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FREQUENCY CONTROL OF ISOLATED NETWORK WITH WIND AND DIESEL GENERATORS BY USING FREQUENCY REGULATOR

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Abstract

Due to the recent expansion of renewable energy applications, wind energy conversion is receiving much interest all over the world. However, output fluctuations of wind generators cause network frequency variations in power systems. This can decrease the power quality and then cause a restriction of wind farm installation, especially in an isolated network, for example, electrical power system in a small island. Therefore the problem of output fluctuation needs to be solved for Expanding further the wind energy conversion. This paper presents a new application frequency regulator to an isolated network with a high penetration no storage wind diesel system for improving the network frequency quality. The validity of the proposed controller is evaluated by computer simulation analysis using Matlab/Simulink.

Keywords wind turbine, isolated network, network frequency, high penetration no storage wind diesel (HPNSWD) system.

I.INTRODUCTION

As a result of conventional energy sources consumption and increasing environmental concern, efforts have been made to generate electricity from renewable sources, such as wind energy sources. Institutional support on wind energy sources, together with the wind energy potential and improvement of wind energy conversion technology, has led to a fast development of wind power generation in recent years. However, the frequency variation of power system due to wind generator output fluctuations is a serious problem. If installations of wind farms continue to increase, frequency control of power system by the main sources, that is, hydraulic and thermal power stations will be difficult in the near future, especially in an isolated network like a small island which has weak capability of power regulation. In such a case, the installation may be restricted even though it is a small wind farm. Though there is such a difficulty, an introduction of the wind energy utilization is much effective in an isolated power system, because main power plant in a small island is mostly a diesel engine driven generating plant and it has no good effect on the environment . Moreover, the price of diesel fuel is continuously increasing. On the other hand, the wind energy is a clean and inexhaustible energy source but due to great variation in wind speed which occurs from season to season, it can not be used as an autonomous source of generation . Hence, it is necessary to explore possibilities of combining a wind generator with the diesel generators in order to reduce the running cost per kWh and to increase the reliability of power supply.Research teams in many countries are now working to store the wind diesel energy. However, owing to the high cost of most forms of energy storage, the complexity ofsuitable storage devices and conversion again to AC electricity, only limited storage capacity will be aviable. The main problem of high penetration no storage wind diesel (HPNSWD) system is the complexity of the control technique. The wind speed variations, dependency of output turbine power on the cube of wind speed, and the configuration of the loads make the control tasks not easy to be achieved. In a distributed control system based on the controller area network is implemented in hybrid wind diesel systems with high wind penetration.

II.Wind turbine

Wind turbines can be classified by their mechanical power control, and further divided by their speed control.All turbine blades convert the motion of air across the airfoils to torque, and then regulate that torque in an attempt to capture as much energy as possible, yet prevent damage.

At the top level turbines can be classified as either stall regulated or pitch regulated. Stall regulation is achieved by shaping the turbine blades such that the airfoil generates less aerodynamic force at high wind speed, eventually stalling, thus reducing the turbine’s torque—this is a simple, inexpensive and robust mechanical system.

Pitch regulation, on the other hand, is achieved through the use of pitching devices in the turbine hub, which twist the blades around their own axes.

As the wind speed changes, the blade quickly pitches to the optimum angle to control torque in order to capture the maximum energy or self-protect, as needed. Some turbines now are able to pitch each blade independently to achieve more balanced torques on the rotor shaft given wind speed differences at the top and bottom of the blade arcs.

Beyond mechanical power regulation, turbines are further divided into

- fixed speed (Type 1),
- limited variable speed (Type 2),
- variable speed with either partial power electronic conversion. (Type 3)
- or full power electronic conversion. (Type 4)

The above speed control types are implemented via different rotating AC machines and with the use of power electronics.Another machine type which is called Type 5 in which a mechanical torque converter between the rotor's low-speed shaft and the generator's high-speed shaft controls the generator speed to the electrical synchronous speed.

The Type 1 WTG is implemented with a squirrel-cage induction generator (SCIG) and is connected to the step-up transformer directly. See Figure below. The turbine speed is fixed (or nearly fixed) to the electrical grid's frequency, and generates real power (P) when the turbine shaft rotates faster than the electrical grid frequency creating a negative slip (positive slip and power is motoring convention).

