A FAMILY OF VACUUM CIRCUIT-BREAKERS WITH WORLDWIDE APPLICATIONS USING COMMON COMPONENTS

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Today’s product development is aiming to lower costs in order to be competitive on the world market. However, besides material and labour costs also the costs of logistics are essential, but difficult to determine. Design factors influencing the logistics are:

- standardisation of parts of products
- modular parts of products and
- least number of different parts.

Customers on the other side are requesting:

- a high variety of products
- adaptation of products to special needs
- short delivery times and last, but not least also
- low price

ABB has launched in 1997 a vacuum circuit-breaker with magnetic drive technology and vacuum interrupters embedded in epoxy resin, which is shown to be capable of balancing the requests from manufacturer and customer giving a highly competitive product.

The operation mechanism of the new circuit-breaker VM1 is based on a magnetic actuator, which needs a much smaller number of parts than a spring-operated actuator. In comparison to a conventional drive, the VM1 only needs 40% of the parts. The lower number of parts reduces the inventory of the factory and the delivery time.

The vacuum circuit-breaker has an inherent need of contact forces pressing the contacts of the vacuum interrupter together against the electro-magnetic opening forces of the short-circuit currents. This ensures the safe conduction of the short-circuit current across the closed contacts, hence the prevention of welding. The actuator has to be adapted to the peak of the short-circuit current. By varying the width of the actuator this adaptation is simply achieved.

The circuit-breaker does not only consist of the driving mechanics and control, but also – and this is the most important part – of the vacuum interrupter and current carrying parts. The physics of current-interruption in vacuum brings with it an almost linear dependency of the size of the contacts on short-circuit current. Since the diameter of the contacts determines the diameter of the envelope, i.e. the ceramics cylinder, the short-circuit current determines the costs of the interrupter. ABB has developed a family of interrupters with least number of different parts and smallest diameter.

The other parameter determining the size of vacuum interrupters is the length of the ceramics cylinder. The longer the outer insulation, the higher is the flashover voltage withstand ability for air or other gases. The technique of embedding the complete interrupter into an insulating material like epoxy resin allows for the utilisation of only one interrupter with rather short length of the ceramics for different voltage levels. The family of embedded poles for 12 and 24kV, 1250 and 2500A is shown in the figure.

Finally, the increasing requirements of power control in distribution and industrial networks demand for specially tailored switching devices. The special requirements from the customers can only be satisfied at a convenient price, if most of the parts necessary for special switches are derived from the mass product. The magnetic actuator technique using electronic control allows for very similar solutions for e.g. a high speed transfer switch, a railway circuit-breaker for 16/3 Hz or a synchronous switch for capacitive or inductive loads.

Dependent on the transient recovery voltage of the network, the stroke of the vacuum interrupter has to receive different values. By keeping the mechanical transmission the same, the stroke of the circuit-breaker can easily be adapted by varying the length of the plunger inside the magnetic actuator.
La technologie de production d’aujourd’hui vise des coûts faibles afin d’assurer la capacité concurrentielle sur le marché mondial. Néanmoins, les frais de logistique représentent un facteur essentiel, mais difficile à calculer, outre les coûts de matériau et de main d’oeuvre. Voici les points principaux qui influencent sur la logistique:

- standardisation des composants de produits
- composants de produits modulaires et
c- nombre décroissant des différents composants.

D’autre part, les clients exigent :

- une grande variété de produits
- l’adaptation des produits aux besoins spéciaux
- des délais de livraison courts, ainsi que
- des prix bas.

En 1997, ABB lança sur le marché un coupe-circuit sous vide qui possède une technologie de commande magnétique et des interrupteurs sous vide encastrés dans de la résine époxyde. Celui-ci est en mesure de satisfaire aux exigences du fabricant et du client grâce à ses propriétés hautement compétitives.

Le mécanisme de fonctionnement du nouveau coupe-circuit VM1 se base sur un actionneur magnétique qui requiert un nombre de composants nettement inférieur à celui de l’actionneur à ressort. Le nombre de composants moins élevé réduit l’inventaire de l’usine et le délai de livraison.

Le coupe-circuit sous vide fonctionne par efforts de contact internes qui pressent les contacts de l’interrupteur sous vide les uns contre les autres, à l’opposé des efforts d’ouverture électromagnétiques des courants de court-circuit. Cela permet la conduction sûre du courant de court-circuit dans les contacts fermés, c’est-à-dire cela évite les soudages. Il est impératif d’adapter l’actionneur à la crête du courant de court-circuit. Cela est exécuté simplement en variant la largeur de l’actionneur.

