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AN EXAMPLES OF A 6-INCH GTO INVERTER DRIVE SYSTEM APPLIED FOR ROUGHER MILLS

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Abstract Recently, AC variable-speed motors are used for many steel rolling mill drive systems, because of their low maintenance and enhanced control performance. We have been applied GTO inverters for these AC motor drive systems since 1993. We have developed world largest 6-inch diameter GTO and large capacity 3-level GTO inverter up to 20000(kVA).

As an example, in this paper, we describe the main circuit, system arrangement and control features of the 6-inches GTO inverters to drive rougher mills for hot strip mill of Pohan Iron & Steel Co.,Ltd. The motor capacity is 6000(kW), and it's overload is 250(%).

Keywords 6-inch GTO, 3-level Inverter, Rougher Mill, Snubber, PWM

1. INTRODUCTION

Nowadays, cycloconverters are widely employed to drive large capacity AC motors for main steel rolling mills. However, they have several drawbacks such as low power factor, high harmonic components and limitation in maximum output frequency.

To solve these problems, need for voltage source PWM inverters is increasing. Because of limitation in maximum switching frequency of high power GTOs, a 3-level inverter is most suitable for large capacity AC motor drives. In order to apply GTOs to voltage source PWM inverters, snubber circuits are necessary for limiting the current rise rate (di/dt) at turn-on and the voltage rise rate (dv/dt) at turn-off. Trapped energy in the snubber circuits has to be regenerated to improve power conversion efficiency, which is one of key factors for substituting GTO inverters for conventional cycloconverters.

This paper proposes high performance 2-parallel 20MVA 3-level GTO inverter drive system for rougher rolling mill drives. As shown in Fig.1, the main circuit of this system consists of a 3-level GTO converter and a 3-level GTO inverter and series-connected DC-link capacitors with a neutral point. To realize an ultra large capacity GTO inverter system, newly developed 6-inch 6kV-6kA GTOs have been applied first in the world.

2. REGENERATIVE SNUBBER CIRCUIT

Fig.2 shows a regenerative snubber circuit developed for the 3-level inverter system in Fig.1. In this figure, CSn and DSn are a snubber capacitor and a snubber diode for GTOn, (n=1-4), respectively. The snubber circuit networks for GTOs with odd numbers are symmetrically arranged with those for GTOs with even numbers. The current rise rate of outer GTO1 is limited by the anode reactor LA1, and that of inner GTO3 is limited by LA1 and LA3.

On the other hand, the voltage rise rate of GTO1 is limited by the snubber capacitor CS1, and that of GTO3 is limited by CS1 and CS3. Therefore, the switching losses of inner GTOs (GTO2 and GTO3) are smaller than those of outer GTOs (GTO1 and GTO4). On the other hand, the conducting losses of inner GTOs are larger than that of outer GTOs, since in normal operation outer GTOs are switched, while inner GTOs are conducting. Consequently, total losses of inner GTOs are almost the same as that of outer GTOs.

Snubber energy trapped in anode reactors LA1-LA4 and snubber capacitors CS1-CS4 is first transferred to voltage clamping capacitors CO1-CO4. Since DC-link capacitor C1 or C2 does not participate in this energy transfer, RMS current of DC-link capacitors can be reduced compared with the conventional regenerative snubber circuits and small-sized capacitors with low sustainable voltage can be employed as the voltage clamping capacitors.

The energy transferred to the voltage clamping capacitors is then regenerated to the DC-link capacitors by DC/DC converters. Thus, snubber energy generated by the switching of all four GTOs can be regenerated. In addition, only four DC/DC converters are necessary for the regenerative snubber circuit for the 3-level GTO inverter system in Fig.1, since they can be used in common among corresponding snubber circuit networks in the inverter and the converter.

In implementing 6-inch GTOs with double package size compared with conventional 4-inch GTOs to the main circuit, one of the most important points is to minimize stray inductance in the snubber circuit. To guarantee maximum current turn-off capability of 6kA of GTOs implemented in the main circuit, we have devised the arrangement of the elements such as diodes and capacitors in the snubber circuit and employed wide-width busbars for connecting these elements. It should be noted that the arrangement of clamping diodes DC1, DC2 and free-wheeling diodes DF2, DF3, also has a great effect on the stray inductance in the snubber circuit. Moreover, flat-packaged diodes which have lower forward recovery voltage characteristics than stud-packaged diodes are suitable for snubber diodes.

