Thyristor Rectifier for DC Arc Furnace with Enhanced Arc Stability

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ABSTRACT

In this paper, the fundamental features of the arc stability DC arc furnace have been investigated, from the converter point of view. To compare of measurement arc data from DC arc furnace and the advanced arc simulations of magneto-hydrodynamics (MHD) and the well known Cassie-Mayr arc model have been extensively used. The MHD based arc simulation has been validated in the subcomponent level, for the free burning arc set up in the laboratory. The arc simulation predicted the arc voltage for different currents with the accuracy which satisfies engineering requirements. It has been shown that the arc current steepness at current zero determines the arc stability, and the associated peak arc resistance can be used as its quantitative measure. Based on the presented insight into the DC arc stability, a converter topology solution which realizes an optimal arc stability has been proposed. The main results presented in this paper provide a design guideline for the future DC arc furnace converter topology developments.

1. INTRODUCTION

The electric arc furnaces have been widely used in metal industry, mainly for melting metals. They are one of many high-power electrical loads operating with alternating current or direct current power supply. Arc furnaces are available both as ac and dc furnaces and ac furnace is the dominating type due to its simpler furnace structure. Major technical challenge in power electronics for the nonferrous metal ac arc furnace is the electrical instability caused by unstable reignition of arc current during the zero-crossing of each half cycle. Once the instability occurs and the arc extinguishes, the interruption of arc current in the electrode gives a rise to a significant reduction in furnace power and productivity. Furthermore, the unfavorable excessive level of power unbalance and negative sequence current are caused by the failure of arc reignition[1]. The understanding of arc physics is indispensible for designing an optimized converter topology capable of supporting a stable arcing. There have been several studies on dc arc furnace and its chopper solutions focusing on flicker issues in ac mains [2]-[4]. This paper presents a criterion for ac arc stability and an optimal power converter topology for the stable operation of power supply system in dc arc furnace. The fundamental features of arc stability in dc arc furnace are investigated using advanced simulation technologies. The validated 3D arc model is setup and utilized in order to get realistic arc parameters. The calculated arc parameters are used to model the arc as a dynamic circuit element, using Cassie-Mayr arc model [5] and [6]. For the evaluation of the thyristor rectifier with respect to proposed arc stability function, the arc model is implemented into a circuit simulation tool. Based on the proposed criterion of arc stability, the thyristor rectifier in the real arc furnace system in tested.

2. DESCRIPTION ON TARGET DC ARC FURNACE

Fig. 1 shows the power conversion configuration for DC arc furnace as a main power supply. The circuit parameters and operating conditions are given in Table I.

TABLE I
CIRCUIT PARAMETERS AND OPERATING CONDITIONS

Parameters	Values
Input power(P_{in})	50MW
Input voltage at promary side of transformer(V_{pri})	2.2 KV
Input voltage at promary side of transformer(V_{sec})	300 Hz
Input current at promary side of transformer(I_{pri})	12 mH
Input current at promary side of transformer(I_{sec})	472 uH
Input frequency	60Hz
Output choke inductance	200uH
Firing angle under rated condition	30~50
Normal arc voltage(V_{arc})	0.18
Normal arc current(I_{arc})	37.5

3. DC ARC STABILITY FUNCTION

The following equations describe the physical dynamics of arc [5]-[6].

$$\frac{dR_{arc}}{dt} = \frac{R_{arc}}{\tau}(1 - \frac{U_{arc}I_{arc}}{P}) \quad (1)$$

$$P = P_0 R_{arc}^{-\alpha} \quad (2)$$

$$Stability\ function = R_{arc}(t) \quad (3)$$

4. SIMULATION AND EXPERIMENT FOR STABILITY FUNCTION BASED ON THYRISTOR RECTIFIER

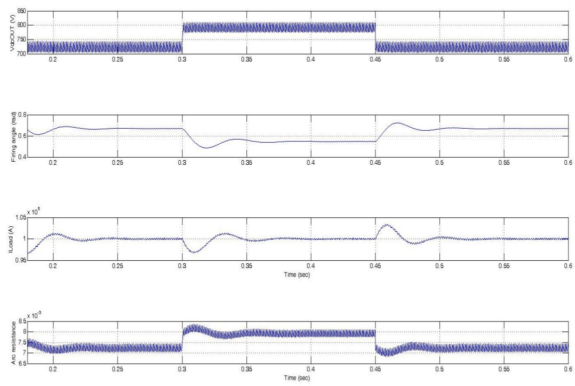

Fig. 2. Simulation result of dc arc furnace based on dynamics arc resistance model.