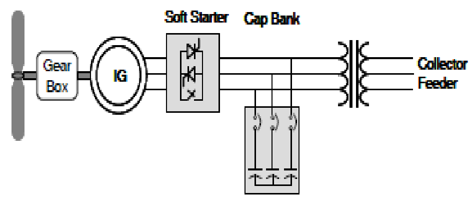

Fig1: Configuration of Type1 WTG

In Type 2 turbines, wound rotor induction generators are connected directly to the WTG step-up transformer in a fashion similar to Type 1 with regards to the machines stator circuit, but also include a variable resistor in the rotor circuit. This can be accomplished with a set of resistors and power electronics external to the rotor with currents flowing between the resistors and rotor via slip rings. Alternately, the resistors and electronics can be mounted on the rotor, eliminating the slip rings. The variable resistors are connected into the rotor circuit softly and can control the rotor currents quite rapidly so as to keep constant power even during gusting conditions, and can influence the machine's dynamic response during grid disturbances.

For an added rotor resistance the turbine would have to spin faster to create the same output power.

This allows some ability to control the speed, with the blades' pitching mechanisms and move the turbines operation to a tip speed ratio (ration of tip speed to the ambient wind speed) to achieve the best energy capture. It is typical that speed variations of up to 10% are possible, allowing for some degree of freedom in energy capture and self protective torque control.

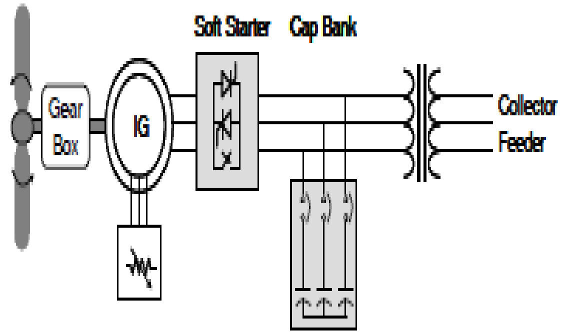

Fig2: Configuration of Type2 WTG

The Type 3 turbine, known commonly as the Doubly Fed Induction Generator (DFIG) or Doubly Fed Asynchronous Generator (DFAG), takes the Type 2 design to the next level, by adding variable frequency ac excitation (instead of simply resistance) to the rotor circuit. The additional rotor excitation is supplied via slip rings by a current regulated, voltage-source converter, which can adjust the rotor currents' magnitude and phase nearly instantaneously. This rotor-side converter is connected back-to-back with a grid side converter, which exchanges power directly with the grid.

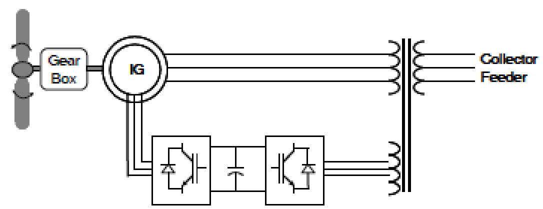

Fig3: Configuration of Type3 WTG

The Type 4 turbine (Figure 4) offers a great deal of flexibility in design and operation as the output of the rotating machine is sent to the grid through a full-scale backto-back frequency converter. The turbine is allowed to rotate at its optimal aerodynamic speed, resulting in a "wild" AC output from the machine. In addition, the gearbox may be eliminated, such that the machine spins at the slow turbine speed and generates an electrical frequency well below that of the grid. This is no problem for a Type 4 turbine, as the inverters convert the power, and offer the possibility of reactive power supply to the grid, much like a STATCOM.

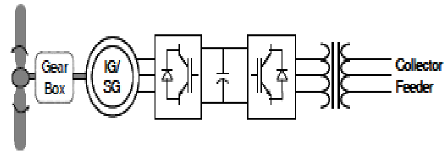

Fig4: Configuration of Type4 WTG

Type 5 turbines (Figure 5) consist of a typical WTG variable-speed drive train connected to a torque/speed converter coupled with a synchronous generator. The torque/speed converter changes the variable speed of the rotor shaft to a constant output shaft speed. The closely coupled synchronous generator, operating at a fixed speed (corresponding to grid frequency), can then be directly connected to the grid through a synchronizing circuit breaker. The synchronous generator can be designed appropriately for any desired speed (typically 6 pole or 4 pole) and voltage (typically medium voltage for higher capacities). This approach requires speed and torque control of the torque/speed converter along with the typical voltage regulator (AVR), synchronizing system, and generator protection system inherent with a grid-connected synchronous generator.

