Control and Design of a Arc Power Supply for KSTAR’s Neutral Beam Injection

Dong-Kyun Ryu*, Hee-Jun Lee*, Jung-Hyo Lee** and Chung-Yuen Won†

Abstract – The neutral beam injection generate ultra-high temperature energy in the tokamak of nuclear fusion. The neutral beam injection make up arc power supply, filament power supply and acceleration & deceleration power supply. The arc power supply has characteristics of low voltage and high current. Arc power supply generate arc through constant output of voltage and current. So this paper proposed suitable buck converter for low voltage and high current. The proposed buck converter used parallel switch because it can be increased capacity and decrease conduction loss. When an arc generated, the neutral beam injection chamber occur high voltage. And it will break output capacitor of buck converter. Therefore the output capacitor was removed in the proposed converter. Thus the proposed converter should be designed for the characteristics of low voltage and high current. Also, the arc power supply should be guaranteed for system stability. The proposed parallel buck converter enables the system stability of the divided low output voltage and high current. The proposed converter with constant output be the most important design of the output inductor. In this paper, designed arc power supply verified operation of system and stability through simulation and prototype. After it is applied to the 288[kW] arc power supply for neutral beam injection.

Keywords: Buck Converter, Neutral injection beam, DCDC Converter, Arc power supply

1. Introduction

Recently, in the power industry, the energy source has been dependent on thermal power and nuclear power generation due to the increased demand for power. Thermal power generation incurs problems such as environmental pollution, exhaustion of fossil fuels, and oil shock. Therefore, the dependence of nuclear power generation has increased [1, 2]. With the development of nuclear power generation, the exhaustion of fossil fuels could be resolved because 1kg of uranium is equal to nine drums of oil and three tons of coal. Nuclear power generation can be produced for the other power generation at the same amount of power. In addition, nuclear power has a near zero carbon footprint. However, nuclear power accidents create serious problems of radiation leakage and environmental pollution [3, 4]. Therefore, the research and development of an alternative energy are urgently needed. The methods of generating nuclear energy are divided into nuclear fission and nuclear fusion power generation. In the case of the nuclear fission method, after the enriched uranium and natural uranium are divided, the power is generated by heat. In the case of nuclear power generation, high temperatures and radiological hazards occur due to the nuclear fission. Also, nuclear waste disposal is a serious problem. In the ultrahigh temperature plasma, when the mixture gas of the heavy hydrogen and tritium is fused, thermal energy and decrease of mass occur. In the nuclear fusion power, if the fuel supply is interrupted, the operation is automatically stopped within 1~2 seconds. The heavy hydrogen, which is the main fuel of nuclear fusion power, creates 0.03[g] per 1[L] of seawater. To produce the same amount of gasoline, 300[L] of seawater is required. In this paper, the arc power supply of Korea Superconducting Tokamak Advanced Research (KSTAR) is designed and controlled for the nuclear fusion power [5].

The next generation superconductivity equipment of nuclear fusion research is aimed at nuclear fusion power generation. After the high temperature plasma of one hundred million degrees is applied in the plant, it is maintained in the tokamak. The power is generated by the high temperature of the plasma [6].

The next generation superconductivity equipment of nuclear fusion research consists of a neutral beam injection (NBI), ion resonance heat, microwave heat, current drive, and super high frequency electron resonance heating equipment. The NBI equipment of the tokamak is the main heat source of the definitive device. The characteristic of NBI is the acceleration of ions due to the high voltage beam electrode. After the neutralization equipment is passed, it is neutralized. The same of the un-neutralized ion is transferred to the ion dump by the electromagnet. To generate the NBI, various power supply is needed.

Fig. 1 shows the fundamental circuit system of the
NBI. The NBI system consists of power supply for the withdrawal and acceleration of hydrogen or a heavy hydrogen ion beam, and for the maintenance of the arc plasma power supply. The ion beam of the withdrawal and acceleration consists of three sources of power supply: G1, G2, and G3. The +120[kV] voltage and 70[A] current are supplied by the G1 power equipment, which is provided by the acceleration power supply that manages the withdrawal of ions. The G2 power supply, which is provided by the G1, is the divider of the resister. The G3 power supply includes the deceleration equipment of -5[kV] and 15[A]. Also, the arc plasma power supply maintains the Arc Power Supply(APS) and Filament Power Supply(FPS) [7, 8].

