Control Strategy of Smoothing Arc for DC Arc Furnace

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Abstract

Fundamental features of the arc stability in DC arc furnace of 720V/100kA/72MW have been investigated. Cassie-Mayr arc model has been employed and applied 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. The MHD based arc simulation has been validated in the subcomponent level, for the free burning arc set up in the laboratory. From 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 increasingly used in steel industries 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 in scrap melting applications due to its simpler furnace structure. In addition, 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]. There have been several studies on dc arc furnace and its chopper solutions in power supply topology replacing classical thyristor rectifiers [2]-[4]. Most of previous studies focused on flicker issues in ac mains and power quality issues employing dynamic reactive power compensation schemes such as SVC and STATCOM. Once the instability occurs and the arc extinguishes in dc arc furnace, 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. Considering the importance of arc stability and its impact on the furnace productivity, there has been a little work in the field of arc stability and a reliable control strategy to maintain stable arcing conditions inside a dc arc furnace. 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. Since thyristor rectifiers are still widely employed in present dc arc furnaces of many steel industries, arc stability and control strategy are investigated with respect to thyristor rectifier as a main power supply topology. The fundamental features of arc stability in dc arc furnace are investigated using advanced simulation techniques of magneto-hydrodynamics (MHD). The validated 3D arc model is setup and utilized in order to get realistic arc parameters of the model. 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]. From the simulation result using MHD, the arc stability within dc arc furnace is characterized both in qualitative and quantitative manner and suitable arc stability function is proposed accordingly. In addition, the control strategy for a complete dc arc furnace system based on the proposed arc stability function is designed. For the evaluation of the thyristor rectifier with respect to proposed arc stability function, the arc model is implemented into a circuit simulation tool. In order to confirm the effectiveness of proposed concept, the arc stability function and its control strategy is tested in the real arc furnace system of 720V/100kA/72MW. Simulation and experimental result are provided to validate the proposed concept in this paper.

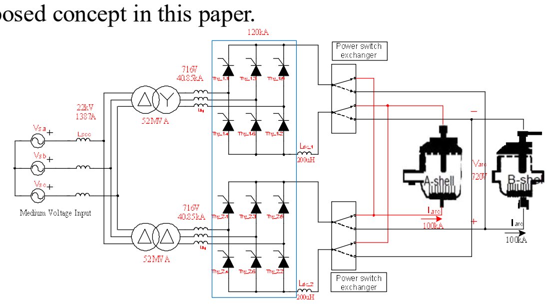

Fig. 1. Schematic of dc arc furnace system

2. Description on Target DC Arc Furnace

Figure 1 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.

TABLE I
CIRCUIT PARAMETERS AND OPERATING CONDITIONS

Parameters	Values
Input power(P_{in})	72MW
Input voltage at primary side of transformer(V_{pri})	22kV
Input voltage at secondary side of transformer(V_{sec})	716V
Input current at primary side of transformer(I_{pri})	1378A
Input current at secondary side of transformer(I_{sec})	40.9kA
Input frequency	60Hz
Output choke inductance(L_{dc})	200uH
Firing angle under rated condition	30~50degree
Nominal arc voltage(V_{arc})	720V
Nominal arc current(I_{arc})	100kA

3. Arc Model and Dynamics

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.

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

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

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

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

Figure 2 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.

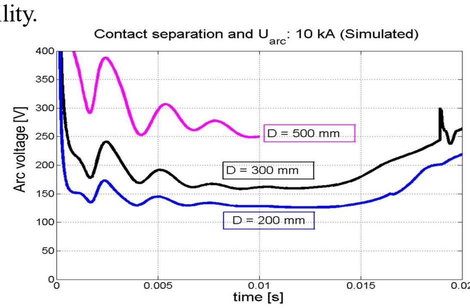

Fig. 2. Variation of arc voltage with contact distance under constant arc current

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.

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

The control algorithm involving proposed arc stability function is explained by the flow chart in Fig. 3. The target reference value of arc stability function depends on the particular manufacturing process and its operating conditions.

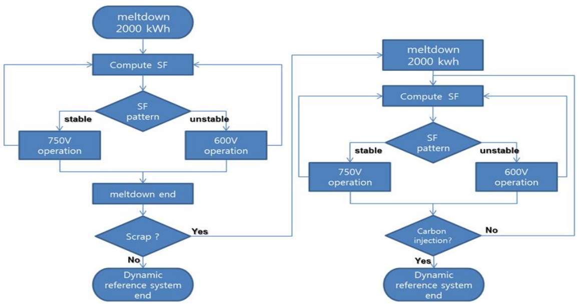

Fig. 3. Control algorithm of dynamic operation in DC arc furnace employing proposed Stability Function (SF).

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. Figure 5 describes the reduced operating time by employing the proposed control strategy based on arc stability function as compared to the conventional control scheme.

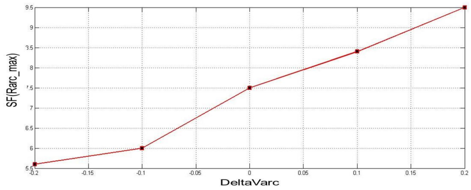

Fig. 4. Variation of dynamic arc stability against step arc voltage change in simulation

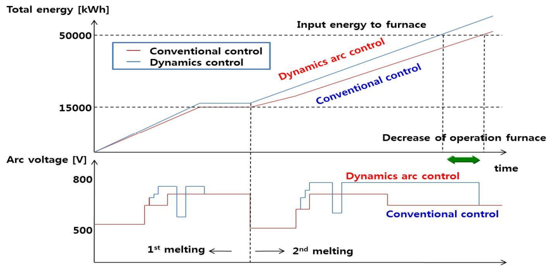

Fig. 5. Experimental result explaining reduction of operating time due to proposed arc stability control strategy as compared to the conventional method.

6. Conclusion

This paper presents a criterion for dc arc stability and investigates the performance of thyristor rectifier in the dc arc furnace system. In order to capture fundamental features of the arc stability, advanced numerical simulations for the arc have been performed. This paper proposes the DC arc stability function and its control algorithm based on dynamics arc resistance. Dynamics arc resistance reflects the physical status of the arc and electrical conditions. An active control strategy to regulate the dynamic stability function is also proposed in this paper. The proposed arc stability function along with the active control strategy has been proved as an effective control variable through simulation and experimental verification. The proposed control scheme has been successfully integrated into the operation of target dc furnace and confirmed to bring about shorter operating time and better productivity.

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