Control Of Photovoltaic (Pv) And Wind Power Generation Fluctuations By Using BESS

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Abstract— The battery energy storage station (BESS) is the current and typical means of smoothing wind- or solar-power generation fluctuations. Such BESS -based hybrid power systems require a suitable control strategy that can effectively regulate power output levels and battery state of charge (SOC). This paper presents the results of a wind/photovoltaic (PV)/BESS hybrid power system simulation analysis undertaken to improve the smoothing performance of wind/PV/BESS hybrid power generation and the effectiveness of battery SOC control. A smoothing control method for reducing wind/PV hybrid output power fluctuations and regulating battery SOC under the typical conditions is proposed. A novel real-time BESS-based power allocation method also is proposed. The effectiveness of these methods was verified using MATLAB/SIMULINK software.

Index Terms — Adaptive smoothing control, battery energy storage station (BESS), solar power generation, state of charge (SOC), wind power generation.

I. INTRODUCTION

In recent years, electricity generation by photovoltaic (PV) or wind power (WP) has received considerable attention worldwide. The State Grid Corporation of China (SGCC) is building the National Wind/PV/battery energy storage station (BESS) and Transmission Joint demonstration project and it is located in the region of Zhangbei, Hebei, China. The Zhangbei belongs to one of the country’s 10 million kilowatts of wind power base. The demonstration project is scheduled in three stages. Now, it is in the first stage and at the end of December, 2011, a 100-MW wind farm, a 40-MW PV farm, and 14-MW/63-MWh lithium–ion BESS have been built at Zhangbei. The battery energy storage system can provide flexible energy management solutions that can improve the power quality of renewable-energy hybrid power generation systems. To that end, several control strategies and configurations for hybrid energy storage systems, such as a battery energy storage system [1]–[5], [13]–[19], a superconducting magnetic energy system (SMES) [6], a flywheel energy system (FES) [7], an energy capacitor system (ECS) [8]–[12], and a fuel cell/electrolyzer hybrid system [20], [21], have been proposed to smooth wind .

development of batteries, battery energy storage systems recently have begun to be utilized for multiple applications such as frequency regulation, grid stabilization, transmission loss reduction, diminished congestion, increased reliability, wind and solar energy smoothing, spinning reserve, peak-shaving, load-leveling, uninterruptible power sources, grid services, electric vehicle (EV) charging stations, and others.

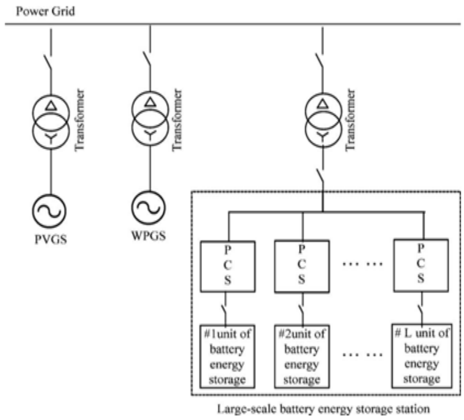


Fig. 1. Wind/PV/BESS hybrid power generation system.

These days, the issue of how power fluctuations in PV and wind power generation are to be smoothed has attracted widespread interest and attention. And even as this issue is being resolved, another one, that of the application of an energy storage system such as BESS, has arisen. When using BESS to control PV and wind power fluctuations, there is a trade- off between battery effort and the degree of smoothness. That is, if one is willing to accept a less smooth output, the battery can be spared some effort. Thus far, although various effective BESS-based methods of smoothing power fluctuations in renewable power generation systems have been proposed [2], [3], [5], smoothing targets for grid-connected wind and PV farms generally have not been formulated. Smoothing control by way of power fluctuation rate limits, for such systems, has rarely even been discussed. The control strategies published in [1]–[5], [13]–[19], [25], [26] were formulated mainly for small -scale BESS-based smoothing; hence, they did not consider power allocation among several BESS. A suitable and effective control strategy for large-scale BESS, therefore, remains an urgent necessity. In the present study, under the assumptions that the capacities of the WP and PV hybrid generation system (WPPVGS) and BESS had already been determined and that we do not have ability to adjust the WPPVGS output power, a large-scale BESS was used to smooth the WPPVGS output power fluctuation. More specifically, Wind/PV/BESS hybrid power generation system (Fig. 1) along with a state of charge (SOC)-based smoothing control strategy was utilized to instantaneously smoothen WP and PV power fluctuations. This was accomplished by modifying smoothed.

