A SYNCHRONOUS INVERTER FOR WIND ENERGY CONVERSION SYSTEMS

G.J. Vachtsevanos and K.C. Kalaitzakis
Polytechnic School
University of Thrace
Xanthi - Greece

Summary

This paper is concerned with the design and performance characteristics of a new dc to ac synchronous inverter to be used in the interconnected operation of a wind energy conversion machine and the power grid. The design of the inverter is based upon a conventional thyristor bridge and readily available and inexpensive components for the firing and control circuits. The synchronous inverter has been tested with a 2.2 KW wind turbine. Performance results indicate a high degree of inverter efficiency, low harmonic distortion content and excellent overall reliability characteristics.

Introduction

The most interesting aspect of the utilization of wind energy conversion devices for power production refers to their interconnection with the utility system. Different types of wind driven generating equipment and appropriate interfacing devices have been proposed[1] and some of them have already found the implementation route. For example, one possible scheme involves a synchronous generator directly connected to the grid[2]. Such an arrangement requires a constant speed drive usually implying expensive and elaborate rotor blade controls and gearing mechanisms. Other possible schemes involve asynchronous drives[3] connected directly to the grid or field modulated generators[4].

In this paper a scheme is proposed which utilizes a variable speed - variable frequency three - phase generator. The variable amplitude - variable frequency power produced is rectified first and then fed to a synchronous dc to ac inverter connected to and providing ac power to the grid. The basic system components are characterized for their simplicity, reliability and low cost. Similar synchronous inverters have been proposed[5] but are rather cumbersome in their design and prohibitevely expensive. The inverter reported herein has been tested with a 2.2 KW wind machine and has been operating reliably and efficiently for a period of over two years. The basic design features and operating characteristics are outlined in the following paragraphs.

Design Considerations

The overall system components are shown on Figure 1. The aerodynamic subsystem with its associated mechanical power transfer equipment is coupled to a three - phase generator. The electrical power output is rectified and fed to the synchronous inverter. This last apparatus is directly coupled to the power line thus providing power to the grid.

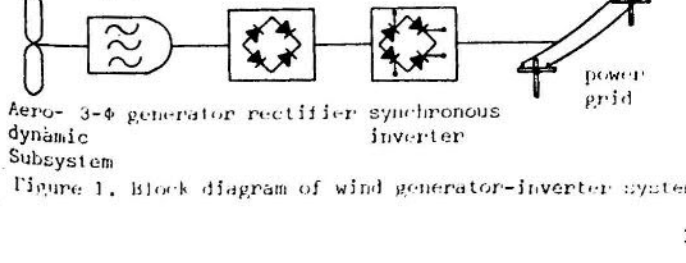


Figure 1. Block diagram of wind generator-inverter system.

Our concern presently is the synchronous inverter. Its design is based upon a classical 4-thyristor bridge shown schematically on Figure 2.

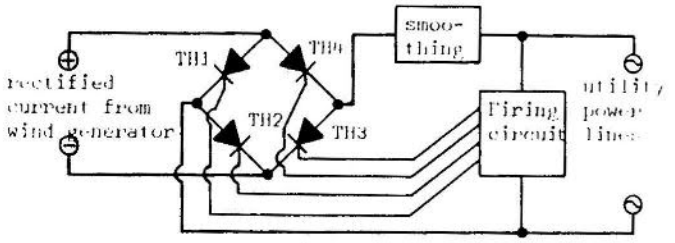


Figure 2. The synchronous inverter.

The input to the inverter is the rectified wind generator current whereas its output is directly fed to the power grid. The thyristor firing circuit consists of one transformer with four secondary taps and simple RC circuits designed to provide the appropriate phase angles for firing the thyristors. In the same circuit, protection mechanisms are included for both high values of the input dc current or overvoltages from the output power lines. The figure also shows, on the side of the power line, a smoothing circuit which consists of an RLC filter suitably designed to improve the ac output current waveform.

