A Study on Medium Voltage Power Supply with Enhanced Ignition Characteristics for Plasma Torch

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ABSTRACT

This paper investigates a power supply of medium voltage with enhanced ignition characteristics for plasma torch. Series resonant half-bridge topology is presented to be a suitable ignition circuitry. The ignition circuitry is integrated into the main power conversion system of a multi-phase staggered three-level dc-dc converter with a diode front-end rectifier. The plasma torch rated for 3MW, 2kA and having the physical size of 1m long is selected to be a high enthalpy source in waste disposal system. The steady-state and transient operations of plasma torch are simulated. The parameters of Cassie-Mary arc model are calculated based on 3D magneto-hydrodynamic simulations. Circuit simulation waveform shows that the ripple of arc current can be maintained within $\pm 10\%$ of its rated value under the existence of load disturbance. This power conversion configuration provides high enough ignition voltage around 5KA during ignition phase and high arc stability under the existence of arc disturbance noise resulting in a high-performance plasma torch system.

1. INTRODUCTION

The high enthalpy plasma torches have been widely used for the incineration of waste materials to reduce organic toxins and vitrify the solid materials through their volume reduction in a non-leachable compact state. The thermal plasma torch is a device believed to have the potential to reduce greenhouse gas emissions in these industry sectors that are currently based on coal-fired furnace technology [1]-[2]. The plasma torch system has an intrinsic electrical characteristic of negative dynamic resistance during steady-state operation [1]. Due to dynamic characteristics of high enthalpy plasma flow and arc fluctuation, the plasma torch system generates an alternating disturbance input to the overall power conversion system [3]-[4]. This alternating disturbance input together with negative dynamic resistance characteristic occasionally lead to the extinguishment of plasma arc unless properly stabilized by a fast regulation of arc current. This paper investigates the power conversion system of medium voltage for plasma torch under dynamic operating conditions during arc ignition phase. The physical characteristics of plasma torch under dynamic operating conditions are modelled and simulated based on three-dimensional magneto-hydrodynamic computation. The result of this three-dimensional simulation is used to formulate the Cassie-Mayr equation for the plasma arc. Series resonant half-bridge topology is presented to be a suitable ignition circuitry in this paper. The ignition circuitry is integrated into the main power conversion system. The arc model based on the Cassie-Mayr equation including proper physical constants for ignition phase is integrated into the circuit simulation of proposed converter topology.

2. MEDIUM VOLTAGE MAIN POWER CONVERSION SYSTEM FOR PLASMA TORCH

Fig. 1 shows a proposed power conversion configuration for plasma torch system 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
Medium voltage ac input (Vsab)	22 KV
Rectifier input voltage (Vsab_sec)	1930 V
IGCT switching frequency (Fsw)	300 Hz
AC line inductance (Lscc)	12 mH (2.4%)
Transformers leakage inductance (Llkg)	472 uH (6%)
DC link voltage (VdcLink)	2500 V
DC load voltage (VdcOUT)	1500 V
DC load currnet (ILoad)	2000 A
Current control loop p-gain (Kpi)	0.18
Current control loop i-gain (Kii)	37.5

3. IGNITION CIRCUITRY FOR PLASMA TORCH

The half bridge series resonant converter is proposed as an auxiliary ignition circuitry in Fig. 2 [5]-[6].

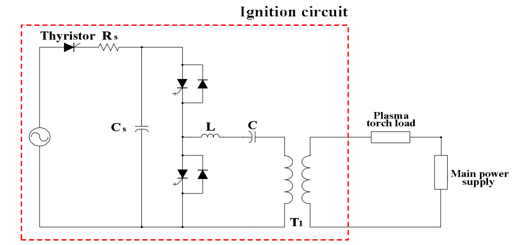

Fig. 2. Employed ignition circuit configuration of half bridge series resonant converter.

4. OPERATING CHARACTERISTICS OF PLASMA TORCH WITH DYNAMIC ARC MODEL

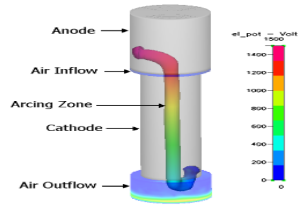

Fig. 3. Equal-current-density surface ($j_{tot} = 5.0 \cdot 10^5 \ A/m^2$) confining arcing zone in plasma torch