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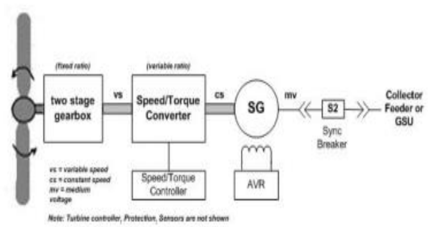


Fig5: Configuration of Type5 WTG

This approach requires speed and torque control of the torque/speed converter along with the typical voltage regulator (AVR), synchronizing system, and generator protection system inherent with a grid-connected synchronous generator.component of the rotor current (this is the component of the current that is in-line with the stator flux). In a Type 4 WTG voltage control is achieved by varying the quadrature (reactive) component of current at the grid-side converter.To allow voltage control capability, the grid-side converter must be rated above the rated MW of the machine. Since a synchronous generator is used in a Type 5 WTG, an automatic voltage regulator (AVR) is typically needed. Modern AVRs can be programmed to control reactive power, power factor and voltage.The voltage control capabilities of individual WTGs are typically used to control the voltage at the collector bus or on the high side of the main power transformer. Usually a centralized wind farm controller will manage the control of the voltage through communication with the individual WTGs. The reactive power capabilities of modern WTGs are significant as most grid codes require the WPP to have reactive power capability at the point of interconnect over a specified power factor range, for example 0.95 leading (inductive) to 0.95 lagging (capacitive). Type 1 and Type 2 WTGs typically use PFCCs to maintain the power factor or reactive power of the machine to a specified setpoint. The PFCCs may be sized to maintain a slightly leading (inductive) power factor of around 0.98 at rated power output.

III.SYNCHRONOUS CONDENSER

A Synchronous Condenser (sometimes synchronous capacitor or synchronous compensator) is a device identical to synchronous motor ,whose shaft is not connected to anything but spins freely.Its purpose is not to convert electrical power to mechanical power or vice -versa, but to adjust conditions on the electrical power transmission grid.Its field is controlled by a voltage regulator to either generate or absorb reactive power as needed to adjust the grid's voltage, or to improve power factor.Unlike a capacitor bank, the value of reactive power from a synchronous condenser can be continuously adjusted.

In an industrial plant, synchronous motors can be used to supply some of the reactive power required by induction motors. This improves the plant power factor and reduces supply current.The system produces no switching transients and is not affected by system electrical harmonics (some harmonics can even be absorbed by synchronous condensers).The reactive power produced by a capacitor bank is in direct proportion to the square of its terminal voltage, and can be adjusted to compensate for falling terminal voltage. This reactive power improves voltage regulation in situations such as starting large motors, or where power must travel long distances from where it is generated to where it is used.

IV.Asynchronous Generator

An induction generator or asynchronous generator is a type of AC electrical generator that uses the principles of induction motors to produce power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip. An asynchronous generator is really only an induction motor used as a generator. It will only supply 1/3 of a facilities power requirements because it still needs to be tied to the grid for excitation currents. The only time it will produce power is when the frequency of the rotor is greater than the frequency of the grid. This is what makes it asynchronous (out of synch). This is also the reason it can't be used to produce 100% of a facilities power generation.

V.The Control Strategies

The Frequency Regulator

The frequency is controlled by the frequency controller block. This controller uses a standard three-phase phase locked loop (PLL) system to measure the system frequency. The measured frequency is compared to the reference frequency (60 Hz) to obtain the frequency error.This error is the input of a PID controller. The output signal of the controller is converted to an 8-bit digital signal controlling switching of the eight three-phase secondary loads. In order to minimize the voltage disturbances, switching is performed at zero crossing of voltage.

VI.An Isolated Power System Model

The turbine power characteristics are illustrated as shown below

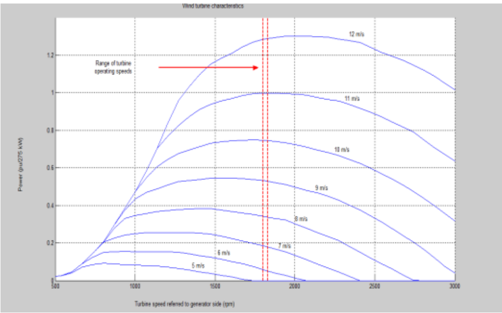
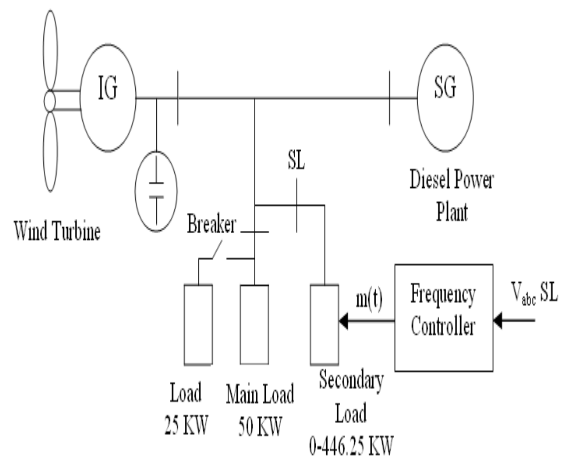


Fig6: wind Turbine characteristics

These characteristics are plotted at pitch angle *=0* (deg).

