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Analysis of Hybrid Energy System

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***Abstract**: This paper focuses on response analysis of Microgrid which consists of wind turbines, photovoltaic panels, with Hybrid DC and AC Buses. In grid-connected operation, voltage of DC bus is kept steady by the inverter. Energy Management System controls hybrid storage system to release or absorb power with the strategies according to grid condition, state of charge of batteries and super-capacitor, electricity price and so on. In islanded operation, voltage of DC bus is controlled by storage system and amplitude and frequency of AC Bus voltage are regulated by parallel inverters with voltage-frequency or droop control strategy. In this work, different control strategies in grid-connected and islanded operation are described which can keep power balanced and AC/DC bus stable. A test case of Permanent Magnet Synchronous Generator connected to a rectifier and inverter has been simulated in MATLAB/Simulink environment and from the results it can be shown that the voltages of AC and DC buses have been maintained steadily. The output voltage from PV modules is lifted using boost converter and given to maximum power point tracking system. The output is connected in parallel with the input from wind system to a common inverter and given to a common load. The desired outputs, power, voltage and current of AC side is observed and maintained within rated values.*

I. Introduction

Now more and more photovoltaic panels and wind turbines are integrated into grid, whose power fluctuation will lead to grid instability. Microgrid system is one of the solutions. There are many benefits of Microgrid including little pollution, higher reliability, better quality of power supply, and higher efficiency. This research presents hybrid DC- and AC-bus Microgrid system, which can be established in a country or island.

To avoid global warming, the consumption of fossil fuels must be reduced. Hence, the installation of renewable energy power production plants has become a burning issue not only for isolated islands but also all over the world. Among various renewable energy systems, photovoltaic power generation systems (PV systems) and wind power source are expected to play an important role as a clean electricity power source in meeting future electricity demands. Photovoltaic (PV) power as an alternative energy resource has been becoming feasible due to Enormous research and development works being conducted. The use of Photovoltaic (PV) generators in isolated sites, where conventional generation is not practical, can pose a problem because PV output power depends on weather conditions and cell temperature, making it an uncontrollable source. Furthermore, it is not available during the night. We consider resolving this problem by installing a hybrid system using an alternative wind energy source along with the PV array. Solar arrays provide dc power.

Hence power from a solar array cannot be directly added to an isolated power utility for using directly in residential, industrial or commercial applications. We require a DC-DC converter to step up the dc voltage from the panel and then an inverter to convert the dc into ac power which can be fed to the utility. A Photovoltaic (PV) system's power output is not constant and fluctuates depending on weather conditions (variations in irradiation and temperature). Therefore we also require a Maximum Power Point tracker (MPPT) along with the DC-DC converter in order to obtain the maximum power output from the Solar Photovoltaic (PV) array. In the hybrid system a wind power generators along with PV generators feeds the utilities loads.

The response of the hybrid system following common disturbances such as solar insulation variations and load changes have to be is investigated for analyzing the effects fluctuating power causes in the isolated power utility. This study is essential for devising a method for leveling the fluctuations in a PV system's power output when large output power from several PV systems has to be penetrated in the utility.

II. Hybrid Power System

A. Isolated Power Utility

This research presents hybrid DC- and AC-bus Microgrid system, as shown in Fig 1, which can be established in a country or island.

There are many units in the system which can be used in a house of a country. All the renewable energy generations and storage devices in the house are connected to DC bus with different converters which can supply power to local DC loads. Inverters are used to transfer power between AC and DC buses. Common and sensitive loads can be connected to AC bus with different coupling points. If there are some faults happened in utility grid, Microgrid system can work in islanded operation. In worse condition, if renewable energy generations can't supply enough power for local

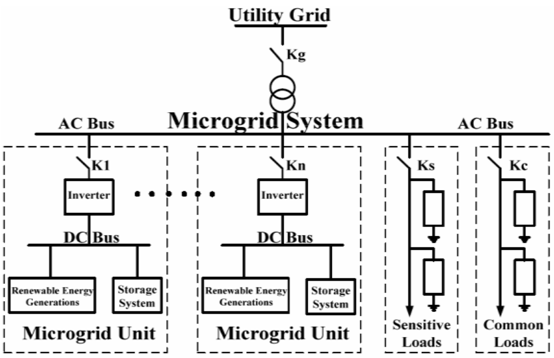

Figure 1 Microgrid systems with hybrid DC and AC buses

Loads and state of charge of storage devices are in low level, Microgrid could cut common loads to keep supplying power to sensitive loads. In hybrid DC- and AC-bus Microgrid system, fewer inverters are needed. So control strategy for parallel inverters is easier in islanded operation. And DC loads can be connected to DC bus directly without rectifier. Also the system can isolate individual units if there is something wrong in the unit.

