A High Power Single to Three Phase Converter for Renewable Application

S. Meenakshi, D. Manimegalai, R. Sivasankari

Abstract-- ***The matrix converter has many advantages in wind power system applications. Matrix converter is compact and highly efficient because it directly converts generated power from AC generator to AC grid without intermediate DC bus while conventional back-to-back converter systems requires many electrolytic capacitors in DC link bus which are bulky and have short life-time. Matrix converter has both motoring and regenerative power flow keeping low harmonics current in grid. It also can provide reactive power to the grid, which is important characteristic for wind farms to stabilize power system during and after grid failure. In this paper, high power matrix converter is introduced for renewable applications. Major technical features and advantages are described. Experimental results with a PM generator show good feasibility for the renewable applications.***

Keywords – DC, AC.

I. INTRODUCTION

The Matrix Converter (MxC) is a direct AC to AC power conversion topology 1) The main circuit of MxC consists of input filter and nine bi-directional switches. 2) It is fully regenerative and has sinusoidal input current with power factor control capability. 3) The one of the big advantages of the MxC is that DC link capacitor is not necessary which is bulky and has short life-time. MxC is high-efficient and more compact than the voltage source back-to-back converter system. A bidirectional switch in Fig.1 typically consists of two anti paralleled IGBT-diode pair By a unique PWM control method, MxC can control output voltage as well as input currents with low current harmonics.

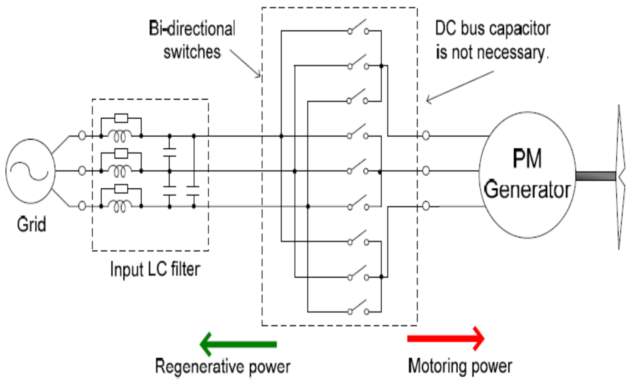

Fig. 1. Basic concept of the matrix converter for wind turbine drivetrain system

The topology in Fig. 2 is a typical configuration of MxC but it is more suitable for the power rating of less than several hundred kW and voltage rating below 690 V because of its limitation in increasing current and voltage rating. Therefore modular type matrix Converters have been developed based on the basic MxC topology.

It provides an attractive solution to the market which needs high power drives with regenerative power capability such as paper winder, large power pump, steel mill, and wind power system. It is compact in size, has low harmonics in input and output waveforms. In this paper, basic modular concepts of the high power Matrix converter will be explained. After then application for wind power system will be explained with experimental results.

