NEW GENERATION OF OUTDOOR VACUUM CIRCUIT BREAKERS WITH RATED VOLTAGE UP TO 40.5 KV

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ABSTRACT

The paper describes design peculiarities of the novel compact vacuum circuit breaker with rated voltage 40.5kV. Design incorporates several novel technical solutions: polycarbonate support insulation, mono-stable magnetic actuator, labyrinth pulling insulator, core-type flexible contact and new compact vacuum interrupter (VI). For current and voltage sensing Rogowsky coil and capacitive dividers are applied. The module is encapsulated into silicon rubber providing required creepage distance and excellent tracking resistance. These novelties together with the extensive modeling of the mechanical and electrical fields followed by design optimization allowed reducing weight by more than 50% compared with alternatives available in the market.

I. INTRODUCTION

Live-tank design

Outdoor vacuum circuit breaker (OVCB) can be divided into two groups: Dead-tank and Live-tank.

In Dead-tank OVCB vacuum interrupter is arranged in a weather-proof way inside a metal enclosure. In comparising with live-tank the dead-design allows implementation of voltage measurement from both side (demands in ring overhand lines) and provides reliable protection internal insulation against weather exposure and contamination. From the other hand the dead-tank modules have higher weight, dimension and cost. As a result for redial line (where enough to measure voltage from a load side) live-tank design looks more attractive.

In live-tank circuit-breakers, the vacuum interrupter is arranged in a weather-proof way inside an insulating enclosure (the vacuum interrupter is at electrical potential, which means “live”). Epoxy and porcelain insulation are usually used for the enclosure.

Overhead lines 36-40,5 kV commonly have radial structure, therefore live-tank outdoor vacuum circuit breaker are generally presented in the market for these voltages.

The live-tank OVCB 36-40.5 kV are possible to divide into two subgroups:

- Assembled design,
- Solid insulated design.

The assembly design is shown in figure 1. A phase consist of two support insulators joined through a lower terminal.

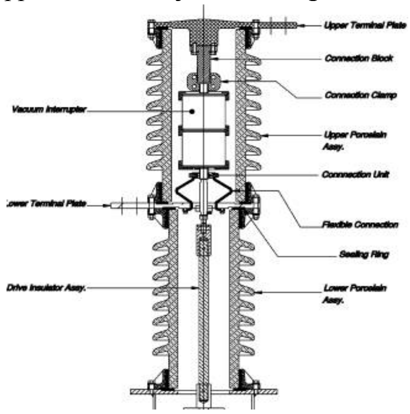

Figure 1: Assembled design

The design may be consider as obsolete because dimensions and weight are beneath of criticism. Current and voltage sensors can be installed as a separate devices, but it leads to transportation, installation and service extra expanses. Moreover epoxy and porcelain lost hydrophobicity within first years of service and together with contamination this leads to developing completely wetted, resistive conductive surface on outdoor insulation. As a result, leakage current are increased which enlarges arcing and risk of insulator flashover.

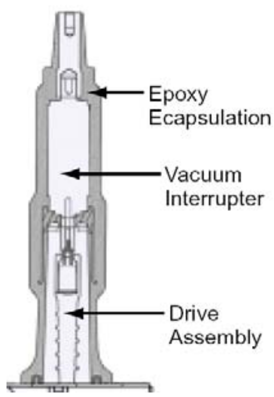

Figure 2: Solid dielectric design

Solidly insulated design have been developed in 1990-s. These OVCB are based on the application of epoxy material, serving simultaneously as mechanical support structure and external insulation (see figure 2). Vacuum

interrupter (VI) is assembled with terminals and then together with sensor are encapsulated by epoxy resin.
Solid insulated OVCB have lower dimensions and weight in comparison with assembled once. Built in voltage and current sensors are also significant advantages of these circuit breakers.
However the solid dielectric design was not avoided disadvantage of assembly one. For outdoor insulation epoxy resins is use. Despite of hydrophobicity and tracking-erosion features increasing, application of an epoxy polymer OVCB is still seems undesirable in region with severely contaminated environments.
Moreover solidly dielectric circuit breakers were designed for IEC and IEEE markets and 38 kV versions have rated power frequency withstand voltage up to Ud=70 kV [2,3] and rated lightning impulse withstand voltage not more than Up=170 kV[2,3]. Russian market needs Ud/Up=95/190 [4], Chinese market requires Ud/Up=95/185 [5]. Solid dielectric OVCB 38 kV are not satisfied requirements of the markets.

Advantages of the silicon rubber for outdoor insulation

The silicon rubber possesses excellent hydrophobicity has high tracking resistance. Though, another feature makes this material attractive for outdoor application. The silicon rubber can transfer hydrophobicity onto polluted layer and this process occurs during lifetime of an insulator [6]. If creepage distance is more than 31 mm/kV hydrophobicity transfer velocity is enough to prevent the flashover in severely contaminated environments. Outdoor circuit breaker OSM/TEL-27-12.5/630-205 with silicon outdoor insulation and creepage distance 860 мм successfully passed environmental test in KIPTS without instance of insulation leakage current exceeding 750 mA [7]. Solid dielectric OVCB OVR-3 (ABB) with the last modification of the Cycloaliphatic Epoxy (so call Hydrophobic Cycloaliphatic Epoxy) and creepage distance 960 mm passed the test with one instance [8]. This is one of the numerous evidences of superiority of silicon rubber for outdoor insulators.
In spite of above mentioned advantages outdoor vacuum circuit breakers 36-40.5 kV with phases fully encapsulated by silicon rubber are not available in the market. The novel outdoor circuit breakers from IG Tavrida Electric are going to change the situation.