PHOTOVOLTAIC (PV) SYSTEM

PV array:

A PV array consists of a number of PV modules or panels. A PV module is an assembly of a large number of interconnected PV cells. The inverter in a PV system is employed to transform the DC-voltage generated from a PV module to a three-phase AC voltage. A three-phase inverter has three legs with two switches in each leg. The switching is performed by carrier-based or space-vector-based Pulse-Width Modulation (PWM) [3]. A detailed discussion on different inverter topologies is provided later in this chapter. The inverter is usually interfaced to the utility grid through a transformer. However, transformer-less PV inverter topologies have also been proposed and implemented for single-phase grid-connected PV inverter. The output quantity of an inverter (voltage in VSI and current in CSI) is pulsed and contains switching harmonics along with a 50 Hz fundamental.

In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650, 000, 0001 tons of hydrogen to helium every second.

The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions.

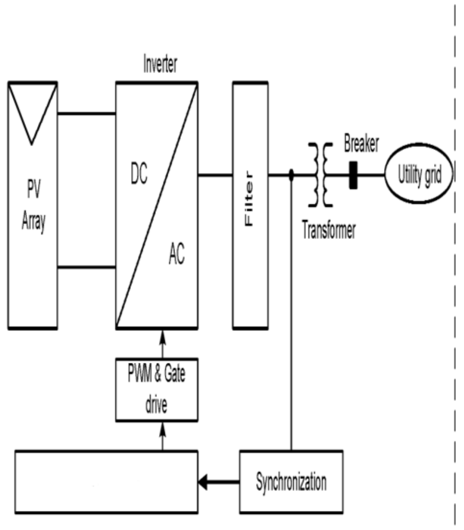


Figure 2 Structure of a typical single-stage PV system.

Scope of PV- grid tied system

Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun. Much of the world's required energy can be supplied directly by solar power. More still can be provided indirectly.

The practicality of doing so will be examined, as well as the benefits and drawbacks. In addition, the uses solar energy is currently applied to will be noted. Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received. At night or during heavy cloud cover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container. Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator. In general, there are three types of collectors and many forms of storage units. The three types of collectors are flat-plate collectors, focusing collectors, and passive collectors. Flat-plate collectors are the more commonly used type of collector today. They are arrays of solar panels arranged in a simple plane. They can be of nearly any size, and have an output that is directly related to a few variables including size, facing, and cleanliness. These variables all affect the amount of radiation that falls on the collector. Often these collector panels have automated machinery that keeps them facing the sun. The additional energy they take in due to the correction of facing more than compensates for the energy needed to drive the extra machinery. Focusing collectors are essentially flat-plane collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collector. Although they can produce far greater amounts of energy at a single point than the flat-plane collectors can, they lose some of the radiation that the flat-plane panels do not.

