GREEN PULSED POWER

ACHIEVED BY EFFICIENT SOLID STATE PULSED POWER TECHNOLOGY

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Abstract

A unique solid-state pulsed power modulator technology has been developed, manufactured and refined by ScandiNova Systems during the past decade. There are now many systems installed world-wide for use in Medical, Industrial-, Defense- and Research-applications. All these applications have in common the need for improved power efficiency - defined as output pulsed power divided by input wall-plug AC-power. The power efficiency of the traditional old Thyratron switched PFN[1]-technology is in the range of 40-60%. The new Solid State pulsed power technology provided by ScandiNova has recorded efficiency in the range 75%-85%. The improved efficiency does not only mean a reduced operational cost because of saving in power consumption, it also means savings in the need for external cooling and saving in space for installation because the system can be made more compact. This means a smaller investment because of reduced cooling system and reduced size of premises.

1 GENERAL FUNCTION DESCRIPTION

The basic architecture of the ScandiNova Solid State Modulator is described below and illustrated in Fig. 1. Three-phase line voltage is fed to a DC Power Supply. It charges up all the Switching Module units to a primary voltage around 1000V. An external trigger pulse enters the modulator, gating all the Switches and discharging some of the stored energy. A pulse transformer steps up the voltage to the level needed for the load in use. All parts of the modulator are located inside a common enclosure. The pulse transformer and the load HV-interface are the only parts surrounded by transformer oil. The DCPS, Switching Modules and Control interface are all in air for easy access and serviceability.

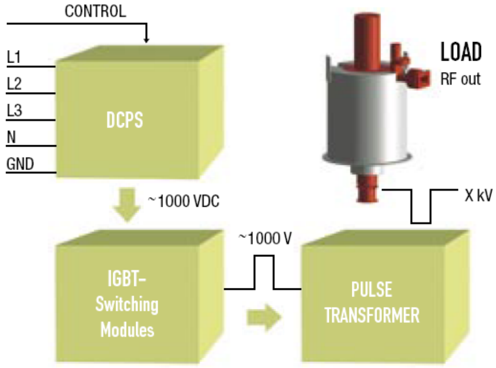

Fig. 1: *The principle of the ScandiNova Solid State System*

2 ANALYSIS OF POWER EFFICIENCY

The main reason for the higher efficiency of the ScandiNova Solid State pulsed power technology is because that energy conversion from AC mains power to output pulsed power is managed in a more efficient way with small and limited losses in each one of the conversion steps than in the older traditional line-type Modulator.

The first step is the conversion from AC mains power to DC power. This step has an efficiency of 90-95% and is handled by the DC Power Supply internal unit.

[1] PFN is an abbreviation of Pulse Forming Network

This efficiency results from the combination of a six-pulse rectifier (efficiency typically 95%) and a series-resonant inverter, operated in the ZCS (zero-current switching) mode, which is also typically 95% efficient.

The second step is handled by the Switch sub-unit. In this step the efficiency is in the range of 97-98%.

This efficiency results from the fast switching speed of modern high-current IGBTs, typically less than 0.5 uS on/off time. The turn-on is at zero current, so the only dissipative step is at turn-off, further improving efficiency. Turn-off commutation and transformer primary reset are both assisted by high-speed diodes, which draw turn-off current away from the IGBT switches.

The third and final step is handled by the Pulse Transformer unit. The pulse transformer has a typical efficiency of 98-99%. In this sub-unit the pulse-tuning circuit is also included. The efficiency of the pulse tuning circuit is very much dependent of the need of flatness of the final pulse but is typically in the range of 95%-99%.

This high efficiency results from the fact that our new drive circuit makes full use of traditional pulse transformer designs, which have steadily evolved since the 1940-ies to the 98-99% efficiency level by adjustments in winding geometry and improvements in magnetic core materials. Our circuit allows one to use an existing pulse transformer unit and simply replace the core with two or more cores, each having a fraction of the original core cross-section area. Each sub-core is driven by a single-turn primary and a set of pulse modules, giving the effect of a fractional-turn primary. This gives a high turns ratio without changing the pulse rise time. The pulse-flattening circuit "throws away" a part of the pulse voltage early in the pulse, and gradually restores this voltage later in the pulse, compensating for the "droop" in module capacitor voltage. Typical power losses in this circuit are 4 to 7 percent, depending on pulse width. The net effect of the pulse transformer and pulse flattening elements is a power transfer efficiency > 93%.