Firstly, the major function of the NBI system is the stability supply of the various DC voltage systems. Secondly, the output voltage and fast control (high speed turn-on/off and re-Trigger time control) need to be operated. Thirdly, if a breakdown occurs in the acceleration part, the load and power supply need to be protected. A fast discharge of power outage is then needed in the transmission line.

The power converter should be designed for the characteristics of low voltage and high current. Also, the arc power supply equipment should be guaranteed for system stability. The proposed parallel buck converter enables the system stability of the divided low output voltage and high current. The operation and characteristic of the arc power supply system are explained in the second chapter. In the third chapter, the output capacitor is eliminated by the arc load feature. The ripple of the output voltage is large due to the absence of the output capacitor. The large ripple has an effect of an arc occurrence. Therefore, the design of the output inductor is important. In the fourth chapter, the NBI control for the arc occurrence is explained. Finally, the stability of the system is demonstrated through the simulation and experimental results. After the prototype of the 2.4[kW] system is verified, it is applied to the 288[kW] arc power supply for NBI.

2. The Arc Power Supply Configuration

Fig. 2 shows the APS as part of the NBI. The main components are rectifier, the filter, and the parallel buck converter. The DC power supply is obtained by authorizing the AC power supply to supply 3 phase 200[V] and by conducting the 3 phase rectifier through the surge suppressor. The input and rectifier include the pre-charge circuit in order to control the inrush current at the start of the operation and to prevent overvoltage of the DC-Link. A stable DC power is maintained using the DC-link reactor and capacitor. The proposed parallel buck converter controls the DC output obtained by the rectifier in the voltage / current that is appropriate for the generation and control of the plasma of the arc chamber [9-11]. The proposed buck converter is basically composed of a high-capacity 6 parallel IGBT and a chopping inductor. The basic output control operation of the APS is conducted in the parallel buck converter. The voltage controller and the current controllers were designed to control the output of the APS.
to have constant voltage and constant current.

The parallel operation can be increased system capacity, but also to reduce the conduction loss at high current. In addition, if a load short-circuit suddenly occurs during the normal operation of the proposed buck converter, the capacitor (which is the main element of the buck converter), is removed permanently. Accordingly, the system is protected by adding a circuit protecting against the short-circuit current. However, the capacitor of the buck converter is removed in order to protect the protection channel when it is operating abnormally. Accordingly, the current and the voltage ripple increase and thus the control technology becomes necessary. In this way, the basic characteristic of the proposed APS is the current source. The operation method of the proposed APS can be selected from the constant voltage, constant current, and constant energy modes, according to the load characteristics of the plasma. The APS is unstable when it deviates from the range of control or when the output ripple is large. Therefore, the operation area of the APS is as shown in Fig. 3.

3. The System design

3.1 LC filter design

An alternating power of 6600[V] is applied to the 1st point of the electric transformer, reduced to 200[V] at the 2nd point, and then passed through the three-phase wave rectifying circuit to acquire direct-current power. The three-phase diode rectifier can deal with high power and a small pulsation quantity on the wave. However, the power conditioning, which comprises a nonlinear load (the same as a diode rectifier), generates severe harmonics in the DC power supply. This can cause problems such as an increase in the capacity of the station connection system, a reduction in its lifespan, and an increased level of damage to the system. An LC filter was used to solve such problems. Furthermore, the input voltage must be stabilized to maintain a constant voltage at the proposed parallel buck converter. However, the output DC voltage of the three-phase diode rectifier contains harmonic elements. The design process of the rectifier involves determining the maximum value of the junction temperature and the maximum rating of the semiconductor. A satisfactory maximum rating is determined from the maximum value of the diode’s inverse voltage and the maximum values of the average rectified current and inrush current. The energy of the capacitor is as follows:

$$ E = \frac{1}{2} CV^2 $$  \hspace{1cm} (1)

Thus, the capacity of capacitor is expressed by (2).

$$ C = \frac{P}{f_{eq} \cdot V_o \cdot \Delta V} $$  \hspace{1cm} (2)

$$ L = \frac{1}{C (2\pi f)^2} $$  \hspace{1cm} (3)

After the cut off frequency is determined, the capacity of Inductor L can be obtained as follows. Therefore, the damping resistor was added to the capacitor and thereby the peak of the cut off frequency was restrained.

