Application of A High Voltage Capacitor Charger to Nanosize Powder Production

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Abstract – Electrical wire explosion (EWE) is characterized by great current density and rapid metal heating, which make itself an ideal tool for nano-materials manufacturing technology. The EWE requires a high voltage electric-energy source. In the current experimental set-up a high voltage capacitor is used for the purpose. Hence, a power supply that is capable of charging the capacitor to a target voltage is required. One of the special requirements is the precise controllability of the stored energy level in the capacitor.

Through this study a high voltage capacitor charger using a series resonant converter technology has been developed for the production of nanosize powder. A load capacitor of 32μF can be charged up to 20kV by the developed capacitor charger and discharged through a gap switch and a copper wire.

Keywords – Electrical wire explosion, capacitor charger, nanosize powder.

I. INTRODUCTION

Typical applications of power electronics include power supplies, power conditioners, UPS systems, high voltage DC transmission systems, electronic ballasts, motor drives, and more recently, electric vehicles. Frequently, new applications for power electronics are being suggested and created [1]-[2]. A high voltage capacitor charger finds its new application in nanosize powder production. In this application, a nanosize powder production system requires a high voltage regulation power supply that charges the source capacitor to a desired voltage. With solid state semiconductor switches and high frequency switching technology, the physical size of a high voltage capacitor charger has decreased dramatically and also, the cost has been reduced.

Nanosize powders have unusual physical, chemical, and metallurgical properties, owing to the large proportion of atoms that are at the surface. The electrical wire explosion provides an unusual way to produce such powders.

This paper will provide an overview about a nanosize powder production system, with focusing on the high voltage capacitor charger and the EWE method [3]-[5].

II. ELECTRICAL WIRE EXPLOSION FOR NANOSIZE POWDER PRODUCTION

Nanosize powders made by the EWE show unusual properties. In the process, a high pulsed current of only a few microseconds duration is applied to a wire, which is fed into a chamber. When the closed circuit is completed and the high pulsed current starts to flow, the wire is heated rapidly to a temperature past the boiling point. After that, the heated wire rapidly expands to 2-3 times as large as its original volume and the conduction electrons in the wire become localized on the atoms. Under its influence, the wire bursts into the finest particles and streams. When scattered at great speed, the products of that destruction cool down and finally form nanosize powders.

The powder production process is semi-continuous in that the wire is constantly fed into a chamber. When the contact is made with an electrode, the wire is pulsed and the explosion occurs.

Fig. 1 shows the developed powder production system, using the EWE method. In practice, this process is applied to a copper wire, 0.6mm in diameter and 80-150mm long, and a 32μF load capacitor charged to maximum 20kV.

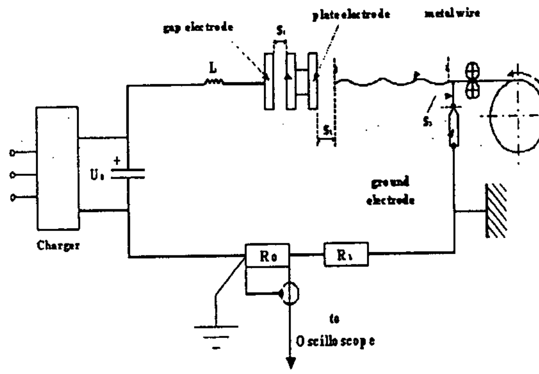

Fig. 1. System configuration for nanosize powder production.

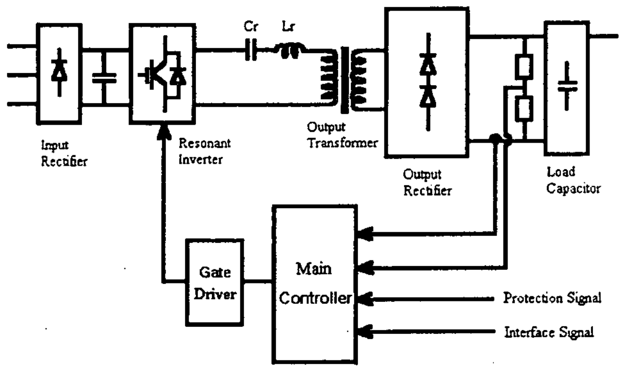

Fig. 2. Simplified capacitor charger configuration.

