Control Algorithm of Thyristor Rectifier to Improve Arc Stability in DC Arc Furnace

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Abstract

In this paper fundamental features of the arc stability in DC arc furnace of 720V/100kA/72MW have been investigated. Cassie-Mayr arc model has been employed for the target dc arc furnace. In order to characterize the parameters of Cassie-Mayr arc model and the behavior of unstable arc dynamics, the advanced arc simulations of magneto-hydrodynamics (MHD) has been performed. Based on the results of MHD simulation, dc arc dynamic resistance is proposed to be an effective arc stability function reflecting the instability of dynamic arc behavior. The experimental result confirms the usefulness of proposed dynamic arc resistance as arc stability function. The proposed arc stability function can be regarded as an effective criterion for the overall power conversion system to maintain highly stable arcing operation leading to better productivity and reliability.

1. Introduction

Electrical arc furnaces are used in the steel industry to melt scraps. They are one of many high power electrical loads and can be supplied by either alternating current or direct current. Arc furnaces are available both as ac and dc furnaces and dc furnace is the dominating type due to its simpler furnace structure. The dc solution is less polluting in power networks, regarding flicker, power factor, and harmonics aspects. Classically, MW-range power input required by dc arc furnace is supplied by thyristor rectifiers [1]. 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. The understanding of arc physics is indispensable for designing a control strategy 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 dc arc stability and related control strategy 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 techniques. 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 as in [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 target arc furnace system is tested and the experimental result is provided.

2. Description on Target DC Arc Furnace

Figure 2 describes the power conversion configuration of a main power supply in target DC arc furnace of 720V/100kA/72MW. The circuit parameters and operating conditions are given in Table I.
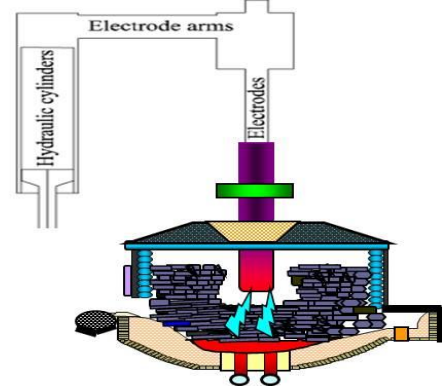

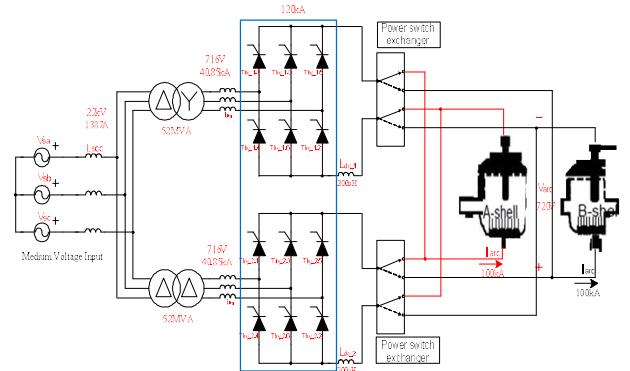Fig. 1. Scrap melting dc arc furnace

Fig. 2. Schematic of dc arc furnace system

TABLE I
CIRCUIT PARAMETERS AND OPERATING CONDITIONS

Parameters	Values
Input power(P_{in})	72MW
Input voltage at promary side of transformer(V_{pri})	22KV
Input voltage at promary side of transformer(V_{sec})	716V
Input current at promary side of transformer(I_{pri})	1378A
Input current at promary side of transformer(I_{sec})	40850A
Input frequency	60Hz
Output choke inductance	200uH
Firing angle under rated condition	30~50degree
Nominal arc voltage(V_{arc})	720V
Nominal arc current(I_{arc})	100kA

3. Arc Model and 3-D Simulation
3.1 Arc model description

Physical arc models are based on the equations of fluid dynamics and obey the laws of thermodynamics in combination with Maxwell's equation. In general, the arc conductance is a

function of the power supplied to the arc channel and the power transported from the arc channel by cooling and radiation time.