3.2 The parallel buck converter design

The APS for the KSTAR NBI is designed to provide low voltage and high current. Therefore, if a parallel structure is not used, the rating is compromised which endangers the stability of the system during incidents. The current is distributed using parallel switches and diodes in the proposed parallel buck converter in order to improve the rating of the system. This enhances the most important feature stability. The voltage is generated during the arc generation, which renders the use of the output capacitor impossible. Therefore, the design of the output filter, using only an inductor and removing the capacitor according to the load characteristics, is also important.

The buck converter design condition is such that the current ripple must be within 2% of the current value when the rating load is 10%. Furthermore, the voltage generated during arc generation renders the use of the output capacitor impossible. Thus, the design of the output inductor is important for obtaining the output voltage and current performance necessary for the arc load. Fig. 4 shows a simplified schematic of the buck converter.

![Fig. 4. Simplified buck converter circuit](image-url)
Fig. 5. Equivalent buck converter

Fig. 5 shows an equivalent circuit during normal operation used to design the parallel buck converter output filter. The proposed parallel buck converter does not have a capacitor on the output. Therefore, the converter can be expressed as being equivalent to a first order RL circuit. Inductor current can be defined $I_{omin}$ and $I_{omax}$ at the steady state. Thus, inductor current ripple is expressed by $I_{omin} = 39.6[A]$ and $I_{omax} = 40.4[A]$.

Switch turn on initial state

$$t = DT_{s}, \ i(0) = I_{omin} \quad (4)$$

Switch turn off initial state

$$t = (1-D)T_{s}, \ i(0) = I_{omax} \quad (5)$$

At the switch turn-on and off, substituting initial value of output current is shown as follows:

$$i_{on}(t) = \frac{V_o}{R} \left( I_{omin} - \frac{V_o}{R} \right) e^{\frac{t}{T_s}} \quad (6)$$

$$i_{off}(t) = I_{omax} - e^{\frac{t}{T_s}} \quad (7)$$

The steady state response of the output current and voltage of buck converter is shown in the Fig. 6. Duty of Buck converter is defined using switch turn-on and off. Inductance is expressed using (6), (7).

At the switch turn-on and off, output inductance is calculated using (8) and (9). Thus, $K_1$ and $K_2$ value can be calculated. The $K_1$ and $K_2$ value is included current ripple and voltage variation rate of buck converter at steady state. two inductance can be calculated through (5), (6). And two inductance is equal $6[mH]$.

Switch turn on

$$L = \frac{RDT_{s}}{-\ln K_1} = \frac{V_o}{I_o} \frac{G_{min}}{(-\ln K_1) f_{sw}} = \frac{V_o \cdot G_{min}}{(-\ln K_1) \cdot f_{sw} \cdot I_o} \quad (8)$$

Switch turn off

$$L = \frac{R(1-D)T_{s}}{-\ln K_2} = \frac{V_o (1-G_{min})}{(-\ln K_2) f_{sw}} = \frac{V_o \cdot G_{min}}{(-\ln K_2) \cdot f_{sw} \cdot I_o} \quad (9)$$

where,

$$K_1 = \frac{1+r}{2} \frac{1}{G_{min}}$$

$$K_2 = \frac{1-r}{2} \frac{1}{G_{min}}$$

Current ripple ratio : $r = \frac{\Delta I}{I_o}$

Minimum voltage gain $(G_{vmin})$ : $\frac{V_o}{V_{omin}}$

4. System control

4.1 Arc power supply control

In the case of the PI controller, the fast response is good, the composition is simple, and it is thus well used. In addition, the PI controller includes the integral, and thus the steady-state deviation can be guaranteed as 0 for the unit step input.