The following steps outline the bridge operating characteristics: At the beginning of the positive half-cycle of the grid ac waveform, thyristors 1 and 3 are fired so that a dc voltage appears at the bridge output terminals. This state continues until the ac voltage waveform reaches the level of the dc whereat the operation of the thyristors ceases. At the beginning of the negative half-cycle the firing circuit initiates thyristors 2 and 4 and an analogous operating sequence takes place. The resultant bridge output waveform is shown on Figure 3. Figure 4 shows the filtered waveform at the power line terminals.

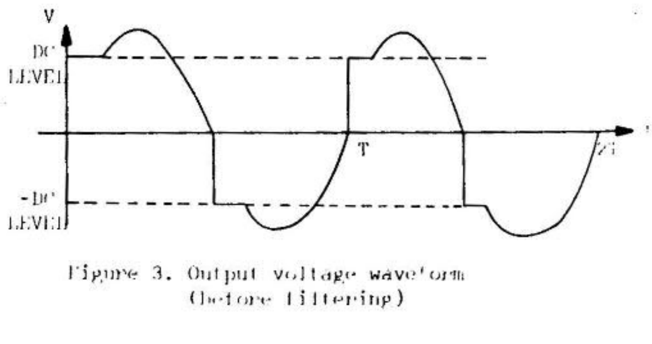


Figure 3. Output voltage waveform (before filtering)

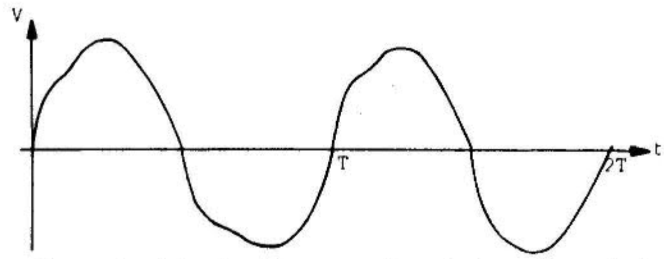


Figure 4. Output voltage waveform (after filtering)

It is obvious from the above analysis that the dc level must be restricted to be less than or at least equal to the peak value of the ac waveform. In the event that this condition is violated, an appropriate control circuit interrupts the operation of the thyristors and, consequently, the bridge disconnects the wind generator output from the power grid. Problems are not encountered during utility power failure since the firing circuit ceases operating.

The components used for the construction of the bridge and the associated circuitry are low cost and readily available commercially. The inverter tested has a power capacity of 2.5 KW and is coupled to a three - phase wind generator of 2.2 KW nominal power output at a dc voltage level of 110 volts. The inverter output is fed through a transformer to the Greek Public Power Corp. grid at the 220 volt level. A three - phase version of the inverter contains a minimum of six thyristors and appropriate firing and control circuitry.

Results

The wind generator - synchronous inverter system has been operating reliably and efficiently without any stability problems. The output current waveform, shown in Figure 5(b), usually contains a sizable degree of harmonics. Its harmonic content is minimized via suitable filtering circuits. Figure 5 shows the actual voltage, current and firing pulse waveforms as they have been recorded on the oscilloscope screen.

