MR PUBLICATION

# VACUTAP® Technology
# New Standard for Users of Regulating Transformers

VACUTAP®

# 1 Vacuum Switching Technology

In the course of the last two decades, the vacuum switching technology has developed to become the predominant switching technology in the area of medium voltage substations and high-capacity power contactors. Today, worldwide more than 60% of the demand for circuit breakers in the medium voltage range is covered by vacuum-type circuit breakers.

The importance of the vacuum switching technology is also growing in the field of regulating transformers, which is due to a number of reasons:

Along with the increase in the demand for electrical energy in metropolitan areas, the necessity for installing transformers in buildings creates a need for regulating transformers with reduced fire hazards. In addition to this and with respect to the prevention of water pollution, those regulating transformers are preferable that do not require mineral oil as insulating or switching medium.

Apart from gas-immersed transformers, mainly used in Japan, dry-type transformers, and transformers with alternative insulating liquids meet these requirements which are increasingly asked for.

For this sort of regulating transformers, the conventional tap-changers are little suitable, because the use of mineral oil as switching medium is - for the reasons mentioned above - not desirable and would moreover require technically complex and expensive overall solutions.

For the realization of the features that are increasingly demanded and expected by users, such as

- Low failure rate
- Long-term, uninterrupted availability of the regulating transformer
  - -> Reduced inspection work
  - -> Longer inspection intervals
- Low maintenance costs

the vacuum switching technology offers the best qualification. The special qualities of the vacuum interrupter are that it is a hermetically sealed system, thus, despite arcing, not interacting with the surrounding medium. In addition, high-vacuum generally offers optimal conditions for an extremely quick dielectric recovery after current zero.

## Contents



# 2 Characteristics of the Vacuum Switching Technology

The triumph of the vacuum switching technology is due to a number of technical features giving the vacuum interrupter a significant superiority to competitive switching technologies in the range of low and medium voltage.

These characteristics are as follows:

– The arc in vacuum has a considerably lower arc (drop) voltage, as compared to the arc in oil or $SF_6$.
  - -> Low energy consumption during breaking of the contacts
  - -> Little contact wear

– The already low material wear resulting from the low arc voltage is still more reduced by a high rate of condensation of the metal-vapour plasma on the contact surfaces.
  The combination of both effects helps to achieve a substantially longer contact life, than what OLTC users would expect from e. g. tungsten-copper contacts operated in oil.

– As a result of the hermetically sealed switching chamber, the arc does not get in contact with any quenching medium. Thus the switching characteristics are independent of the ambient media, resulting in the following advantages:
  - No decomposition of the quenching agent
    - -> No carbon by-products when working in insulating oil
    - -> No oil filter plant required
    - -> Easy disposal
  - No aging of quenching material
    - -> Constant switching characteristics during the entire life of the vacuum interrupter.
      The quality of the vacuum in the vacuum interrupter is even increased during the performance of switching operations, because the metal-vapour plasma coming from contact material produced by the arc absorbs free gas molecules (getter effect).
  - No oxidation of the contact surface
    - -> Constantly low contact resistance

– The extraordinarily fast dielectric recovery of up to 10 kV/µs ensures short arcing times of a maximum of one half-cycle even in case of a large phase angle between current and voltage or in special applications (converter transformer) with high dU/dt after current zero.

– Vacuum interrupters only need small contact gaps, which enables a comparatively easy drive with little energy required.

# 3 Application of the Vacuum Switching Technology to On-Load Tap-Changers (OLTC)

**Definition:**
VACUTAP®: OLTC with vacuum interrupters
OILTAP®: conventional OLTC with arcing contacts in oil

Because of the extremely attractive overall profile of the vacuum switching technology, MR decided to design new on-load tap-changer series based on this technology.

This decision was supported by the fact that vacuum interrupters now, after more than two decades of development, have reached a high technical performance and owing to modern vacuum furnace soldering technology eliminating the need of a suction pipe have become so compact that it is possible to install them in on-load tap-changers with the same outer dimensions as OILTAP® OLTC designs.

On the basis of this technology, MR has developed vacuum interrupters for the use in on-load tap-changers.

