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Multi-wind generators to supply water pump system based on cascaded H-bridge inverters

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Abstract—**In this paper authors propose the supply of a water pumping system by small scale wind turbines designed for remote area. The power conversion is based on cascaded H-bridge inverters controlled by asymmetrical Phase Disposition Pulse Width Modulation. Simulation results in both identical and different wind conditions are presented. The proposed structure improves reliability and also allows operation in fault tolerant operating mode.**

Keywords— **Cascaded H-bridge inverter, small scale wind turbines , PDPWM, water pumping.**

I. INTRODUCTION

The exploit of renewable energy is attractive for water pumping applications in remote rural areas. Wind turbines have an increasing importance in the field of standalone generation systems especially in the agriculture system irrigation [1],[2].

To such purpose, the adoption of wind turbines directly coupled to permanent-magnet generators represents a convenient solution, thanks to the insensitivity towards the wind direction, to the capability of exploiting turbulence in short distances and to the high efficiency of the PM generators [3].

Otherwise, in agriculture the reliability and availability of farm system irrigation are critical and crucial factors in the good crop production. Therefore, the design of high-level reliability solutions is very required.

A water storage tank is used instead of electric battery energy storage in order to guarantee, low cost and high-level reliability. In fact, the variable frequency three-phase induction machine is used since the voltage delivered to the pump varies with wind speed and accordingly a variable water flow.

In this paper, the authors propose a solution for water pumping system based on the integration of the cascaded H-bridge inverters in the power supply of three phase induction machine driving a water pump from several small scale wind turbines designated for remote area.

Compared with conventional solution, the one proposed in this paper has two major advantages: the structure modularity existing both on the energy source and on the power converter; the ability of the structure to drive the water pump even in degraded mode.

In the first part of this paper, the general aspect of the configuration of the water pumping system is presented. The main topology based on the cascaded H-bridge inverter and its different elements are shown. Secondly, the authors present the simulation results of the three phase induction machine driving a water pumping system in different cases of wind conditions. Finally, degraded operation mode of the system is presented when one of the converter cell fails.

II. THE CONFIGURATION OF THE WIND POWER CONVERSION SYSTEM

The different elements of the studied water pumping system based on water storage are presented in Fig. 1.

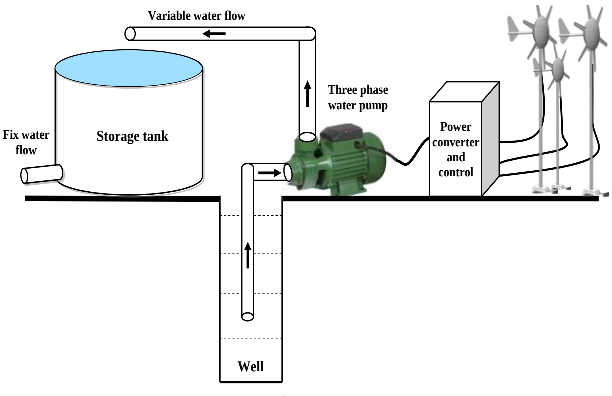

Fig. 1 Schematic diagram of the studied water pumping system

The system is composed from three small scale wind turbines based on axial flux direct-drive permanent magnet synchronous generator PMSG. Each generator delivers three AC output voltages feeding the induction motor via power converters.The three phase IM drives a water pump. This pump sucks water at a variable flow rate because it is influenced by the wind speed. The extracted water is stored in a tank for use in a fixed flow irrigation system. Two topologies of the conversion power system are feasible.

The first one is given by Fig. 2. Each generator is connected to a diode rectifier and a DC/AC converter feeding

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then a phase of the three phase motor pump. This structure offers the segmentation of power between the three wind turbines and consequently uses modular power converters. Furthermore, the direct-drive PMSG wind turbines are exposed to different wind speed which is changing on time. This unequal variable distribution of wind energy leads to unequal dc bus voltages. Thus, this phenomena can cause phase failure or unbalance that is not suitable for the motor pump.