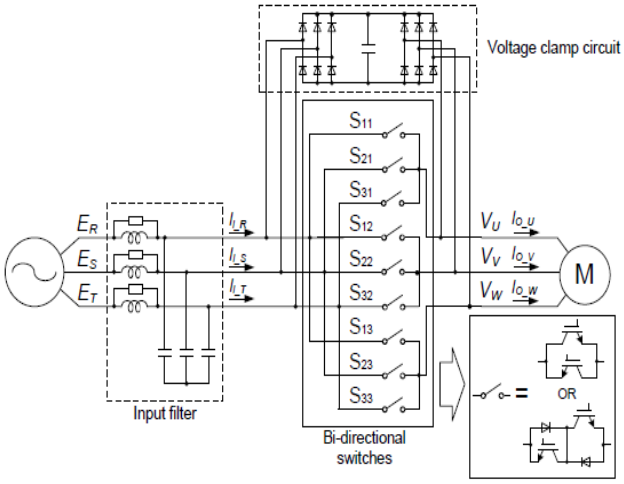

Fig. 2. Main circuit of the low voltage matrix converter

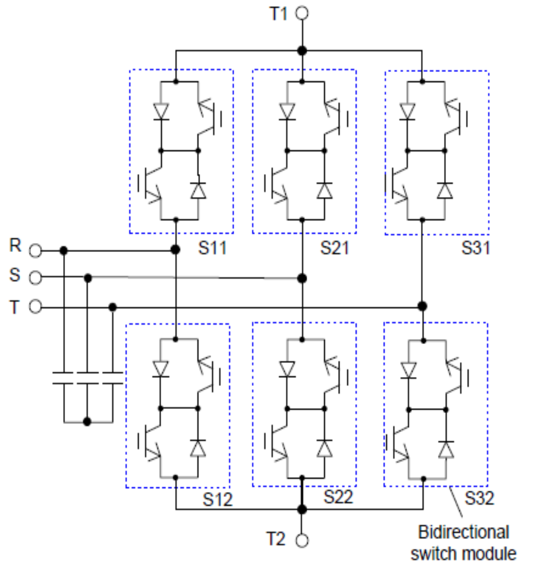

Fig. 3. Configuration of the single-phase matrix converter power cell.

Manuscript received January 15, 2014.

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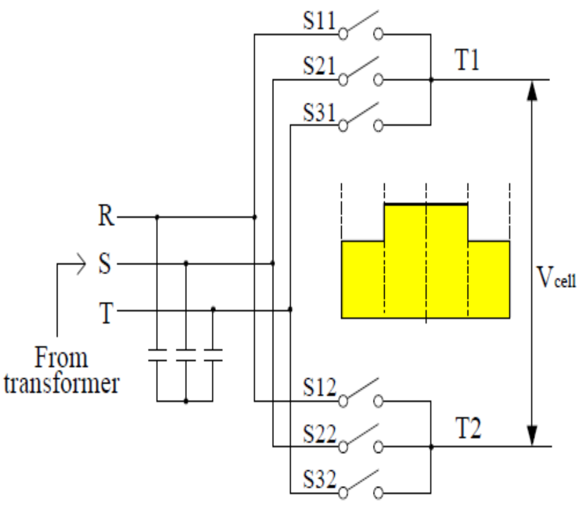

Fig. 4. Simplified single-phase matrix converter circuit.

II. MATRIX CONVERTER TOPOLOGY FOR RENEWABLE APPLICATION

A. Modular Concept of Matrix Converter

Flexibility of power and voltage ratings in converter design is important to meet various customers' request. The matrix converter for turbine drive train system employs modular design concept which has great flexibility in providing quick and optimal solutions to various demands in power and voltage ratings. Wind power system voltage is expected to increase gradually from standard 690 V to Medium Voltage (MV) as the power ratings of the system increase. The advantages of MV are lower transmission loss between the generator and the power converter and reduction of volume and weight of nacelle, and cost .A basic module for the modular drive is Single-Phase output Matrix Converter (SPMC) as shown in Figs. 3-4.The cascaded H-bridge voltage source inverter topology and three-level inverter using high voltage power switches are popular in medium voltage drives.

But back-to-back converter-inverter system should be used for the applications which require regenerative power flow. The power cell in Fig. 3 consists of six bidirectional switches and ac capacitors. Basically this circuit is a three-phase input single-phase output matrix converter as simplified in Fig. 4. It generates single phase output voltage to according to the reference of three-phase output voltage. It is similar to the H-bridge of VSI. Power factor of input current is controlled by adjusting conduction ratio of the each switch according to the input voltage waveforms The SPMC cell can be added in parallel or in series according to the voltage and current ratings of the drives. In Fig. 5(a), power cell input voltage is 690 V and single phase output voltage rating is 635 V. Two cells are connected in parallel to increase current rating. Output voltage can be designed up to line-line 1kV which has 5-level characteristics.

In Fig. 5(b), the output voltage rating of each cell is 635 V, and three cells are connected in series. Phase voltage is 1905V and line-to-line voltage becomes 3.3 kV with 13 level output. Therefore it is very close to sinusoidal wave as shown in Fig. 6. 1700 V class IGBTs are used for the power cell. The current rating of IGBT is determined by the current rating of the SPMC cell.