III. HIGH VOLTAGE CAPACITOR CHARGER

The high voltage capacitor charger is comprised of several major elements. Those are input rectifier, inverter, output transformer, output rectifier, protection circuit, and main controller. In medium capacity of the capacitor charger, insulated gate bipolar transistors (IGBTs) are used currently, which mounted on specially designed heatsink.

The main advantages of the developed capacitor charger are a compact design, reduced switching loss, and more stable operation from the long wires between capacitor charger and load capacitor. Some problems of those long wires are loss of regulation at high output voltage, excessive noise on the output, and instability, especially at repetitive charging operation. Inner small capacitors, minimizing these problems give the capacitor charger the ability to stabilize charging current.

A simplified block diagram of the developed capacitor charger is shown in Fig. 2. This capacitor charger is designed for charging a load capacitor to maximum 20kV, 10kW and based on a series resonant three phase inverter followed by step-up transformers. In the next sections, each major element will be described.

A. Input Rectifier

The high voltage capacitor charger rectifies the AC line, 3-phase 380V, directly without requiring a low-frequency line isolation transformer between the AC main and the input rectifier.

As depicted in Fig. 3, a simple three phase rectifier with no voltage control is used. The capacitor charger may develop extremely high peak inrush current during turn-on, unless we incorporate some part of current limiting in the input section. To improve the power factor and reduce the harmonic distortion, we use the input filter. Also, a dc link fuse (60A, rapid type) and a small resistor are chosen to obtain more reliable protection in this application.

In this case, we use thyristor-diode modules, 1600V 40A, as the input rectifier, followed by a high frequency switching stage. The control of this switching stage determines the input characteristics of the input rectifier.

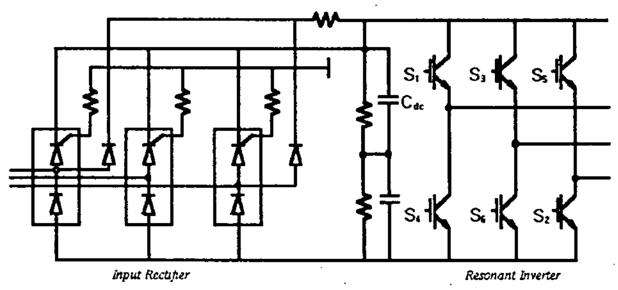

Fig. 3. Input rectifier and series resonant inverter.

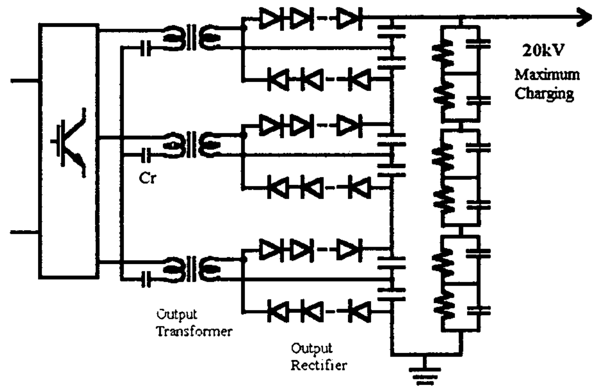

Fig. 4. Step-up transformer and output rectifier.

B. Resonant Inverter

The use of resonant switching in the high frequency stage is a new trend. Such soft switching, that is, switching at zero voltage or zero current, reduces the switching losses and the problems caused by fast switching transients, which also reduces the RFI generated by this switching stage. So, we use a series resonant technology for the developed capacitor charger. Fig. 3 shows the series resonant three phase inverter for the capacitor charger.

The practical switching action of the inverter is simply realized by using six step pulse. The output of the inverter can be represented in the form of a square wave whose amplitude is dependent upon the dc link voltage and whose frequency is determined by the rate at which the switches change from one state to the other. To ensure that the off-going switch has sufficient time to turn off before the on-coming switch is turned on, there is a small dead time.

In practice, the switches are replaced by dual IGBT modules, 1200V 100A, and the inverter load by the primary of the high frequency output transformer. The switching frequency remains constant about 20kHz. This high switching frequency helps improve output dynamic response and reduce the size of the transformer and the cost of other components.

C. Output Transformer

The design of output transformer has an important influence on overall weight, power conversion efficiency, and cost. Because of the interdependence and interaction of parameters, reasonable trade-offs are necessary to achieve design optimization.