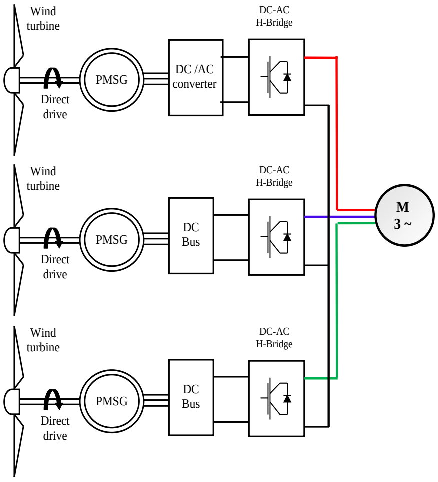

Fig. 2 Three phase motor pump fed by three H-bridge inverters

Accordingly, a second structure given by Fig.3 is proposed to overcome the limitations of the previous one, specially the phase unbalance. In fact, the integration of the multilevel cascaded H-bridge inverter in the conversion system seems to be interesting in terms of reliability, flexibility, extensibility and power segmentation [4],[5].

In this structure, each phase is supplied by three H-bridge DC/AC converters associated in series and having different dc input voltages E1,E2 and E3 which are provided respectively by the three wind generators G1,G2 and G3.

According to the wind speed distribution, each turbine is responsible of the value of the dc bus of the corresponding level of the power converter.

For example, the three cells of the first level are connected to equal dc bus voltages (E1) since they are delivered by the same generator G1. Thus, the motor pump is always supplied by a three phase balanced system.

Besides, the three dc voltages of the same generator are electrically separated since they are the outputs of different single phase rectifiers connected to the PMSG via a multiwinding transformer with an unified transformation ratio.

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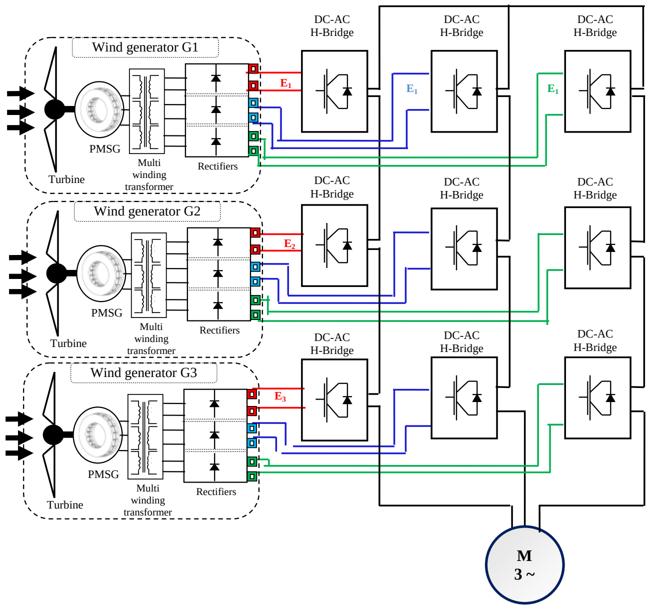

Fig. 3 Three phase motor pump fed by multilevel cascaded H-bridge inverter

A more detailed description of the multilevel converter and the PWM control is given in the following section of the paper.

III. THE CASCADED MULTILEVEL CONVERTER

The cascaded multilevel converter can synthesize an important output voltage from several small voltages since the resulting voltage is the sum of the output voltages of the different cells. For a given phase, non identical inputs are attributed to the multilevel inverter through the dc sides. This is the so called asymmetrical cascaded multilevel inverter [6].

The three phase cascaded multilevel converter represented in Fig. 4 contains three H-bridge converters per phase. Each H-bridge inverter is composed from two legs and a dc source; each leg is composed of two IGBT switches called $T_k\ (i,j)$ and $T_k^{'}(i,j)$, having complementary switching signals $S_k\ (i,j)$ and $S'_k(i,j)$.

The indexes k, i and j indicate respectively the half H-bridge index $k \in [1,2]$, the phase's number $i \in [1,2,3]$ and the cell's number $j \in [1..p]$ where $\boldsymbol{p}$ is the total number of the commutation cells per phase.

