping with the re-closing schedule of the operating duty. Despite of short-circuit fault in load, all the main SCR ought to become ON. the system will once again gain normal MODE, and this procedure repeats each time a short circuit appears within the system.

Overload fault. The definition of overload isn't just about when a switch or breaker are operated too long – there's also when they're carrying more power than they can handle safely. When there's an overload, the voltage drops (but it never reaches zero) and the current climbs rapidly but not as much as when there's a short circuit. An overloaded situation heats up things quickly – but while they might look okay initially, repeated exposure over time leads to burns and damage to the electrical system. It also damages the devices you connect them to – like an inverter rated for 400 watts might explode if you try running 800 watts through it.

Short circuits happen when there is an interruption in the flow of electricity, usually due to a breakage somewhere along the power lines. On the other hand, an overload happens when too much electrical current flows through one wire, so it burns out and makes your device shut down. Like the above experiments, Overload conditions are tested on both single-phase and 3-phase systems as shown in Fig.1,2. The overload value is 100MW+j25MVar.

Charging Mode ($t_0 \leq t < t_5$*).* In the charging mode, commutation capacitors charge to its fullest capacitance value without operation of main or auxiliary SCRs. As explained in the section III of the paper, the capacitors are charged before normal flow of current to loads because they break the power system by supplying reverse voltage to main SCRs. Results in Fig.4 shows the complete process of charging mode. The reason behind the same outcomes is the same circuitry of ac SSCB for both fault conditions.

Normal Mode ($t_5 \leq t < t_6$). In the Normal Mode of operation, the single-phase and 3- phase voltage sources supplies required power to the loads and commutation capacitors remains charged without disturbing any type of SCR. The Main Thyristors are fired at t_5 by the external pulse generator so a path for supplying the current is created. This process continues until an overload fault appears in the system. As explained earlier, in Normal Mode, Source Voltage(s), Aux Thyristors Currents and Capacitor Voltages (Charged) will remain same as in the Charging Mode. Fig.5 illustrated the results of this mode.

Normal Mode (Overload Fault: $t_6 \leq t < t_7$). As soon as the Overload condition occurs in the system, the current requirement from the single and 3-phase source is significantly increased. With this, voltage drop on the supply side also seem to appear. It should be noted that rise in current in the overload fault is less than the short-circuit current. After the presence of fault in the system, the SSCB does not break the system until a preset value of fault is reached. When the value matches, the proposed ac SSCB interrupts the overload fault at t7, accordingly starting the subsequent breaking mode.

Breaking Mode ($t_7 \leq t < t_9$). In this mode, the fault current is completely eliminated from the system by the use of reverse voltage supplied by commutation capacitors to Main SCRs. At the same moment, auxiliary SCRs are turned ON for a very short duration and automatically gets turned off in a small piece of second. Fig. 8 shows the breaking of the fault current in overload fault conditions.