In the practical case, two situations arise from a poor transformer design. First, high voltage spikes are generated by the rate of transitions in current. Second, the possibility of core saturation increases during an abnormal operation. Voltage spikes are caused by a physically loose winding construction of a transformer. When the windings are physically wound distant from one another, the leakage inductances store and release a portion of the energy supplied to a winding in the form of voltage spikes. Spikes can cause the semiconductors to enter avalanche breakdown and also cause significant RFI problems.

Fig. 4 shows the output transformer and rectifier schematic to be used for the developed capacitor charger. The primary windings of output transformers are wye connected and UU type ferrite cores are used due to the operation at high frequency and high power. Finally, using the voltage doubler technique, it is possible to decrease the electrical isolation level of the output transformer.

D. Output Rectifier

The capacitor charger demands that power rectifier diodes must have low forward voltage drop, fast recovery characteristics, and adequate power handling capability. Because the capacitor charger operates at much above 20kHz, the high efficient fast recovery diodes are used as the output rectifier. Usually these types of diodes offer reduced reverse recovery time and also reduce the switching spikes that are associated with the output ripple voltage.

E. Protection Circuits

For good regulation and system stability, there are a number of peripheral and control circuits that enhance the performance and reliability of the capacitor charger. For example, the protection circuits for soft-start, over-current, over-temperature, over-charging time, and voltage surges are used to guard the capacitor charger against failures due to external stresses.

The electronic circuits of the capacitor charger are uniquely vulnerable to power line disturbances because they bring together the high power lines and sensitive low power circuits. Various protection circuits for voltage surges and line noises are used to improve and assure the safe operation of the capacitor charger. Surges are commonly caused when a load capacitor rapidly discharges and the electrical wire explosion starts. Surges don't reach the magnitude of sharp spikes, but generally exceed the normal voltage. This deviation can cause the damage of the operating capacitor charger. We simply divert surges from the hot line to the neutral and ground wires, where they are assumed to flow harmlessly to earth, the ultimate surge sink.

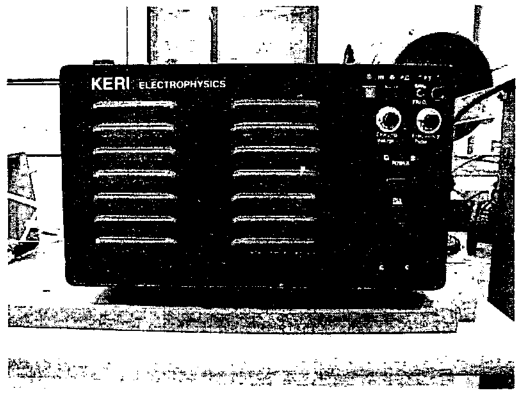

Fig. 5. High voltage capacitor charger.

In practice, we can improve the incoming waveforms by clipping, filtering, and isolating method. The ancillary and supervisory circuits are used to protect the capacitor charger as well as the load capacitor from fault conditions.

IV. EXPERIMENTAL RESULTS

In order to investigate the validity and practical capability of the proposed powder production system, experimental results were obtained by applying the developed capacitor charger to the proposed EWE system with a copper wire, 0.6mm in diameter and about 100mm long. The AC input line was 3-phase 380V.

The experimental setup is shown in Fig. 5, and consists of the load capacitor of 32μF 40kV usually charged to 10kV, storing 1.6kJ, connected to the air-filled chamber. After the load capacitor is charged, the voltage across the electrodes is at the full charging voltage. As the copper wire approaches the plate electrode, a breakdown occurs when the distance from the plate electrode is a few milli-meters. Once the breakdown occurs, a high pulse current (30-50kA, 10-20us duration) starts flowing through the system. The current is measured by a Rogowski coil.

Fig. 6 and 7 show the current waveforms of the capacitor charger during charging process. Next, the state of the electrical wire explosion is shown in Fig. 8. From these explosions, we have been able to produce agglomerated copper-oxide powders with average sizes about 2um and particle grain sizes 100-200nm. Fig. 9 shows the oxide copper powders made by the developed EWE system.

V. CONCLUSIONS

Future research in a nanosize powder production will be aimed at application development in metal coatings, battery electrodes, bonding metals to electronic substrates and semiconductors. With the EWE systems more improvements such as higher power density, more efficient power conversion, and highly advanced controls are expected in the design of the capacitor charger.