The per-cell output voltage is given by the following equation $V_{ij} = S(i,j) V_c\ (i,j)$

Where $S(i,j) = S_1\ (i,j) + S_2(i,j) - 1$

For ***p*** power cells, the output voltage per phase contains ***p+1*** levels and it is equal to

$$V_{in} = \sum_{j}^{p} V_{ij} = \sum_{j}^{p} S(i,j) \cdot V_c\ (i,j)$$

The line to line output voltage of a three phase cascaded converter has ***2p+1*** levels

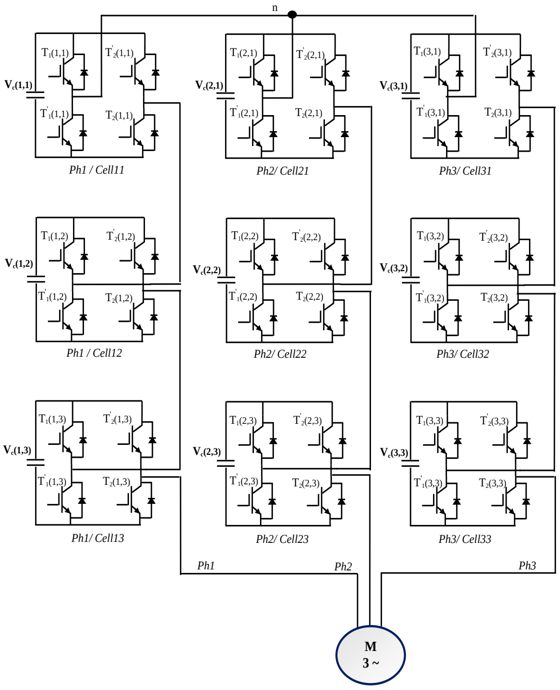

Fig. 4 Detailed structure of the power conversion system

The modulation control used for controlling the gate drive signals for the cascaded inverter is based on the multicarrier PWM strategies. Phase Disposition PWM is among the commonly used control technique and offers satisfying harmonics reduction results [7]. Further, it is adopted to the asymmetrical structure [8].

It is based on applying six triangular signals (Ap1...Ap6) vertically disposed and comparing them separately with three sinusoidal reference signals corresponding to the three phases. The synoptic scheme presenting the PWM principle for phase1 is given by Fig.5. For the other phases, the same carriers are kept, only the reference signal has to be shifted by the adequate angle.

Note that there are two triangular carriers for each cell having different offsets and same amplitude equal to the value of the corresponding dc voltage value (Ej=Vc(i,j)). In fact, the Ej values are given by a real time voltage measurements of the different dc voltages delivered by the three generators.

The sinusoidal signal has an amplitude Am equal to Am=2Σ Ej.

Consequently, each time the DC input value changes, the amplitude of the triangular carriers and the sinusoidal reference signal will change.

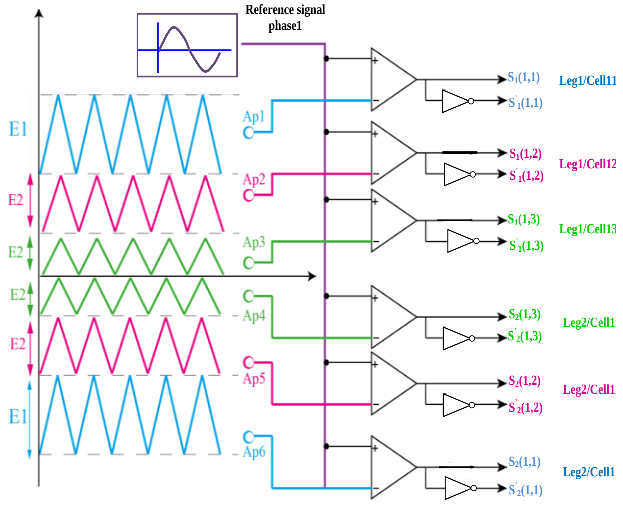

Fig. 5 Principle of asymmetrical PWM per phase (phase 1)

IV. SIMULATION RESULTS

A. Simulation Conditions

The whole system is implemented and simulated in Matlab/Simulink environment. Each wind generator has a nominal power equal to 500W. The three small scale wind turbines are associated to the cascaded multilevel converter for feeding a 1.5kW three phase water pump.

The induction machine is controlled using constant (V/Hz) law with a resistive torque proportional to the square of the speed:

$$Cr = k\Omega^2$$

The simulations are assured for different cases given in the following sections.