B. Pv-Wind Hybrid Power System

The PV-Wind hybrid system model consisting of a wind turbine, PV power generation systems, and a load is shown in detail in Fig. 2,

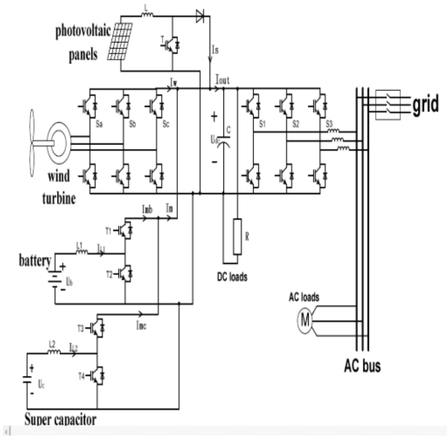

Fig. 2 Isolated hybrid power system model.

One unit of the Microgrid system is established in the lab as shown in Figure 2. It consists of a wind turbine, photovoltaic panels, batteries series connected and super-capacitor. The stability of DC- and AC-bus voltage is very important. When Microgrid system is connected to the utility grid, the amplitude of DC-bus voltage (200V) is regulated by the inverter, and voltage of AC bus is the same with the utility grid. However when the Microgrid works in islanded operation, DC-bus voltage must be regulated by renewable energy generations and storage devices, and the voltage and frequency of AC bus are controlled with voltage-frequency or droop control strategy of parallel inverters

III. Modeling Of Pv Array

A. Modeling Of Pv Cell

The equivalent circuit of the ideal PV cell is shown in Fig 3. The ideal PV cell be modulate as diode parallel with a current source

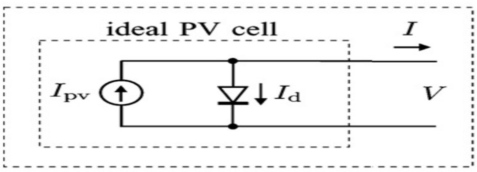

Fig 3 Ideal PV Cell

Thebasic equation from the theory of semiconductors that mathematicallydescribes the *I–V* characteristic of the ideal PV cellis

$$I = I_{pv,cell} - I_d \qquad (1)$$

Where, $I_d = I_{0,cell}[\exp\left(\frac{qV}{akT}\right) - 1]$ (2)

Therefore, $I = I_{pv,cell} - I_{0,cell}[\exp\left(\frac{qV}{akT}\right) - 1]$ (3)

Where, $I_{pv,cell}$is the current generated by the incident light (it is directly proportional to the Sun irradiation), *I*d is the Shockley diode equation, $I_{0,cell}$is the reverse saturation or leakage current of the diode, *q* is the electron charge (1.60217646 × 10−19 C), *k* is the Boltzmann constant (1.3806503 × 10−23 J/K), *T* (in Kelvin) is the temperature of the *p–n* junction, and *a* is the diode ideality constant. The origin of I-V curve from the equation (2) is shown in fig 4.

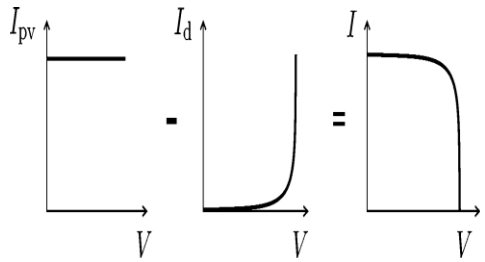

Fig 4 Origin of I-V equation of an Ideal PV cell

In addition to this modeling, the PV array is also modeled. With the help of this the amount of power which is produced through the solar cell can be estimated in a clear manner.

Boost Converter

A. Modes Of Operation

In a boost converter, the output voltage is greater than the input voltage-hence the name "boost". A boost converter is shown in Fig 5.

