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Dynamic Analysis of Hybrid Wind/Diesel System with Three-Level Inverter.

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DYNAMIC ANALYSIS OF HYBRID WIND/DIESEL SYSTEM
WITH THREE-LEVEL INVERTER

التحليل الديناميكى لنظم طاقة الرياح/الديزل المركبة

المزودة بمحول ذو ثلاثة مستويات

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خلاصة :

تعتبر السنظم المركبة المحتوية على نظم طاقة الرياح والديزل إحدى البدائل لتغذية الأحمال الكهربية بتكلفة منخفضة ودرجة إعتمادية عالية ، ويجب بحث كيفية تشغيل هذه النظم من حيث جودة الطاقه المغذية للأحمال حيث أن وجود تذبذب فى الطاقة الميكانيكية المولدة من الرياح يسبب ظهور تيارات ذات ترددات مختلفة عن التردد القياسى بحيث يمكن أن تحتوى الطاقة المغذية للأحمال على تردد خماسى أو سباعى أو أعلى أيضا لذا يقدم هذا البحث تصميما لنظام مركب محتوى على محول ذو ثلاثة مستويات لمعالجة مشكلة ظهور الترددات الأعلى من التردد القياسى يسمح بعزل التردد الخماسى تماما عن الأحمال و تقليل تأثير التردد السباعى بدرجة كبيرة ، وذلك باستعمال برامج محاكاة ذات كفاءة عالية لتمثيل تشغيل النظام فى حالتين من تغير سرعة الرياح ، الأولى هى تغير مفاجئ بين قيمتين وهو ما يعرف بالتغير السلمى والثانى هو تغير دورى ذو تردد منخفض . وقد أثبت السنظام المقترح إمكانية تغذية الأحمال الديناميكية المتمثلة فى مضخات رى بطاقة كهربية غير محتوية تقريبا على الترددات الخماسية أو السباعية التى تقلل من نوعية هذه الطاقة.

ABSTRACT
Hybrid systems combining wind energy conversion systems and diesel generators are considered one of the alternatives to feed demands at lower energy cost and acceptable reliability. Nevertheless, this combination must be investigating from the power quality point-of view. Due to different sources of fluctuating electrical power, the power delivered to the load contains different orders of harmonics. A three-level inverter is designed to suppress the fifth- harmonic of the phase voltage because of its undesired effects. The operation modes of the hybrid system and the design of the multi-level inverter are illustrated using simulation techniques.

Key word: Wind/Diesel hybrid systems, Three-level inverters, Harmonics

INTRODUCTION
At locations with promising climatic conditions, the coupling of wind energy conversion systems (WECS) with diesel generators as back-up systems can reduce energy cost and at the same time increase the security of a minimum supply. In other words, it would lead to design a reliable hybrid system. For a grid independent energy supply, the capacity of a hybrid system is dictated by the demand capacity and specifications. A small size hybrid system could be composed of single unit of

WECS and single unit of back-up facility connected to the load, defined as autonomous system. A medium size hybrid system consisting of different number of WECS's and back-up units compose a local utility feeding different a.c. loads. This configuration could be considered as a weak isolated hybrid system feeding a.c. loads [1,2].

Within the recorded wind speeds at the requested locations, wind turbines (WT) integrated in hybrid systems must show favorable operational conditions. Technical constraints imposed on the wind turbines that are installed for inland operation include high starting torque and high output power at low wind speeds. Low noise emission in urban areas, capability to handle the large wind speed gradient and the high turbulence in the swept rotor area due to the comparatively low towers are also major guidelines in selecting WT's [3,4].

As the wind turbine represents a mechanical system with unidirectional, unducted air flow, fluctuations in mechanical and consequently in electrical power supplied to the load occur due to two main sources. Firstly, fluctuations occur due to wind velocity changes; gradual changes which are statistical in nature, and sudden changes which are called turbulent conditions. Secondly, fluctuations that take place each time the blades of the turbine pass the tower, which can be considered of periodic form and result in distorted input mechanical power. This disturbance is of periodic nature too. Similar to the second type of fluctuations, the diesel engine could produce variable electrical power due to non-alignment of the machine shaft. Therefore, the power supplied by the generating units could contain harmonics of different orders. This condition must be investigated to meet the power quality constraints imposed on the hybrid system. The intermediate stage between the generating units and load is to be properly designed to suppress these sources of distortion [5].