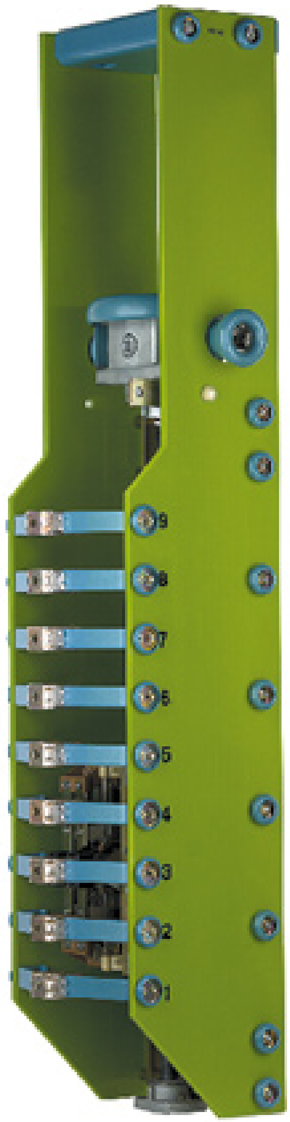
Apart from the size, the central parameters for this development are mechanical life in oil or other liquids in the requested temperature range, the switching behaviour, and the contact wear.

Thus the contact material or contact arrangement, the shielding electrode and the connecting interfaces were optimised, to mention just a few.

These measures ensure reliable operation and a high number of permissible switching operations, as well as low chopping currents of an average of 3 A.

Since the mid 80s, MR has been manufacturing reactor-type on-load tap-changers with vacuum interrupters for the US market. These OLTCs are designed for attached mounting and are filled with insulating oil. Instead of transition resistors, transition reactors are used.

Already 6,500 on-load tap-changers VACUTAP® RMV **(Figs. 1, 4)** with a total of 19,500 vacuum interrupters are in use today.



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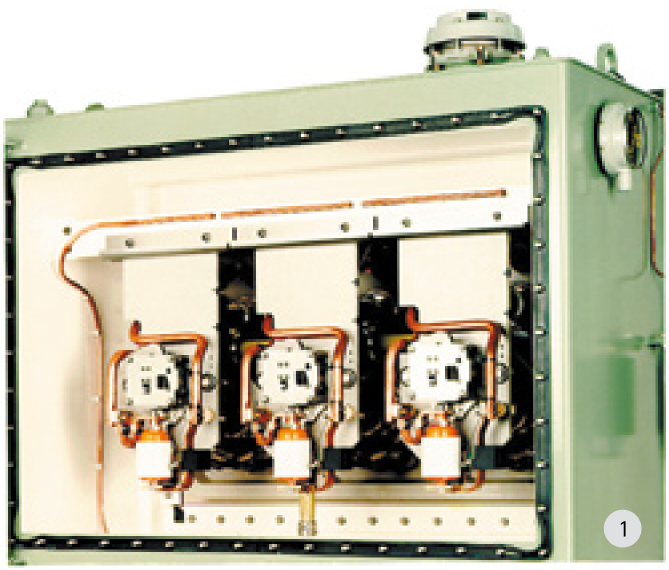

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Particularly in industrial applications (furnace transformers) with extremely high numbers of switching operations (> 100,000 per annum) the vacuum interrupters have demonstrated their opera-tion safety and superiority compared to the switching process in oil.

In 1995, MR produced and marketed its first high-speed resistor-type on-load tap-changer operating according to the vacuum switching technology: VACUTAP® VT **(Fig. 2)**.

This on-load tap-changer is designed for the regulation of dry-type transformers and is operating in air.
So far, approximately 1,000 single-phase units with 3,000 vacuum interrupters have been delivered and are successfully in operation.

Based on the outstanding operating experience gained with vacuum interrupters and the improvements in operation behaviour for the user resulting from this technology, MR is now consistently applying the vacuum switching technology to further product segments.

## 4 On-Load Tap-Changer VACUTAP® VV with Vacuum Interrupters

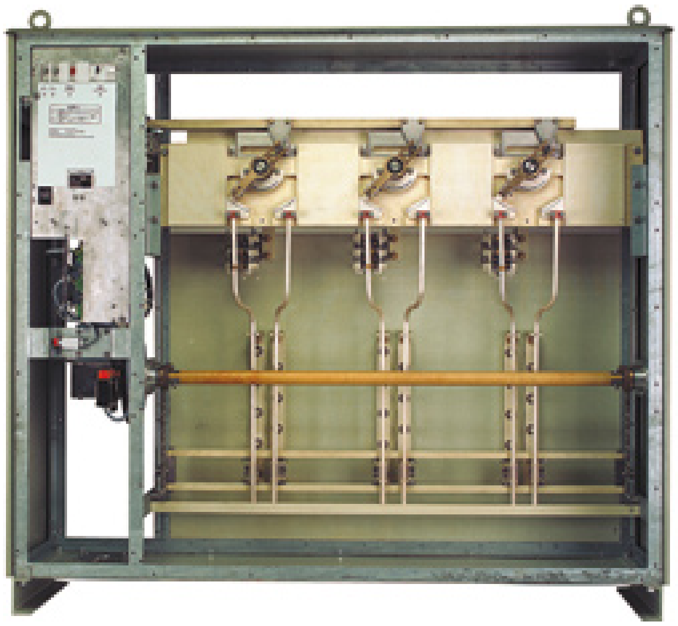
Vacuum interrupters are installed in VACUTAP® AVT **(Fig. 3)** for the regulation of dry-type transformers in the lower power segment supplied to the Chinese market.