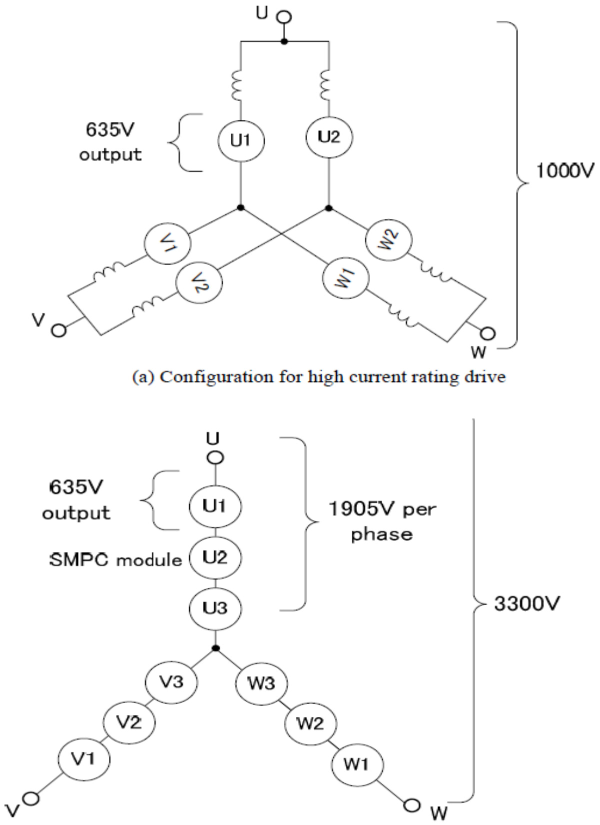

Fig. 5. Modular concept of matrix converter for high power applications.

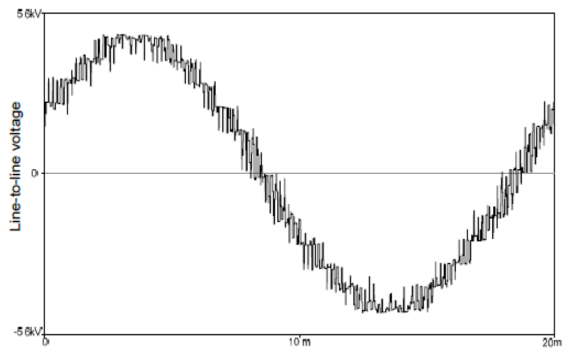

Fig. 6. Line-line output voltage of 3.3 kV medium voltage matrix converter.

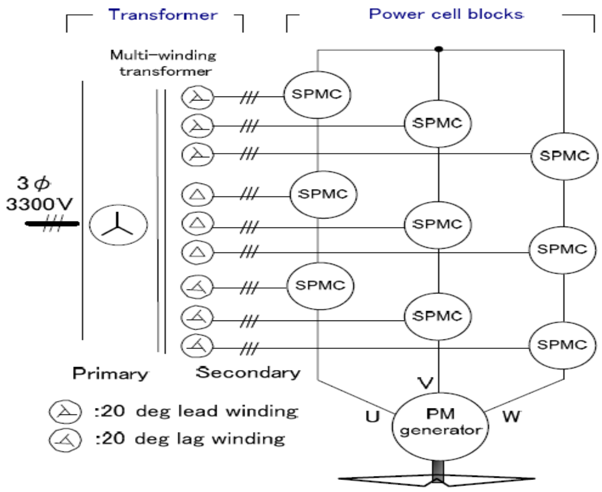

Fig.7. Schematic of matrix converter for wind turbine drivetrain .

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B. Configuration of High Power Matrix Converter

Fig. 7 shows overall configuration of the 3.3 kV medium voltage matrix converter including a multi winding transformer which steps down from 3300 V to 690 V. Phase shifts of +20, 0, and -20 degree in the secondary windings improve input current harmonics. It is the same principle as widely known the 18-pulse rectifier. The phase-shifting is also helpful to eliminate input voltage ripple in the output voltage waveform. It also compensates the relatively lower output voltage issue than inverter topology. The standard low voltage MxC requires LC filters to reduce PWM harmonics in the grid but in the modular MxC topology, the reactors are eliminated by using leakage inductance portion of the transformer. PWM timing of the power cells are shifted by 120 degree with each other to achieve smooth output voltage step change. For 6.6 kV line-line voltage drive, six power cells are connected in series.