B. Case of Identical Wind Speeds

For this case, the wind turbines turn at the same wind speed (20m/s) corresponding to the maximum allowed value. Thus, all dc voltages have the same value(E1=E2=E3= 110V) ;it is the case of symmetrical cascaded inverter. The single voltage waveforms of phase1 and phase2 as well as the phase to phase voltage applied to the induction machine are given in Fig. 6. A zoom effect shows that the simple phase voltage has seven equal levels counted peak to peak. The phase to phase voltage has eleven levels.

Fig. 7 presents the evolution of the stator currents of the first phase, the speed and the torque of the motor pump. After a transient mode, the machine reaches its nominal speed and provides the resistive torque.

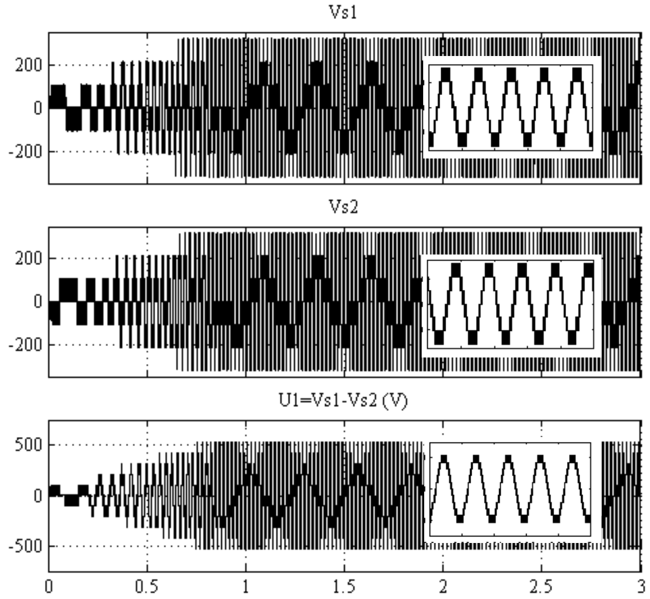

Fig. 6 Waveforms of output voltages of phase 1, phase 2 and phase to phase voltage with a zoom effect in steady state

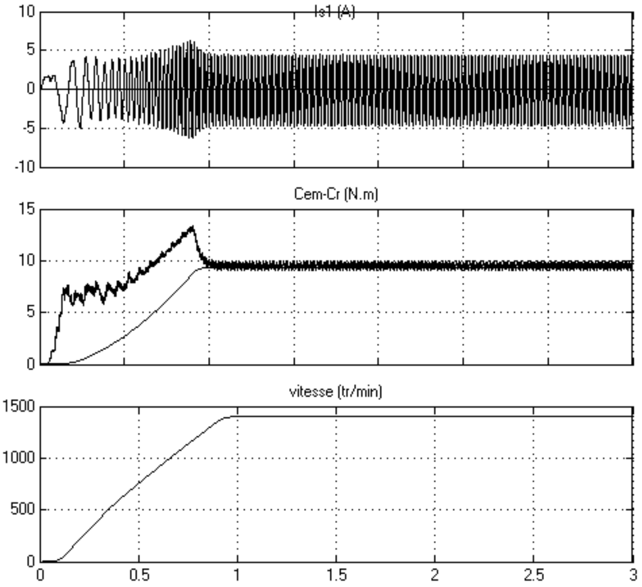

Fig. 7 Waveforms of stator current, electromagnetic torque and the speed of the induction machine

C. *Case of Different Wind Speeds*

Different wind speeds are applied to the three turbines. Consequently, the dc voltages delivred by the permanent magnenet genrators are not equal as shown in Fig. 8. Besides, at time equal to 2s, the wind turbine 2 has a velocity variation that the dc voltage is changing from 42 V to 108 V. Trough real-time simulation, the triangular carriers are adapted to the variations of the dc voltages.

Fig. 9 shows the waveforms of the different voltages and a zoom effect is done around 2s to present the evolution of the voltages. The stator current, the rotor speed and the torque are represented by Fig. 10.

Although variations, the rotor continues running and variable speed and assures the load torque which guarantees extracting water but with varaible flow.