Vacuum interrupters are also installed in VACUTAP® RMV-A **(Fig. 4)**, which is the most recent model of its series and is replacing the last model of reactor-type on-load tap-changers with arcing contacts in oil, thus covering the complete RM product range with vacuum switching technology.

The VACUTAP® VV now represents the implementation of the vacuum switching technology in the segment of high-speed resistor-type on-load tap-changers for in-tank installation in transformers. Already 2,100 units with 12,000 vacuum interrupters are at site since the year 2000.

VACUTAP® VV **(Fig. 5)** looks like OILTAP® selector switches V or H. OILTAP® V and H simultaneously select the tap and switch under load (selector switch switching principle).

As opposed to this, VACUTAP® VV has the vacuum interrupter connected in series with tap selector contacts. The vacuum interrupter breaks the current flowing through the path just before the tap selector contacts open, thus ensuring that they are opened while not on load.



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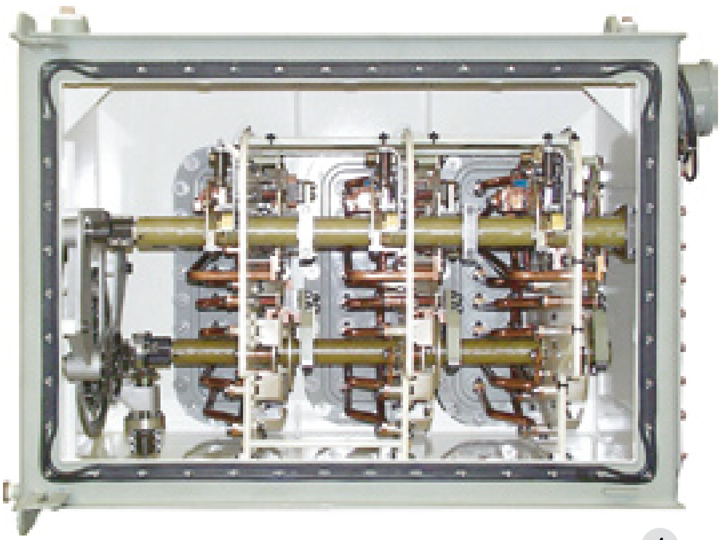

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The path is closed again by the corresponding vacuum interrupter immediately after the tap selector contacts have switched off-load to the neighbouring fixed contact, thus ensuring that the tap selector contacts are closed while not on-load.

Although the outward construction without separate tap selector seems to be contradicting it, VACUTAP® VV can in fact in its function be considered an on-load tap-changer, consisting of a diverter switch and a separate tap selector.

**Fig. 6** shows the connection diagram and the switching sequence from tap 1 to tap 2 (switching steps 1-9).

VACUTAP® VV has two paths: the main path with the main switching contacts (vacuum interrupter) MSV and the corresponding tap selector contacts MTS connected in series, as well as a transition path comprising the transition contacts (vacuum interrupter) TTV, the corresponding tap selector contacts TTS connected in series, and the transition resistor R.

In the initial positions (switching step 1 or 9) both vacuum interrupters are closed, thus not under voltage stress.

The switching operation starts with the opening of the tap selector contacts TTS, disconnecting from the fixed contact of tap 1 (switching step 1 –> 2). As the main path bridges the transition path, no current flows through the transition path despite TTV being closed.

TTV opens (switching step 3) before TTS closes to the fixed contact of tap 2 (switching step 4), as otherwise the tap selector contacts TTS would make the circulating current, which would then result in predischarge arcs, thus producing some carbonised oil.

Therefore, the vacuum interrupter TTV makes the circulating current (switching step 5).

Subsequently, MSV opens (switching step 6) and commutates the load current to tap 2 and to the transition path. Simultaneously, the circulating current is interrupted.