III. MAIN FEATURES OF MATRIX CONVERTER SYSTEM

High power MxC has advantages in reliability (life time), size, and efficiency thanks to the elimination of the DC bus capacitor which has a relatively short lifetime. Higher reliability reduces maintenance cost. Modular design MxC using power cells is very compact, and maintenance and service are very easy. Small individual modules can be quickly replaced therefore it reduces down time.

TABLE I. MV MATRIX CONVERTER SYSTEM FEATURES.

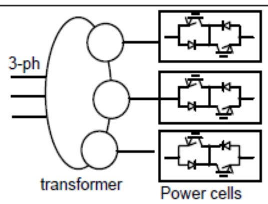
Items	MV Matrix Converter
Circuit Diagrams	
Harmonics to the grid	Less than 5 %
System Efficiency	98%
Maintenance	No DC bus capacitor Maintenance of the modular power cells is easy
Total footprint	Small No external transformer

Fig. 8 shows the external view of the matrix converter for wind power application. It consists of a controller panel, a multi-winding transformer panel, and a main circuit panel. The power cells are stacked in the main circuit panel. Standard product lineup includes 2 MW and 3 MV drives for 1 kV class, and 2 MW 3 MW drives for 3 kV class. The possible output power ratings are in the range from 200 kW up to 6 MW, and voltage ratings are in the range from 690 V to 6.6 kV. Fig. 9 shows speed, torque, power, and input/output currents of 3.3 kV, 800 kVA matrix converters during four quadrant operations which are fundamental characteristics of the wind turbine drive train. 600 kW, 1200 rpm induction motor is used in the experiment. It shows smooth transition from motoring to regeneration. Torque and motor current are controlled well during acceleration and deceleration. The motor speed also follows the speed reference nicely. Overall efficiency of 3.3 kV systems including the multi-output transformer is about 98% while typical back-to-back converter inverter system efficiency is about 97%.

IV. FAULT RIDE THROUGH OF MATRIX CONVERTER

As the impact of the wind power generation on the power system is getting stronger world-wide, fault ride through (FRT) capability is an important factor for large scale wind farms to secure the reliable operation of the grid. Under a sudden low voltage condition, wind power systems must remain connected to the grid for a given time duration and contribute to the power system stability by supplying reactive power during and after fault clearance. Fig. 10 shows low voltage ride through requirement described in Eon grid code. Above the voltage limit curve, there must be no disconnection from the grid. Renewable power systems have to provide reactive current (capacitive or inductive) during a voltage drop and in the event of a voltage rise as shown in Fig. 11. Grid side current control of the matrix converter are similar to a current source rectifier

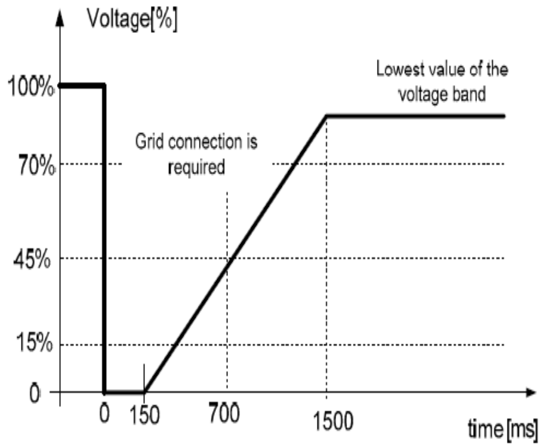


Fig. 10. Eon code : Limit curve for voltage pattern at the grid connection.