However, the trend of continuously conducting an integral calculus of error can cause a problem when the output of the controller is limited. The output of the controller is limited mostly for the following reasons. The voltage command, which is the output of the current controller, occurs in the actual power rectifier. Limitations are given to the output value of the power rectifier following the available DC voltage level and the used PWM method. In a system with a limited output of the controller, when there is actually a limitation to the output, the handling of the
generated error is delayed. In this case, the integrator becomes saturated due to the accumulated error (integral value), and this phenomenon is called the wind-up of the integrator. In this case, even if the load of error is reversed, the output of the controller remains at the maximum value or the minimum value, regardless of the value of the feedback, because of the integral value inside the integrator which is already accumulated. Until this is resolved, a phenomenon occurs in which the closed-loop control cannot actually function. As a result, the output of the controller does not properly react to the error and thus a large overshoot to the response occurs. In order to prevent this phenomenon, the internal value of the integrator needs to be properly limited after determining whether or not the output of the controller is limited.

For this, the Anti-Windup control was conducted for the buck converter. Fig. 7 shows a block diagram of the tracking calculation anti wind-up controller. The tracking calculation method is used to solve the wind-up. Ka is used to refer to the anti wind-up feedback gain. When the controller saturation occurs, the feedback gain is multiplied following the saturated amount and eventually reduces the input value of the integrator; however, its weakness is that it differs following the operation conditions.

The saturation value can also measure the output of the driver. The proposed system demands a fast dynamic characteristic without overshoot. When overshoot occurs, the system is unstable, and thus an unwanted arc occurs. In addition, the slow dynamic characteristic cannot guarantee the occurrence of plasma and the beam injection time.

Therefore, this system demands a controller with a fast dynamic characteristic and no overshoot.

In order to examine the control characteristic of the proposed system, the response of the output voltage regarding the voltage command was expressed in a transfer function. If the composition is conducted as Closed-Loop following the Mason equation, it is the same as \( H1 \) and \( H2 \).

The forward path gain of the system is as follows.

\[
P_I = \frac{k_p s + k_i}{s} \cdot \frac{1}{Ls + R_{load}} \quad (10)
\]

The gain of each loop \( H1 \) and \( H2 \) :

\[
H1 = \frac{1}{Ls + R_{load}} \quad (11)
\]

\[
H2 = \frac{k_p s + k_i}{s} \cdot \frac{1}{Ls + R_{load}} \quad (12)
\]

\[
V_{in} = \frac{P}{1 - \Delta} = \frac{k_p s + k_i}{s} \cdot \frac{R}{Ls + R_{load}} + \frac{1}{s} \cdot \left( \frac{k_p s + k_i}{s} \cdot \frac{R}{Ls + R_{load}} \right)
\]

It can be expressed as \( \Delta = H1 + H2 \). In addition, the transfer function was obtained following the Masson equation.

The controller design and system stability were analyzed using the transfer function. The main characteristic of the proposed system is stability. Therefore, the PI controller to which the Anti-Windup method (which has a good transient state of dynamic characteristic) is applied, was applied to the system.

4.2 NBI control

The NBI ion source accelerator forms an acceleration electric field by using high voltage and high current and then generates an arc plasma. Even during normal operation, dielectric breakdown frequently occurs through the plasma between the acceleration and deceleration electrodes inside the ion source. Therefore, the rapid
control of the current and voltage was an important aspect of the design for all power supplies in order to protect the ion source and to secure the continuity of the experiment. In addition, a circuit and a control mechanism that can protect the ion source when dielectric breakdown occurs are also needed.

Fig. 8 shows normal operation control of arc generation. The FPS is first heated to produce the arc electric discharge. The arc electric discharge is then started after injecting the electric discharge gas (hydrogen or heavy hydrogen). The FPS is operated in CV mode. This operation mode has the advantage of maintaining a constant heating temperature of the filament, and the arc electric discharge occurs stably when additional heating is executed during the beam extraction. In addition, the gas for the arc electric discharge is injected for about 1.5 ~ 2 seconds prior to the occurrence of the arc. If gas is injected at a faster rate, the gas accumulates in the electric discharge container, placing a burden on the operation of the vacuum pump. However, if it is injected too slowly, the occurrence of the plasma arc becomes unstable.