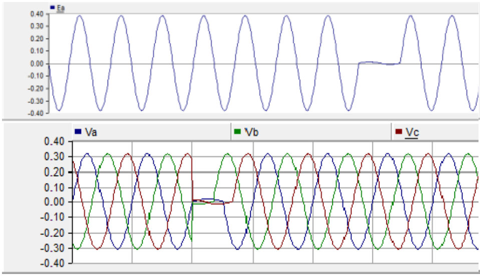


Figure 8 (a) – Single and 3-phase voltage source

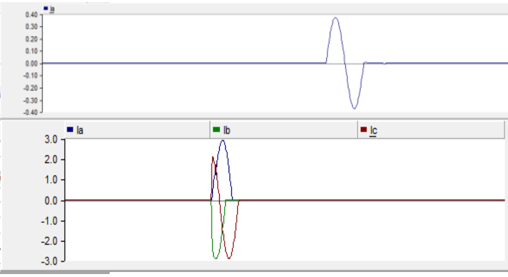


Figure 8 (b) – Single and 3-phase current source

Figure 8 (c) – Single and 3-phase load currents

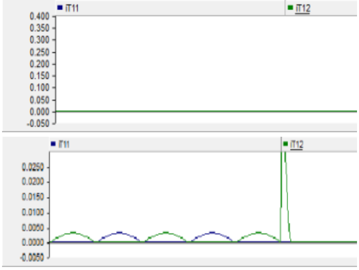


Figure 8 (d) – Main SCR currents

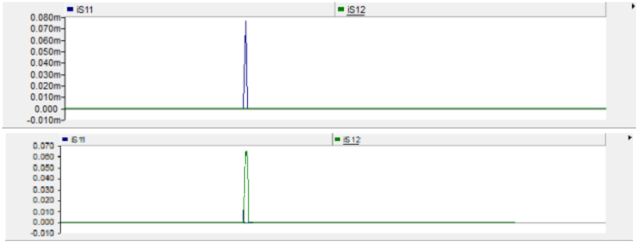


Figure 8 (e) – Auxiliary SCR currents

Recharging Mode ($t10 \leq t < t13$). As explained earlier, the commutation capacitors in the system once again charges to its peak voltage value. This process is carried when both type of SCRs are turned off as it was in charging mode. This voltage of capacitors is helpful in re-closing the SSCB if the fault has eliminated from the system.

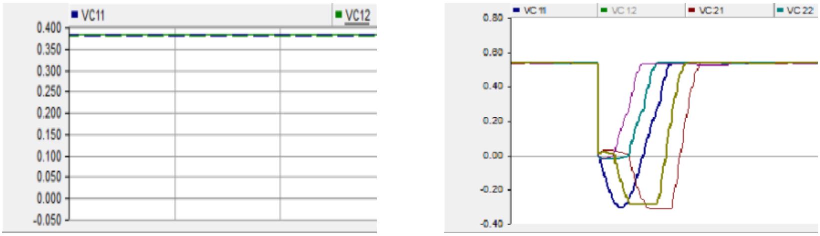


Figure 9 – Capacitor Voltages

Reclosing Mode ($t_{13} \leq t < t_{14}$). In this mode, the ac SSCB that was opened because of the overload fault is now reclosed by the operation of commutation capacitors. This shows the capability of the proposed of being breaking and closing the system without use of SCRs. This not only help in reliable applications but also provide fast and accurate switching.

Design of the proposed ac SSCB.

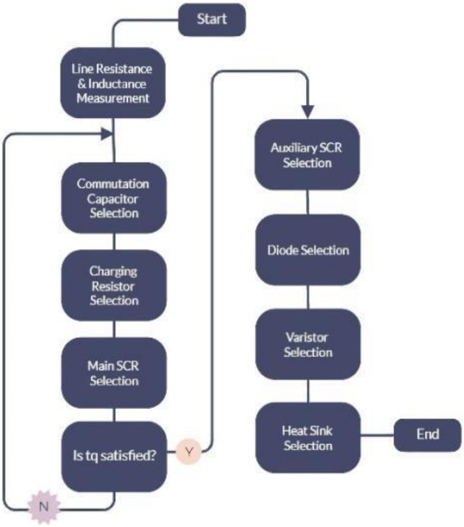


Figure 10 – Design Flowchart

Fig. 10 suggests the design flowchart which accommodates four steps: line condition measurement, charging circuit design and main circuit device design, commutation circuit design, and heat generation layout. The detailed design system of the proposed ac SSCB is:

A. Line Condition Measurement. Lines need to be properly inspected when designing circuit breakers because they can cause interruptions. The resistance of the line will determine how much charge goes into the resistor that aids in charging electronics, so it is important for it to be calculated properly. Additionally, inductance is another factor for consideration when planning for a breakdown because it feeds energy from a line back into the capacitor which can cause shocks if it isn't accounted for during design. In this paper, the line resistance and inductance where the breaker is located are measured as 100 [mΩ] and 35 [μH].

B. Commutation Capacitor Selection. As the whole fault current flows through the commutation capacitors in duration of fault presence, hence it is significant to calculate the maximum fault current through the capacitors in order to carry out suitable value of capacitance. To make things easier to understand, an equivalent circuit of proposed ac SSCB is designed shown in Fig. 11. The equation derived from the circuit will result maximum fault current of the system.