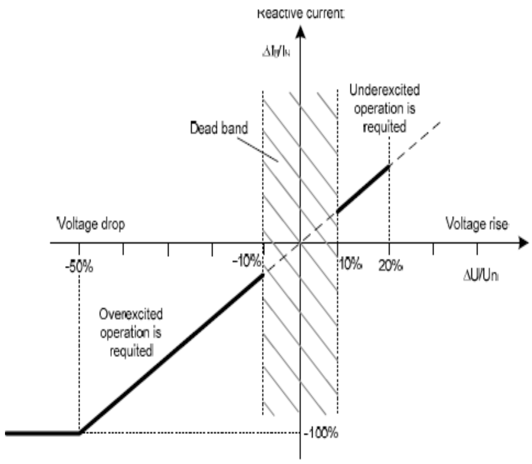


Fig. 11. Eon code : The principle of voltage support in the event of grid faults (reactive power demand).

The reactive current of the grid side is determined by following control variables:
- Generator side current amplitude
- Generator side power factor
- Grid side power factor.

The grid side current amplitude of the matrix current depends on the generator side active current component because the reactive current component circulates at the generator side, and it does not affect the grid side. During low voltage power failure, the reactive current of the grid side is controlled by adjusting input power factor and output voltage reference waveforms.

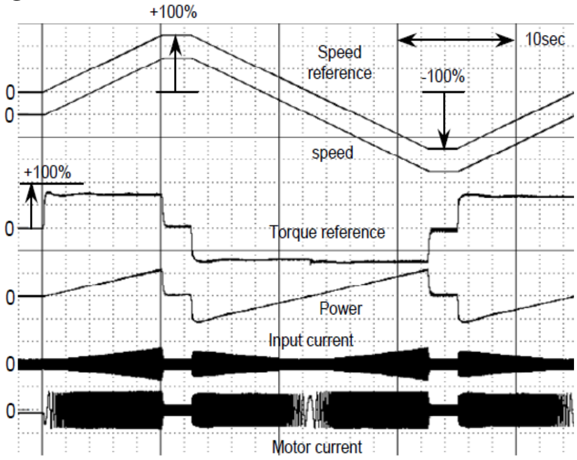


Fig. 9. Experimental 4-quadrant operation of 3.3kV, 800kVA matrix converter.

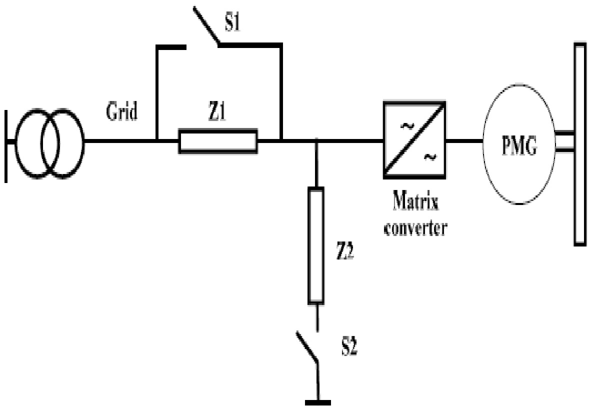


Fig. 12. Ride through test setup for matrix converter based on IEC 61400-21.

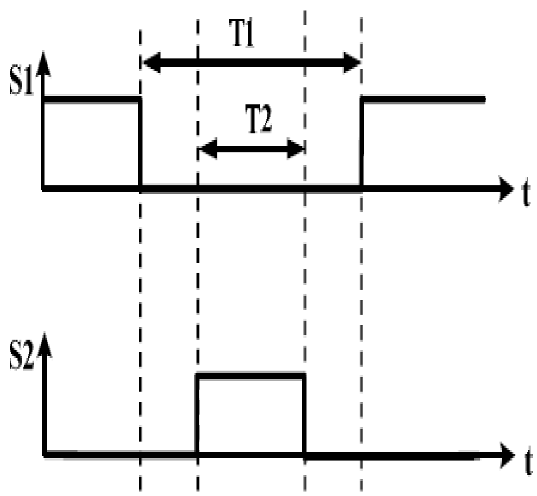
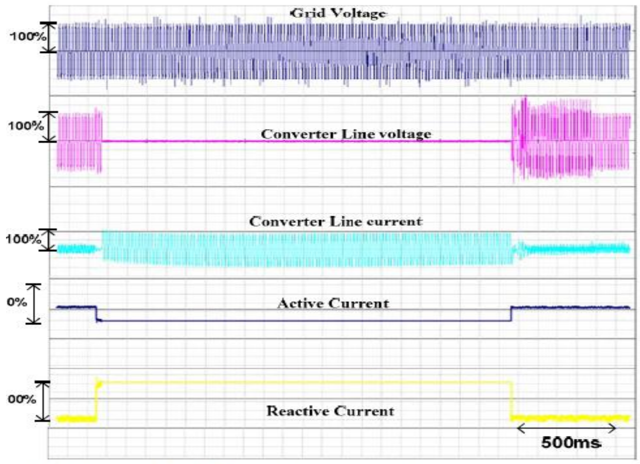