The wind speed is 10 m/s such that the wind turbine produces enough power to supply the load.Here, the diesel generator is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. The dynamic performance of the frequency control system is illustrated when an additional 25 KW customer load is switched on.For the IG mode, its speed is slightly above the synchronous speed (1.011 p.u). According to the turbine characteristics, for a 10 m/s wind speed, the turbineoutput power is 0.75 p.u (206 KW). Because of the IG losses, the IG produces 200 KW. As the main load is 50 KW, the secondary load absorbs 150 KW to maintain a constant 60 Hz frequency. At t=0.2 s, the additional load of 25 KW is switched on. The frequency momentarily drops and the frequency controller reacts to reduce the power absorbed by the secondary load in order to bring the frequency back to 60 Hz. The voltage stays at the rated value without any fluctuations.Here, the HPNSWD system presented uses a 480 V, 300 KVA synchronous machine as diesel power plant, a wind turbine driving a 480 V, 275 KVA induction generator, a 50 KW customer load and a variable secondary load (0- 446.25 KW). The data of wind turbine, IG, and the diesel power plant are illustrated in Appendix.At low wind speeds both the induction generator and the diesel driven synchronous generator are required to feed the load. When the wind power exceeds the load demand, it is possible to shut down the diesel generator.A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand. The secondary load block consists of eight sets of three phase resistors connected in series with GTO thyristors switches. The control signal m(t) is converted to 8-bit digital signal to control the thyristors



VII.Simulation Results:

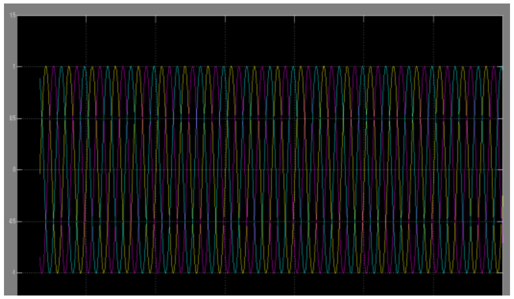


Fig7: voltage waveform

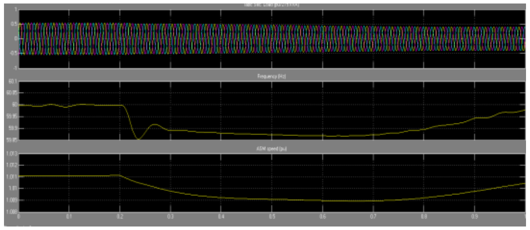


Fig8: current frequency and asm speed

Waveform

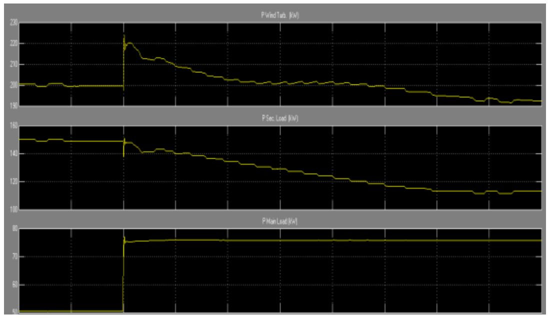


Fig9: Waveform for power across turbine,secondary load, main load

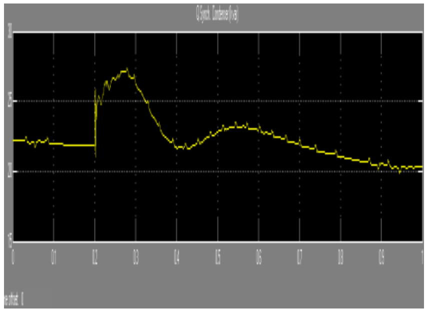


Fig10: waveform for power across synchronous condenser

VIII. Conclusion

This paper has proposed a new method of network frequency control by using the frequency regulator for an isolated power system including a high penetration no storage wind diesel (HPNSWD) system.

The validity of the proposed method has been evaluated by computer simulations. This method can contribute to expand wind energy utilization into isolated power systems like in small island.

IX. Appendix

a) Induction Generator Data

The apparent power	275 KVA
frequency (fref)	60 Hz
Stator Resistance	0.016 p.u
Rotor Resistance	0.015 p.u
The stator inductance	0.06 p.u
The Rotor inductance	0.06 p.u
Line to line voltage	480v
Number of pole pairs	2
The inertia constant	2s
The friction factor	0

TABLE 1. Induction Generator Data

b) Wind Turbine Data

mechanical power	275kw
wind speed	10m/s

TABLE 2. Wind Turbine Data

c) Power Plant Data

The apparent power	300KVA
Line to Line voltage	480V
Friction Factor	0
Pole Pairs	2

TABLE 3. Synchronous Condencer Data

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