La course de l’interrupteur sous vide doit avoir diverses valeurs selon la tension transitoire de rétablissement du réseau. Si la transmission mécanique reste la même, il est possible d’adapter aisément la course du coupe-circuit aux différentes longueurs du conducteur mobile à l’intérieur de l’actionneur magnétique.

Les principes physiques de l’interruption du courant dans le vide est liée à une dépendance presque toujours linéaire de la dimension des contacts sur le courant de court-circuit. Comme le diamètre des contacts de l’interrupteur sous vide détermine le diamètre de l’enveloppe, le courant de court-circuit détermine les coûts de l’interrupteur. La société ABB a développé toute une famille d’interrupteurs dont le nombre de composants différents est inférieur et avec un diamètre plus petit.

L’autre paramètre qui détermine la dimension des interrupteurs sous vide est la longueur des cylindres en céramique. Plus l’isolation extérieure est grande, plus la résistance à la tension d’amorçage pour l’air ou d’autres gaz augmente. La technique d’encastrement de l’interrupteur au complet dans un matériau isolant, tel que la résine époxyde, permet d’utiliser seulement un interrupteur avec une courte longueur de céramique pour différentes plages de tension. La famille de pôles encastrés pour 12 et 24 kV, 1250 et 2500A est illustrée dans la photographie.

Pour finir, les exigences croissantes de la commande de puissance dans la distribution et les réseaux industriels requièrent des appareils de commutation fabriqués spécialement sur mesures. Il n’est possible de satisfaire aux exigences particulières posées par les clients à un prix favorable, que si la plupart des composants nécessaires aux commutateurs spéciaux proviennent de produits fabriqués en série. La technique d’actionneurs magnétiques combinée avec le contrôle électronique permet des solutions très similaires, comme par exemple un commutateur de transfert à haute vitesse, un coupe-circuit sur rail pour 16/Hz ou un commutateur synchrone pour les charges capacititives ou inductives.
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ABSTRACT

The need of increasing the efficiency of production processes in order to be competitive on the world market is a must nowadays. Besides material and labour costs the expenses due to logistic processes are considerable. The new vacuum circuit-breaker from ABB with magnetic drive technology and vacuum interrupters embedded in epoxy resin is an excellent example of how product development can match the factory needs on one side to the customer requirements on the other side. A modular system is described with a family of actuators and interrupter units with the least number of different parts serving the complete range of short-circuit and dielectric ratings. Minor design modifications allow the application to special purpose breakers for synchronous or high speed switching duties.

INTRODUCTION

Today’s product development is aiming to lower costs in order to be competitive on the world market. However, besides material and labour costs also the costs of logistics are essential, but difficult to determine. Design factors influencing the logistics are:

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Customers on the other side are requesting:

- a high variety of products
- adaptation of products to special needs
- short delivery times and last, but not least also
- low price.

ABB has launched in 1997 a vacuum circuit-breaker with magnetic drive technology and vacuum interrupters embedded in epoxy resin, which is capable of balancing the requests from manufacturer and customer giving a highly competitive product [1].

The operation mechanism of the new circuit-breaker VM1 is based on a magnetic actuator, which needs a much smaller number of parts than a spring-operated actuator. In comparison to a conventional drive, the VM1 only needs 40% of the parts. The lower number of parts naturally reduces the inventory of the factory as well as the delivery time, simply because the probability for a missing part is lower.

The vacuum circuit-breaker has an inherent need of contact forces pressing the contacts of the vacuum interrupter together against the electro-magnetic opening forces of short-circuit currents. This ensures the safe conduction of the short-circuit current across the closed contacts, hence the prevention of welding. The actuator has to be adapted to these forces, which depend on the peak of the short-circuit current. In section 2.1 it is shown how this adaptation is simply achieved by varying the width of the actuator.

Dependent on the transient recovery voltage of the network, the stroke of the vacuum interrupter has to receive different values. By keeping the mechanical transmission the same, the stroke of the circuit-breaker is easily adapted by varying the length of the plunger inside the magnetic actuator, which is explained in more detail in section 2.2.

The circuit-breaker does not only consist of the driving mechanics and control, but also – and this is the most important part – of the vacuum interrupter and current carrying parts. The physics of current-interruption in vacuum brings with it an almost linear dependency of the size of the contacts on short-circuit current [2]. Since the diameter of the contacts determines the diameter of the envelope, i.e. the ceramics cylinder, the short-circuit current determines the costs of the interrupter. ABB has developed a family of interrupters with the least number of different parts and smallest diameter, which is found in section 3.1.

The other parameter determining the size of vacuum interrupters is the length of the ceramics cylinder. The longer the outer insulation, the higher is the flashover voltage withstand ability for air or other gases. The technique of embedding the complete interrupter into an insulating material like epoxy resin allows for the utilisation of only one interrupter with rather short length of the ceramics for different voltage levels. Naturally the outer dimensions of the embedded pole are still given by the flashover voltage insulation in air (see section 3.2).