High voltage and/or high power applications need series or parallel combinations of power switching devices to cope with the limitations of the device ratings. This arrangement may be problematic. Current trends in inverter technology include development of multi-level structures in order to extend the known advantages of the low and medium power inverters to high power levels. Multi-level inverters can reach high voltage and reduce harmonics by their own structure. At the same time, the blocking voltage of each power switch in such inverters is clamped to much lower voltage level. These inverters are able to generate output line voltage of higher levels than that of the conventional two-level inverters, without output transformers or reactors. Therefore, the harmonic contents of the output voltage can be much less than those of the two-level inverters at the same switching frequency [6,7,8].

This paper presents the operation modes of the hybrid system and the design of multi-level inverter to suppress the harmonics induced due to above mentioned distorted operating conditions.

SYSTEM CONFIGURATION

The schematic diagram of the proposed Wind/Diesel hybrid system is shown in Fig.1. It includes the following components:

-A fixed-pitch stall regulated, variable speed wind turbine (WT) is coupled with an induction generator forming the wind energy conversion system (WECS). This WT is preferred for its increased reliability, reduced maintenance and low cost.

-A diesel-driven generator, coupled in parallel with the WECS, operates as a back-up generating system.

-The two generating components are connected to the non-linear load through diode rectifier, RLC-filter and three-level inverter. As the rectifier generates non-sinusoidal currents, which increase the system losses, the RLC-filter is used to smooth the ripple of the direct current. The three-level inverter is designed to eliminate the undesired harmonics.

-A control unit is managing the operation of all system components according to the generation status and demand.

-A set of electrical industrial water pumps represents the main item of the system demand. Lighting, heating and cooling equipments are among different types of loads that to be fed by the generating system with pre-specified priority in case of reconnection after forced disconnection. Another dump load is connected in parallel before the inverter stage to absorb surplus power.

OPERATION MODELS OF HYBRID SYSTEM

The configuration of the proposed system would allow of having three different operation modes with different ranges of frequency and/or voltage. These operation modes are specified as follows:

-Operation mode I: the WECS is operating with constant frequency/ voltage as long as the wind speeds available are above cut-in speed of the turbine and the power consumption of the connected users does not exceed the generated power. In case of persisting mismatch between the power consumption and the WECS output, the diesel engine is to be started to compensate for this difference. Hazardous loads can be disconnected when this deficit exists and reconnected according to certain priority after this operation mode is exceeded.

-Operation mode II: the generation of electricity with maximum power output of the WT. This operation occurs when the wind speeds lie between rated and cut-off values of the wind turbine. It yields to the operation of the WT according to the line of maximum power coefficient cp of the rotor independent of the actual power consumption of the connected utilities. Surplus power is to be used in dump loads. This mode produces a variable frequency/voltage.

-Operation mode III: the generation of the WT will drop to zero in case of having wind speeds below cut-in or above cut out values. Thus, the load will be fully supplied by the diesel engine/generator set. From technical and economic stand-point of view, only non-hazardous loads are to be supplied during this mode of operation.

DESIGN OF THREE LEVEL INVERTER

The three-level inverter has the advantage that the harmonic distortion can be relatively low with respect to the conventional two-level inverter. The dc-link voltage can be raised two times higher than that of the two-level inverter (with the same voltage ratings of switching devices), so that it is considered suitable for high power applications [8].