II. THE OSM/TEL-40.5 DESIGN

The OSM/TEL-40.5 design is symbiosis of the two above mentioned designs: solid dielectric and assembled. Support insulation consists of two insulators (1, 2, see figure 3) which are jointed through a lower terminal (3). The lower terminal performs three functions : current carry, screening sharp edges of the VI bellow and flexible contact, heat dissipation. The compact VI (4) is fixed between upper (5) and lower terminal (3). The terminals configuration is so design as to decrease induced potential shift of the screen of VI in open position.
Rogovsky coil and capacitor-type voltage sensor (6) are installed near the lower terminal.
Assembled phase together with current and voltage sensors are encapsulated by RTV silicon rubber. The silicon rubber forms:

- insulation of terminals and sensors
- protective layer of support insulator
- ribs in order to provide crepage distance 1020 mm (the ribs shape meets the requirement of IEC60815 [9]).

The OSM/TEL-206 provide Ud/Up=70/170 kV. Creepage distance 1020 mm definitely allows to use this modules in regions with the 3-rd polluted level [9]. Possibility to use the circuit breaker in very heavy polluted areas (the 4-th level IEC 60815 classification [9]) are going to prove by KIPTS test.
In markets with higher Ud and Up requirements (Russia, Chine, ets), in regions with hard requirement concerning creepage distance, the OSM/TEL-40.5 are going to supply with extensions (figure 5). The extensions allow to increase creepage distance up to 1260 mm and BIL level up to 190 kV. The circuit breaker has phase to phase distance 280 mm. Arrangement of the extensions provides minimum strike distance 400 mm (table 1).
Basic parameters of the OSM/TEL-40.5 are shown in the table 1. Dimensions are presented in figure 4.

