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# Life time enhancement of a Vacuum Interrupter for AC Smart Grid Applications

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**Abstract.** A smart grid is a modern system combined from power system and a network of computers which communicate and process the data achieved from measuring centers located in the power system network. They achieve specific local goals such as: enhancement the reliability, fast and easy control of power network and on-line monitoring.

To control the blocks of a smart grid (entrance or outage), HV, MV and LV switching actions frequently are needed. Nowadays Vacuum interrupters (VI) are the most widespread switching devices especially in LV and MV voltage levels (up to 38 kV), through their reliability, heavy duty and maintenance free characteristics.

In this article, the important lifetime factors of a VI for smart grid applications will be discussed. Further more the closing and opening speed of a proposed circuit breaker mechanism, as the most important lifetime factor, will be so planned that an important enhancement in the total lifetime of the VI is achieved.

**Keywords:** smart grid; vacuum interrupter; lifetime; power system; measuring center.

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## 1 Introduction

Power system consists of generation, transmission, distribution and utilization of electrical power. The distribution and utilization need to embrace active network management technologies with an interface to the transmission system [1].

A smart grid contains new technologies i.e. telecommunication, control, self - healing, efficiency, reliability and security of power systems [1],[2]. The need to meet increasing electricity demand, integrate more distributed sustainable resources including renewable energy sources and advanced storage devices (batteries, compressed air system, fuel cell etc.)[2].

The role of the electric grids is becoming very important to balance the energy demand variations with the fluctuating power generation from the irregular sun and wind [3]. Smart grids must provide the electric energy to all consumers with a highly reliable, cost effective power supply, fully utilizing the large centralized generators and smaller distributed power sources [4].

To switch from modern grid to smart grid all the relevant must be involved: government, regulators, consumers, generators, traders, power exchangers, transmission companies, distribution companies, power equipment manufacturers, etc. [3][4].

The vacuum interrupter is widely established as the technology of choice for the many applications of medium voltage switching from 1kV to 38 kV[5]. It is well known that vacuum interrupters have excellent interrupting capabilities of short circuit currents [5], [6]. They provide good protection for power system equipment including the important load to reduce the intimation time from a fault occurrence to a fault current interruption, also Light weight, simple structure, long life, free maintenance, no explosion and particularly not harmful to atmospheric environment are targets that lead toward recognition of vacuum circuit breaker as the most practical path to reach these ideal goals [8],[9]. An overview of the theory of operation and the internal components of the vacuum interrupter is provided in [7].

### 1.1 Smart Grids

A smart grid is a network of computers and power infrastructures that observe power system parameters and control energy usage. The electrical parameters are sending to the utility by measuring centers equipped with suitable facilities for communication. This electronic device at each consumer premises is called a smart meter. Each smart meter contains a processor, nonvolatile storage, and communication facilities. Smart meters can track usage as a function of time of day, disconnect a customer via software, or send out alarms in case of problems [2]. The smart meter can also interface directly with consumers, in following way:

- Consumers receive a “high cost period” pricing signal.
- Plug-in hybrid electric vehicles stop charging and pump power onto the grid.
- The set points on air conditioning thermostats

are raised by two degrees or turn down the air Conditioner during peak periods.

- The heating coils in cloth dryers turn off.
- One of two heating coils in each storage electric water heater turns off.
- The lights at large retail stores are gradually reduced by 20%.
- Refrigerator and freezer compressors are cycled off.
- Back-up generation at commercial and industrial facilities come on-line.

Smart Grid necessitates two-way flow of electricity and information for monitoring the operation of power system including consumer appliances [1][3]. Consumer may play active role to minimize the demand and supply gap by generating power by installing the solar panels on their roof. Consumers can sell excess energy generated back to the utility, thereby reducing or eliminating energy costs.

Smart grid provides attractive incentives for customers to install green power generation technology. [4]. A scheme of a smart grid is illustrated in Fig. 1.

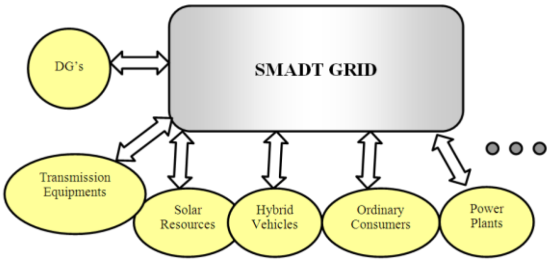

**Fig. 1.** Schematic of a typical Smart Grid

## 1.2 Vacuum Interrupter

### 1.2.1 History and advantages

Commercial products based on vacuum technology first appeared in the late1960's and since then Vacuum Interruption has replaced Oil, Air and SF6 interruption technology to become the dominant MV switching technology world wide (Fig. 2). The main reasons for wide utilization of this type of breakers are:

- Maintenance free property.
- Low cost.
- Environment compatibility (against SF6 greenhouse gas).
- Long life.
- Fast current extinguishing, no explosion danger.
- Light weight and small size.