Finally, the increasing requirements of power control in distribution and industrial networks demand for specially tailored switching devices. These special requirements can only be fulfilled at a convenient price, if most of the parts necessary for special switches are derived from the mass product. The magnetic actuator technique using electronic control allows for very similar solutions for e.g. a high speed transfer switch, a railway circuit-breaker for 16/3 Hz or a synchronous switch for capacitive or inductive loads [3, 4]. These applications are presented in section 4.
When closing the two contacts of a vacuum interrupter, the mechanism has to provide a certain overtravel, in order to compensate for unavoidable contact wear and tolerances in the transmission chain. The overtravel is balanced by a spring, which is part of the transmission chain and called contact spring. The closed position of the breaker has to be secured properly, otherwise the contact spring would discharge again. For a spring operated drive, the closed position is secured by latching levers and shafts. For a magnetically operated drive, latching is simply provided by the hold force of a permanent magnet. For tripping, the latching shafts of the mechanism have to be turned and released by an electrical coil, whereas for the actuator the magnetic flux is simply converted by an electrical current. The function of such an actuator is described in [5].

The magnitude of the contact spring is determined mainly by the peak of the short-circuit current. The force of the spring has to be larger than the repelling forces of the magnetic fields induced by the current. On one side, the distribution of current in the leads and the contact construction possesses directions with opposing paths trying to repel the contacts. On the other side, the contraction of current in the contact points themselves try to open up the two electrodes. As known from physics, these repelling forces are proportional to the square of the magnetic flux i.e. the intensity of the current.

The larger the current, the higher the width of the yoke is simply increased by piling up more iron lamination sheets.

At different rated voltages, vacuum interrupters need to withstand different lightning impulse voltages. Therefore, the vacuum interrupters require higher strokes to be suitable for higher voltages. The drive has therefore to be adapted: One option is the variation of the transmission lever ratio, while the other option is the variation of the length of the plunger inside the actuator.

The first option requires the modification of many parts. This is a disadvantage regarding the idea of standardisation.

The second option is much easier. Figure 3 shows, how different strokes are realised with different lengths of the plunger.
linear – 10% more stroke requires 10% more ampere-turns to start the closing operation.

Figure 4 shows the typical shape of the current in the coils of the actuator: It begins exponentially (L/R combination), reaches a maximum that is close to the value required to unlatch the device, decays due to the back e.m.f during the motion of the plunger, and increases again after the plunger has reached its end position and back e.m.f. has vanished. Finally the current is switched off by the control device.

It can be seen that the current increases faster for longer strokes, due to the reduced inductance. Nevertheless, the level of current required to start the operation is reached relatively late (trace 2). For many CB applications, this delay is not acceptable. The delay can be compensated by a reduction of the number of turns of the coil (trace 3). The slope of the current is further increased, as the lower number of turns reduces the inductance.

The family of actuators is extended for higher rated voltages by replacing only plunger and coils. All other parts are standard parts.

FAMILY OF INTERRUPTING UNITS

V

The vacuum interrupter is the “heart” of a vacuum circuit-breaker. In order to cope with the prices achieved for a certain rating, the interrupter has to be tailored to the short-circuit rating. The investigations on current interruption in vacuum have revealed an almost linear relationship of the diameter of the contacts and short-circuit current [2]. This shows a linear proportion of the area of the contacts and the resistive heat generated by the vacuum arc. Since the diameter of the contacts determines the inside dimension of the enclosure i.e. the ceramics and all other parts like shields and covers, the short-circuit rating decisively determines the costs of an interrupter.

Due to its strong development efforts in the vacuum technology, ABB has created a new vacuum interrupter family with smallest diameter and length.

Figure 5 shows the family of vacuum interrupters specially designed with respect to the embedding technique (see 3.2). In comparison with the traditional design, the shape of the different types of interrupters is characterised by the short length of the two ceramics and the long cover on the movable contact side. The two separate ceramic rings fix the inner main shield needed to prevent the ceramics from metal vapour condensation. The long cover on the movable contact side, which gives the new vacuum interrupter family an asymmetrical shape, is required to hide the bellows. Since the covers are made of stainless steel with excellent mechanical properties, there is no mechanical drawback due to their special shape.

All vacuum interrupters displayed in figure 5 contain radial magnetic field contacts, which show – especially for currents <50 kA – a similar or even better short-circuit interruption performance compared with axial magnetic field contacts. Thanks to the embedding technique, one and the same vacuum interrupter can be applied to different voltage ratings without nothing but adapting the rated short-circuit current properly. Thereby the number of interrupters and different parts and therefore the logistic effort is reduced considerably.