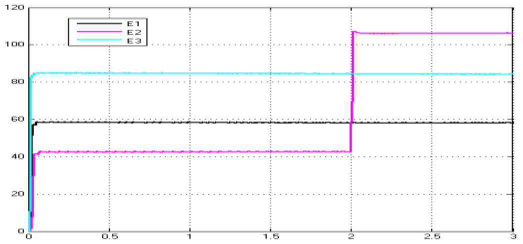

Fig. 8 Variation of the three dc voltages E1,E2 and E3

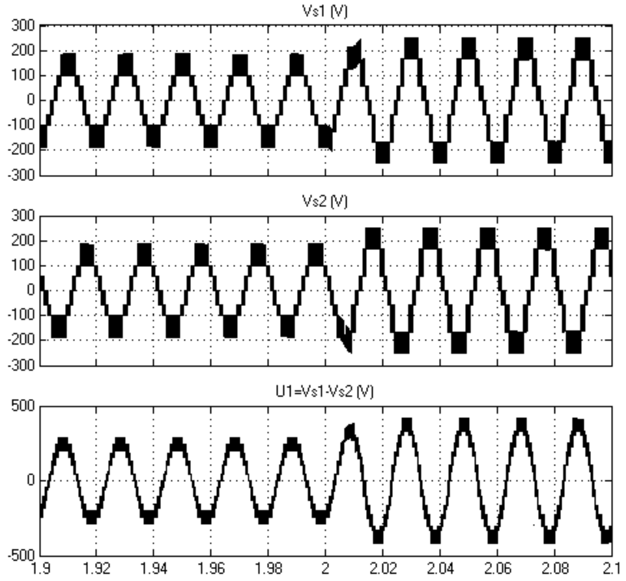

Fig. 9 Waveforms of the output voltages Vs1, Vs2 and U1 for different wind speeds and after a variation of E2 at 2s.

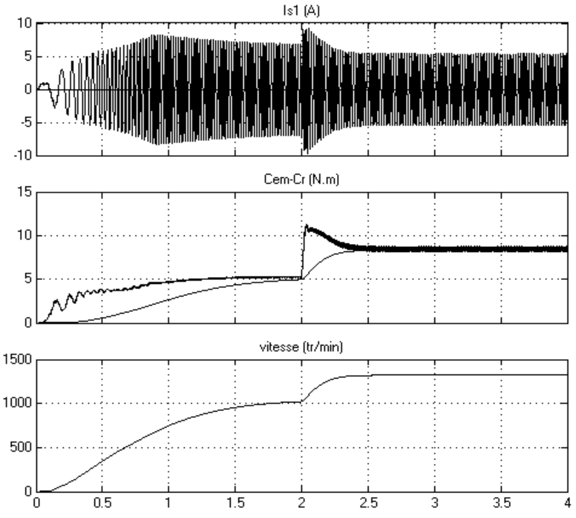

Fig. 10 stator current, torque and speed of the induction machine in case of different wind speed.

D. *Operation in Degraded Mode*

One of the advantages of the CHBI structure is to ensure the supply of the load even if a fault (open or short circuit) occurs at a semiconductor device of a cell [9].

Of course, the Cascaded inverter will not operate at full rated power after the bypass of a level. Surely a reduction of the rated power is more desirable than a complete shutdown specially in the application of water pumping.

The reconfiguration method adopted in this case consists on bypassing the faulty cell. For instance, if cell 12 has an open-circuit fault at $T'_{1}(1,2)$, hence, $T'_{2}(1,2)$ and $T_{1}(1,2)$ need to be turned on while $T_{1}(1,2)$ needs to be turned off to bypass cell 12 as shown in Fig. 11.

The two other cells (cell 22 and cell 32) should also be bypassed to ensure a balanced supply of the motor pump.

The 7 level cascaded inverter is equivalent to a 5 level one in this kind of degraded mode. The number of levels of the simple phase voltages is reduced after the reconfiguration of the structure as shown by Fig.12. Otherwise, Fig. 13 shows the continuity of service of the motor pump at reduced speed and torque. Consequently, the operation of the pumping system is ensured in reduced flow rate.