The circuit configuration of the three-level diode-clamped inverter is shown in Fig. 2. In this figure 'O' indicates the negative side of the dc source; (Su1, Su4), (Sv1, Sv4), (Sw1,Sw4) are the main switching devices; and (Su2,Su3), (Sv2,Sv3), (Sw2,Sw3) are auxiliary devices added together with (Du1-Dw2) to clamp the output terminal voltage to the neutral point voltage. Each pair of the auxiliary switching devices (Su3, Su2) is driven complementary to the corresponding pair of the main switching devices (Su1, Su4). The output pole voltage has three possible levels (0,Vdc/2,Vdc) with respect to the negative side of the d.c. supply, and the output line voltage has five possible levels (0, Vdc/2, Vdc, -Vdc/2, -Vdc). Therefore, the harmonics of the output voltage are less than that of the 2-level, so the inverter efficiency becomes higher. The output voltage of the 3-level inverter depends mainly upon the switching modes of the main and auxiliary switches of the inverter. In this case, the selected switching mode leads to eliminate the fifth harmonic in the output pole voltage, since this component causes high-ripples in the output torque of the motor.

SIMULATION RESULTS

The simulation of the complete system using the SIMULINK in conjunction with MATLAB software package is considered. The simulation results of the studied cases are given below:

Case I : Step change of wind speed

The simulation results of this case are given in figures 3 and 4 . A step change of 1.5 p.u. for 1 sec, then down to 0.8 p.u. of the rated wind speed is activated as the source of disturbance. The frequency and the r.m.s. values of the output voltage of the induction generator (I.G.) show constant values at 50 Hz and 152 v respectively w.r.t. the first step change, a 6% decrease due to the second step change. The 3-phase output voltage of the induction generator is a sinusoidal wave with small decrease in maximum amplitude after the second step change. The output voltages of the 3-phase rectifier and the RLC-filter show almost constant values for 4 sec, a decrease of about 4% due to the decrease in wind speed. The pole, line and load voltages of the 3-level voltage source inverter are given in Fig. 4. These diagrams show an optimum operation of the designed 3-level inverter; nevertheless a slight reduction in the amplitude of the load voltage is recorded after the second step change. The stator current, speed and output torque of the motor are also given in Fig. 4, showing an ideal performance of the inverter. The harmonic spectrum analysis of the stator voltage indicates the complete suppression of the 5th harmonic, while the 7th harmonic has negligible amplitude.

Case II: Sinusoidal change of wind speed

The simulation results of this case are given in Fig. 5. A 1.5 rad./sec sinusoidal change in wind speed is superimposed on the steady state value after 3 sec. as the second source of distortion. This sinusoidal change reflects the change in mechanical power fed to the shaft of the I.G. Even when a change in the output voltage of the 3-phase I.G. is recorded, the input voltage of the I.M. has the same undistorted waveform. The speed and the stator current of the I.M. are kept almost unaffected, while the output torque shows a slightly fluctuated behavior. The harmonic spectrum analysis of the stator voltage

indicates also in this case the complete suppression of the 5th harmonic, with negligible amplitude of the 7th harmonic.

CONCLUSION

A hybrid system consists of WECS/ diesel generator, diode rectifier and three-level inverter is proposed to feed nonlinear loads. The demand is mainly pumping units, lighting and dump load. A key measure to meet the demand requirements is to investigate not only the power matching between the generating units and the load, but also to study the power quality of the total supplied power. Using simulation program, the response of the system is evaluated for two characteristic disturbances. The first distortion is a step change in wind velocity, and the second is a superimposed low frequency periodic change representing distorted input mechanical power. The system performance has been investigated showing acceptable power quality at the inverter output in both studied cases. The designed inverter suppressed completely the fifth-order of harmonics and reduced the seventh-order.