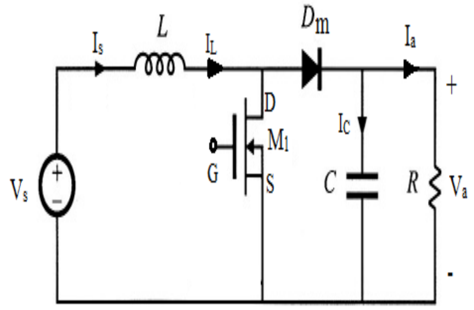

Fig 5 Boost Converter Circuit

The circuit operation can be divided into two modes. Mode 1 begins when the MOSFET M_1 is switched on at t=0. The input current, which rises, flows through inductor L and MOSFET M_1. Mode 2 begins when the MOSFET M_1 is switched off at $t=t_1$. The current that was flowing through the MOSFET would now flow through inductor L, capacitor C, load and Diode D_m. The inductor current falls until MOSFET M_1 is turned on again in the next cycle. The energy stored in the inductor L is transferred to the load. The equivalent circuits for the two modes of operation are shown in Fig 6.

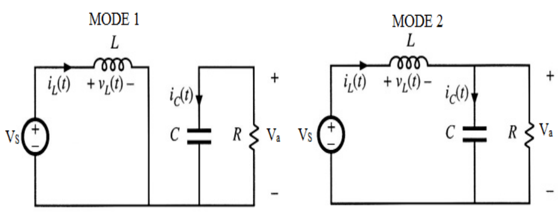

Fig 6. Equivalent Circuits

The waveforms for voltages and currents are shown in Fig 7 for continuous load current, assuming that the current rises or falls linearly.

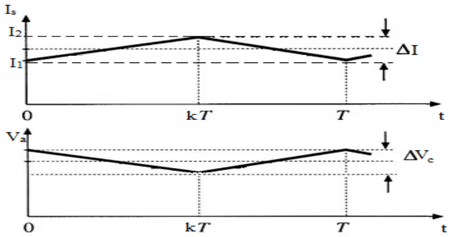

Fig 7 Current and Voltage waveforms

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1,

$$V_s = L\,\frac{(I_2 - I_1)}{t_1} = L \qquad (4)$$

$$t_1 = \frac{\Delta I\, L}{V_s} \qquad (5)$$

and the inductor current falls linearly from I_2 to I_1 in time t_2,

$$V_s - V_a = -L\,\frac{\Delta I}{t_2} \qquad (6)$$

or $t_2 = \frac{\Delta I L}{V_a - V_s}$ (7)

Where, $\Delta I = I_2 - I_1$ is the peak-to-peak ripple current of inductor L.
From equations (5) and (7),

$$\Delta I = \frac{V_s t_1}{L} = \frac{(V_a - V_s)t_2}{L} \qquad (8)$$

Substituting t_1=kT and t_2= (1-k)T yields the average output voltage,

$$V_a = \frac{V_s}{1-k} \qquad (9)$$

Which gives

$$(1-k) = \frac{V_s}{V_a} \qquad (10)$$

Assuming a lossless circuit, $V_s I_s = V_a I_a$ and the average input current is

$$I_s = \frac{I_a}{1-k} \qquad (11)$$

The switching period T can be found from

$$T = \frac{1}{f} = t_1 + t_2 = \frac{\Delta I\, L\, V_a}{V_s(V_a - V_s)} \qquad (12)$$

And this gives the peak-to-peak ripple current:

$$\Delta I = \frac{V_s k}{f L} \qquad (13)$$

When the MOSFET is on, the capacitor supplies the load current for $t = t_1$. The average capacitor current during the time t_1 is $I_c = I_a$ and the peak-to-peak ripple voltage of the capacitor is

$$\Delta V_c = v_c - v_c(t=0) = \frac{1}{C}\int_0^{t_1} I_c\, dt = \frac{1}{C}\int_0^{t_1} I_a\, dt = \frac{I_a t_1}{C}$$

Substituting $t_1 = (V_a - V_s)/(V_a f)$,

$$\Delta V_c = \frac{I_a k}{f C} \qquad (14)$$

B. Inverter In A Pv System

The principle of a stand-alone inverter used in a PV-Diesel hybrid system can be explained with reference to the single-phase equivalent shown in Fig 8.The inverter has a full-bridge configuration realized using four power electronic switches (MOSFET or IGBTs) S_1, S_4. In this scheme, the diagonally opposite switches (S_1, S_4) and (S_2, S_3) are switched using sinusoidal pulse-width modulated gate pulses. The inverter produces sinusoidal output voltage. The inductors X_1, X_2 and the ac capacitor C_2 filter out the high-switchfrequency components from the output waveform.