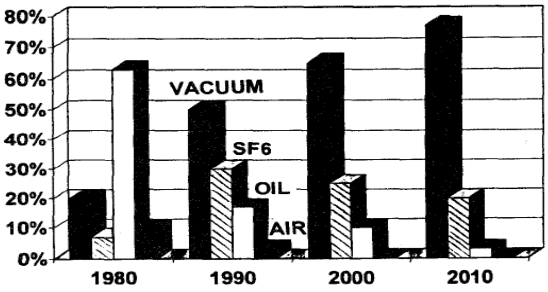

**Fig. 2.** Expansion of vacuum interrupter utilization in MV.

Unfortunately the low dielectric recovery speed of the vacuum gap after the post arc process gets a significant utilization

Limit equal and below medium voltage level.

### 1.2.2 Structure and extinguishing mechanism

A simple structure of a VI chamber, as an active part of a VI, is illustrated in Fig. 3.

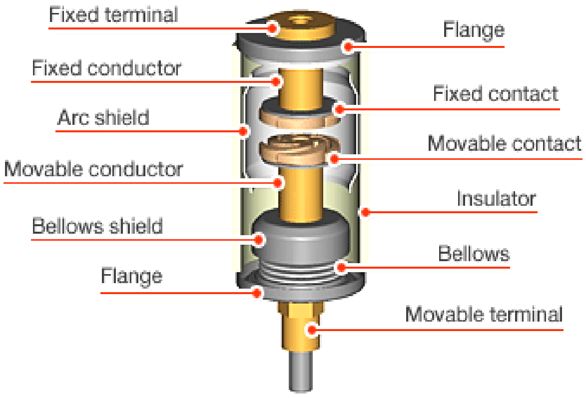

**Fig. 3.** Basic Structure of a Vacuum Interrupter

Simply The vacuum arc will be extingushed when crossing current zero curve(Fig.4). this phenoma is because; the current and hot metal vapor inters the arc space via small points located on the cathode surface named 'cathode spot', and when the total current crosses the zero point the last cathode spot disapears and dielectric recovery process begins.

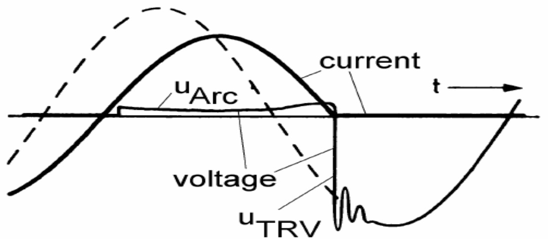

**Fig.4.** Current interruption of a VI when crossing zero point.

### 1.2.3 Life time of a vacuum circuit breaker

The bellows structure and the speed of operation determine the mechanical life of the vacuum interrupter also the electrical life (i.e., the number of close–open operations switching current) of the vacuum circuit breaker is determined by two parameters:

- The arc erosion of the contacts.
- The deposit of metal on the interior walls of the ceramic envelope.

The measured electrical erosion as illustrated in Fig. 5 is a function of the total charge passed by the vacuum arc and the ratio of the final contact gap <*g*> to the diameter of the contact <*φ*>, (i.e., <*g*>/<*φ*>).

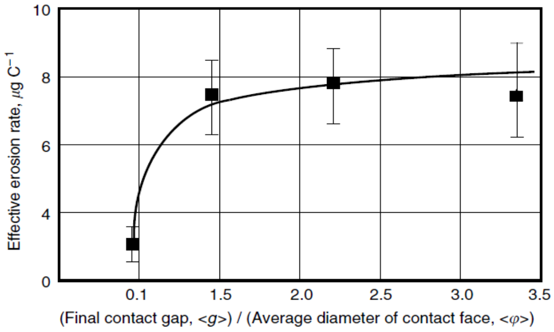

**Fig. 5. Erosion rate of a** Cu-Cr (25%wt.) contact caused by a vacuum arc

The contact structure of a contact also affects the erosion rate of a VI during its operation as illustrated in Fig. 6.

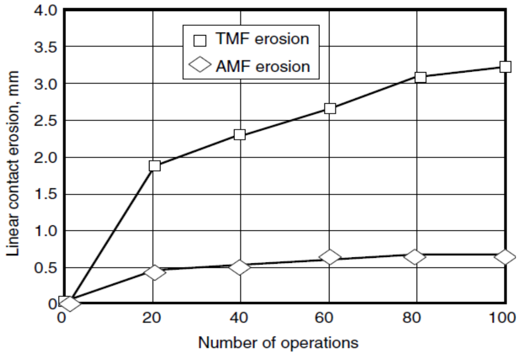

**Fig. 6.** A comparision between erosion rate of AMF and TMF contacts.

Most manufacturers design over-travel distance $d_t$ (free course) about 3 mm for VI's (Fig. 7).