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APPENDIX A

A.I. Wind turbine & generator parameters
A horizontal wind turbine of 3.63 m radius with rated power of 5.5 KW at 8 m/sec wind speed, Cp = 0.43 is selected for the simulation.
The generator is a squirrel cage induction machine with the following parameters:
Rs=0.94 ohm , Rr=0.73 ohm,Ls=0.0069 H/ph , Lm=0.00302 H/ph , Lr=0.0069 H/ph
J=0.569 Kg.m2 , p=2 , wr=1164, P=5.5KW , V= 380/220 Y/ , 50 Hz
Steady state magnetizing characteristics are determined by the following relation: [9]
Eg / f = 272.506 - 1.169 Xmg
The diesel-generator set has the same parameters as the induction generator.
A.II. Motor parameters
The motor is a squirrel cage induction motor with the following parameters
Rs=0.294 ohm , Rr=0.156 ohm, Ls=0.00424 H/ph , Lm=0.041 H/ph , Lr=0.000417 H/ph
J=0.4 Kg.m2 , p=6 wr=1164
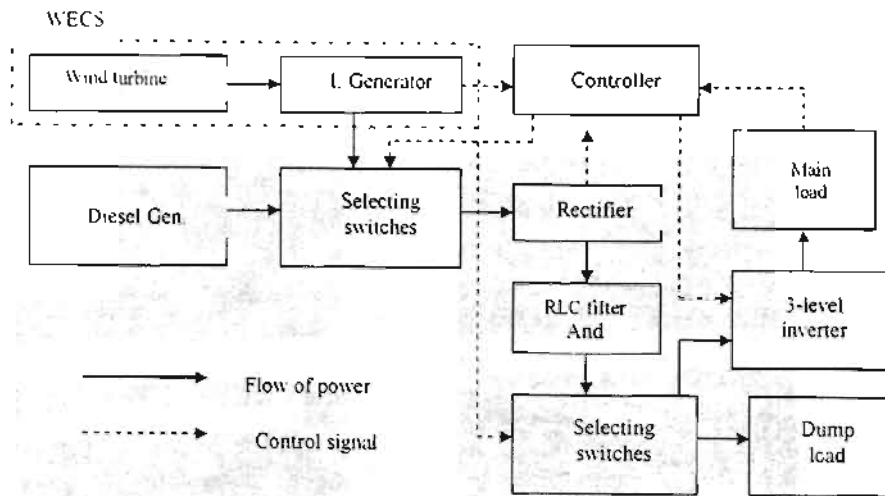P=5 KW , V= 380/220 Y/ delta , 50 Hz

WECS

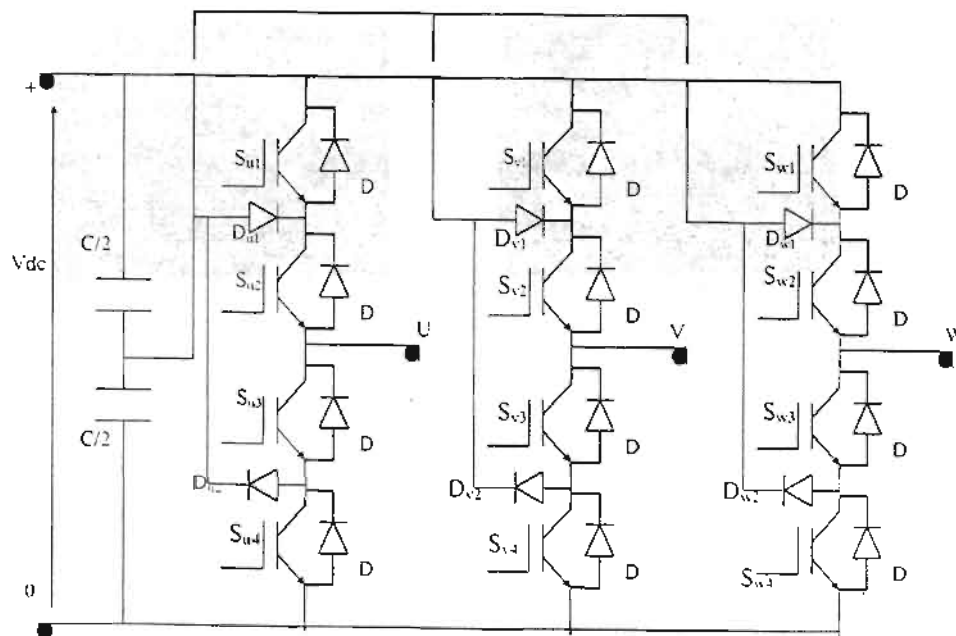Fig. 1 Block diagram of the hybrid wind/diesel system with 3-level inverter