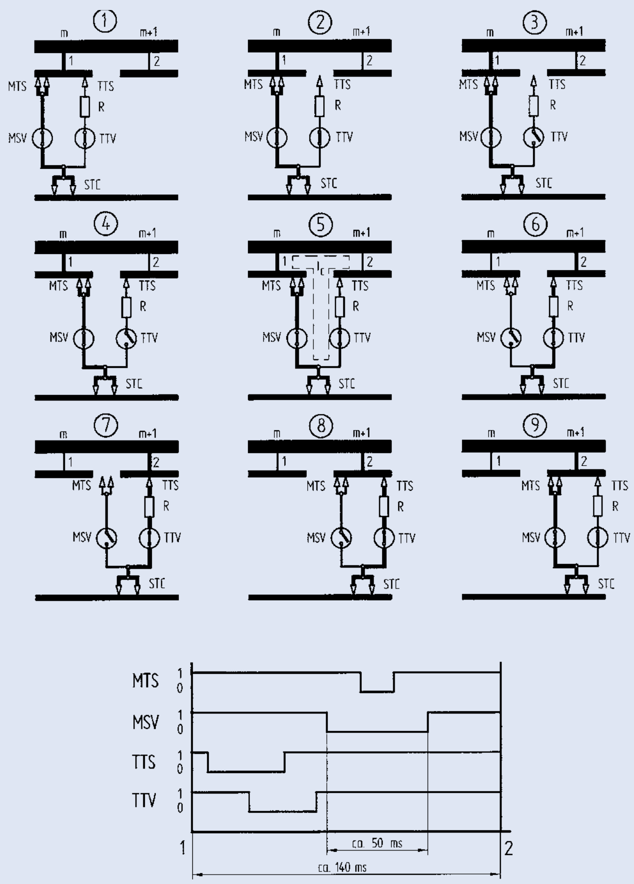
The tap selector contacts MTS now switch from the fixed contact of tap 1 to the fixed contact of tap 2 (switching steps 7, 8) without carrying current.

By the closing of the MSV, shunting the transition path, the switching operation is completed and the new initial position is reached (switching step 9).

Every switching operation in this direction (m –> m + 1), here defined as "RAISE", is performed in the just described manner.

Switching operations in the direction "LOWER" are performed in the order reverse to the one just described: 9 –> 1.

The illustrated switching sequence applies to the 10-pitch VACUTAP® VV. For a 12-pitch VACUTAP® VV, the distance between the fixed contacts is shorter, so that the tap selector contacts TTS are not switched to a fixed contact in any of the two initial positions. Apart from that, the switching operation proceeds as described. The arrangement of the fixed contacts in the area where the voltage for the regulating range may occur is the same way for the 12-pitch as for the 10-pitch VACUTAP® VV.



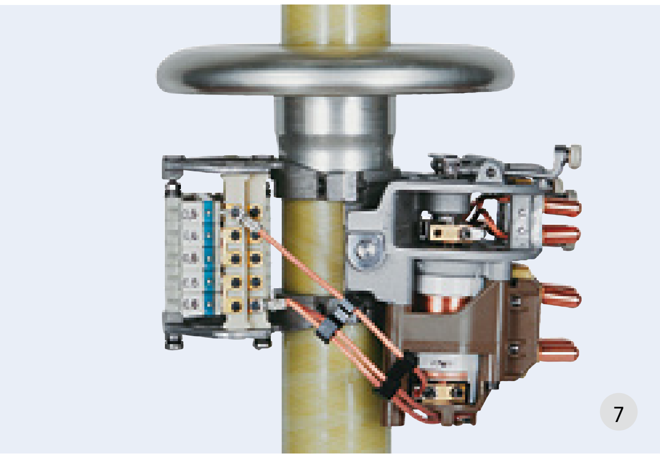

| | |
|---|---|
| MTS | Tap selector contacts, main path |
| MSV | Main switching contacts (vacuum interrupter), main path |
| TTS | Tap selector contacts, transition path |
| TTV | Transition contacts (vacuum interrupter), transition path |
| STC | Sliding take-off contacts |
| R | Transition resistor |
| $I_c$ | Circulating current |

Switching sequence, 10-pitch VACUTAP® VV

6

**Fig. 7** shows a single-phase switching element of VACUTAP® VV. The design and the arrangement of the above described contacts, vacuum interrupters, and transition resistor is illustrated as follows:

- Finger-type contacts on top left: sliding take-off contacts STC.
- Finger-type contacts on bottom left: tap selector contacts MTS of main path. The tap selector contacts TTS of the transition path are located behind the MTS, thus not visible in the figure.
- The vacuum interrupter MSV is shown in axial arrangement between the MTS and the switching column. The vacuum interrupter TTV of the transition path is located behind the MSV, thus not visible in the figure either.
- On the right of the switching column, the supporting frame of the transition resistor is shown in profile. Established transition resistors made of meander-shaped resistor tapes are used, which are also used for the product range of the OILTAP® MR OLTCs.