2 POWER EFFICIENCY MEASUREMENTS ON A HIGH POWER MODULATOR SYSTEM

This section describes how the power efficiency was verified on a High Power Solid State Modulator.

There are two Solid State Klystron Modulators of type K2 to be analyzed in this section. These that are used for industrial E-beam sterilization of medical disposal products (see Fig 2). Each Modulator is pulsing a L-band Klystron of type TH2022B from Thales. Power efficiency and reliability are of high importance in such an application. These two systems were installed in December 2008 and July 2009 respectively in San Diego, CA, USA, and had within a year accumulated 8500 hours of operation for generating E-beam.

The performance of the K2-modulator systems is show in Table 1 below.

Fig. 2: *High Power Klystron Modulator type K2.*

Parameter	Unit	Value
RF frequency	MHz	1300
RF peak power	MW	20
RF average power	kW	36
Modulator peak power	MW	47
Modulator average power	kW	100
Klystron Pulse Voltage	kV	220
Klystron Pulse Current	A	215
Pulse width (FWHM)	us	12
Pulse Repetition Frequency	Hz	180
Input average AC mains power	kW	125
Power efficiency	%	80

Table. 1: *Perfomance of the High Power Klystron Modulator type K2.*

The input power measurement was done by using a true rms current clamp sensor type APPA

30R. The current recorded per phase, the total inpot power in kVA and kW are shown in the table below:

Parameter	Unit	Value
Voltage phase 1-2	VAC	479
Voltage Phase 2-3	VAC	479
Voltage Phase 1-3	VAC	479
Current phase 1	A	165
Current Phase 2	A	172
Current Phase 3	A	173
Apparent power	kVA	141
Power factor	%	0,87
Input power	kW	122

Table. 2: *Input power measurement on system no 2.*

The output power is measured on a resistive dummy load using a calorimetric method. By measuring the difference in temperature on cooling water in/out on the dummy load and the flow the power can be calculated by the formula:

$$P = Q\,\Delta T\, c_{H2O}$$

P is the Power into the Load (kW)
Q is the flow of the cooling water through the heat exchanger in the Load (liters/sec)
ΔT is the temperature difference (°C)
c_{H2O} is the heat capacitivity for water (kJ / (kg K)

The results from the calorimetric measurement is shown in Table 3 below.

Parameter	Unit	Value
Flow of cooling water	l/min	162
Input temperature	°C	20
Output temperature	°C	28,9
Temp difference	°C	8,5
Output power into load	kW	98,2

Table. 3: *Calorimetric measurement on the Dummy Load.*

In order to verify the internal power loss of the Modulator the calorimetric measurement is also done on the cooling of the Modulator system itself. By measuring the flow and the temperature difference between inlet and outlet water the total power loss can be verified. The results are shown in Table 4 below:

Parameter	Unit	Value
Flow of cooling water	l/min	78
Input temperature	°C	20
Output temperature	°C	25,2
Temp difference	°C	5,2
Power loss in Modulator	kW	25,2

Table. 4: *Calorimetric measurement on the Modulator system.*

By using the above recorded values the total power efficiency of the K2-Modulator system can be established (see Table 4 below).

Parameter	Unit	Value
Input power	kW	123
Output power	kW	98,2
Power efficiency	%	80

Table. 4: *Calorimetric measurement on the Dummy Load.*

Finally, the power loss into the air has to be considered. The main power loss inside the modulator transferred to the air is from snubber circuits in each DCPS. At this operational power level we estimate that each power supply generates about 90W of heat loss. There are 6 DCPS units in the system, so the total power loss becomes 540W.

Another power loss (gain) is generated from the Dummy Load that, even though it has been insulated on most of the surface, generates some heat loss to the air. The surfaces have been covered about 80% but the remaining surface can generate about 850W to the air.

The net result is 540W - 850W = -310W, which will improve the overall result somewhat.

2 CONCLUSIONS

This new and unique Solid State Pulse Power Technology demonstrates a significantly higher wall-plug to output load efficiency than older traditional technology. In a general perspective this “Green Power” can offer a more environmental friendly and long-term cost effective solution for many applications in Pulsed Power.