3. PWM METHOD

Concerning a PWM method for a 3-level GTO inverter, we have to consider the minimum on-/off- pulse width of GTOs. The insufficient consideration for the minimum pulse width limitation may cause the distortion in the output voltage and current waveforms. Another problem of the 3-level inverter is the fluctuation of the neutral point DC voltage. Since the neutral point is floating as shown in Fig.1, the neutral point DC voltage is fluctuated by several causes such as the difference in the switching characteristics of individual GTOs and the unsymmetrical switching by an asynchronous PWM method.

To solve these problems, we have developed a novel asynchronous PWM method named "Diamond Modulation", which

is based on space voltage vectors. This PWM method can minimize harmonic distortion of AC input/output currents under minimum pulse width limitation of GTOs by selecting appropriate voltage vectors according to the reference voltage vector. And the imbalance and fluctuation of the neutral DC voltage can be suppressed by adjusting duration of a pair of voltage vectors concerned upswing and downswing of the neutral DC voltage according to the voltage error between two DC-link capacitors.

By applying this PWM method, torque ripple of a synchronous motor driven by the 3-level GTO inverter system can be minimized in all speed region, namely, from stand still (0 Hz) to top speed. On the other hand, harmonic components of AC input currents at the converter side can be minimized. As a result, compensation equipment of harmonic components which is necessary for a cycloconverter can be eliminated.

4. HIGH POWER FACTOR CONTROL

Fig.3 shows the configuration of high power factor control system with the 3-level GTO converter. By keeping the reactive current to be equal to zero, power factor of unity can be obtained. Fast response current control performance is required to minimize harmonic components of the input AC currents.

Input AC currents are separated into the d-axis current (the reactive current) and the q-axis current (the active current) by coordinates transformation. The DC-link voltage can be adjusted by controlling the active current according to its command, which is generated from the voltage controller. Power factor of unity can be obtained by giving the null reactive current command. Instantaneous voltage control performance realized by our PWM method greatly contributes to the improvement in current control response.

In the motor drives for rougher mills, active power supplied to the motor varies tremendously according to the change in the load torque and the motor speed during rolling operation. Therefore, fast response DC-link voltage control performance is necessary to keep the DC-link voltage constant. In addition to the DC voltage controller, predictive control has been applied to satisfy this requirement.

5. SYNCHRONOUS MOTOR CONTROL

To realize fast response torque and speed control of a large capacity synchronous motor, we have developed a vector control system as shown in Fig.4. In this system, both the 3-level GTO inverter and the thyristor converter for field control are cooperatively controlled to achieve stable constant power control in wide speed range by automatic field weakening.

A high-resolution resolver is employed to detect precise speed and pole-position of the motor. Armature and field currents are detected by DC current transformers (DCCTs) so that the stable control performance may be obtained in very low speed region.

Speed and flux controllers generate torque- and magnetizing-current commands to adjust the motor speed and the armature linkage flux, respectively. In this control system, the magnetizing current corresponds to flux-axis component of the field current. The armature-flux oriented vector control ensures independent and fast control performance of torque and flux, and also enables unity power factor control of the synchronous motor. Armature flux is calculated from motor currents based on a current model of the motor. The armature- and field-current controllers are included in vector control block in Fig.4.

By applying this vector control method, the increase in inverter output voltage during speeding up in the constant power control range can be suppressed. Capacity of the inverter can be minimized by the unity power factor control.

6. APPLICATION TO A ROUGHER MILL DRIVE SYSTEM

Specifications of our developed 3-level GTO inverter system used 6-inch GTOs are shown in Table 1. Maximum output power of this system is 20(MVA) and a 6000(kW) synchronous motor with maximum overload of 250(%) is driven by this inverter. This system is applied to a rougher mill drive of a hot strip line at Pohang Works of Pohang Iron & Steel Co.,Ltd.

We performed a full load test at our factory to check the inverter performance. Fig.5 shows the test circuit. Two 20(MVA) GTO inverters and two 6000(kW) synchronous motors are used and are arranged to a back-to-back connection. One motor act as a driver with speed control, and the other act as a sham load with torque control. By this test circuit, we have done a full load test (100(%) continuous, 250(%) overload 1minute), and a dynamic test to check the over-speed ratio just after a plate pass through by shut down the gate signal of load side inverter. The factory test was successfully completed.

Fig.6 is outside view of 6-inch GTO inverter. Fig.7 shows two 6000(kW) rougher mill motors connected in series at factory test. Fig.8 shows 4-quadrant operation of the 3-level GTO inverter system.