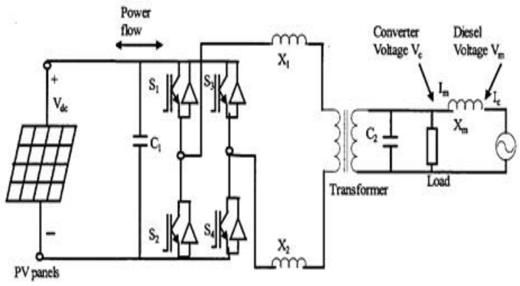

Fig. 8 Inverter in a PV system

Most inverter topologies use a low-frequency (50 or 60 Hz) transformer to step up the inverter output voltage. In this scheme, the diesel generator and the converter are connected in parallel to supply the load. The voltage sources, diesel and inverter, are separated by the link inductor X_m. The bidirectional power flow between inverter and the diesel generator can be established. The power flow through the link inductor, X_m, is

$S_m = V_m I_m$ (15)

$P_m = (V_m V_c \sin$ □ □ □ X_m (16)

$Q_m = (V_m/X_m)(V_m V_c \cos$ □ □ □ □ □ □□□ □□ □ □ □□ □□ □

□ □Where□ is the phase angle between the two voltages. From Eq.(16), it can be seen that the power supplied by the inverter can be controlled by controlling the phase angle□. The PWM pulses separately control the amplitude of the converter voltage, V_c, while the phase angle with respect to the diesel voltage is varied for power flow.

Wind Turbine

The synchronous generator is currently used in WECS, especially in law power for battery charging, for example. But the use of PMSG in high power generation is recent. It's facilitated by the technologic progress realized in power electronics and permanent magnet materials used in generator rotors. The use of PMSG allows to eliminate the gearbox and to operate at variable and low speed; which is adequate with wind speed nature.

Variable speed operation of wind energy conversion system contributes to decrease the mechanical stress and acoustic noise and offers possibility to control of active and reactive powers; the PMSG is connected to the grid via two power electronics converters with an intermediate DC link bus. The generator side converter is controlled via hysteresis regulation of generator currents with zero direct current; in order to obtain a maximal torque for a minimal current.

The MPPT algorithm is used to determinate the optimal rotational speed reference for any value of wind speed under the nominal regime in order to maximizing power captured by the wind turbine. The grid side converter is controlled by pulse width modulation (PWM) obtained from proportional integral (PI) regulation of currents sanded to the electrical grid. The DC link voltage is kept at constant value with a DC/DC converter and PI regulation of DC voltage at its reference. Power limitation for high wind speed values is achieved by varying the blade angle (Pitch control) which corresponds to decrease in power coefficient.

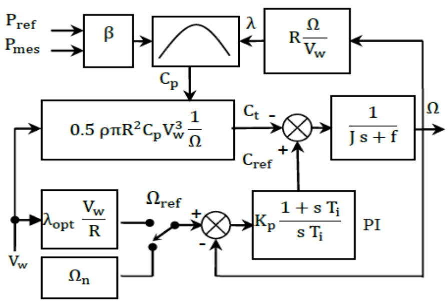

Figure 9. Control diagram of wind turbine

The speed reference allows to maximizing the power captured by the wind (MPPT strategy) is given by:

$$\Omega_{ref} = \frac{\lambda_{opt} V_w}{R} \quad (18)$$

When the wind speed reached the nominal value, the pitch angle regulation (based on fuzzy logic algorithm) enter in operation in order to decrease the power coefficient. The simplified representation of wind turbine control diagram is shown in Figure 9.

Grid Connected Operation

Micro grid works in grid-connected operation. In this case, the wind and solar generators should work in Maximum Power Point Tracking (MPPT) strategy to get higher energy efficiency. In order to reduce the influence of fluctuation to utility grid, energy storage system should be controlled to supply the power difference between renewable energy generations and loads.Fig 10.