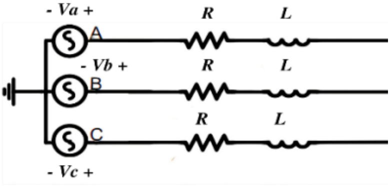


Figure 11 – Equivalent circuit in fault condition

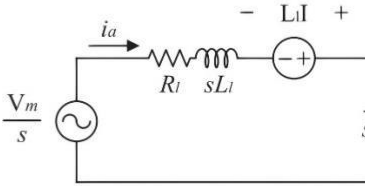


Fig 12 – Equivalent circuit of phase «a»

As the direction of commutation capacitor C11 charging from the phase «a» is different from the other two capacitors C22, and C32, hence the neutral point «Vn» cannot be declared as zero. So, with the help of following equations, we can obtain a compensation voltage V_{Ceq} of the capacitor.

$$\frac{V_n - V_a - V_{ch}}{Z} + \frac{V_n - V_b + V_{ch}}{Z} + \frac{V_n - V_c + V_{ch}}{Z} = 0 \qquad (1)$$

$$V_{Ceq} = -V_n = \frac{V_{ch}}{3}[V](V_a + V_b + V_c = 0) \qquad (2)$$

Here, Z is the total impedance formed by capacitor and line resistance and inductance. The current for each phase can be obtained by simply providing a phase shift of 120°.

Laplace equivalent circuit of Fig.11 is given in Fig.12 where Ia (3) is the phase current flowing through phase «a» and I is the preset value of current flowing through the commutation capacitor that must be achieved to alert the SSCB.

$$I_a(s) = \frac{sL_l I + \frac{4+\sqrt{3}}{3} V_{ch}}{L_l s^2 + R_l s + \frac{1}{C_{11}}} \qquad (3)$$

The maximum value of fault current can be found by hit and trial method shown in Fig. 13. As the commutation capacitor capacitance and its voltage capacity increases, the peak value of current also show expansion.

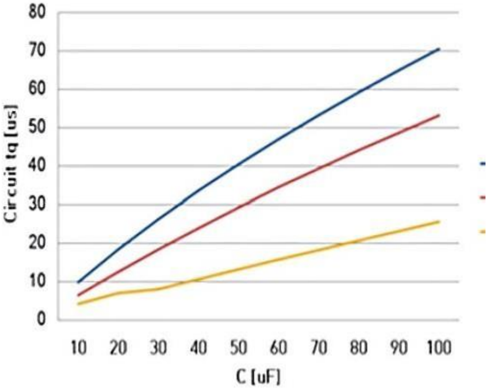


Figure 13 – Max Value of fault current
due to Capacitor

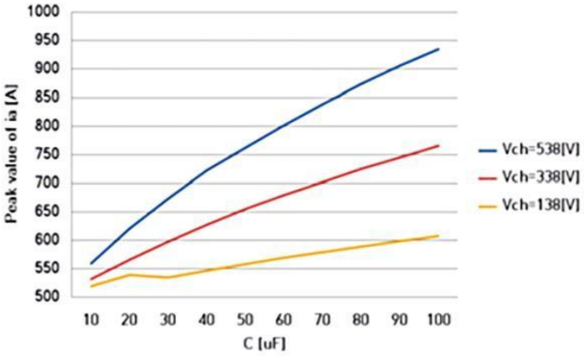


Figure 14 – Value of Circuit tq to Capacitance and Voltage

In the selection of commutation capacitor, another issue that comes in to sight is turn-off time of Main SCRs. Despite the fact that current flowing through the main thyristors is zero, but complete turn-off is required to avoid any hazard. Therefore, turn-off time tq is required to turn SCR off properly. For this purpose, commutation capacitors voltage needs to be positive until the SCR get turned off completely.

In this research, device tq and circuit tq are two terms that will be used several times. Device tq is the turn-off time of SCR which is provided in product datasheet. While, circuit tq is the time duration between Thyristor current reducing to zero and commutation capacitor voltage becoming zero.