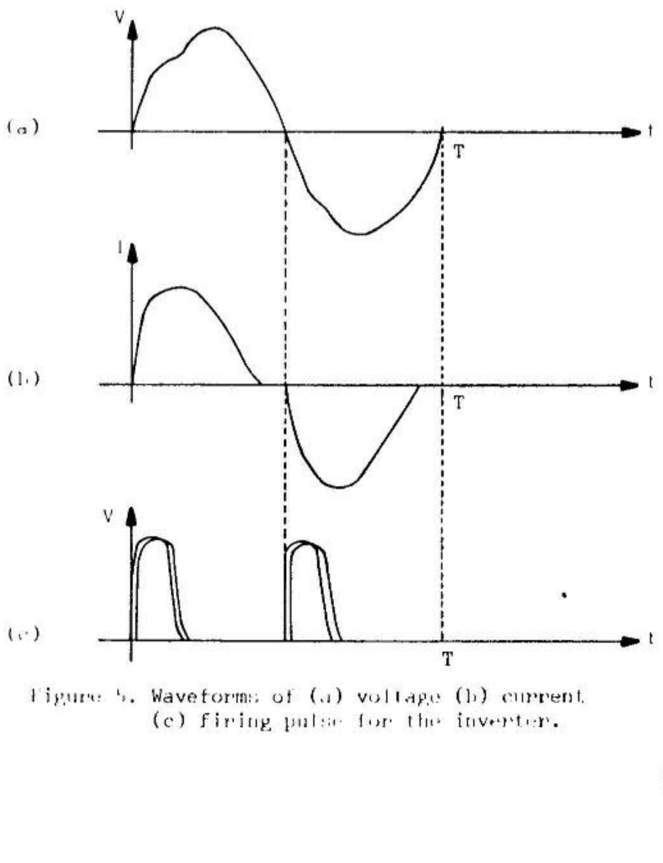
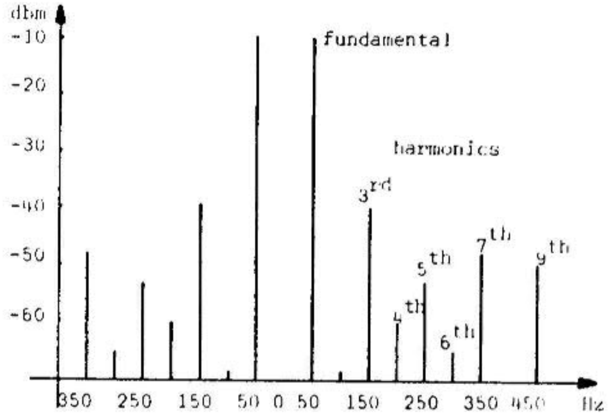


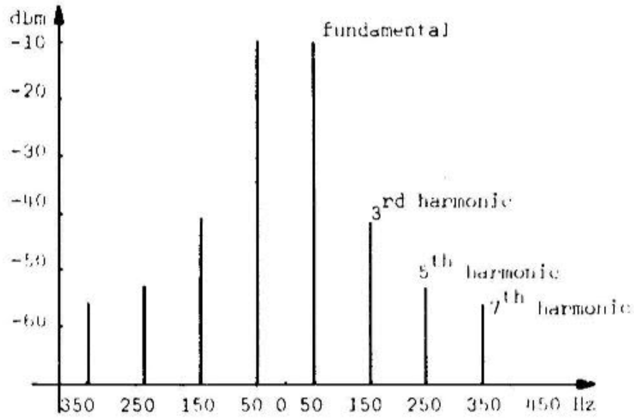
Figure 5. Waveforms of (a) voltage (b) current (c) firing pulse for the inverter.

The inverter efficiency at the nominal wind generator power level of 2.2 KW has been recorded to be approximately 95%. This efficiency figure improves further with a corresponding increase in the size of the generator - inverter equipment.

The harmonic content of the output waveform at the power line side has been recorded with a spectrum analyzer. Figure 6(a) shows the grid harmonics without the wind generator - inverter in operation whereas Figure 6(b) depicts the frequency spectrum at the nominal (2.2 KW) power level of the wind converting apparatus. Figure 7 shows curves of the power input, power output, efficiency and total harmonic distortion at the output side as functions of the dc voltage level at the input terminals of the bridge. Finally, a detailed circuit diagram of the synchronous inverter is shown on Figure 8.



Frequency spectrum of output waveform
(with inverter in operation)



Frequency spectrum of output waveform
(without inverter in operation)

Figure 6.

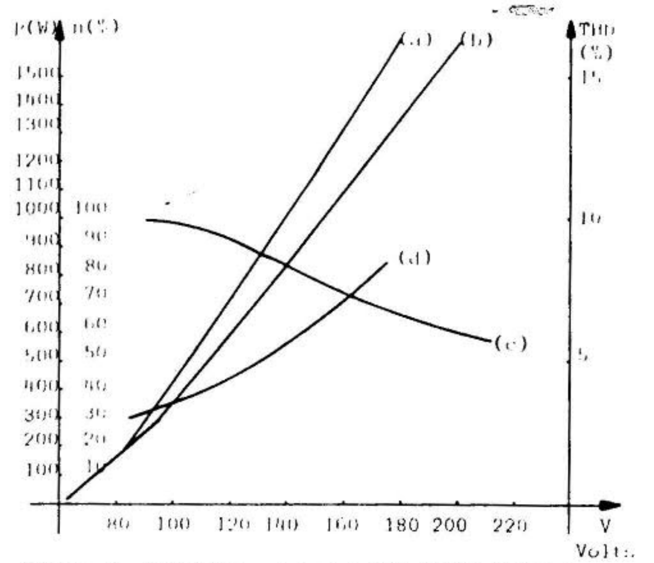


Figure 7. Waveforms of (a) power input (b) power output (c) efficiency and (d) total harmonic distortion of the inverter.