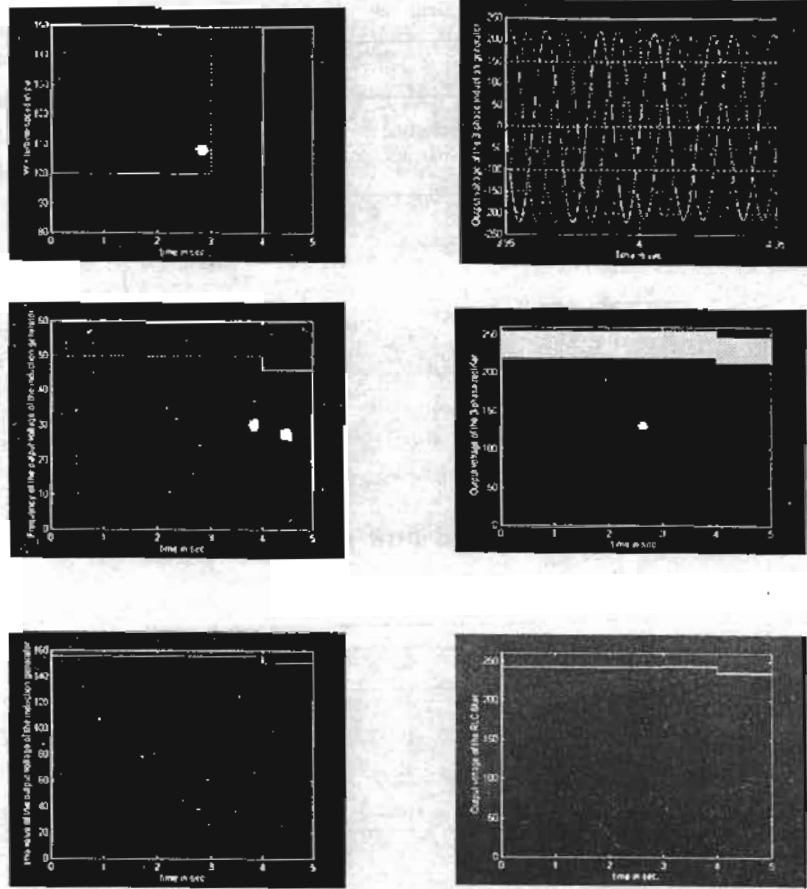Fig. 2 Three-level diode clamped inverter