$$\frac{d[\ln(g)]}{dt} = \frac{F'(Q)}{F(Q)}(P_{in} - P_{out}) \quad (1)$$

$$g = F(p_{in}, p_{out}, t) = \frac{i_{arc}}{u_{arc}} = \frac{1}{R_{arc}} \quad (2)$$

$$\frac{dR_{arc}}{dt} = \frac{R_{arc}}{\tau}(1 - \frac{U_{arc}I_{arc}}{P}) \quad (3)$$

$$P = P_0 R_{arc}^{-\alpha} \quad (4)$$

TABLE II
PARAMETERS OF GENERAL ARC EQUATION

Symbols	Parameters
p_{in}	Power supplied to the plasma channel
p_{out}	Power transported from the plasma channel
i_{arc}	Momentary arc current
u_{arc}	Momentary arc voltage
R_{arc}	Momentary arc channel resistance

3.2 3-D arc simulation

Figure 3 describes the arc voltage fluctuation under the condition of constant arc current and different contact separation distance. The larger the contact separation distance considered, the larger arc voltage fluctuation caused leading to higher chance of arc instability.
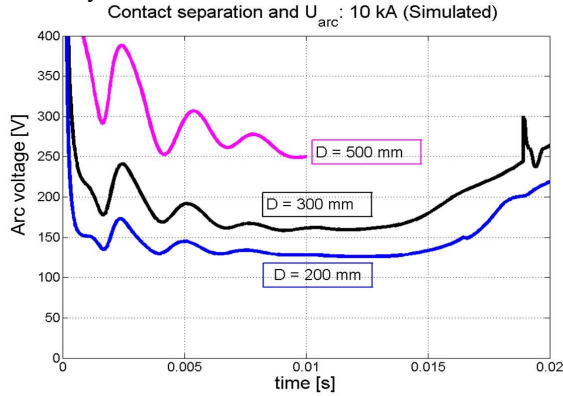
Fig. 3. Variation of arc voltage with contact distance under constant arc current

4. Proposed Criterion on Arc Stability

The proposed arc dynamic resistance serves as an effective criterion for the arc instability condition. The dc arc in general becomes unstable and loses its conductivity when arc channel cools down due to diminishing arc current. Therefore, for stable operation of the dc arc, the peak arc resistance must be kept as low as possible. This understanding can be formalized in mathematical terms.

$$Stability\ function = R_{arc}(t) \quad (5)$$

5. Simulation and Experiment Result

The maximum dynamic arc resistance has been plotted as a function of step arc voltage change in Fig 4. It confirms the fact that larger arc disturbance causes higher arc instability, i.e. higher arc resistance. The improved operational behavior due to newly employed arc stability function is confirmed through the experiment and illustrated in Fig. 5
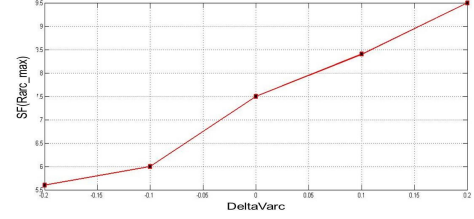
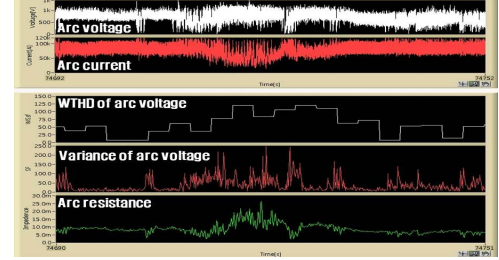Fig. 4. Variation of dynamic arc stability against step arc voltage change in simulation

Fig. 5. Experiment result employing proposed control strategy to enhance arc stability

6. Conclusion

This paper presents a criterion for dc arc stability and 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. Electromagnetic and flow-simulations have been carried out to determine arc parameters for the selected arc furnace specification. The Cassie-Mayr arc model with realistic arc parameters for the selected furnace rating has been implemented into a power electronics circuit simulation tool. This paper proposes the DC arc stability function based on dynamics arc resistance. Dynamics arc resistance reflects the physical status of the arc and electrical conditions. The proposed arc instability function has been proved as an effective control index through simulation and experimental verification.

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