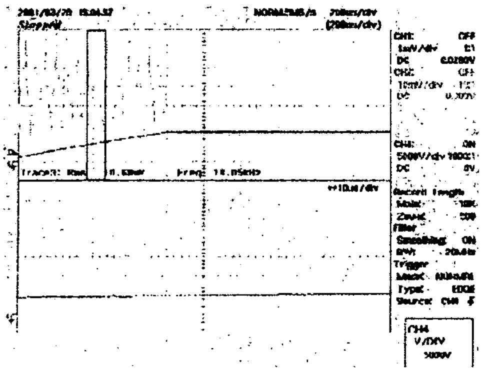

Fig. 6. Current in output transformer and charging voltage in load capacitor.

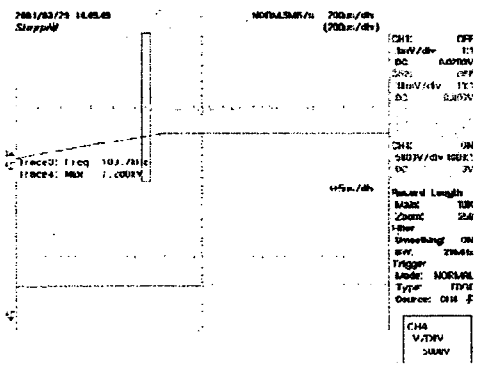

Fig. 7. Output current in capacitor charger and charging voltage in load capacitor.

In addition, an important technical requirement of the future switching-mode capacitor chargers will be the power factor correction (PFC) because of the inherent characteristic of switching modes power supply, where the input current waveform in the AC line will be non-sinusoidal and pulsed. However modern PFC ICs have made it possible to include every control circuit in a single chip. Thus, these ICs will be applied widely to the future capacitor chargers to minimize the cost of the control circuits and stabilize the total control operation.

The next generation of the EWE based nanosize-powder producing system will be in wide demand for mass production of the nanosize powder.

REFERENCES

[1] A. C. Lippincott and R. M. Nelms, "A capacitor-charging power supply using a series-resonant topology, constant on-time/variable frequency control, and zero-current switching," *IEEE Trans. Ind. Electron.*, vol. 38, no. 6, pp. 438-447, 1991.

[2] M. Souda, F. Endo, C. Yamazaki, K. Okamura, and K. Fukushima, "Development of High Power Capacitor Charging Power Supply for Pulsed Power Applications," in *Proc. 12th IEEE Int. Pulsed Power Conf.*, vol. 2, June 27-30, 1999, pp. 1414-1416.

[3] Y. Me-Bar and R. Harel, "Electrical explosion of segmented wires," *J. Appl. Phys.*, vol. 79, no. 4, pp. 1864-1868, Feb. 1996.

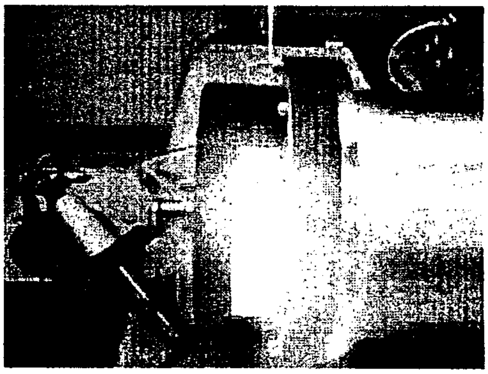

Fig. 8. Gap switch during the electrical wire explosion.

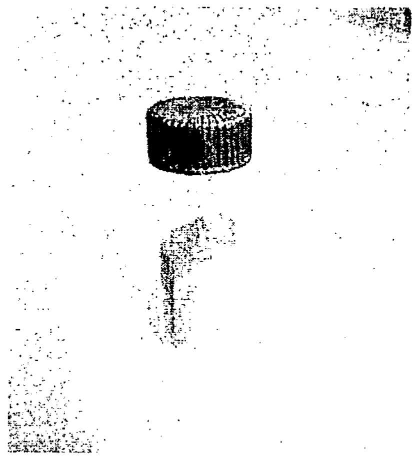

Fig. 9. Produced copper-oxide powder.

[4] W. Jiang and K. Yatsui, "Pulsed Wire Discharge for Nanosize Powder Synthesis," *IEEE Trans. Plasma Science*, vol. 26, no. 5, pp. 1498-1501, Oct. 1998.

[5] Y. H. Jung, K. S. Kim, H. S. Lee, and G. H. Rim, "A Study on the Characteristics of Pulsed Discharge for Nanopowder Production," in *KIEE Summer Annu. Conf.*, 2001, pp. 1640-1642.