The APS can be operated by selecting the CC, CV or CP mode. In the case of the CV mode or the CC mode, as the filament heating voltage increases, the arc current reacts sensitively to the filament voltage. Therefore, the arc electric discharge is controlled in the CP mode.

Plasma = Filament + Gas + Arc
(14)

Eq. 14 is the arc electric discharge plasma. Due to the arc electric discharge, at the time of beam extraction, the deceleration voltage is first authorized by operating G3, and soon after the acceleration voltage is authorized by operating G1. If G1 is authorized before G3, a mass backflow electronic current is included in the beam current from the start of beam extraction, causing the high-voltage power supply to stop. Afterwards, the arc electric discharge plasma is generated and the beam extraction is started. The beam extraction with high voltage is described by (15).

Ion Beam = Plasma + G3 + G1
(15)

However, if disorder ensues due to high voltage occurring at acceleration during the beam extraction, or if the NBIS operates abnormally or an unwanted beam occurs in the output terminal of the arc power supply, the abnormal arc output is rapidly discharged and the system is quickly stopped.

Fig. 9 shows the arc occurrence control logic at the time of an abnormal operation.

When the high-voltage disorder of the ion source in which the arc beam is generated occurs, the arc power supply and the G3 and G1 supplies stop. However, the filament power supply and the gas injection do not stop. When the system restarts, the recurrence of the arc plasma is difficult, and the system operation restarts within 10 ms, with the continuous authorization of the regeneration of the arc plasma by the filament voltage. The pre-arc increases the heating voltage by about 10% 10 ms prior to the start of the electric discharge. This method effectively reduces the time required for the electric discharge plasma to reach the stabilization state. It also maintains the stabilization of the plasma during the electric discharge or the progress of the beam extraction. In addition, it controls the power supply so that the filament

![Fig. 9. Abnormal operation control of arc generation](image)

![Fig. 10. Power supply signal flow diagram](image)

http://www.jeet.or.kr | 221
heating voltage can be lowered or raised. Fig. 10 shows the NBM entire control system. The Cooling and Gas control conducts radiant heat by using a water cooling system and thus the radiant heat system control and the control for Gas injection were conducted. In addition, the NBI system control controlled each power supply system (FPS, APS, G1, G2, and G3). The parameter of the NBI system control has setting the voltage control and current control parameter. It then conducts an operation time setting. During the setting, if Hardwired interlock (Fast) occurs, the NBIOS operation is stopped even during the beam injection, thus becoming the Not Ready state. In addition, if Abnormal Interlock (slow) occurs, the operation is possible by only obtaining the Run permission again after the end of the beam injection. In order to operate by integrating all the power supply systems included in NBI, communication is conducted with the DSP built in the power supply system itself. The input and output voltage of each power supply, Fault list, Fast & slow interlock and run/stop/Emergency are sent and received through the Optic Digital in/out.

For the control system, the Allen-Bradley Control Logix 5000 Serise was used, in which the compatibility of the supervisory controller of the top rank is possible. Other ancillaries include the timing module for the timing needed at the time of the beam injection, the signal process module for the gang control and the interrupt correlation between each power supply, and the power supply system to stably supply power supply, etc.

5. Simulation and Experimental Results

As described in this paper, In order to prove the theoretical analysis, simulation were conducted on the proposed systems, this paper conducted simulations and experiments using the 2.4[kW] APS in order to verify the performance of the output voltage and current needed for the arc load. Table 1 shows the parameters of the 2.4[kW] APS.

Fig. 11 shows the simulation schematic of the APS. The simulation parameter was composed of various factors in order to examine the general system operation characteristics, and the control algorithm was realized with a delay-locked loop (DLL). The composition of the DLL is realized with a constant voltage and constant current controller.

Fig. 12 shows the synchronized PWM signal of the parallel switch.