Fig. 13.Switching sequence of the breakers for the low voltage ride through test.



ig. 14. Zero voltage ride through test setup for matrix converter using test setup in Fig. 12.

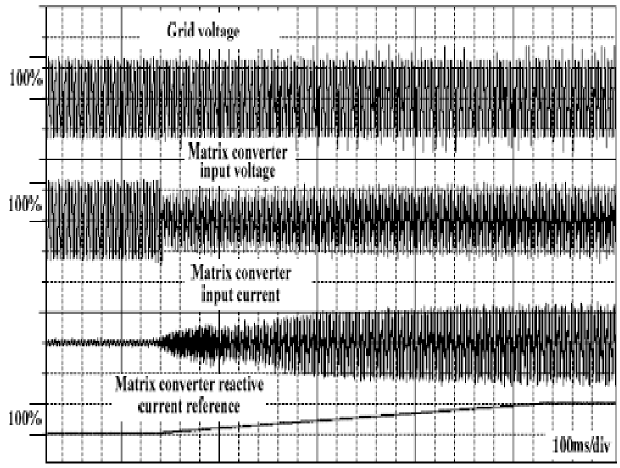


Fig. 15. 50% voltage dip test of the matrix converter using test setup in Fig. 12.

Fig. 12 shows the experimental setup for the low voltage ride through test based on the standard IEC 61400-21(2008). The grid voltage dip is emulated with a simple voltage divider circuit. The matrix converter input voltage is determined by the impedance ratio of two inductors Z1 and Z2. Fig.13 shows the switching sequence of the switches. S1 is closed and S2 is open under normal operation. Voltage dip occurs during S1 is open and S2 is closed. Fig. 14 shows small scale LVRT test results using a 440V, 100 KVA matrix converters and a 400V class PM generator. When switch S2 is closed, input voltage drops to almost zero, and the matrix converter starts providing reactive component current to the grid because the grid voltage is lower than normal level. In the real wind farms, the reactive current command is calculated based on the requirement from TSO but, for the test, the compensation level is predetermined according to the percentage voltage drop of the grid. In the test, the reactive current reference is 100%. The active current of the grid side decreases to zero as the generator torque is reduced. After the grid failure is cleared, the reactive current is reduced to zero and active current returns to the previous normal level.

Fig. 15 shows fault ride through test results under 50% voltage dip condition.

The reactive current compensation level is set to 100 %. Maximum output voltage is reduced due to decrease in the input voltage and increase in the grid-side displacement angle, the generator torque control capability is limited. When the grid voltage is very low, the grid voltage phase angle can be shifted for the better reactive current control. Figs. 14 and 15 prove that the reactive current compensation of the matrix converter is possible during fault ride through condition.

V. CONCLUSION

In this paper, high power matrix converter technology is introduced for the wind power application. Modular design concept using a single-phase MxC cell is employed to implement high power drive. The modular concept provides great flexibility in power and voltage ratings. High power matrix converter has advantages in efficiency, sizing, and reliability over the back-to-back converter inverter system. Four-quadrant speed torque operation proves the fundamental performances of the matrix converter, and low voltage ride test results prove the feasibility of the matrix converter for the renewable applications.

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