Fig. 3 Simulation results of the induction generator and rectifier when a step change is occurred
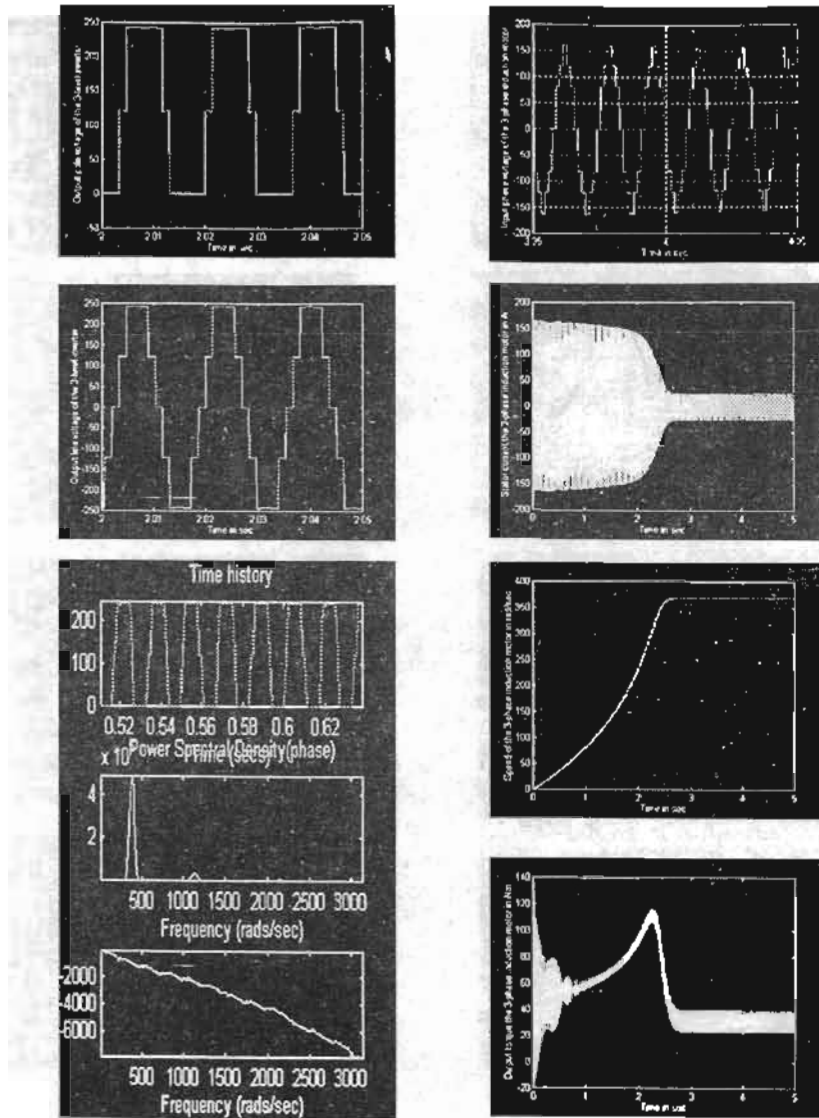
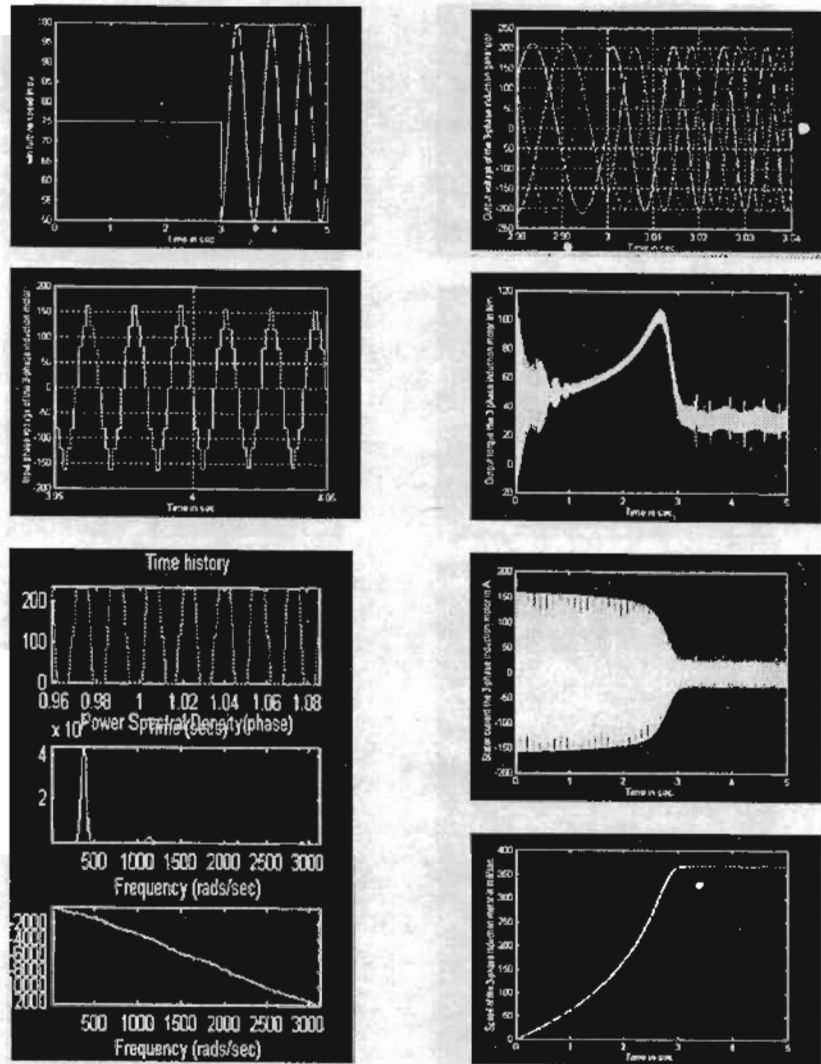Fig. 4 Simulation results of the inverter and induction motor
when a step change is occurred

Fig. 5 Simulation results when a sine change is occurred