Fig. 13 shows the output voltage and the output current at the time of the full load of the 2.4[kW] APS.

### Table 1. 2.4[kW] arc power supply system parameter

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>Vin</td>
<td>200 V ac</td>
</tr>
<tr>
<td>Output voltage</td>
<td>Vo</td>
<td>80 V dc</td>
</tr>
<tr>
<td>Output current</td>
<td>Io</td>
<td>40 A</td>
</tr>
<tr>
<td>Output inductor</td>
<td>L_{buck}</td>
<td>6 mH</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>F</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Input filter</td>
<td>L</td>
<td>50 μH</td>
</tr>
<tr>
<td>Input filter</td>
<td>C</td>
<td>6800 μF</td>
</tr>
</tbody>
</table>

![Fig. 11. Simulation schematic](image)

![Fig. 12. The PWM waveforms of parallel buck converter](image)
Table 2. 288[kW] arc power supply system parameters

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>$V_{in}$</td>
<td>200</td>
</tr>
<tr>
<td>Output voltage</td>
<td>$V_o$</td>
<td>160</td>
</tr>
<tr>
<td>Output current</td>
<td>$I_o$</td>
<td>1800</td>
</tr>
<tr>
<td>Output inductor</td>
<td>$L_{out}$</td>
<td>0.8</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>$F$</td>
<td>5</td>
</tr>
<tr>
<td>Input filter</td>
<td>$L$</td>
<td>72.4</td>
</tr>
<tr>
<td>Input filter</td>
<td>$C$</td>
<td>4560</td>
</tr>
</tbody>
</table>

Fig. 14 shows the 2.4[kW] APS. The controller used is TMS320F28335. The 2.4[kW] APS consist of LC filter, diode rectifier, controller, 6 parallel IGBT, Gate drive. The gate drive was created using the opto isolation so that it could be used at low voltage and high current.

Fig. 15 shows the synchronized PWM signal of the parallel switch. In order to conduct the parallel control of the proposed parallel buck converter, the PWM signal needs to be synchronized. In addition, the synchronized PWM that shows 2.4[kW] was equally applied in the 288[kW].

Fig. 16 shows the output voltage and the output current at the time of the full load. The output voltage is 60[V] and the output current is 40[A].

Table 2 shows the parameters of the 288kW APS.

Fig. 17 shows the 288kW APS applied to the NBI system. The actual system was cooled using a water cooling system depending on the temperature. In addition, a notch filter was used for the protection of the system. At the time of the experiment, the Arc verified the experiment by considering the normal mode and the abnormal mode.

Fig. 18 shows the output voltage and current of the 288kW APS. It can be seen that the voltage and current are constantly supplied by the output while the real NBI was operating in the system.

Through this, it can be seen that the voltage and current of the load are maintained at constant temperature. Therefore the experiment was conducted using the resistance load. During restart after the pre-arc, if overshoot occurs in a state of excess output voltage and at the current of the APS, an unwanted arc electric discharge occurs in the system. Therefore, above all, an output which has a rapid transient response and no overshoot should be forced to occur in the system.

Fig. 18(a) shows the voltage and current of the APS at

http://www.jeet.or.kr | 223
the time of abnormal operation or restart.

Fig. 18(b) shows the output voltage and current wave forms of the 288kW Arc power supply.

Fig. 19 shows the output voltages and currents of the filament, the arc, G1, and G2 in the normal mode while the NBI was undergoing integrated operation. The load is the ion source at the time of the integrated operation. The pre-arc was operated for 2 seconds, and the main-arc was operated for 5 seconds.

Fig. 19(a) shows the arc output voltage, 50.32[V], and the current, 725[A].

Fig. 19(b) shows that the G1 voltage is 97.2[kV] and the current is -43[mA], and the G2 voltage is 82[kV] and the current is 36.48[A].