The outer insulating surface of a vacuum interrupter is normally controlled by the dielectric properties of air or other gases. This requires a length of the ceramic envelope exceeding the full stroke of the interrupter contacts by at least a factor of 10 to 20. Especially at network voltages of 24kV and higher, the length of the vacuum interrupter is no longer determined by the excellent dielectric insulation ability of contacts in vacuum, but by the flashover voltage of the insulating enclosure in air. Also, sometimes an extended creepage length is required under severe climatic conditions. A rippled shape of the ceramics might be appropriate, but not an optimum because of the limited facilities of shaping the ripples.

By embedding the vacuum interrupter into an insulating material like e.g. epoxy resin, which can be shaped very
easily, the drawbacks described above are avoided. First, the vacuum interrupter can be designed with the shortest possible length of the ceramic envelope as described in section 3.1. Second, an extended creepage length can be easily implemented by properly shaping sheds in the casting mould.

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Figure 6: Embedded poles for:
12kV / 1250A, 24kV / 1250A
12kV / 2500A, 24kV / 2000A
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Figure 6 presents embedded poles for 12 and 24kV at a rated current of up to 1250A and up to 2500A. All poles are equipped with one and the same vacuum interrupter giving a big cost saving potential considering the economy of scale.

The embedding technique has other advantages besides the employment of a universal vacuum interrupter and extended creepage length. The interrupter is perfectly shielded from external influences like dust and moisture. Any additional mounting and securing elements for the current-carrying parts are unnecessary, but provided by the surrounding cast resin. This reduces the number of parts, the assembly time and the failure modes.

**SPECIAL APPLICATIONS**

The principle of the magnetic actuator enables new applications. Three of these shall be presented briefly in this paper: The railway circuit-breaker, the high speed transfer system and the synchronous circuit breaker.

**R**

Railway circuit-breaker for 16.7 Hz applications require fast opening times to prevent damages to the overhead lines in case of short circuits. While this task is difficult to fulfil with a modified mechanical drive, the magnetic drive only needs an adapted coil with a lower number of turns. The required opening time of 15ms can be reached easily.

**H**

The high speed transfer system can be used where two independent feeders are present. If one feeder fails, the system switches this feeder off and transfers the load to the alternative feeder (figure 7). If large motors are present in the load, the phase of the load will begin to drift from the phase of the network. A re-connection has either to be fast or to be delayed until the next phase coincidence occurs.

The solution that we propose here uses very fast circuit breakers to minimise the transfer time. The time from the occurrence of the failure until the transfer is completed in approximately 30ms. This time is so short that the phase error in a typical application still allows the re-connection, avoiding severe transients.

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Figure 7: Fast transfer to alternative feeder
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The circuit breaker for the fast transfer system (figure 8) has a characteristic opening time of 10ms and a characteristic closing time of 16ms. The speeding-up has been realised by an adaptation of the number of turns in the operating coils of the standard actuator A2. Since the current in the coils is significantly higher compared with the standard versions, stronger electronic switches had to be installed to control the current. Still, the same electronic control and power module is used as for the standard applications. The extended switching capability is provided by an additional board, which comes on top of the existing boards. The higher energy consumption is considered by a larger number of capacitors.

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Figure 8: VM1 drive for high speed transfer system
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The synchronous circuit breaker for universal application [3, 4] was designed using three single drives - one for each phase. The independently acting drives ensure that there are no constraints to the synchronisation strategies, both for controlled single-phase closing and opening. The circuit breaker can be used with:

- capacitors, avoiding inrush currents and further reducing the probability of restrikes
- cables, having the same advantages
- unloaded transformers, reducing inrush currents and even avoiding them if remanent flux is considered
- motors, excluding multiple re-ignition phenomena

Figure 9 shows how the three separate “A1” standard actuators are installed inside the VM1 housing.

Also, this circuit breaker can be identified as a member of the ABB vacuum circuit breaker family, since its major components are common with the standard versions. The three independent drives are part of the line of magnetic actuators (figure 2), and the interrupter units are taken from the line of standard embedded poles (figure 6).

PROSPECTS

Today’s product development has the two targets to satisfy customer needs and to decrease production costs, in order to be competitive on the world markets. The VM1 family of vacuum circuit-breakers is based on a common line of magnetic actuators, interrupting units and electronic control devices.

The combination of these components allows to comply with all the standard requirements as well as with special applications like railway circuit-breakers for 16 2/3 Hz, high speed transfer switches, synchronous circuit-breakers, and even outdoor circuit-breakers.

The maintenance-free components ensure reliable service and high customer value. The electronic control is also suited best for a future conjunction with integrated intelligence for diagnosis, measurement and protection.

REFERENCES