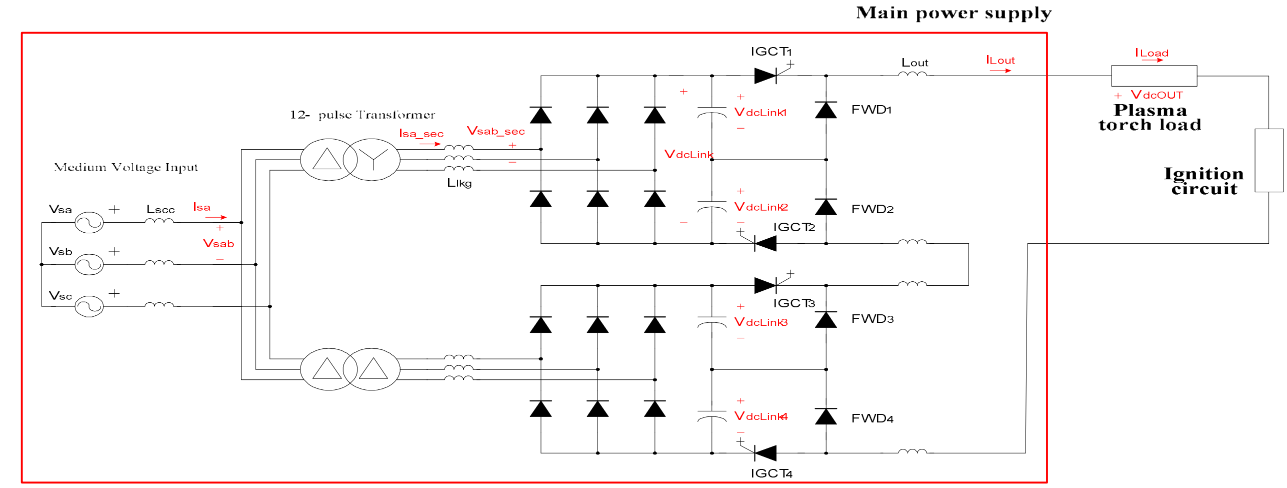

Fig. 1. Proposed power converter configuration for plasma torch system as a main power supply.

Fig. 3 shows the simulated equal-current-density surface and velocity distribution at a vertical cut of plasma torch. The result has been obtained through three dimensional magneto-hydrodynamic simulations. The simulation result of 3-level dc-dc converter in the main power supply is illustrated in Fig. 4.

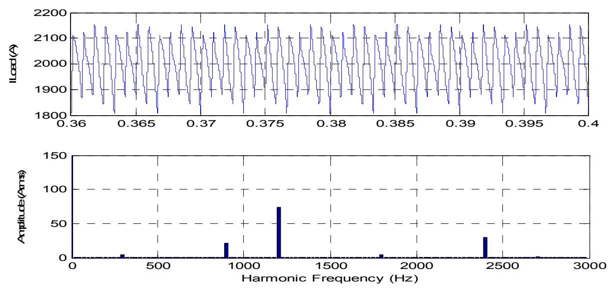

Fig. 4. Frequency spectrum of dc arc current in the dynamic load (From the top: ILoad and frequency spectrum).

The resulting output load current is shown at the bottom of the Fig. 5 confirming the effectiveness of the proposed converter system under the dynamic operating condition.

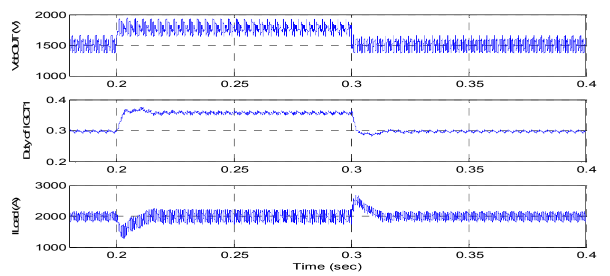

Fig. 5. Transient response to step arc voltage change due to arc instability in the plasma system
(From the top: VdcOUT, turn-on duty ratio of IGCT1, and ILoad).

5. Conclusion

This paper proposes a power supply of medium voltage with enhanced ignition characteristics for plasma torch. Series resonant half-bridge topology is presented to be a suitable ignition circuitry.

The ignition circuitry is integrated into the main power conversion system. The plasma torch rated for 3MW, 2kA and having the physical size of 1m long is selected to be a high enthalpy source. The dynamic characteristics of the DC arc in plasma torch are investigated using advanced 3D magneto-hydrodynamics simulation. These simulations show the existence of arc disturbance noise of 900Hz due to the periodic pressure wave inside plasma torch during steady-state operation. This arc noise can give a rise to arc instability unless properly compensated by current control scheme. Simulation waveform confirms that the proposed power converter system has superior dynamic performance under the existence of load disturbance. The proposed power conversion configuration including the ignition circuitry provides high enough ignition voltage around 5kV during ignition phase and high arc stability under the existence of intrinsic arc disturbance noise resulting in a high-performance plasma torch system.

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