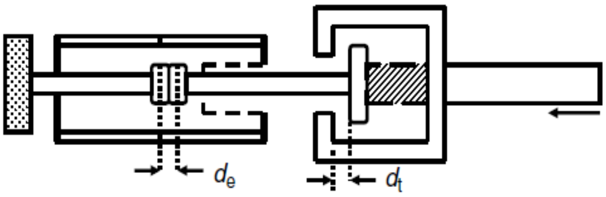

**Fig. 7.** The over-travel distance , $d_t$ ,designed for a VI.

Experimental tests illustrate only 0.3 mm erosion at the surface of contact boot for a typical MV vacuum circuit breaker after 30000 electrical operations regarding to nominal current( $d_e$ in Fig. 7). In conclusion one obtains $3\times10^5$ electrical operation life time for proposed VI. This life time is much more than 30000 guaranteed mechanical life time.

Also the bellows structure and deposit of metal on the interior walls of the ceramic envelope returns to the internal design process of the VI and the arc current. So the only parameter which can be used to enhance the bellows lifetime for repetitive switching operation in a smart grid is mechanical mechanism speed.

## 2 Design Smart Vacuum Circuit Breaker

The bellows cycle life or bellows fatigue life is defined as the total number of complete cycles which can be expected from the expansion joint based on data tabulated from tests performed at room temperature (Fig. 8). A bellows cycle can be defined as one complete movement of an expansion joint from initial position to the extreme position and return to initial position. The bellows fatigue life or bellows cycle life is affected by the following design factors.

- Operating pressure

- Operating temperature
- Bellows material
- Thickness of bellows and number of plies/layers
- The movement per convolution
- Pitch , depth and shape of convolutions
- Heat treatment of bellows

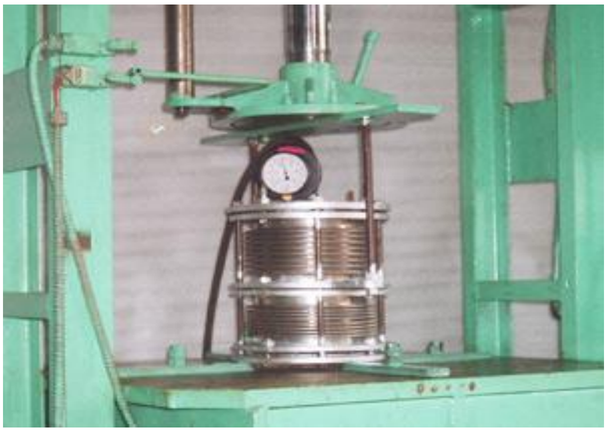

**Fig. 8.** Cyclic life testing of a bellow under pressurised condition

The most important factor in life time of a bellow is operating pressure which is defined by eq. 1.

$$P = \frac{F_M}{A} = \frac{F_M}{2\pi R_B} \qquad \textbf{(1)}$$

In this equation $F_M$ specifies maximum mechanism force and $R_B$ refers to internal bellow radius. From *witzenmann S-N curve* (Fig. 9) we can obtain the relation between lifetime of a stainless steel bellow and the maximum pressure inserted by the mechanism on the bellow.

If the speed of mechanism for a operation cycle is defined by 'u' and supposed constant also consider Δt as a change time for the speed vector in the beginning of motion of the movable contact, regarding to Newton's second law, we get:

$$\Sigma F = F_M - F_B = Ma = M\frac{du}{dt} = M\frac{u}{\Delta t} \tag{2}$$

$$F_B = K_B \cdot \Delta x \ ,(2),(3) \Rightarrow P = \frac{Mu + K_B \cdot \Delta x \cdot \Delta t}{A \cdot \Delta t} \tag{3}$$

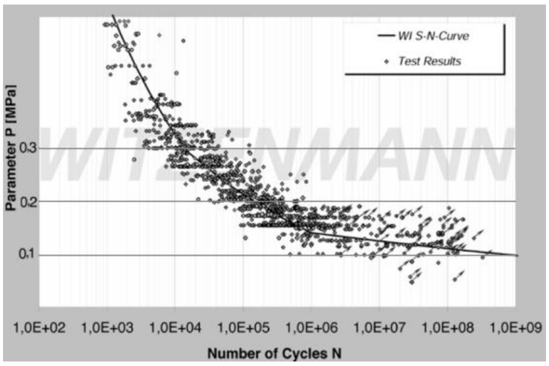

**Fig. 9.** WITZENMANN S-N curve for stainless steel metal bellow

From eq.3 we can obtain direct the relation between deriving speed and the applied pressure by the mechanism. An important factor in the eq. 3 is Δt factor that in a well designed VI should be considered as long as possible regarding to one half periods.