Pstorage = Pbatt + Psc

= Pwind + Psolar – P load (19)

- **Pstorage** is the total power of storage system including batteries and super-capacitor.
- **Pbatt**and Psc are power released from battery and super-capacitor resp
- **Pwind** is generated by wind turbine.
- **Psolar** is generated by photovoltaic panels.
- **Pload** is power absorbed by DC and AC loads.

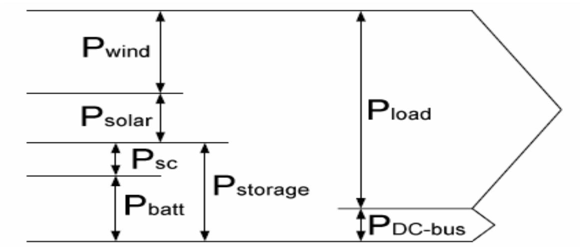

Figure 10. Power Flow in the system

In grid-connected operation voltage of DC bus is controlled by inverter and amplitude and frequency of AC-Bus voltage are the same with utility grid. When power from renewable energy generations is fluctuant or loads change quickly, hybrid storage system including batteries and super-capacitor must absorb or release power difference very fast. According to the character of different storage devices, high frequency power is released or absorbed by super-capacitor

Simulation Results

Integration Of Pv Array With Boost Converter And Pwm Inverter

The integrated circuit for simulation of PV array, boost converter and PWM inverter with MPPT is shown Fig 11, the voltage and current output waveforms are shown in Fig.12 and the power output shown in Fig 13.

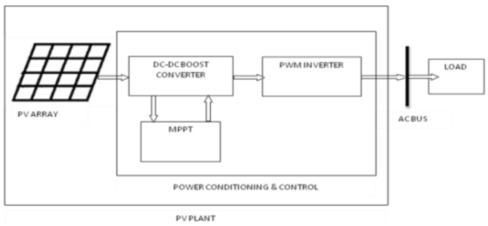

Fig 11. Integrated PV array – boost converter – PWM inverter circuit

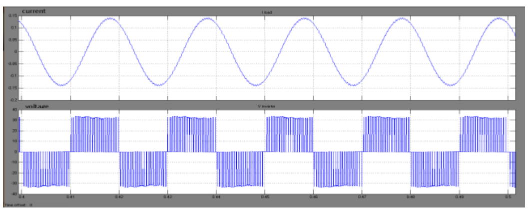

Fig 12. PWM Inverter output voltage and current

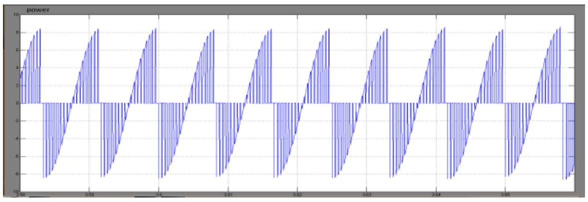

Fig 13. PWM Inverter output power

Step change in insulation was mentioned in literature as the source of power fluctuations. Fig 14.shows the integrated circuit for simulation of a step change in insulation from 800 W/sq.m. to 1000 W/sq.m. The output waveforms are also shown.

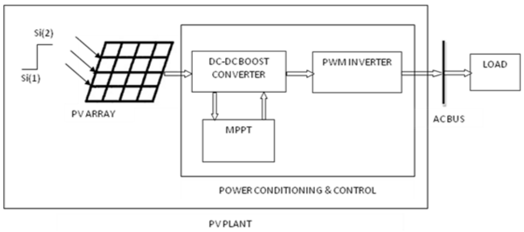

Fig 14. Integrated circuit for simulation of a step change in insulation

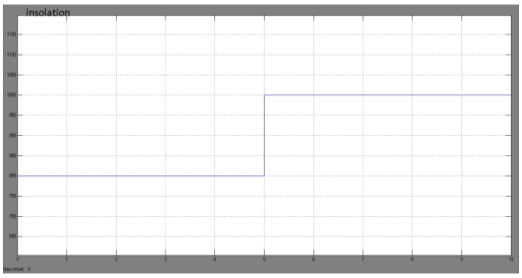

Fig 15. Step change in insulation

The step change in insulation is shown in fig 15.. Here the insulation changes from 800 to 1000 at the 5th second.

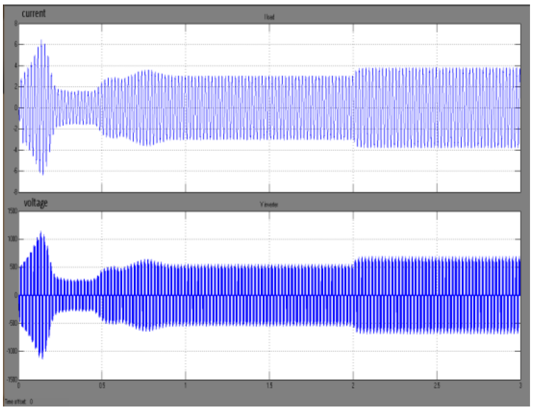

Fig 16. Integrated circuit power output for a step change in insulation

Fig 16. Shows the change in current and voltage waveforms. Followed by the step change in insulation at the 5th second the voltage and current magnitude increases.

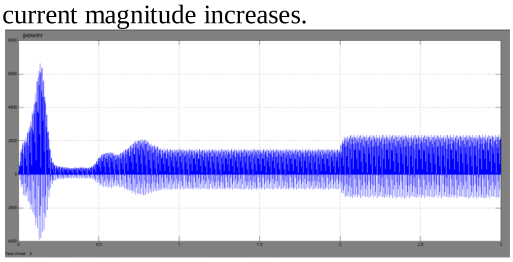

Figure 17. Integrated circuit voltage and current output for a step change in insulation

Fig 17.Shows the variation of power after the step change in insulation.

Integration Of Wind And Solar

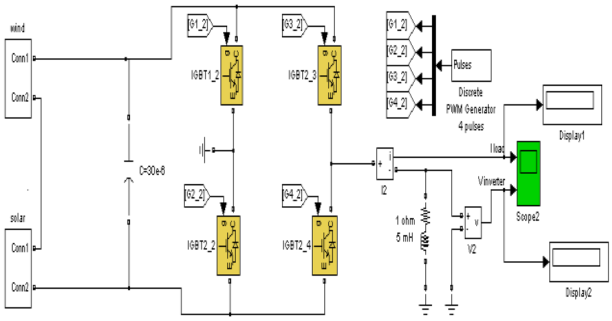

Figure18.Integration of wind and solar

The power obtained from the solar and the wind energy conversion systems are given to an inverter as shown in Fig 18.

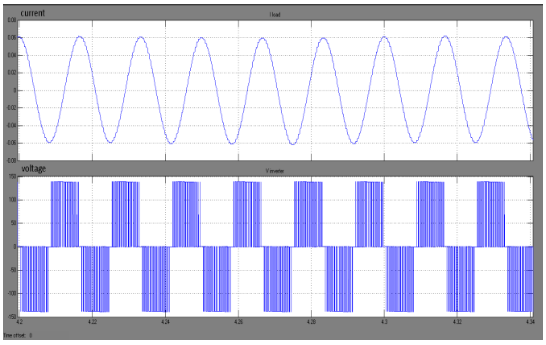

Figure 19. Output voltage and current of pv-wind

The voltage and current waveforms obtained at the inverter ends are shown in Fig 19.

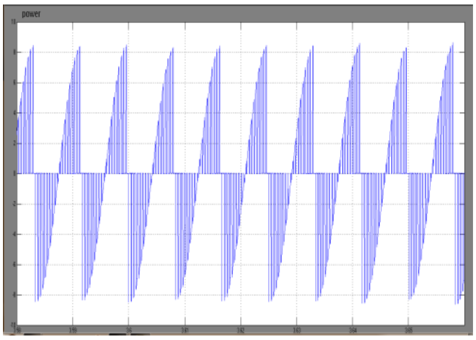

Figure 20. Combined output power of two PV plants and wind turbine

IV. Conclusion

This paper aims at implementing a PV Wind, hybrid system connected to an isolated power utility. The basic concepts of solar array, DC-DC boost converter, PWM inverter, Wind turbine are discussed. The modeling methods of all components of the hybrid system are described. Simulation studies are done for the standard test conditions using MATLAB/Simulink. The response of a PV - Wind hybrid system connected to an isolated power utility following common disturbances such as solar insulation variations and wind speed change and load changes were simulated to understand the power fluctuation caused.

The results of the simulation are analyzed to understand the significance of the power fluctuation caused, so that a method for leveling the fluctuations in a PV system's power output when large output power from several PV systems has to be penetrated in the utility could be defined.

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