After installation and site test, this rougher mill drive system came into operation. Fig.9 shows the configuration of the system. Two rougher mill motors of a hot strip mill line, top and bottom, are controlled by two 3-level high performance GTO inverters.

Fig.10 shows a dynamic operation of the GTO inverter drive system at running condition. From this figure, it can be recognized that smooth and stable operation is realized in all region including the constant power control region.

7. CONCLUSION

To realize a large capacity GTO inverter system for rougher mill drives, we have developed a high performance 2-parallel 20(MVA) 3-level GTO inverter system using 6-inch GTOs. Many new techniques such as a regenerative snubber circuit and a PWM method have been developed and applied to this system.

The regenerative snubber circuit and the low inductance structure of the main circuit and the snubber circuit have especially contributed to realize a compact and high efficiency GTO inverter system.

The availability of our system for rougher mill drives has been confirmed by those results. We hope that our system will prelude practical use of voltage source GTO inverters for main rolling mill drives.

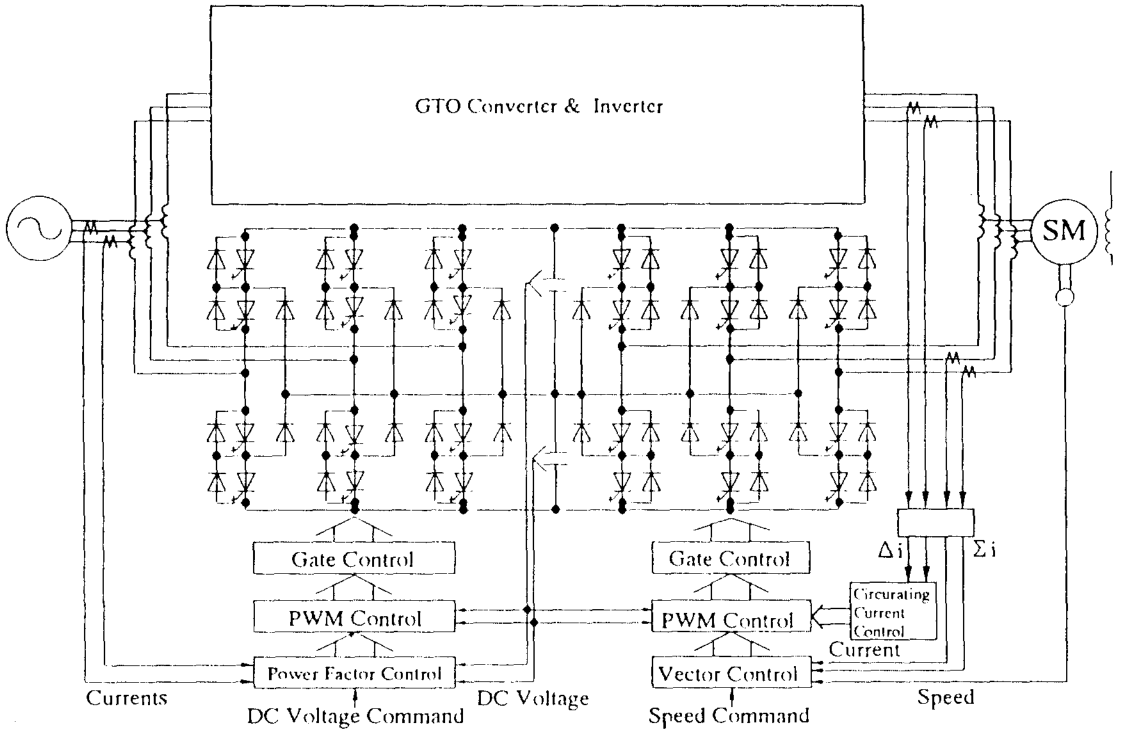

Fig.1 Configuration of proposed 3-level GTO inverter system

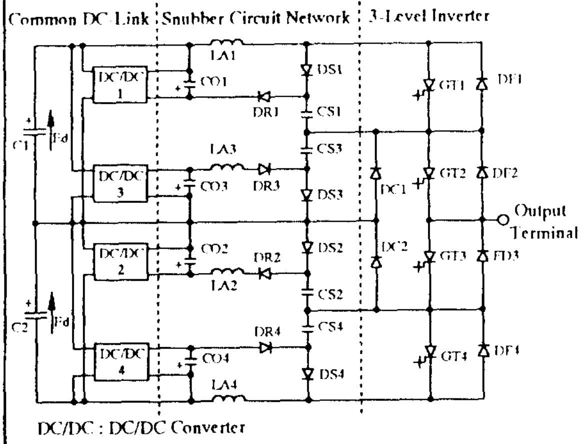

Fig.2 Regenerative snubber circuit topology for 3-level GTO inverter

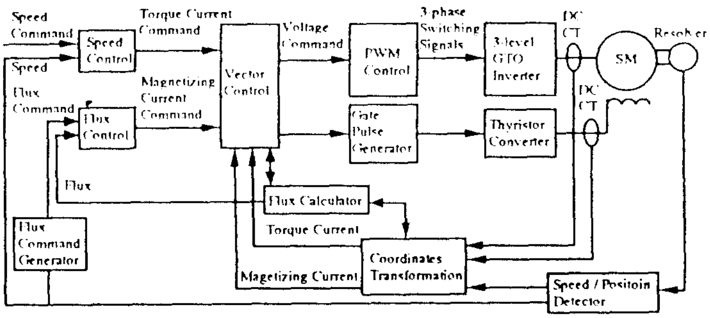

Fig.4 Vector Control system of synchronous motor

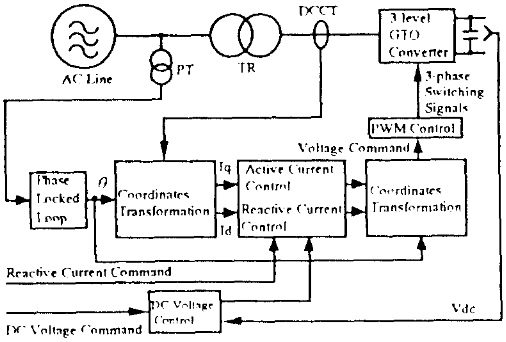

Fig.3 High power factor control system with 3-level GTO converter