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It is a known fact, that vacuum interrupters can restrike within up to 50 ms after the completed quenching of the previous arc and remain live until the next current zero, if particles of contact material are moved by vibrations or electrical field forces between the open main switching contacts of the vacuum interrupter. This phenomenon is called late restrike. With respect to the number of interruptions performed, the probability of such an occurrence is only some ppm.

The tap selector contacts of VACUTAP® VV, however, open immediately after the arc in the corresponding vacuum interrupter has been extinguished (see switching steps 6 –> 7 (direction "RAISE"); 8 –> 7, 4 –> 3 (direction "LOWER") of the switching sequence), so that the vacuum interrupter is not under voltage stress. Phenomena such as late restrikes and the resulting danger of short-circuits between taps cannot occur.

As a protective device for the on-load tap-changer, the well-tried protective relay RS 2001 is used which is to be connected to the tripping circuit of the circuit breaker in the usual manner.

As there are no operating arcs in oil which may produce gas, the protective oil-surge relay RS 2001 can be adjusted to the VACUTAP® VV in such a way that malfunctions with relatively small energy consumption already energize the RS 2001.

The innovative use of the vacuum switching technology in the high-speed resistor-type on-load tap-changer VACUTAP® VV offers the user a long-term availability of the transformer - as compared with OILTAP® V or H - resulting from the following facts:

- Maintenance-free up to 300,000 operations
  - –> no time based maintenance
  - –> maintenance-free for more or less all network applications
  - –> significant reduction of life-cycle-costs

| VACUTAP® VRx | Since 2004 $I_{um}$ (A) | | | Since 2006 $I_{um}$ (A) | | | $U_{im}$ | Tap selector | $U_{m\ max}$ (kV) | Comparable OILTAP® |
|---|---|---|---|---|---|---|---|---|---|---|
| VRC I | 401 | 551 | 701 | 1001 | 1301 | | | | | M I 351, M I 501, M I 601, M I 802, M I 1203 |
| VRC II | 402 | 552 | 702 | | | | | | 300 | M II 352, M II 502, M II 602 |
| VRC III | 400 | 550 | 700 | | | | 3.3 kV | Typ M | 245 | M III 350Y, M III 500Y, M III 600Y |
| VRE I | | | 701 | 1001 | 1301 | | | | 300 | RM I 601, RM I 1201, RM I 1201, RM I 1201 (M I 1203) |
| VRE III | | | 700 | | | | 4.0 kV | Typ M | 245 | RM III 600Y |
| VRD I | | | | | 1301 | | | | 300 | M I 1203 (R I 1201) |
| VRD III | | | | 1000 | 1300 | | 3.3 kV | Typ R | 245 | R III 1200Y, R III 1200Y |
| VRF I | | | | 1001 | 1301 | 2600* | | | | R I 1201, R I 2402 |
| VRF II | | | | | 1302 | | | | 362 | R II 1202 |
| VRF III | | | | 1000 | 1300 | | 4.0 kV | Typ R | 245 | R III 1200Y |
| VRG I | | | | 1001 | 1301 | 2600* | | | | R I 1201, R I 2402 |
| VRG II | | | | | 1302 | | | | 362 | R II 1202 |
| VRG III | | | | 1000 | 1301 | | 4.0 kV | Typ R | 245 | R III 1200Y |