From the data, it is found that if circuit tq is greater than device tq, the main SCRs will turn off normally. While, if the device tq is set greater than circuit tq, the main SCRs cannot be turned off normally. Thus, circuit tq is need to be set so it should be always greater than the device tq.

Fig.14 illustrates the variation of circuit tq on varying the capacitance and voltage capacity of commutation capacitors. From the figure, it can be carried out that larger value of capacitance and voltage rating of capacitors can result in longer circuit tq. However, another problem that appears in this selection is the larger value of fault current that will exist if larger value of capacitance is chosen. Therefore, by using Fig. 13 and 14, suitable value of capacitance is selected.

In our model, the capacitance of commutation capacitors is chosen as 25 [uF] and charging voltage as 583 [V]. In result of this, the circuit tq is 22 N[us] and maximum fault current is 648 [A].

C. Charging Circuit Design and Main SCR Design. After the selection of commutation capacitor and circuit tq, the charging resistor which limits the current flow to commutation capacitors needs to be selected. This disturbance in between the supply and charging capacitors is to avoid over-charging.

$$I_{ch\,1}(s) = \frac{V_{ch}\sqrt{2}}{2L_l s + (2R_l + R_{ca}) + \frac{1}{sC_{11}}} \tag{4}$$

$$R_{ca} \geq \sqrt{\frac{8L_l}{C_{11}}} - 2R_l \tag{5}$$

Charging capacitor current can be expressed as (4). And to avoid over-charge condition, the equation (5) must be satisfied.

Assuming the resistance of short-circuit fault to be very small, the equation can be expressed as:

$$I_{Rab}(s) = \frac{C_{11}V_{C11}}{R_{ab}C_{11}s + 1} \tag{6}$$

As illustrated in (6), as value of Rab becomes smaller, the greater current flows through capacitors in breaking mode thus reducing circuit tq. But if the value of a resistor is made large, the charging time of computation capacitors will increase. Therefore, the proper value of charging resistors must be selected. In our case we have chosen the value of charging resistance as 5 Ohm. After the selection of the resistor the main SCR need to be selected.

If a short circuit fault or overload fault occur in the system, the value of current significantly increase and the SSCB will brake system when the preset value is reached. So, it can be said that the highest value of current flowing through the SCR is equal to the predefined value. For our model the preset value is selected as 500 [A], so the maximum current flowing through the main thyristor will also be 500 [A]. Since the connection of the main SCR is parallel to the series connected capacitor and auxiliary thyristors, the applied voltage of the main SCR can be written as

$$V_{Tmain} = V_C + V_{Saux.ON} \approx V_C \tag{7}$$

where V_C and $V_{\text{Saux.ON}}$ are the commutation capacitor voltage and the on-drop voltage of the auxiliary SCR, respectively.

The total reverse voltage applied on the main SCR can be said as the Capacitor Voltage V_C because $V_{\text{Saux.ON}}$ is very small as compared to V_C. So, V_C can be determined by commutation capacitor capacitance and its current.

Fig.15 shows the variation of maximum voltage of the main SCR in accordance with the commutation capacitor capacitance. From the figure it can be seen that capacitance of commutation capacitor has a direct relation with the voltage of main SCR and as the capacitance increases the voltage applied also increase. In our model we have selected the maximum voltage of SCR as 716 [V] and device tq as 8[us].