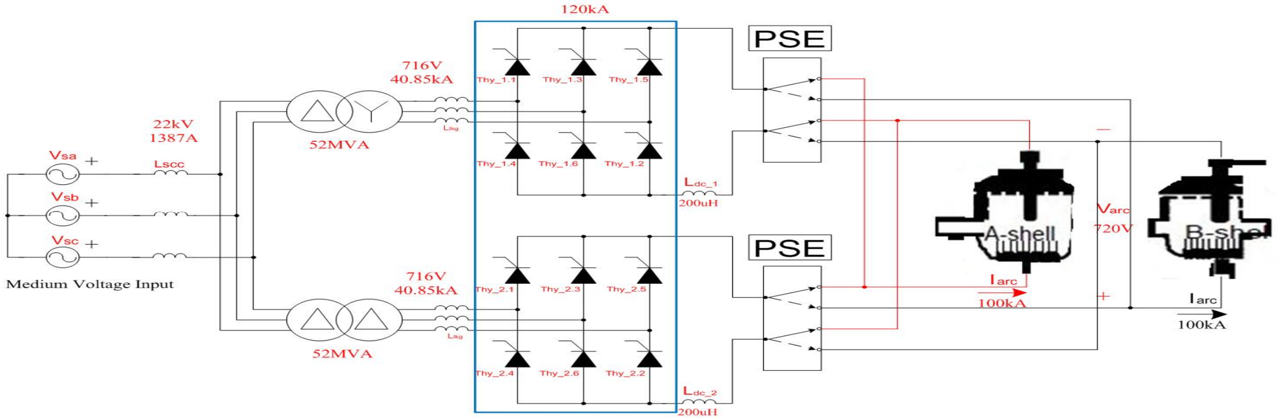

Fig. 1. Schematic of dc arc furnace system furnace

In Fig. 2, the waveform at the top is the arc voltage. It clearly describe the step load disturbance generated at the instant of 0.2 and 0.3s. The waveform at the middle of figure 2 correspond to the firing. The resulting output load current is shown at the bottom of figure.

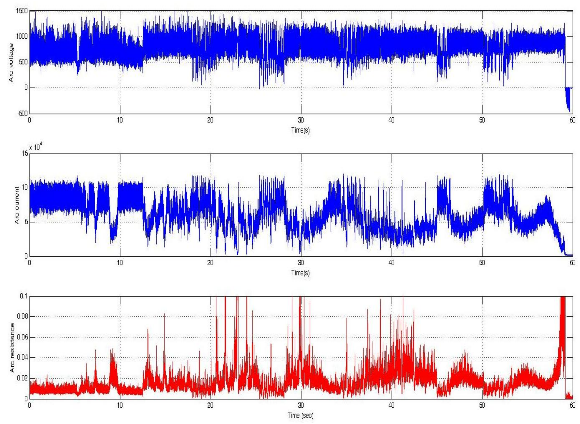

Fig. 3. Experiment result of DC arc furnace based on arc resistance.

Figure 3 shows the operation experiment result of DC arc furnace and Fig. 4 describes the relation of arc resistance with arc voltage.

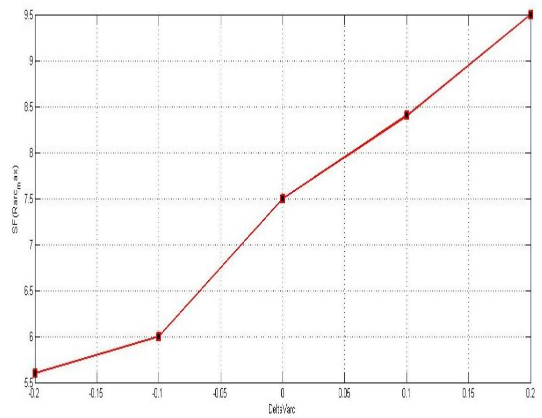

Fig. 4. Arc stability function based on arc dynamics resistance.

5. CONCLUSION

This paper presents a criterion for ac arc stability investigates the performance of thyristor rectifier in the dc arc furnace system. The arc furnace rated for 100kA/720V/72MW has been selected. In order to capture fundamental features of the arc stability, advanced numerical simulations for the arc have been performed. The Cassie-Mayr arc model with realistic arc parameters for the selected furnace rating has been implemented into a power electronics circuit simulation tool. Electromagnetic and flow-simulations have been carried out, in order to determine arc parameters for the selected arc furnace specification. This paper proposes the DC arc stability function based on dynamics arc resistance. Dynamics arc resistance reflect the physical status of the arc and electrical conditions.

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