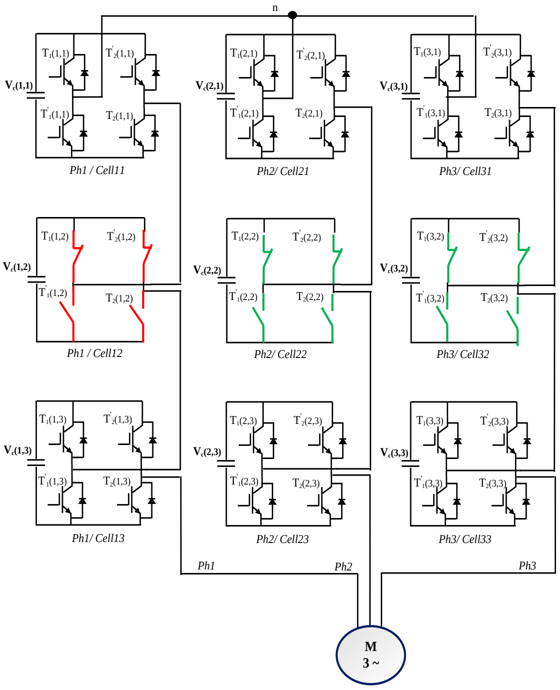

Fig.11 Reconfiguration of the structure in degraded mode

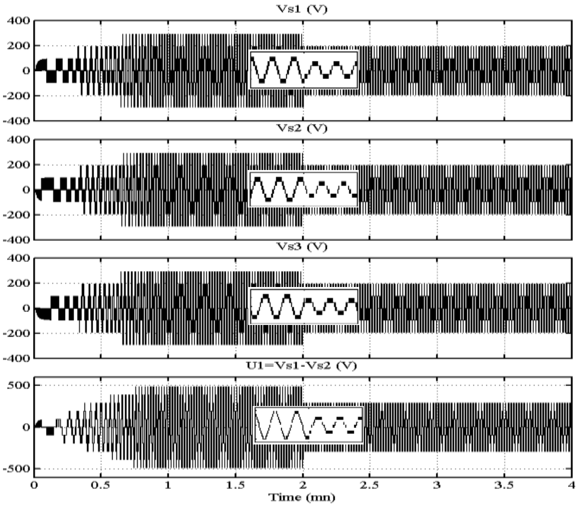

Fig. 12 Evolution of the output voltages when a default in cell12 at t=2s

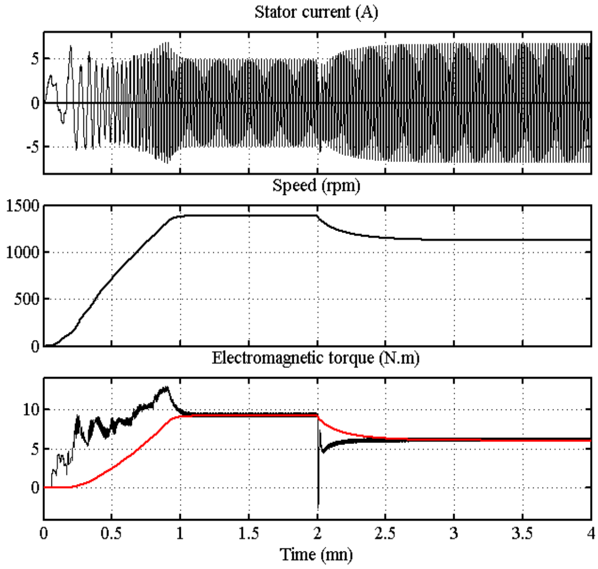

Fig. 13 Behavior of the induction machine : current, speed and torque after a fault at t=2s

V. CONCLUSIONS

In this paper, three small wind generators are used to supply three phase induction machine water pump system through multilevel cascaded H-bridge inverters. The asymmetrical PDPWM is very adapted to the asymmetrical converter which dc buses are depending on wind distribution.

In the simulation results, the operation of the motor pump for different winds and even low values are presented. Also, it has been proved that such topology ensures the pumping in low rated flow in case of degraded mode.

Note that the case of degraded mode is equivalent to a healthy operating in an absence of wind expect that when a faulty occurs, a reconfiguration control must be applied to the structure which is extremely related to the emplacement and the nature of the fault.

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