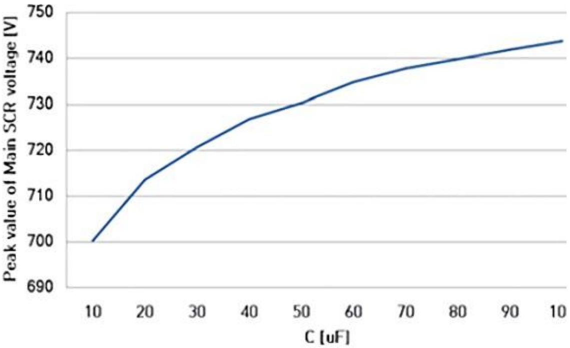


Figure 15 – Variation of SCR voltage
due to capacitance

D. Commutation Circuit Design. Our Research Commutation Circuit includes a broad range of parts including Auxiliary SCRs, Diodes and Varistors. Depending on the specified Maximum Current or Voltage requirement, we choose an appropriate Auxiliary SCR. This Auxiliary SCR is installed exclusively for the breaking function – using only very small periods when it needs to be switched ON so that there is no danger in turn ON-OFF stress. Fig.6 shows that the Auxiliary SCR turns on once the fault current reaches its preset limit. However, since there are resistors in series with this circuit, the flow of charging current is actually much greater than the power lost from an actual fault.

Fig.6 also illustrates that peak current of auxiliary SCR is equal to peak value of phase current. Therefore, value of auxiliary SCR needs to be selected according to max fault current. In our model, the maximum current flowing through auxiliary SCR is selected as 648 [A].

In breaking mode, where commutation capacitor is charged in opposite direction, the voltage is also applied to auxiliary SCR. At that time the maximum voltage of the auxiliary SCR is expressed as

$$\mathrm{V_C} + \mathrm{V_a} = \mathrm{V_{Saux}} \tag{8}$$

In our research, the maximum voltage of auxiliary SCR is found to be 689 [V].

To select the charging diode, the value of current flowing through it in charging as well as breaking mode should be noted. The current through the diode is calculated in (4) and (6). As the current flows through diode for very short duration so it is better to carry out the observation in peak current flowing through diode instead of average current.

In our model, the peak current flowing through charging diode is 255 [A].

One of the main devices of the system is varistor which is selected using the breakdown voltage and energy. The breakdown voltage of the varistor should be selected higher than the charging voltage of the commutation capacitor at normal mode.

Varistor starts to operate when the breakdown voltage of varistor is lower than voltage rating of commutation capacitor and energy starts to flow to the varistor. The varistor energy depends allowable reverse voltage of the commutation capacitor.

E. Heat Sink Design. When designing a heatsink, one should consider how much heat each electronic device produces. Devices such as diodes and SCRs produce a lot of heat but this doesn't last long; hence they're not included in the equation when considering a design. However, devices such as resistors are constantly producing small amounts of heat - so they need to be taken into account when determining the optimal size of the heatsink. The total loss by conduction of the main SCR can be expressed as

$$P_{\mathrm{Total}} = V_{\mathrm{TO}} \times I_{\mathrm{avg}} + I_{\mathrm{rms}}^2 \times R_{\mathrm{T}} \quad (9)$$

where V_{TO} is the threshold voltage of SCR and R_T is internal resistance, respectively. Proper heat dissipation design is crucial to obtain TJ when running at full load. Generally, silicon semiconductors can only handle an ambient temperature of up to 150°C. Because these chips are often used in high-temperature environments with limited airflow, an overheating protection circuit breaker (TSCB) should be added so that the devices can operate within the appropriate safe operating range.

Table 1 – Design parameters and specification

Parameters	**Specification**
Power rating	46.67 [kW]
Line voltage	380 [V]
Full load current	100 [Apeak]
Line resistance R_L	100 [mΩ] (1.316%)
Line inductance L_L	35 [μH] (0.1736%)
R, C	5 [Ω], 25 [μF]
Short fault switch resistance	200 [mΩ]
Range of trip setting	100 [Apeak] → 500[Apeak]

Conclusion

In this research paper, a new Solid-State Circuit Breaker was proposed to carry out the conventional task of breaking and reclosing the system with few added devices. Most common fault known as the short-circuit fault and overload fault was tested in both single phase and 3-phase medium. With the presence of both type of faults in the system, the new SSCB was successful in carrying out the breaker operations. Also, no complex mechanisms of SCR were involved for charging or switching operation. Thus, it can be declared that the proposed SSCB do follows all the principles and requirements of IEEE standards and can safely be implemented to support the modern-day power systems.

REFERENCES

1 **Abbey, C. et al.** «Powering through the storm: Microgrids operation for more efficient disaster recovery» // IEEE Power Energy Mag., May/Jun. 2014. – Vol. 12. – P. 67–76.