* Forced current splitting by two parallel winding branches required

Table 1

# 5 The New On-Load Tap-Changer VACUTAP® VR with Vacuum Interrupters

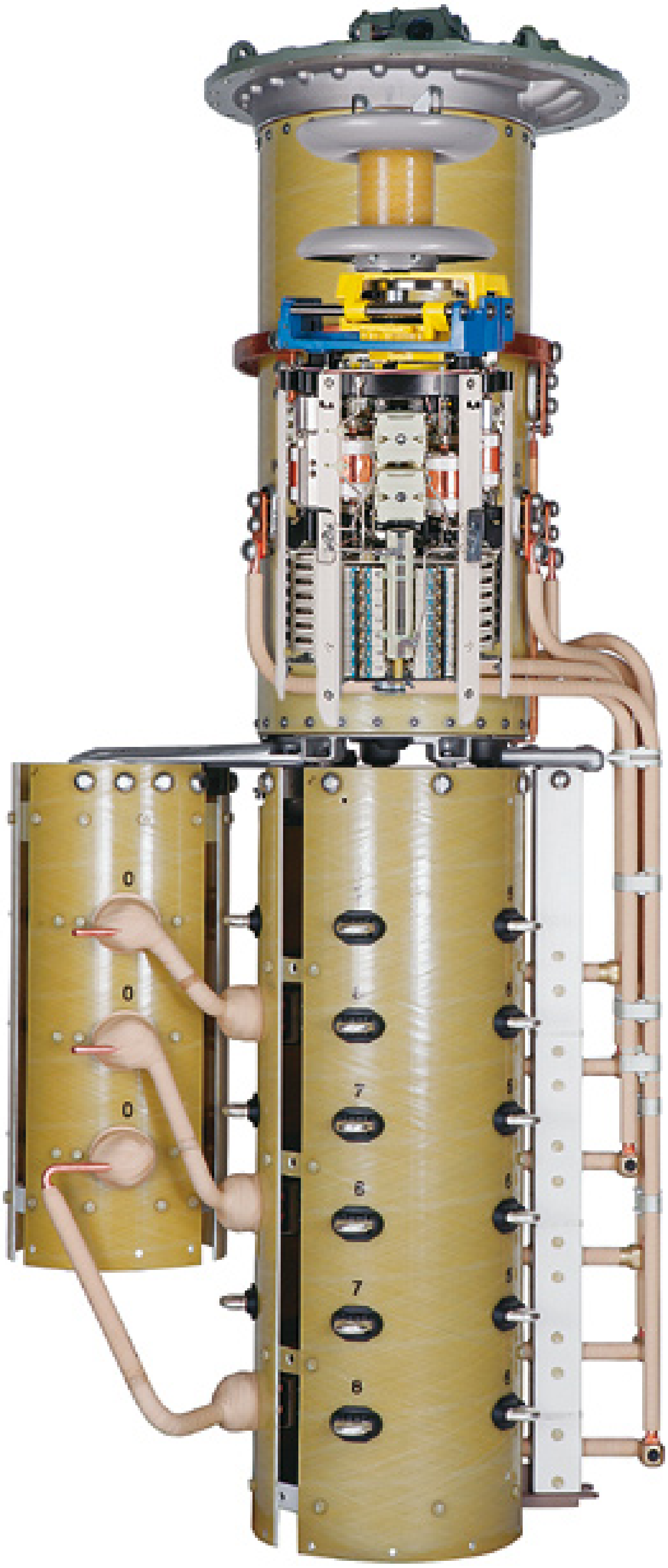
**VACUTAP® VR – Now With Even More Possible Applications**

The VACUTAP® VRC/VRE 700 vacuum on-load tap-changer became available for delivery in September 2004. Since then they have made a name for themselves around the world. Starting in the third quarter of 2006, we will be expanding the high end of the performance spectrum with the new VACUTAP® VRD/VRF/VRG 1300 **(Fig. 8, Table 1).**

The result will convince you: significantly reduced operating costs combined with maximum quality and highest environmental and safety standards.

**Advantages VACUTAP® VR:**

- Experience with the state-of-the-art vacuum switching technology since the 80ies, i.e. 8,000 VACUTAP® OLTCs are in use worldwide.
- Maintenance-free for up to 300,000 operations
  - -> No time based maintenance
  - -> Maintenance-free for nearly all network applications
  - -> Significant reduction of life-cycle-costs
  - -> Increased transformer availability
- Friendly to the environment
  - -> No oil carbonization: no arcing in the insulating oil
  - -> No oil filter unit
  - -> Extended lifespan of the insulating oil
- Designed for selected, alternative liquids
- Extended application of VACUTAP® VR for autotransformers, for regulation at beginning of the delta winding, for HVDC transformers and for sealed transformers
- Ideal for industrial applications and for application in potentially explosive areas
- Vacuum switching technology now also available for almost all the extensive OILTAP® R/RM and M program
- Same diameter (740 mm) of the on-load tap-changer head, same diameter (478 mm) of the oil compartment as for OILTAP® R/RM and M – only minor changes in installation length



8

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