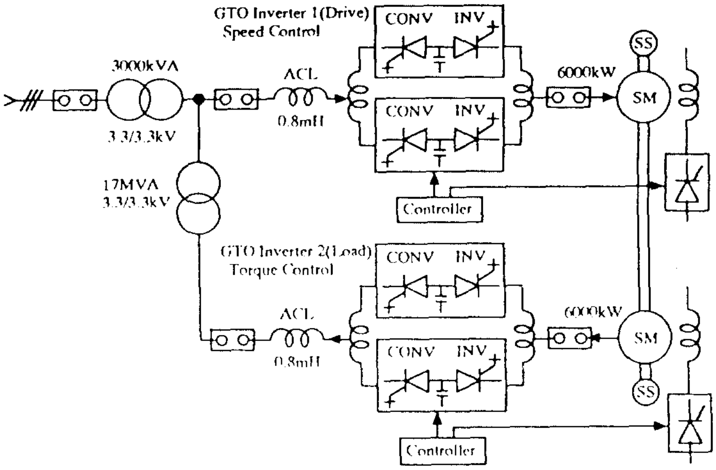

Fig.5 Experimental system at works

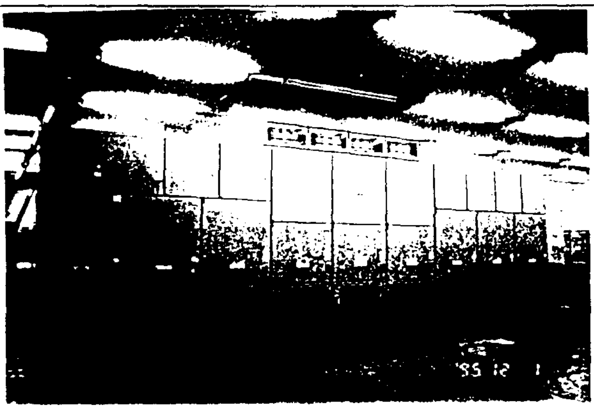

Fig.6 Outside view of 6-inch GTO inverter

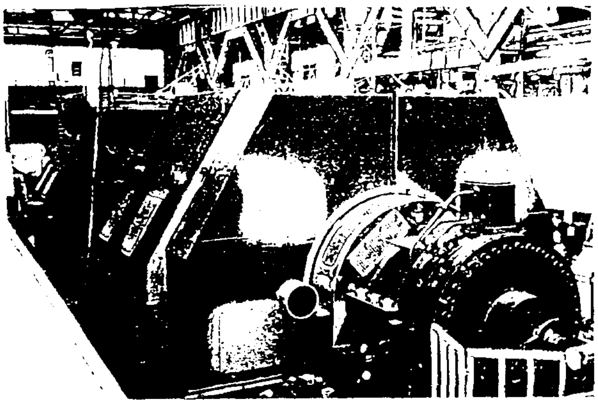

Fig.7 Rougher mill motors at shop test

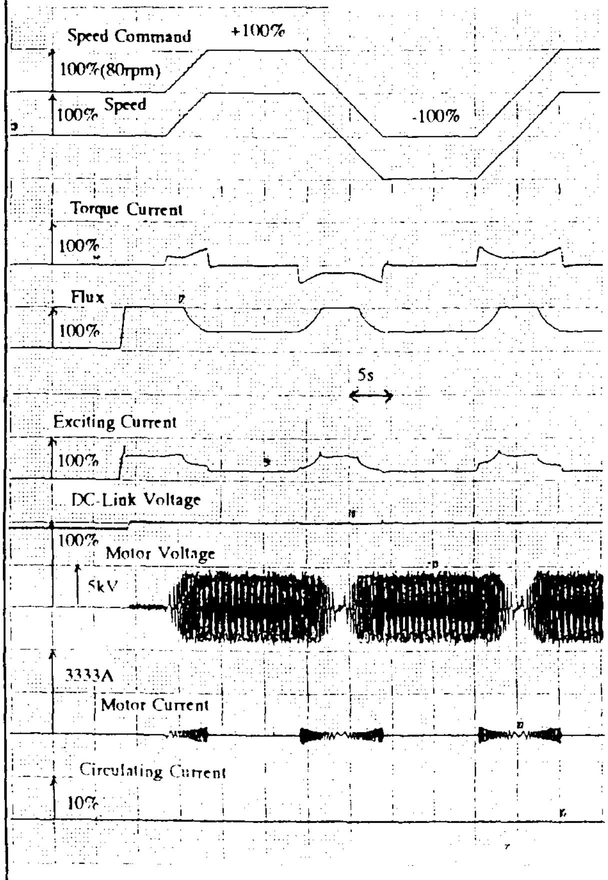

Fig.8 4-quadrant operation of GTO inverter at shop test

Table 1 Specification of 3-level GTO Inverter System

Input Voltage	AC3300(V),60(Hz)
Input Current	1750*2(A)
DC Link Voltage	6000(V)
Output Voltage	3300(V)
Output Current	1750*2(A)
Motor Power	6000(kW)
Motor Speed	35/80(rpm)
Over Load	250(%),1(min)

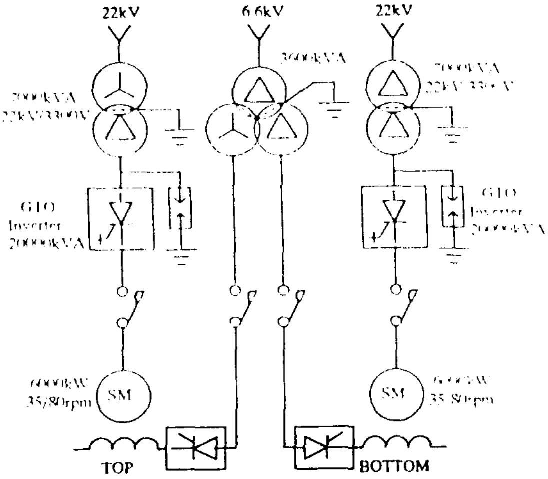

Fig.9 Configuration of rougher mill drive system

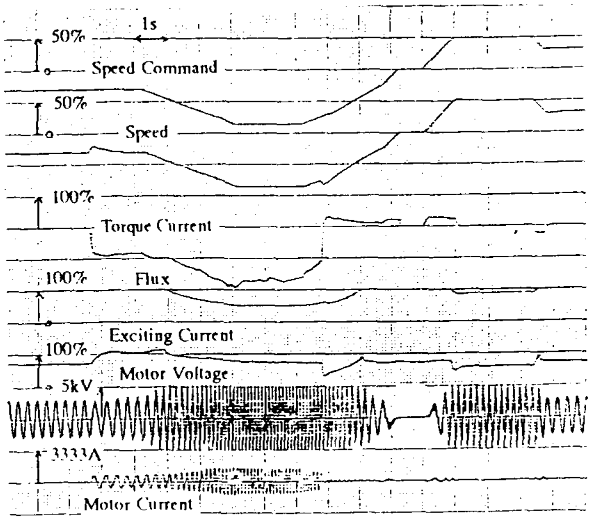

Fig.10 Dynamic operation of GTO inverter at running condition

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