2 IEEE Standard Test Procedure for ac High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis // IEEE Standard-C37.09, 1999.

3 **Shen, Z. J.,** «Ultrafast solid-state circuit breakers: Protecting converterbased ac and dc microgrids against short circuit faults [Technology Leaders]» // in IEEE Electrific. Mag. – Jun. 2016. – Vol. 4. – 2, P. 72–70.

4 **Eldine, R. N., et al.** «Smart low voltage ac solid state circuit breaker for smart grids» // Global J. Adv. Eng. Technol. – 2013. – Vol. 2. – 3, P. 71–79.

5 **Meyer, C., Schroder S., and De Doncker, R. W.** «Solid- State circuit breakers and current limiters for medium- voltage systems having distributed power systems» // IEEE Trans. Power Electron. – Sep. 2004. – Vol. 19. – 5, P. 1333–1340.

6 **Meyer, C. and De Doncker, R. W.** «Solid-state circuit breaker based on active thyristor topologies» // IEEE Trans. Power Electron. – Mar. – 2006. – Vol. 21. – 2, P. 450–458.

7 **Kim, J.-Y., Choi S.-S., Kim I.-D.** «A novel reclosing and rebreaking ac thyristor circuit breaker» // in Proc. 2015 9th Int.

8 Power Electron // ECCE Asia. – Jun. 2015. – P. 2574–2581.

9 **Kim, J.-Y., Choi S.-S., Kim I.-D.** «A novel ac solid-state circuit breaker with reclosing and rebreaking capability» // J. Power Electron. – 2015. – Vol. 15. – 4, P. 1074–1084.

10 **Rahimoon R. Ali, Rahimoon K. Z., Jarwar A. K., Shaikh M. F., Hussain M. A.** Analysis of performance of a pv solar cell and effect of physical parameter // Bulletin ToU, Physics, math., comp.sci. series. – Vol. 4. – 2023. – P. 88–103.

11 **Yusof, Y., Sayuti, S. H., Latif, M. A., and Wanik, M. C.** «Modeling and simulation of maximum power point tracker for photovoltaic system» // in PECon 2004 // Proceedings. National Power and Energy Conference, 2004. – 2004: IEEE. – P. 88–93.

12 **Veerachary M.** «Power tracking for nonlinear PV sources with coupled inductor SEPIC converter», IEEE transactions on aerospace and electronic systems, vol. 41, 3, P. 1019–1029, 2005.

Received 09.02.24.
Received in revised form 19.12.23.
Accepted for publication 27.02.24.

Мұхаммед Файзан Шейх, *Рехан Али Рахимун,
Физза Шейх, Абдул Сабур Гүл, Мужтаба Абид Хуссейн
NED Инженерлік-Технологиялық Университеті, Карачи, Пәкістан.

09.02.24 ж. баспаға түсті.
09.09.24 ж. түзетулерімен түсті.
27.02.24 ж. басып шығаруға қабылданды.

ЖАҢА ҚАРАПАЙЫМ ҚҰРЫЛЫМДЫ АЙНЫМАЛЫ ТОКТЫҢ ҚАТТЫ КҮЙДЕГІ АЖЫРАТҚЫШЫН СЫНАУ

Біз үшін дәстүрлі электромеханикалық ажыратқыштардың жанынан өтетін кез келді. Дәстүрлі ЕМ модельдері алғаш ойлап табылғаннан бері біздің күнделікті өміріміздің бір бөлігіне айналды және үнемі өзгеріп отыратын әлем үшін резервтік шара ретінде баға жетпес қызмет көрсетеді, бірақ бүгінгі күні жаңа жоғары технологиялық опцияларды ауыстыру мүмкін емес. Тұрақты ток микрожелілері сияқты электр энергиясын беру мен таратудың жаңа әдістерінен бастап, жартылай өткізгіштер сияқты электроника материалдарының жетістіктеріне дейін, электротехника әлеміндегі бүгінгі жетістіктер электр энергиясын пайдалануды қалай басқаратынымызды қайта қарауды талап етеді-әсіресе оның ең негізгі элементіне келетін болсақ: үзілістер. Қазіргі уақытта бұл процесс ажыратқыштың жабылуын күту кезінде қандай да бір қосалқы механикалық құрылғыны пайдалануды қамтиды; дегенмен, жаңадан ұсынылған