Fig. 20 shows the NBI abnormal mode. The pre-arc was

![Fig. 18. The arc power supply output voltage and current (Resistance load): (a) The normal operation; (b) The abnormal operation without overshoot](image)

![Fig. 19. The normal operation of The NBI (Load: Ion source): (a) FPS and APS output voltage and current; (b) G1 and G2 output voltage and current](image)

![Fig. 20. The abnormal operation of The NBI (Load: Ion source): (a) FPS and APS output voltage and current; (b) G1 and G2 output voltage and current](image)

![Fig. 21. The arc chamber of arc power supply](image)
operated during the experiment for 2 seconds and the main was operated for 5 seconds. At the time of abnormal output, the arc power supply and the G1 and G2 power supply system restart. The arc output voltage is 51.68[V] and the current is 750[A]. Fig. 20 shows that the G1 voltage is 100.5[kV] and the current is -46[mA], and that the G2 voltage is 82[kV] and the current is 38[A].

Fig. 21 shows the arc electric discharge generated in the ion source by normal operation of the NBI system. The generated arc is incident upon the tokamak. The reason for conducting the arc to the tokamak in the state of neutral beam injection is that if it is conducted as such for a beam of ions with an electric charge, it is impossible to penetrate the strong magnetic field over the tokamak.

6. Conclusion

This paper describes the design and manufacturing of the proposed 2.4kW APS as a simplified model. The proposed 288kW APS was verified through simulations and experiments. It obtained the following results.

Firstly, APS designed the capacity of the buck converter output inductor and solved the problem of the parallel operation of the IGBT by following the movement characteristics of each switch with the current source converter.

Secondly, the most salient requirement of the operation at low voltage and high current is system stability. Therefore, this paper verified the stability of the APS in order to design the system and to obtain nuclear fusion energy. Accordingly, this work is expected to significantly contribute to the development of the future nuclear reactor, which is attracting attention as a next-generation energy source. It is one of a number of realistic countermeasures for the energy crisis that may occur due to the exhaustion of fossil fuels.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(No: 2014R1A2A2A05006744)

This work was supported by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20124010203300)

References


Dong-Kyun Ryu

He received the Ph.D degree in Electronic Electronical and Computer Engineering from Sungkyunkwan University, Suwon, Korea., in 2012. He is a Principal engineer of Circuit Drive Solution Division Power Development Group-1 in Samsung Electro-Mechanics, Suwon, Korea. He is currently working toward Ph.D degree in Electronic Electronical and Computer Engineering from Sungkyunkwan University, Suwon, Korea. His research interests include robust control of power electronic devices and Powr converters for renewable energy system.

http://www.jeet.or.kr | 225
Hee-Jun Lee  He received the B.S degree in Information and Communication Engineering from Soonchunhyang University, Asan, Korea, in 2004, and the M.S degree in Mechanical System Engineering from Sungkyunkwan University, Suwon, Korea, in 2011. He is currently working toward Ph.D degree in Electronic Electronical and Computer Engineering from Sungkyunkwan University, Suwon, Korea. His research interests include robust control of power electronic devices and advanced motor drive control.

Jung-Hyo Lee He received the B.S. degree in electrical engineering from Konkuk University, Seoul, Korea, in 2006, and the M.S. and the Ph.D. degrees in electrical engineering from Sungkyunkwan University, Suwon, Korea, in 2008 and 2013, respectively. From 2013, He has been a senior researcher of automotive component R&D Team in LG Innotek. His research interests include converters and inverters for motor drive application.

Chung-Yuen Won  He was born in Korea in 1955. He received the B.S. degrees in Electrical Engineering from Sungkyunkwan University, Suwon, Korea, in 1978, and the M.S. and Ph.D. degrees in Electrical Engineering from Seoul National University, Seoul, Korea, in 1980 and 1987, respectively. From 1990 to 1991, he was with the Department of Electrical Engineering, University of Tennessee, Knoxville, as a Visiting Professor. Since 1988, he has been with a member of the faculty of Sungkyunkwan University, where he is a Professor in the College of Information and Communication Engineering; also he is the director of Samsung Energy Power Research Center. He was the President of the Korean Institute of Power Electronics in 2010. Since 2011, he has been a director of the Korean Federation of Science and Technology Societies. His current research interests include the power electronic of electric machines, electric / hybrid vehicle drives, power converters for renewable energy systems. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE).