Design and Test of Induction Voltage Adder Driven by 3 Blumlein PFLs

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ABSTRACT

We designed an induction voltage adder with three induction cells. Each induction cell is driven by a Blumlein pulse forming line. The Blumlein pulse forming lines have gas switches triggered by a compact Marx generator. We used amorphous metal tape cores for the induction cells because of their large flux swing. The induction voltage adder was tested for a copper sulfate liquid resistor. We have presented the features of design and the preliminary test results.

Index Terms — **PFL, Blumein, Induction**

1 INTRODUCTION

Induction voltages adder (hereinafter referred to as the IVA) is used in high current high voltage pulse applications such as flash X-ray generators, ion beam generators etc [1, 2]. Since IVA uses n pulse generators of the lower voltage to obtain the higher output voltage level, it is safer from high voltage breakdown in the systems and more reliable to operate in repetition mode. Also IVA based pulse power generators are more flexible to upgrade its level of output voltage.

We designed and evaluated an IVA using amorphous metal cores. The drivers for the IVA are the Blumlein pulse generators using pure water, which are triggered simultaneously by single Marx generator.

2 SYSTEM DESIGN

The IVA pulse generator system consists of an IVA, drivers, a controller, and a supporting system such as a pure water circulator, gas supplier etc. Figure 1 is a block diagram of the IVA system. The IVA is consisted of several cells. The cells are driven by pulse generators. If the IVA pulse generator is perfectly matched, the voltage difference on each cell is around the load voltage divided by the number of cells, which determines the voltage requirement of the deriving pulse generator. The number of deriving pulse generators depend on those impedance and the load's impedance.

In short and high voltage pulse applications, generally pulse forming line filled with a pure water is used because of its high dielectric constant and high breakdown field strength. This means that we can make a more compact and higher pulse generator at a given space.

The product of the voltage and pulse width of the cell of the IVA related with the total flux swing cross-section of the cores in the cell. We used an amorphous metal magnetic cores rather than ferrite cores because of their higher magnetic flux swing to make it more compact system. The loss of the magnetic core was also considered in its design, because it effects on the overall system size and power requirements.

The output pulse shape of an IVA depends mainly on the pulse shape of the driving pulse generator. When the IVA is driven by multiple pulse generators, it is important to reduce the jitters as small as possible between the pulse generators. The best way to remove the jitter is using a single pulse generator, but that requires a larger pulse forming line. However, the larger is a pulse forming line, the more difficult is to generate a fast rising pulse because of increasing of inductance, and to sustain high voltage insulation because of increasing of charging energy. One of the schemes to reduce the jitters is using the low jittering switches triggered by a single trigger with a fast rising pulse.

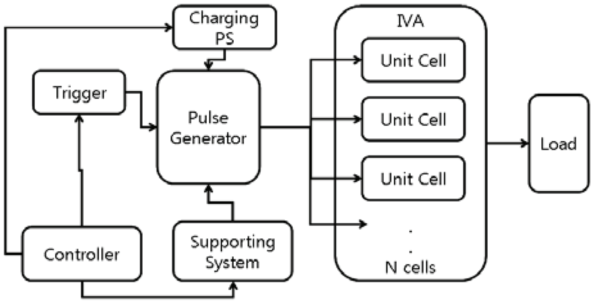

Figure 1. Block diagram of IVA system.

The controller controls the charging power supply system, the supporting systems like as a gas supply, a high purity water supply, and a vacuum system. It also controls the timing of each trigger and the communication from an external computer. Since electromagnetic noises are strongly generated from many switching units in the IVA system, the controller must be protected from the electromagnetic noises by using electro optic isolation or noise filters.

Figure 2 is the block diagram of our IVA pulse generator. We used three Blumlein pulse forming lines. Each Blumlein is filled with pure water and is switched by a gas spark gap switch. It is designed to generate a 60 ns pulse for each Blumlein pulse generator [3]. Every Blumlein is triggered by the single trigger pulse generator for the purpose of reducing the jitters between the Blumlein pulse generators. We used a compact Marx generator as the trigger pulse generator. The Marx generator was triggered by a pulse generator using an IGBT switch and a trigger pulse transformer. In order to charge the three Blumlein pulse forming lines, a high voltage step up transformer was used. Since Blumlein pulse forming lines behave like a capacitor before discharging, we designed a simple capacitor charging circuit using a transformer. We decided the capacitance of the capacitor bank and the step up ratio of the transformer by considering the peak current and peak voltage of the switch. We controlled the charging time of the Blumlein pulse forming lines by changing the inductance of the primary side circuit to control the current flowing the switch. The capacitor bank and the Marx generator are charged by the capacitor charging power supplies, which are controlled by a charging inhibit controller to reduce the jitter of the Marx generator.

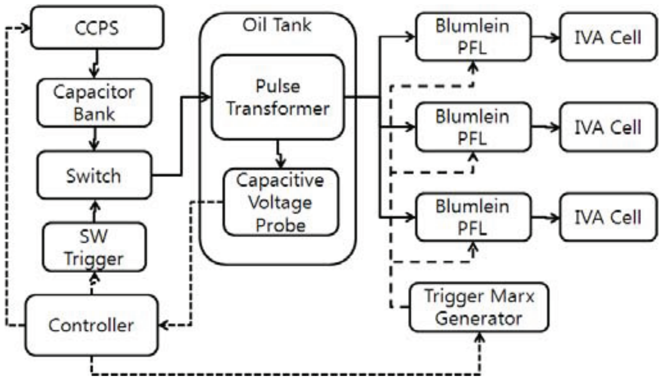

Figure 2. Block diagram of our IVA pulse generator.

3 IVA DESIGN

Figure 3 is the three dimensional CAD drawing of the IVA. The IVA has three unit cells driven by three Blumlein pulse generators. The unit cell has magnetic cores laminated with amorphous metal film and polyimide film. We designed the insulator which separates the oil insulated region from the vacuum region. Since the triple point, where metal edges contact with insulator surfaces in vacuum, is one of the weak breakdown positions, we carefully designed the shape of the insulator. We made the insulator with acrylic considering not only the electrical but also mechanical properties of it because it must seal the inside of the IVA maintaining high vacuum state. We chose the inner radius of the core considering the maximum voltage and the impedance of the cell. Since the center stalk of the IVA must be prohibited from vacuum field emission, we chose the radius of the stalk to be safe from the vacuum field emission. We chose the outer radius considering the flux swing of the magnetic core and the voltage time product of the cell. The pulse from each Blumlein pulse generator is transmitted through three high voltage coaxial cables in order to match those impedance with that of the Blumlein as close as possible. We used a single input port for each cell because of its simple structure.

Figure 3. 3D CAD drawing of the IVA.

Figure 4 is the PSPICE simulated voltage pulse of the IVA generator. We modeled the unit cell as a one to one transformer with a resistance to considering the core loss, and the IVA is connected in series with each cell by a transmission line. In this model we considered the inductance and the capacitance between the gap of the cell and characteristic impedance between center stalk and inner cylinder of the cell.

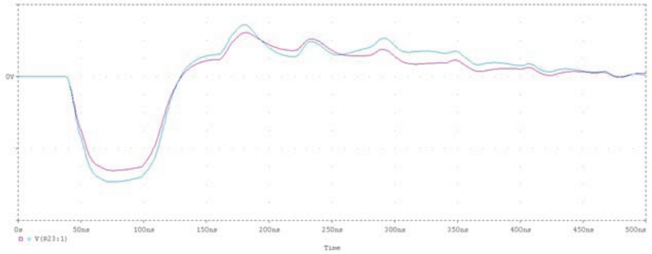

Figure 4. PSPICE simulated voltage pulse of the IVA pulse generator. The voltage reaches a peak of 500 kV.

4 EXPERIMENTAL RESULTS

Figure 5 is the block diagram of the setup for the IVA experiment. We installed an aqueous load connected with the output inner cylinder of the IVA. This $CuSO_4$ aqueous load was designed to work in vacuum environment. We measured the voltage at the load by using a d dot probe and a passive integrator, or by using the aqueous voltage divider installed in the load itself. The signals were recorded by a Tektronix 7104A digital storage oscilloscope.

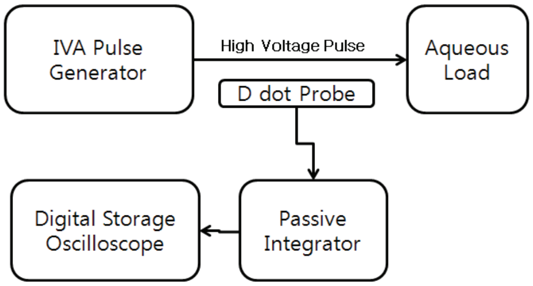

Figure 5. Block diagram of setup for the IVA experiment.

We precisely controlled each switching conditions of the Blumlein pulse generators in order to minimize the jitter between the driving pulses. Figure 6 is typical voltage signals of the IVA pulse generator measured with the d dot probe and the passive integrator. The three signals captured with the digital storage oscilloscope shows good reproducibility. The pulse width at half maximum is about 60 ns, which is quite a similar to the result expected in the PSPICE simulation.

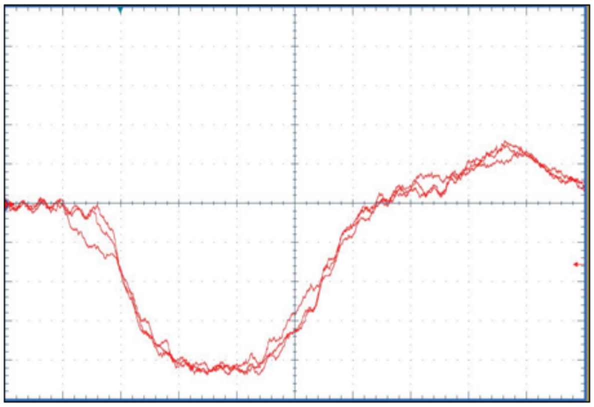

Figure 6. Typical measured voltage pulse waveform of the IVA. The horizontal axis shows time at 20 ns/div, and the measured peak voltage is 500 kV.

5 SUMMARY

We designed and manufactured the IVA pulse generator. The IVA system is driven by three Blumlein pulse generators triggered by a single compact Marx generator.

We obtained good pulse adding performance and reproducibility by controlling precisely each of the drive pulse generators.

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