OPTIMUM OPERATION OF WIND ELECTRIC CONVERSION SYSTEMS INTERFACED WITH THE UTILITY GRID

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ABSTRACT

One of the main applications of Wind Energy Conversion, Systems (WECS) in recent years, is the interconnection of the devices to the utility grid, mainly for "fuel displacement" purposes, due to the intermittent nature of wind power.

One of the most advantageous small-sized WECS, is the combination: wind turbine-synchronous generator-rectifier-synchronous inverter, which is a Variable (rotating) Speed - Constant (output) Frequency (VSCF) system characterized by high efficiency over a wind range of wind speed values. Besides, the synchronous inverter offers the ability for matching the characteristics of the generator and the grid.

The relatively high cost of a WECS installation necessitates the investigation of any possible improvements in the output of such systems. A method of "matching" for maximum power transfer between the WECS and the utility grid is the main purpose of this paper.

The proposed output power improvement method is characterized by such features as low cost, simplicity, reliability and optimum operational characteristics for both the given WECS and the utility grid.

INTRODUCTION

Wind energy is one of the alternative energy sources that has recently attracked the interest of many investigators due to the increasing rareness of conventional fuel deposits on one hand and the increasing power demand on the other. The most cost effective use of wind energy is its conversion into electric form and integration of the system to the existing utility grid. Such a system is called a Wind Electric Conversion System (WECS).

WECS are divided into two categories: Large WECS (rated power above 100kw) and Small WECS[1] (rated power below 100kw). Large WECS, almost generally, utilize synchronous generator directly connected to the grid; in this case optimumoperation is achieved by the use of complicated control instrumentation. In small WECS, the electric power production is achieved either by synchronous generators indirectly connected to the grid or by inductive generators directly connected to the utility lines. Both categories (large and small) have advantages and disadvantanges so that the choice for any specific application is a function of many parameters. One main advantage of large WECS is their relatively lower cost, but energy production with small WECS (a cluster of such similar devices) seems to result in a more reliable operation. Besides, the use of small WECS in isolated communities (i.e small islands) is preferred over large ones[2].

The high cost of WECS necessitates the study of their optimum operation at any wind speed and any loading of the grid. In the case of induction generator WECS, some attempts have been reported in this direction[5], but the high reactive power demand and the need for synchronization detection equipment, makes the use of those systems problematic. Small WECS, based on the synchronous generator design, connected to the grid by means of a rectifier-synchronous inverter, are characterized by some features that make their application attractive. Optimum operation of such systems (i.e maximization of penetrating power) could be achieved, in a simple way by controlling properly the inverter characteristics. A schematic representation of the above mentioned system is shown in Fig. 1.

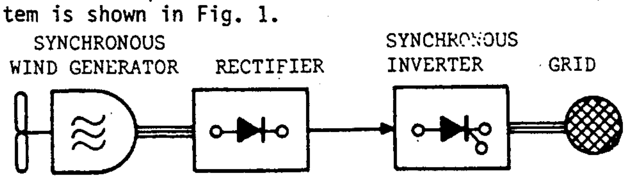

Figure 1. WECS interconnected to the grid.

THE NECESSITY OF "MATCHING"

It is well known, that the power delivered by a linear electric source, reaches a maximum amount when the source is "matched" to the load. This condition corresponds to a unique operating point on the linear characteristic curve of the source. The same principle is valid for some special cases of non linear sources[3] i.e. a wind generator system. The characteristic curves of Fig. 2 referred to point A of Fig. 1, are obtained by a suitable computer simulation of the WECS under consideration for certain values of the wind speed. It can be shown that, for every curve of this form, there is a unique operating point, for which the corresponding v.i product is maximized. This product represents the power supplied by the wind generator, the greatest percentage of which is transferred to the grid via the synchronous inverter. The maximum power point is directly depended upon the wind velocity so that for optimum operation of the system a continuous matching procedure is required.

