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MPPT Control of Solar and Wind Energy of a Standalone Hybrid Power Generation System

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Abstract: ***Modern hybrid power systems, which combine conventional and renewable power conversion systems, are characterized by extensive system interconnections and increasing dependence on control for optimum utilization of existing resources, especially photovoltaic and wind energy, are the best solution for feeding the mini-grids and isolated loads in remote areas. The supply of reliable and economic electric energy is a major concern of industrial progress and consequent rise in the standard of living. Properly chosen renewable power sources will considerably reduce the need for fossil fuel leading to an increase in the sustainability of the power supply. At the same time, conventional power sources aide the renewable sources in hard environmental conditions, which improve the reliability and stability of the electrical system. The increasing demand for electric power coupled with resources and environmental constraints pose several challenges to system planners. With deregulation of power supply utilities (ex. Distributed Generation: such as non-conventional energy systems) there is a tendency to view the power networks as highways for transmitting electric power from wherever it is available to places where required, depending on the pricing that varies with time of the day. A stand-alone hybrid power system is proposed in this work. The MPPT control of solar Power system (SPS) is achieved by perturbation and observation method and the TSR control method was used for implementing MPPT control of SCIG WECS and field oriented mechanism of MSC control system enabling the WECS to extract optimum energy, while the LSC of both the RES's uses synchronous VSI control system. DG-set employs governor for speed control and excitation for voltage control. In order to minimize the fuel consumption, the speed demand (optimum speed) for the diesel engine is calculated by building up a lookup table where the optimal power-speed curve is implemented. The dynamic performance of a stand-alone wind-solar system with battery storage was analyzed. MATLAB/SIMULINK was used to build the model and simulate the system. The results shows the better performance of MPPT controllers under the variation of input constraints such as insolation and wind speed as well as output constraints such as varying different types of loads.***

Keywords: MPPT, SPS, SCIG

1. Introduction

Hybrid power systems, which combine conventional and renewable power conversion systems, are the best solution for feeding the mini-grids and isolated loads in remote areas. Properly chosen renewable power sources will considerably reduce the need for fossil fuel leading to an increase in the sustainability of the power supply. At the same time, conventional power sources aide the renewable sources in hard environmental conditions, which improve the reliability of the electrical system.

Over the present year's hybrid technology has been developed and upgraded its role in renewable energy sources while the benefits it produces for power production can't be ignored and have to be considered. Nowadays many applications in rural and urban areas use hybrid systems. Many isolated loads try to adopt this kind of technology because of the benefits which can be received in comparison with a single renewable system.

Technically a system which is entirely dependent only on renewable energy sources cannot be a reliable electricity supply, especially for isolated loads in remote areas. This is because the availability of the renewable energy sources cannot be ensured. Therefore, winds, solar PV hybrid systems, which combine conventional and renewable sources of energies, are a better choice for isolated loads.

A hybrid system using wind, solar PV, diesel generator as a backup system, and a battery as a storage system is expected to: satisfy the load demands, minimize the costs, maximize the utilization of renewable sources, optimize the operation of battery bank, which is used as back up unit, ensure efficient operation of the diesel generator, and reduce the environment pollution emissions from diesel generator if it is used as a stand-alone power supply.

The high capital cost of hybrid systems is affected by technical factors such as efficiency, technology, reliability, location, as well as some non-technical factors, so the effect of each of these factors shall be considered in the performance study of the hybrid system.

One of the important factors, which directly affect the electricity cost, is correct system-sizing mechanism of the system's components. Over-sizing of components in hybrid system makes the system, which is already expensive, more expensive, while under-sizing makes the system less reliable. Thus optimum sizing for different components gives economical and reliable benefits to the system.

2. Objectives

- To develop TSR based MPPT controller of SCIG WECS with field oriented control mechanism for MSC in back to back converter topology.

- To develop an optimum fuel consumption control by using look-up table method of Diesel engine along with governor and excitation controller for synchronous generator.
- To develop MPPT controller of a solar PV system using P&O method and synchronous control of three phase voltage source inverter.
- To develop Battery energy storage controller for steady state operation of Wind and PV system.
- Integration of renewable energy resources like solar, wind along with BESS and Diesel to form a Standalone Grid.

Hybrid Power Generation System

A hybrid renewable energy system is a system in which two or more supplies from different renewable energy sources (solar-thermal, solar photovoltaic, wind, biomass, hydropower, etc.) are integrated to supply electricity or heat, or both, to meet the same demand. The most frequently used hybrid system is the hybrid which consists of Photovoltaic (PV) modules and wind turbines.

Benefits of a Hybrid System

The possibility to combine two or more renewable energy sources, based on the natural local potential of the users.

- Environmental protection especially in terms of CO_2 emissions reduction.
- Low cost – as wind and solar energy can be competitive with nuclear, coal and gas especially considering possible future cost trends for fossil and nuclear energy.
- Diversity and security of supply.
- Rapid deployment - modular and quick to install.
- Fuel is abundant, free and inexhaustible.
- Costs are predictable and not influenced by fuel price fluctuations although fluctuations in the price of batteries will be an influence where these are incorporated.

3. Block Diagram of A Hybrid System

There are many possible configurations of hybrid power systems. One way to classify systems architectures is to distinguish between AC and DC bus systems. DC bus systems are those where the renewable energy components and sometimes even the backup diesel generator feed their power to a DC bus, to which is connected an inverter that supplies the loads. This is for small hybrid systems. Large power hybrid systems use an AC bus architecture where wind turbines are connected to the AC distribution bus and can serve the loads directly.

The configuration used to be evaluated in this thesis has an individual DC link, which is formed by using either rectified or induced DC and an inverter, while some of the DC power is bypassed to battery bank before to get inverted. The AC bus of this configuration combines all the outputs of the bidirectional inverters, the output of the back-up diesel generator and the load. This parallel configuration requires no switching of the AC load supply while maintaining flexibility of energy source, but the bidirectional power inverter shall be chosen to deal with this mode of operation. Figure 1.1 illustrates the block diagram of this configuration.

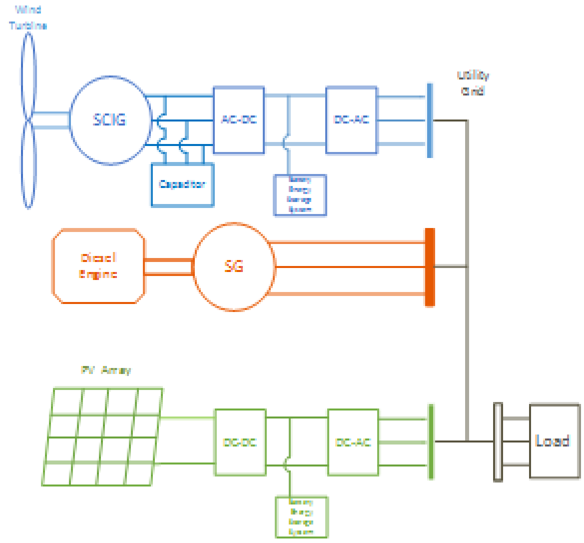

Figure 1.1: Proposed block diagram of hybrid system

The proposed solar and diesel–wind hybrid system is shown in Fig. 1.1. Detailed analysis of controllers for corresponding components of hybrid system were developed using MATLAB/Simulink, consisting of

1) Wind energy conversion system (WECS);
2) Diesel generator system;
3) PV generation system;
4) Battery energy storage system (BESS).

4. Necessity of Maximum Power Point Tracking

PV arrays are known to be nonlinear, and there exists one operating point where the PV array generates maximum power. In order to achieve maximum utilization efficiency of the PV array, the MPPT control technique, which extracts the maximum possible power from the PV array, is essential. Various MPPT control methods have been proposed, such as the lookup table method, incremental conductance (IC) method, and perturb-and-observe (P&O) method. The lookup table method requires prior examination of the PV array characteristics. However, PV array characteristics depend on many complex factors, such as temperature, aging, and the possible breakdown of individual cells. Therefore, it is difficult to record and store all possible system conditions. In contrast, the IC method and P&O method have an advantage of not requiring solar panel characteristics. The IC method uses the PV array's incremental conductance $\frac{dI}{dV}$. At the MPP, it utilizes an expression derived from the condition $\frac{dP}{dV}=0$. This method provides good performance under rapidly changing conditions. The P&O method perturbs the operating voltage of the PV array in order to find the direction change for maximizing power. If power increases, then the operating voltage is further perturbed in the same direction, whereas if it decreases, then the direction of operating voltage perturbation is reversed. This paper suggests a simple MPPT method with the boost converter. This MPPT control uses power hysteresis to track the MPP, giving direct duty control.

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its I–V curve and the load line which is the I-V relationship of load. For example in figure (2.2), a resistive load has a straight line with a slope of $1/R_L$ as shown in figure (2.3). In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP. Thus it is not producing the maximum power. A study shows that a direct-coupled system utilizes a more 31% of the PV capacity. A PV array is usually oversized to compensate for a low power yield during winter months.

This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost. To mitigate this problem, a maximum power point tracker (MPPT) can be used to maintain the PV module's operating point at the MPP. MPPTs can extract more than 97% of the PV power when properly optimized.

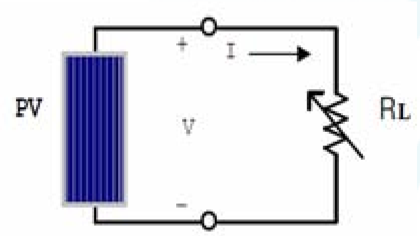

Figure 1.2: PV module is directly connected to a (variable) resistive load.

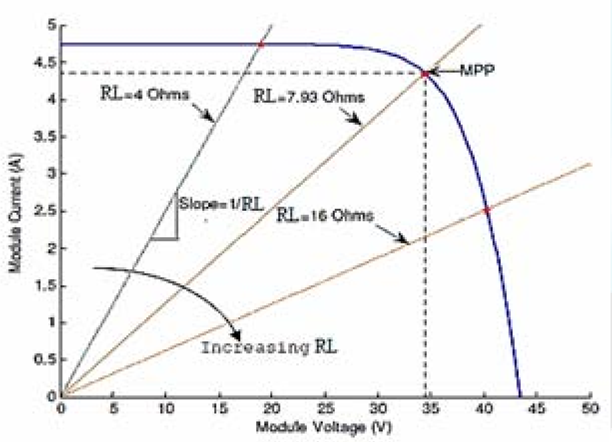

Figure 1.3: I-V curves of SURANA SVL - 230 PV module and various resistive loads were simulated with the MATLAB model (1kW/m2, 25°C)

Maximum Power Point Tracking (MPPT) Techniques
MPPT techniques are used to control DC converters in order to extract maximum output power from a PV array under a given weather condition. The DC converter is continuously controlled to operate the array at its maximum power point despite possible changes in the load impedance. Several techniques have been proposed to perform this task [18].

- Constant Voltage (CV) Method
- Open Voltage (OV) Method
- Incremental Conductance (IC) Methods

Variable Speed Wind Turbines
Variable-Speed wind turbines have many advantages that are well documented in the literature. The wind turbine can operate with maximum aerodynamic efficiency, and the power fluctuations can be absorbed as an inertial energy in the blades. In some applications, the wind turbine may be augmented by an additional power source, usually a diesel generator. These systems are called wind–diesel systems and may be used to supply electricity energy to stand-alone loads, e.g., small villages that are not connected to the main utility. Most diesel generation systems operate at a constant speed due to the restriction of constant frequency at the generator terminals. However, diesel engines have high fuel consumption when operating with light load and constant speed. In order to improve the efficiency and avoid wet stacking, a minimum load of about 30% to 40% is usually recommended by the manufacturers. Variable-speed operation can increase the efficiency, where the fuel consumption can be reduced up to 40%, especially when operating with a light load. Moreover, the life expectancy can increase with a lower thermal signature. To avoid the frequent start/stop of the diesel generator, an energy storage system is often used.

5. System Control and Analysis

The MPPT controller based on the "Perturb and Observe" technique is implemented by means of a MATLAB Function block that generates embeddable C code, which builds a direct connection between the duty cycle of DC-DC converter and the output power of PV array. The advantage of this method is to avoid PI controller design and for this reason the PV generation system got simplified and the cost got reduced.This converter uses a MPPT system which automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

The proposed PV system is composed of the boost converter and the three-phase inverter as showing Fig. 2 The boost converter performs MPPT control and also gives step-up function of the PV voltage. The three-phase inverter regulates the dc link voltage and generates the ac power. Thus, the three-phase inverter performs a step-down function. The power converter with step up/down function allows a wide range of PV voltages.

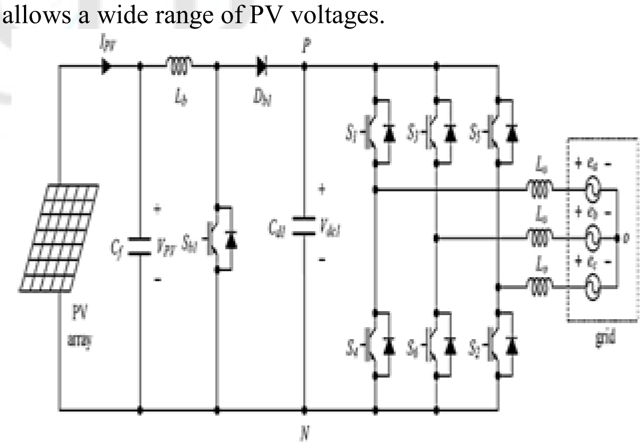

Figure 2: Proposed three-phase PV system.

Maximum Power Point Tracking
The P&O method has an advantage of not requiring solar panel characteristics as inputs and being easy to implement. This project suggests a simple P&O method for the boost converter. The MPPT process and its flowchart are shown in Figs. 2.1 and 2.2, respectively.

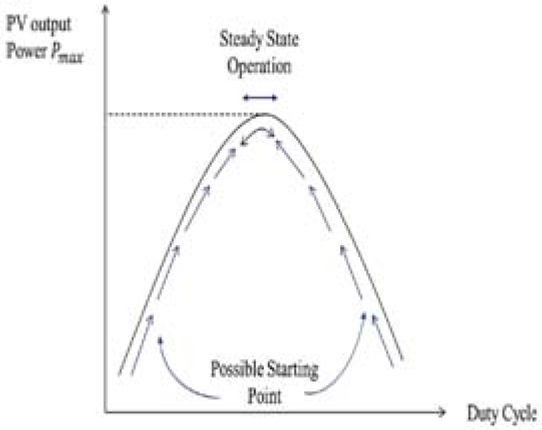

Figure 2.1: The principle of P&O MPPT strategy

The principle of P&O MPPT strategy is to periodically vary next step direction by a fixed factor $\pm\Delta P_{PV}/\Delta V_{PV}$, which is considered as the perturbation cycle. As shown in figure 3.4, regardless of where the tracking point firstly starts, the final goal is to arrive at the steady state operation region around the maximum power point. By comparing the current PV array output power with that of the previous perturbation cycle, the decision of the subsequent perturbation direction can be made as follows:

If the PV array output power increases, the subsequent voltage perturbation should continuously increase in the same direction, otherwise the voltage perturbation direction should be reversed in the next perturbation cycle. In this case, the operating point of the system gradually moves towards the maximum power point and finally oscillates around it in steady state region.
Two parameters need to be designed carefully to achieve faster tracking of maximum power point with smaller P&O MPPT strategy voltage step size. One of them is the time interval between iterations while another one is the step size of each voltage perturbation. Large step size ΔV_{PV} leads to fast tracking of the maximum power point under varying atmospheric conditions yet results in reduced overall average power conversion in steady state due to large oscillations around the maximum power point. Likewise, the design of time interval between iterations should leave enough operating time for computer calculation, but if the time interval is designed too long, the MPPT algorithm will lose the fast response capability to a varying environmental condition.

The flowchart of P&O algorithm is shown as below:

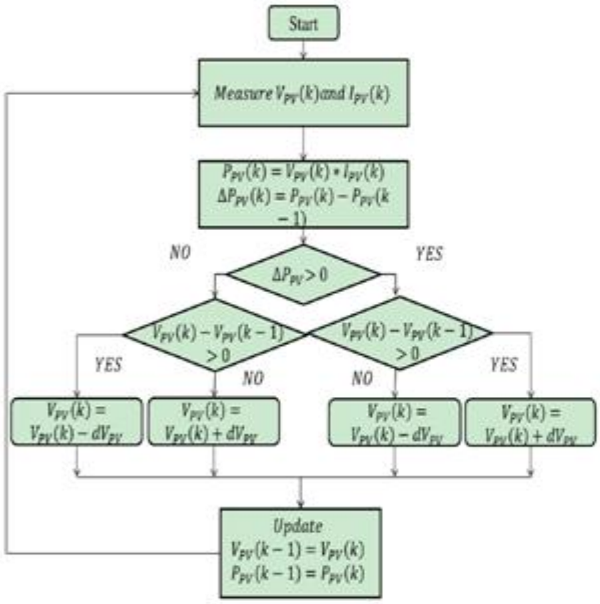

Figure 2.2: Flowchart of the MPPT control

6. Result

The hybrid system shown in Fig. 3 is implemented in the MATLAB/Simulink environment. Parameters of the WECS, the diesel generator, and the PV system used in the simulation are shown in Table I. Many tests were conducted to show performance of the model under various conditions, with the conventional MPPT techniques, such as typical TSR control and P & O method.

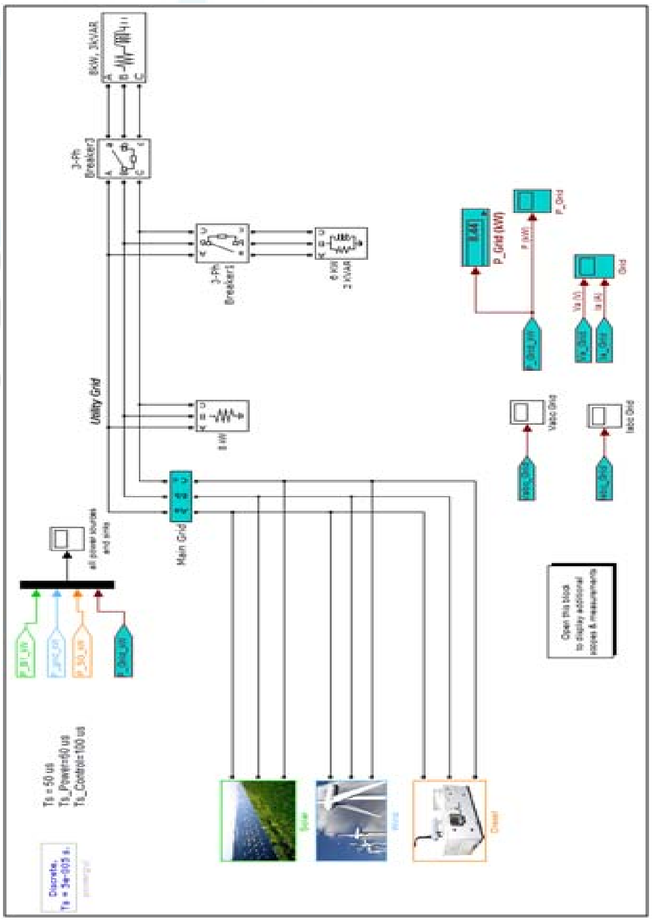

Figure 3: SIMULINK diagram of Hybrid power generation system

Solar and Wind power systems are operated as base load plant and diesel will work as peak load plant.

The simulation is run on 10 secs.

The entire simulation can be divided into three sections:
a) MPPT System Performance with constant load.
b) MPPT with Load Change.
c) MPPT under Variable Conditions.

7. MPPT System Performance

Wind Power MPPT: Time domain simulation was run for the hybrid power system with varying load under sufficient wind and irradiance. The output power from WECS is shown in results. From results, it can be seen that the PI with less transient and smaller vibrations. The average power available is 5.1 kW.

The SCIG reaches its rated speed at 1.5sec, until then the load feeds on the battery. The rotor speed will adjust corresponding to the changes in the wind speed (as shown in the results); this shows the better performance of the MPPT controller.

The effect of variation of wind speed is also considered along with load changes in order to show stability of the system. The wind speed falls from 12m/s to 8m/s at interval between 3-5.5secs.

Solar Power MPPT: The output power from PV is shown in results. We can see that the average modeled MPPT controller provides a better performance, both in the transient and the stability. The average power is 4.4 kW.

Here the ramp up/down signal is given as irradiance, which is varied rapidly from 1000-800-1000 at time interval between 1-3secs.

The average model of the system quickly and accurately track the maximum power output for solar array than detailed model.

The *P–V* and *V–I* characteristics of the PV system for MPPT are shown in Results. It shows a robust control performance of the proposed algorithm.

MPPT with Load Change

With sufficient wind and irradiance, show the comparison of the proposed algorithms with PI and P&O methods for a sudden load change from 10 to 13 kW. The dc-link voltage slightly decreases and then recovers in around 0.1 s.

The grid frequency response will not change posed method can track faster with a more stable output power under load disturbance.

MPPT under Variable Conditions

This case demonstrates a changing environment, where at t = 5 s we have
1) The wind speed changed from 12 to 8 m/s;
2) The irradiance level changed from 1000 to 800 W/m2;
3) And the load changed from 8 to 22 kW.

We can see from Fig. that with the drop of wind speed, the wind power also dropped to a low level around 0.2 kW. The diesel generator works with the wind turbine and PV array to meet the demand by picking up more loads. With a short transient in the beginning, the hybrid system quickly reaches stable operation. From Fig. the relationship between the optimal rotational speed and the power of the DGS is almost linear in this research. With normal load i.e. 8kw up to base load the mechanical input of the DGS is 0.1 With increase in load i.e., 14-kW load, the optimal speed, mechanical input of the DGS is 0.6 p.u, i.e., 43% rated speed. With 20-kW load, the control strategy drives the generator to a new optimum speed; mechanical input of DGS is 1.1p.u., i.e., 51% rated speed. The fuel savings at these reduced speeds are around 19% and 11% in comparison with the rated speed, respectively.

Synchronous Generator will regulate the frequency of the grid, under minimum load or No-load on the utility; solar, wind and BESS would feed the load, in that condition synchronous generator will act as synchronous condenser delivering leading power factor

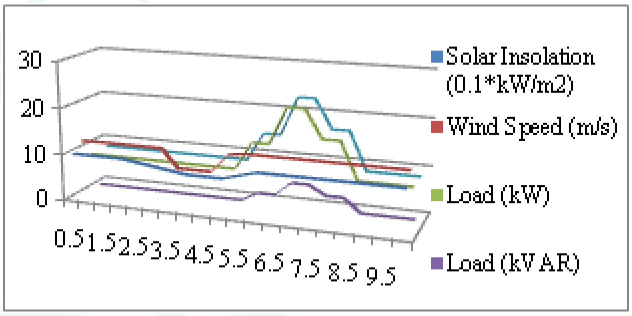

Figure: Overall changes in input and output parameters of the HPGS.

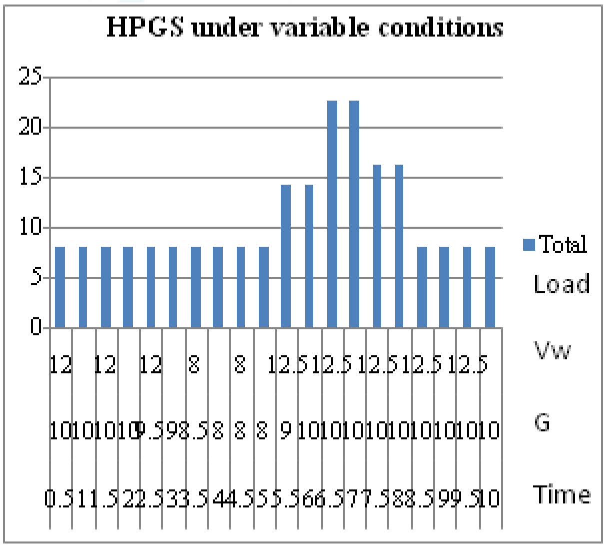

Figure: HPGS under different Load profile along with other operating conditions

8. Conclusion

In this project, a solar and diesel–wind hybrid generation system was proposed and implemented. This stand-alone hybrid generation system can effectively extract the maximum power from the wind and solar energy sources.

From the case studies, it shows that voltage and power can be well controlled in the hybrid system under a changing environment. An efficient power sharing technique among energy sources are successfully demonstrated with more efficiency, a better transient and more stability, even under disturbance.

The simulation model of the hybrid system was developed using MATLAB/Simulink. The load frequency is regulated by the diesel generator by imposing the rotor currents with the slip frequency. The electrical torque of the WECS generator is controlled to drive the system to the rotational speed where maximum energy can be captured. Depending on the load size and the power supplied by the WECS generator, the control system regulates the DGS rotational speed to minimize the fuel consumption. The Power Quality of the system from the results obtained has been very good and right value for the money invested.

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