References

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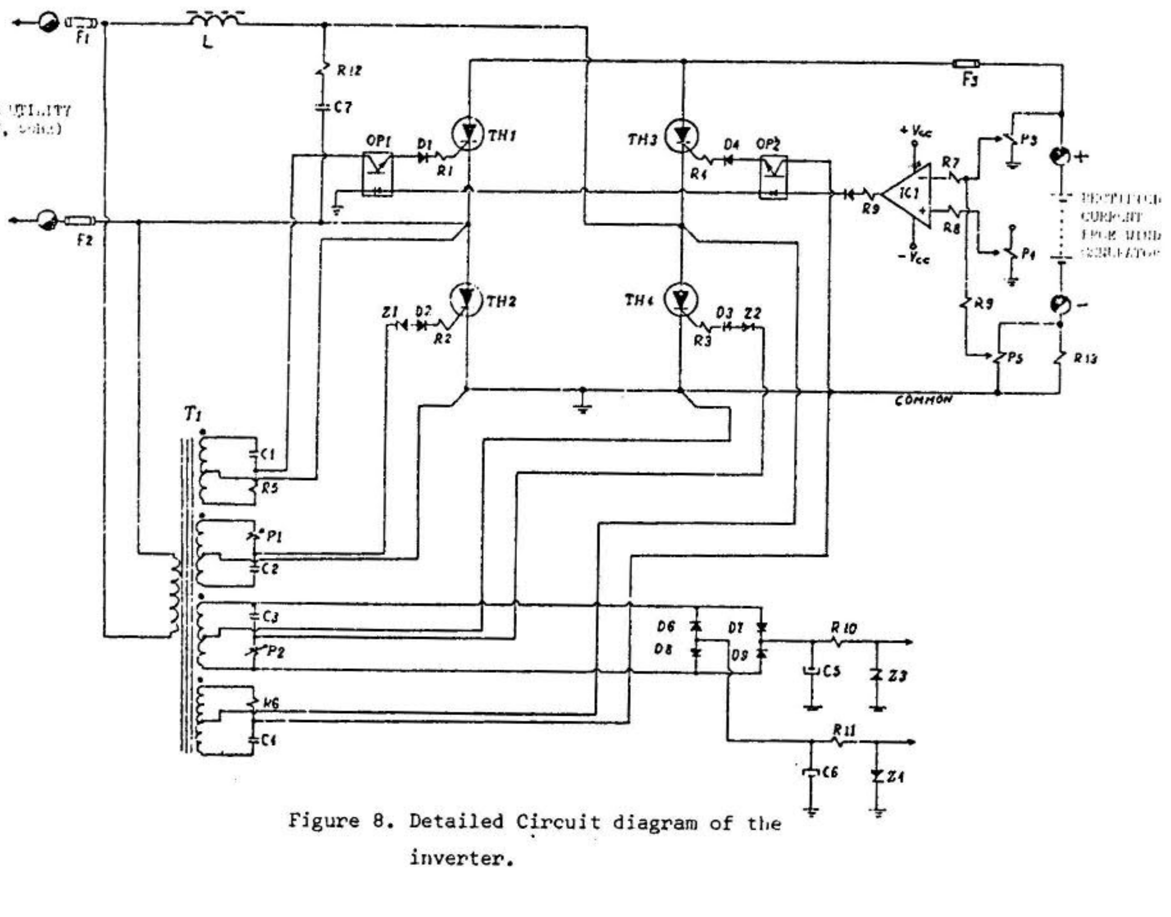

Figure 8. Detailed Circuit diagram of the inverter.