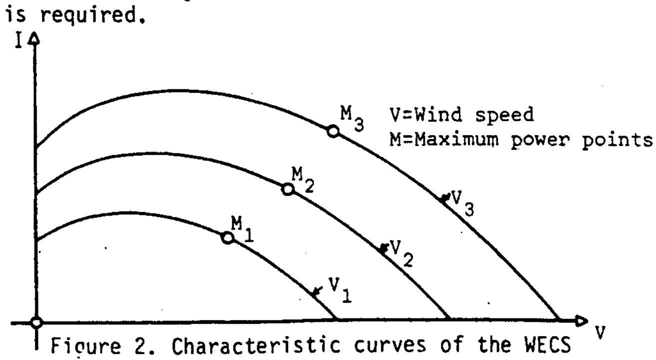

Figure 2. Characteristic curves of the WECS

The grid impedance at point B of Fig 1, is another parameter which affects the energy penetrating into the grid. This impedance, appearing at the output of the inverter, is reflected to the input and represents the load of the WECS at point A. Due to variations of the loading and generation on the side of the grid, the impedance at point B is varying continuously. Accordingly, the impedance at point A varies and this is an additional reason for some form of continuous mathcing.

MAXIMUM POWER TRACKING

An integral component of the WECS under consideration is the synchronous inverter, which converts the dc power present at point A, to ac form, in absolute synchronism with the waveform of the grid voltage at point B, thus injecting the energy recovered from the wind into the utility lines. The inverter is based on a thyristor three-phase bridge with a firing circuit properly designed, so that the conducting angle of the thyristors is controlled by an external control voltage. This type of inverter offers some advantages (i.e. non-reversible power direction, protection against grid over-and under-voltages) and a main disadvantage which is the relatively high harmonic distorsion of the grid voltage and current waveforms at point B. The harmonic distorsion percentage may be kept well within specified limits by connecting appropriate filters at the output of the inverter. Also electronic protection circuitry prevents equipment damage due to dc overvoltage or thyristor mistriggering.

Another significant advantage of this inverter is its ability to match the WECS characteristics to those of the grid, by means of the thyristor conducting angle. Thus, an optimum or suboptimum operation for the interconnected system is achieved by adjusting the control voltage. This is accomplished automatically by an electronic device called Maximum Power Tracker (MPT) illustrated on Fig 3. The maximum power tracker consists of an electronic wattmeter, a power level gradient detector and a control circuit.

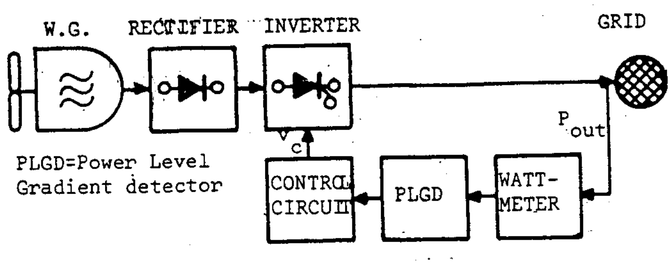

Figure 3. Connection of the maximum power tracker.

The MPT performs the following provedural steps: assuming that wind speed and grid impedance are constant quantities for the moment, the wattmeter supplies an output signal, directly proportional to the power injected to the grid. The power level gradient detector, compares this signal with the value stored previously and feeds the control circuit with a logic signal,which depends on the sign of the power change during two consequtive time intervals and the sign of the control voltage change. In this way the control circuit modulates properly the next value of the control voltage which inturn changes the conduction angle. Thus, a higher value for the output power is obtained and the cycle is repeated until the maximum power level is achieved. A change of wind speed or grid impedance causes the MPT to search for the new maximum power operating point. Therefore, the demand for continuous matching, as stated in the previous paragraph, is satisfied.

THEORETICAL AND EXPERIMENTAL RESULTS

The operation of the wind energy conversion systems including the MPT as illustrated in Fig 3, is simulated with digital computer; a prototype has also been constructed in the laboratory. The improvement in the output power of the WECS has been studied, by means of the mathematical model of the system, considering the MPT feedback loop initially disconnected and then in place. The resulting improvement is an increasing function of output power and depends on the characteristics of the synchronous generator and the nominal impedance of the grid at the interconnection point. The maximum improvement in power transfer recorded is 10%.

The experimental results are in good agreement with the theoretical ones. The actual systems implemented is of 2.2kw rated power.

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