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Study on Improvement in Operational Stability of Mercury Arc Converter

Keiji KISHI (岸 敬 二)

This doctoral thesis treats the probability of arc backs in mercury arc rectifiers, experimentally discusses what relationship the probability of arc backs has with the operating conditions and, based on the outcome of the experiment, proposes a concrete method for reducing such probability of arc backs. This method consists of inserting a damping circuit made up of a capacitance and a resistance between the anode and cathode of the mercury arc rectifier. Thus, the thesis further furnishes an explanation on the optimal method for designing the damping circuit and, at the same time, cites actual instances in which arc backs of the mercury rectifier have been reduced. With respect to the operation of dc motors with mercury arc rectifiers, this thesis also cites effects exerted by the voltage and current ripple of a mercury arc rectifier output upon dc machines as well as giving recommended measures for prevention of troubles due to such effects.

The mercury arc rectifier which is dealt with in this thesis is of the six-anode sealed-off iron tank type that finds an extremely wide range of applications such as for iron manufacturing, paper making and for traction. In this thesis, two types of mercury arc rectifier (continuous dc output 850 V 1500 A and 850 V 1800 A) were mainly tested. Arc backs can be broadly divided into "abnormal arc backs" and "arc backs related to anode blocking duty". The former group originates in defective formation of mercury arc rectifiers and therefore has bearing upon the production process. Such a formation defect is rare in recent mercury arc rectifiers.

"Arc backs related to anode blocking duty" of the latter group occur randomly immediately after the commutation and, in terms of Poisson relationship $\left(e^{-\mu}\frac{\mu^n}{n!}\right)$, have the following relationship:

$$W=e^{-\mu}\frac{\mu^n}{n!}=f\left(I_d,\quad \frac{di_a}{dt},\quad T_c, e_i(t).\quad \frac{de_i(t)}{dt},\ Q\right) \tag{1}$$

wherein, I_d: Load current

$\frac{di_a}{dt}$: Rate of decrease of anode current (A/Sec)

T_c: Controlled tank temperature (C)

$e_i(t)$: Maximum value of inverse voltage immediately after commutation (V)

$\frac{de_i(t)}{dt}$: Rate of rise of inverse voltage (V/Sec)

Q: Quality factor of mercury arc rectifier

μ: Constant

n: Constant defined as "operating condition factor" by the author

A large number of mercury arc rectifiers were tested by the equivalent arc back test equipment. From the test results, the author found that the following relations exist:

$$\mu \fallingdotseq 4.0\times10^{-11}\times\left(\frac{di_a}{dt}\times e_i(t)\right) \tag{2}$$

$$n \fallingdotseq No+1.52\times\log_{10}K_1 \tag{3}$$

wherein,

$$No=10^{\frac{1}{2.08}(K_2-T_c\times10^{-2})} \tag{4}$$

K_1 is coefficient of

$$\frac{de_i(t)}{dt} \tag{5}$$

$$K_2=Q-2.0\times10^{-4}\times I_d \tag{6}$$

$$Q=2.63\sim2.84\ . \tag{7}$$

The probability of arc backs W under a given operating condition, could be calculated by substituting Formulas (2) through (7), derived from the current experiments for Formula (1), and it was verified that the value of W thus calculated was close to the actually measured value.

A study was conducted to determine which of the six factors enclosed in parentheses in Formula (1) would have the largest effect upon the probability of arc backs. It was found that $\frac{de_i(t)}{dt}$ had the largest effect. It was experimentally confirmed that arc backs would occur mostly during the approximately 30 μ sec of time immediately following the start of inverse voltage to the anode. It was also found that the probability of arc backs could be reduced by more than about two decimal places by connecting a damping circuit between anode and cathode and lowering the value of $\frac{de_i(t)}{dt}$ from, say, 500 V/μs to 40 V/μs.

On the basis of this observation, the author has proposed an effective damping circuit, establishing the methods for determining the constants of damping circuit, for connecting the circuit, and for designing it.

To ascertain the effect of the damping circuit in field operation, large continuous iron mill installations at three different iron works were placed under continuous observation for a long time with respect to the probability of arc backs. As a consequence, incorporation of the damping circuit was found to lower the probability of arc backs to about one sixth of the value obtained in the absence of the circuit.

Subsequently, another study was made on the effect which the ripple contained in the dc output of the mercury arc rectifier would exert upon the dc motor. As a result of tests, the author determined the allowable value of the ripple contained in the armature current in accordance with the commutation condition of the brush. He proposed that the ripple in the armature voltage would harm the bearing metal, and demonstrated that the use of a ground brush could be an effective countermeasure.

This thesis, which collectively treats the test results obtained over many past years is believed to lend itself of the reduction of the probability of arc backs occurring in power conversion units using mercury arc rectifiers and consequently eliminating possible troubles in dc motors.

The author published a part of his achievements in Electrical Engineering in Japan, Vol. 83, No. 9, Sept. 1963, pp. 7-14, in English, ("Anode Blocking Duty of Mercury-Arc Rectifier"; The Journal of the Institute of Electrical Engineers of Japan). Based on the series of researches, the author has presented 14 papers to the Institute of Electrical Engineers of Japan, and has secured a total of 12 Japanese patents.