Айнымалы ток SSCB көмегімен сіз қосымша жабдықты қажет етпей-ақ жылдам операцияларды орындай аласыз. Бұл жұмыста ұсынылған айнымалы ток SSCB өнімділігінің ерекшеліктері алдымен бір фазалы SSCB жобалау және модельдеу нәтижелерімен, содан кейін үш Фазалы модельмен және нәтижелермен көрсетіледі. Жұмысты жеңілдету үшін схеманы жобалауға арналған блок-схема да қарастырылған.

Кілтті сөздер: ажыратқыш, қатты күйдегі ажыратқыш, шамадан тыс токтан қорғау, шамадан тыс жүктемеден қорғау, жұмыс режимі.

Мухаммад Файзан Шейх, *Рехан Али Рахимун, Физза Шейх, Абдул Сабур Гул, Муджтаба Абид Хуссейн
Инженерно-технологический университет NED,
Карачи, Пакистан.

Поступило в редакцию 09.02.24.
Поступило с исправлениями 09.02.24.
Принято в печать 27.02.24.

ТЕСТИРОВАНИЕ НОВОГО ТВЕРДОТЕЛЬНОГО ВЫКЛЮЧАТЕЛЯ ПЕРЕМЕННОГО ТОКА ПРОСТОЙ КОНСТРУКЦИИ

Нам пора отказаться от традиционных электромеханических выключателей. Традиционные модели ЕМ были частью нашей повседневной жизни с момента их изобретения и оказывают неоценимую услугу в качестве резервной меры в постоянно меняющемся мире, но сегодня просто нет замены новым высокотехнологичным вариантам. От новых способов передачи и распределения электроэнергии, таких как микросети постоянного тока, до достижений в области электронных материалов, таких как полупроводники, сегодняшние достижения в мире электротехники требуют, чтобы мы пересмотрели то, как мы управляем энергопотреблением, особенно когда речь *заходит о его самом основном элементе: перебоях в работе. В настоящее время этот процесс предполагает использование какого-либо вспомогательного механического устройства в ожидании замыкания выключателя; однако с более новым предлагаемым AC SSCB вы сможете выполнять быстрые операции без какой-либо необходимости в дополнительном оборудовании. В этой статье эксплуатационные характеристики предлагаемого SSCB переменного тока сначала демонстрируются путем проектирования и моделирования результатов однофазного SSCB, затем выполняется трехфазная модель и результаты. Чтобы упростить задачу, также приведена блок-схема для проектирования схемы.*

Ключевые слова: автоматический выключатель, твердотельный автоматический выключатель, защита от перегрузки по току, защита от перегрузки, режим работы

Теруге 11.03.2024 ж. жіберілді. Басуға 29.03.2024 ж. қол қойылды.
Электрондық баспа
7,50 Mb RAM
Шартты баспа табағы 10,01. Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: Е. Е. Калихан
Корректор: А. Р. Омарова
Тапсырыс № 4206

Сдано в набор 11.03.2024 г. Подписано в печать 29.03.2024 г.
Электронное издание
7,50 Mb RAM
Усл.печ.л. 10,01. Тираж 300 экз. Цена договорная.
Компьютерная верстка Е. Е. Калихан
Корректор: А. Р. Омарова
Заказ № 4206

«Toraighyrov University» баспасынан басылып шығарылған
«Торайғыров университеті» КЕ АҚ
140008, Павлодар қ., Ломов к., 64, 137 каб.

«Toraighyrov University» баспасы
«Торайғыров университеті» КЕ АҚ
140008, Павлодар қ., Ломов к., 64, 137 каб.
+7(718)267-36-69

e-mail: kereku@tou.edu.kz
www.vestnik.tou.edu.kz
https://vestnik-pm.tou.edu.kz/