So in a smart VI we can propose an smart strategy to control the speed of the moving contact speed so that for nominal current extinguishing, u vector amount is so reduced that in one half period of the wave the maximum contact gap is reached, but when extinguishing short circuit current the interruption speed should increase to its maximum value to prevent high short circuit erosion process.

## 2.1 Example

For a typical Siemens VI model (3AFS 6211) nominal values are given as below:

" u=2.1 (m/s), Δt=0.1 msec., M=0.73Kg ,A=0.003215 $m^2$ , $d_{gap} = 15mm$ ,operation life=10000,"

Considering the proposed strategy for f=50Hz, one half period of the power wave longs about 10 msec. and the contact speed should be considered about 1.5 (m/s). This reduction in the operation speed regarding to eq. 3 and witzenmann S-N curve increases the operation life about 28000 times. This sever change in life operation is because of the nonlinearity nature of witzenmann S-N curve.

## 3 Conclusion

Smart grids need frequent switching action so that minimize the existing gap between generations, DG's, loads demand etc. and increase the efficiency of the power system. Vacuum interrupters have some inherent suitable properties like maintenance free, low cost and small size, that makes them suitable for MV switching purposes. Switching operation in a smart grid because control goals is more than a common power network, so we studied important factors in the life operation limit of a VI. These factors were divided to electrical and mechanical items. But for nominal current switching only mechanical factor dictates the lifetime limitation.

In continuation the mechanism speed was fully discussed and some essential equations were derived to estimate the lifetime operations number of a VI regarding to different operation speeds and witzenmann S-N curve. Finally an example for a real Siemens VI was solved that illustrated %29 reduction in the speed, increases the life operation of the proposed VI from nominal 10000 times to 28000 operations.

## References

1. M. G. Kanabar, L.Voloh, D. McGinn, “Reviewing smart grid standards for protection, control, and monitoring applications“IEEE smart grid conference,2012,pp.1-8.
2. S. Rahman, “Smart Grid Expectations” IEEE energy magazine, October 2009 pp 34-79.
3. P. McDaniel ,S. W. Smith “Security and Privacy Challenges in the Smart Grid” IEEE SECURITY & PRIVACY, May/June 2009, pp 75-77.
4. M. PAUN, G. LORENZ, “Smart Grids And Networks Of The Future- Eurelectric Views”, 20th International Conference on Electricity Distribution Prague, June 2009, paper 0678.

5. J. Wu, J. Yan, H. Zhao, Z. Ma , "Study on High Voltage and Large Capacity Vacuum Interrupters", International Conference on Power System Technology, 2006,pp.1-5.
6. P. A. van Lanen, R. P. P. Smeets, "Vacuum Circuit Breaker Post-arc Current Modelling Based on the Theory of Langmuir Probes", IEEE TRANSACTIONS ON PLASMA SCIENCE, 2007,pp1-8.
7. P. G. Slade, "The Vacuum Interrupter, Theory,Design and Application ", Book,2010.
8. S.Temborius, M.Lindmayer, D.Gentsch, "Switching Behavior of Different Contact Materials for Vacuum Interrupters under Load Switching Conditions", IEEE 19th Int.Symp.on Discharges and Electrical Insulation in Vacuum, Xi'an,2000.
9. M. B. Schulman and J. A. Bindas, "Evaluation of AC axial magnetic fields needed to prevent anode spots in vacuum arcs between opening contacts," IEEE Trans. Comp. Packag. Manufact. Technol. , Mar. 1994 vol. 17, pp. 53–57.
10. E. D. Taylor, P. G. Slade, and M. B. Schulman, "Transition to the diffuse mode for high-current drawn arcs in vacuum with an axial magnetic field," IEEE Trans. Plasma Sci, Oct. 2003, vol. 31, no. 5, pp. 909–917.
11. S. Cheng and J. Wang, "Study on high-current vacuum arc characteristics under self-generated axial magnetic field of contact at a long contact gap for high-voltage vacuum interrupters," IEEE Trans. Plasma Sci. , Jan. 2009, vol. 37, no.1, pp. 243-253.
12. P. R. Emtage, C. W. Kimblin, J. G. Gorman, F. A. Holmes, J. V. R. Heberlein, R. E. Voshall, and P. G. Slade, "Interaction between vacuum arcs and transverse magnetic fields with application to current limitation," *IEEE Trans. Plasma Sci.* ,Dec. 1980, vol. PS-8, no. 4, pp. 314–319.
13. H. Schellekens and M. B. Schulman, "Contact temperature and erosion in high-current diffuse vacuum arcs on axial magnetic field contacts," IEEE Trans. Plasma Sci. , Jun. 2001, vol. 29, no. 3, pp. 452–461.