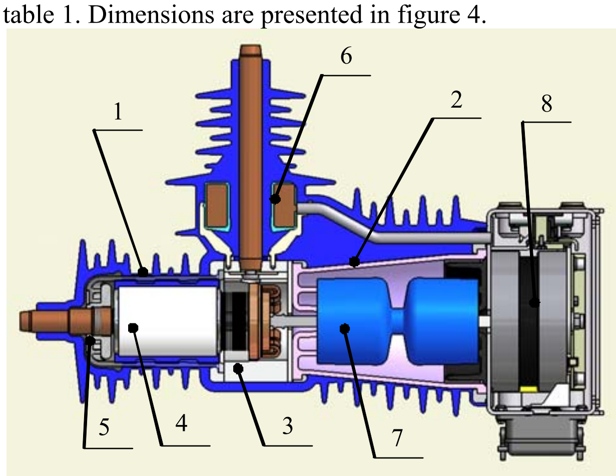

Figure 3: OSM/TEL-40.5 cross section

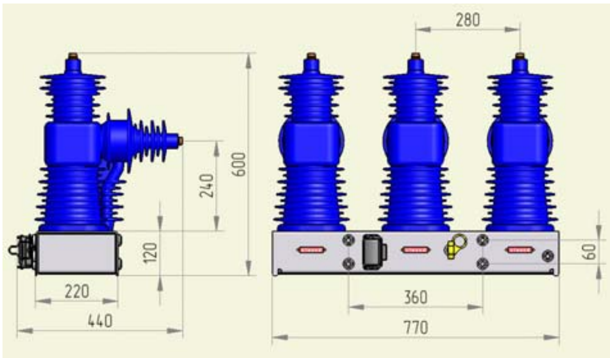

Figure 4: OSM/TEL-40.5 dimensions

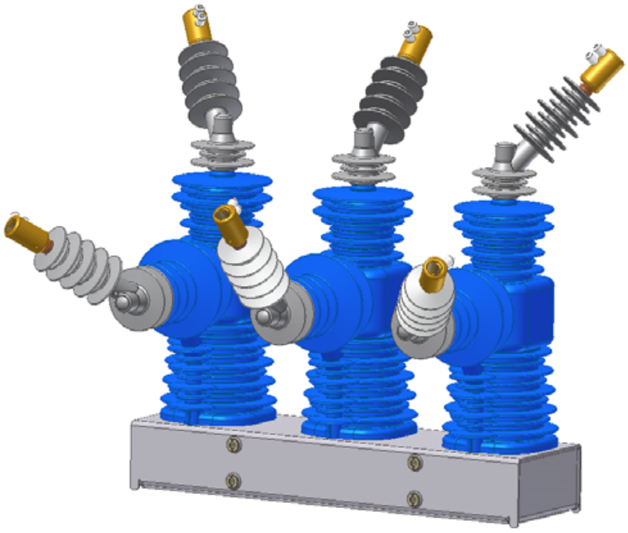

Figure 5: OSM/TEL-40.5 with extensions

Table 1. The OSM/TEL-40.5 parameters

№	Parameter	Value	
1	Rated voltage, kV	40.5	
2	Rated current, A	630	1250
3	Rated symmetrical interrupting current, kA	12.5	20
4	Rated power frequency test voltage Ud, kV	70 (95*)	
5	Rated impulse voltage Up, kV	170 (190*)	
6	Creepage distance, mm	1020 (1260*)	
7	Min external strike distance, mm	240 (400*)	
8	Mechanical life, CO cycles	10 000	
9	Ambient temperature, °C	-60…..+55	
10	Weight, kg	72 (84*)	90 (115*)
11	Dimensions (WxHxD), mm	770/600/440 (870*/820*/710*)	
*- with extensions			

How the parameters have been reached are shown in the following clauses.

Compact VI

The key points of Tavrida's 40.5kV vacuum interrupter design is very compact. The vacuum interrupters have height 153 mm. Such miniaturization has been achieved due to the long-run research in the field of high current vacuum arc and using the finite element analysis

The miniaturization of vacuum interrupter by

1. decreasing of contact gap and height of ceramic envelope
2. reduction of flexible contact mass and bellow rigidity
3. minimization the holding force and providing the minimal VI resistance

simplifies the magnetic actuator design, reduces the energy of control module and simplifies following temperature-rise tests requirements.

Core-type flexible contact

Application of core-type flexible contact allows to decrease the phase height, reduces the actuator energy consuption.

The flexible contact increase height of the phase on 16 mm only. Having resistance near 4 mkOhm it has negligible low opposite force.

The Core-type contact required laborious technological elaboration in order to achieve chip design with stabile resistance under serial manufacture.

Pulling insulator

Pulling insulator length substantially defines a phase height. Application of the labyrinth pulling insulator for the OSM/TEL-40,5 (7, figure 3) allowed to decrease terminal to frame distance up to 200 mm. Meanwhile the pulling insulator provides Ud/Up=95/200 kV.

Concept of labyrinth pulling insulators is described in Tavrida Electric patent [10].

Polycarbonate support insulation

Tavrida Electric has applied polycarbonate polymer for support insulation of vacuum circuit breaker more than 10 year. Field experience enables to claim that polycarbonate is one of the advanced polymer for middle voltage switchgear:

- Mechanical properties, impact strength, thermal properties are enough to design support insulation with wall thickness not exceeded 6 mm (technology requirement)
- Injection molding provides manufacture insulation without minor porous in it.
- Low polymer cost (5.3 EUR/kg) together with chip processing ensures to manufacture low cost insulators.

Application such polymers like polycarbonate has demanded to discover criteria for static and dynamic structural analysis. Positive field experience of Tavrida Electric indoor circuit breaker allows to find out necessary criteria that make possible to design support insulator without huge strength margins.

Silicon rubber encapsulation

Except advantages mentioned in clause I, phase encapsulation by silicon rubber allowed to decrease dimensions to values which require the internal part of the vacuum circuit breaker. For example, lower terminal to frame distance is defined by dimension of labyrinth pulling insulation only.
RTV silicon rubber is used for the encapsulation. The rubber injects in a mould form under low pressure (several bars) so support insulators, terminals, sensor shapes have been optimized in order to prevent shutting an air inside the encapsulation.
Moreover great amount of experiments and calculation have been undertaking in order to guaranty stabile adhesion of RTV rubber to substrates (support insulators, terminals, sensors) in temperature range -60…+90 °C.

Mono-stabile magnetic actuator

All Tavrida Electric circuit breakers are equipped with mono-stabile magnetic actuators. Each phase has separate actuator. All movable parts travel linearly along the phase axis. Lack of transmission knots and friction surfaces provide reliable operation during life cycle of the TEL-type circuit breaker without any maintenance.
Novel magnetic actuator design has been used for the OSM/TEL-40.5 [10, 11]. Phase to phase distance 280 мм allowed to increase outside diameter of the actuator up to 150 mm. This gave an opportunity to decrease height of magnetic actuator up to 100 mm and made frame height 120 mm.
Distinctive feature of actuator's block of the OSM/TEL 40.5 is lack of synchronizing shaft. Each magnetic actuator is operated by separate driver to allow single-phase tripping and eliminate complicated linkage (in compare with shafted variants).
Compact and lightweight design of the mono-stable magnetic actuator has been achieved with the aid of finite-element analysis optimization.

III. CONCLUSION

Long-run research works, skills in finite-element methods analysis, application of advanced materials and technologies has made possible to create compact, lightweight, low cost outdoor vacuum circuit breakers with rated voltage up to 40.5 kV.
On the basis of present parameters the OSM/TEL-40.5 can be done new milestone in development of medium voltage outdoor vacuum circuit breakers.

Figure 6: OSM/TEL-40.5 and assembled design outdoor vacuum circuit breaker with the same parameters

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