Radiation reflected off the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components. Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation and convert it to heat naturally, without being designed and built to do so. All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make it worthwhile. Often their natural ability to convert radiation to heat is enhanced in some way or another (by being painted black, for example) and a system for transferring the heat

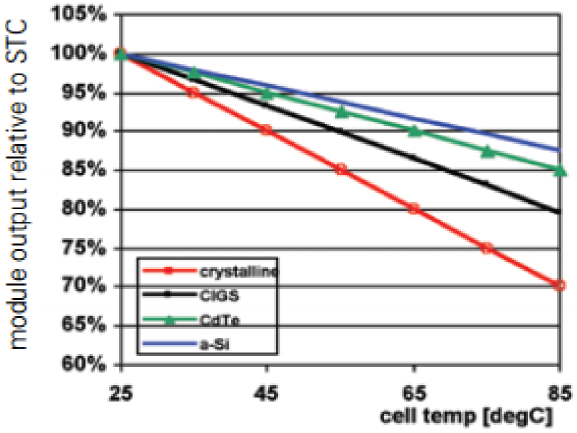
STRUCTURE OF THE PV SYSTEM

A photovoltaic system, also photovoltaic power system, solar PV system, PV system or casually solar array, is a power designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar panels to absorb and directly convert sunlight into electricity, a solar inverter to change the electrical current from DC to AC, as well as mounting, cabling and other electrical accessories to set-up a working system. It may also use a solar tracking system to improve the system's overall performance or include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS). Moreover, PV systems convert light directly into electricity and shouldn't be confused with other solar technologies, such as concentrated solar power (CSP) and solar thermal, used for both, heating and cooling.

Effects of Temperature:

Another important differentiator in solar PV performance, especially in hot climates, is the temperature coefficient of power. PV cell performance declines as cell temperature rises. For example, in bright sunlight, cell temperatures in Singapore can reach over 70ºC, whereas PV modules are rated at a cell temperature of 25ºC. The loss in power output at 70ºC is therefore measured as (70 - 25) x temperature coefficient. Most thin film technologies have a lower negative temperature coefficient compared to crystalline technologies. In other words, they tend to lose less of their rated capacity as temperature rises. Hence, under Singapore’s climatic condition, thin film technologies will generate 5-10% more electricity per year A PV module data sheet should specify the temperature coefficient

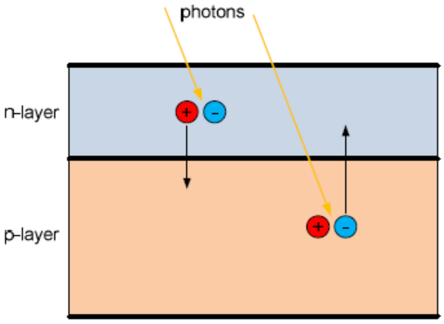
Technology	Temperature Coefficient [%/°C]
Crystalline silicon	-0.4 to -0.5
CIGS	-0.32 to -0.36
CdTe	-0.25
a-Si	-0.21



The single-line diagram of the proposed three-phase, single-stage, grid-connected PV system with a CSI as the power- in the dc-side current and allows its control. The ac-side of the inverter is interfaced with the primary side of the transformer through a capacitive filter composed of three Y-connected capacitors. The function of is to absorb switching harmonics and produce clean sinusoidal current at the grid interface. Breaker is an integral part of the PV system and is provided to protect the PV system by isolating it when there is fault on the secondary side of the transformer. The primary side of the transformer is delta-connected whereas its secondary side is star-connected with a solidly grounded neutral point. The resistance and inductance of the distribution line are represented by and, respectively. And, respectively, represent the active and reactive powers supplied by the PV system to the distribution system. The breaker is part of the protection system installed by the utility.

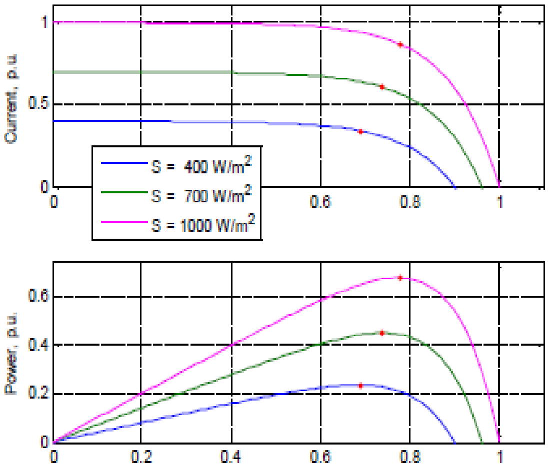
Solar Cell operating principle:

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell, as will be explained in brief below solar cell is basically a p-n junction which is made from two different layers of silicon doped with a small quantity of impurity atoms: in the case of the n-layer, atoms with one more valence electron, called donors, and in the case of the p-layer, with one less valence electron, known as acceptors. When the two layers are joined together, near the interface the free electrons of the n-layer are diffused in the p-side, leaving behind an area positively charged by the donors. Similarly, the free holes in the p-layer are diffused in the n-side, leaving behind a region negatively charged by the acceptors.



Temperature and irradiance effects:

Two important factors that have to be taken into account are the irradiation and the temperature. They strongly affect the characteristics of solar modules. As a result, the MPP varies during the day and that is the main reason why the MPP must constantly be tracked and ensure that the maximum available power is obtained from the panel. The effect of the irradiance on the voltage-current (V-I) and voltage-power (V-P) characteristics is depicted in Figure , where the curves are shown in per unit, i.e. the voltage and current are normalized using the *VOC* and the *ISC* respectively, in order to illustrate better the effects of the irradiance on the V-I and V-P curves. As was previously mentioned, the photo-generated current is directly proportional to the irradiance level, so an increment in the irradiation leads to a higher photo-generated current. Moreover, the short circuit current is directly proportional to the photogenerated current; therefore it is directly proportional to the irradiance. When the operating point is not the short circuit, in which no power is generated, the photogenerated current is also the main factor in the PV current, as is expressed by equations for this reason the voltage-current characteristic varies with the irradiation. In contrast, the effect in the open circuit voltage is relatively small, as the dependence of the light generated current is logarithmic, as is shown in equation.



V-I and V-P curves at constant temperature (25°C) and three different isolation values

CHARACTERISTICS OF PV ARRAY

The PV array – characteristic is described by the following [9]:

$$i_{\mathrm{pv}} = n_p i_{\mathrm{ph}} - n_p i_{\mathrm{rs}} \left[\exp\left(\frac{q}{kT_c A} \frac{v_{\mathrm{pv}}}{n_s} \right) - 1 \right]. \tag{1}$$

In (1), are the unit charge, the Boltzmann’s constant, the p-n junction ideality factor, and the cell temperature? Current is the cell reverse saturation current, which varies with temperature according to

$$i_{\mathrm{rs}} = i_{\mathrm{rr}} \left[\frac{T_c}{T_{\mathrm{ref}}} \right]^3 \exp\left(\frac{qE_G}{kA} \left[\frac{1}{T_{\mathrm{ref}}} - \frac{1}{T_c} \right] \right). \tag{2}$$

In (2), is the cell reference temperature, the reverse saturation current at . and the band-gap energy of the cell.

The PV current depends on the insulation level and the cell temperature according to

$$i_{\text{ph}} = 0.01 \left[i_{\text{scr}} + K_{\vartheta} \left(T_c - T_{\text{ref}} \right) \right] S. \tag{3}$$

In (3), is the cell short-circuits current at the reference temperature and radiation, a temperature coefficient, and the insulation level in kW/m. The power delivered by the PV array is calculated by multiplying both sides of (1) by

$$P_{\text{pv}} = n_p i_{\text{ph}} v_{\text{pv}} - n_p i_{\text{rs}} v_{\text{pv}} \left[\exp\left(\frac{q}{kT_c A} \frac{v_{\text{pv}}}{n_s} \right) - 1 \right]. \tag{4}$$

Substituting from (3) in (4), becomes

$$\begin{aligned} P_{\text{pv}} = {} & 0.01 n_p \left[i_{\text{scr}} + K_{\vartheta} \left(T_c - T_{\text{ref}} \right) \right] S v_{\text{pv}} \\ & - n_p i_{\text{rs}} v_{\text{pv}} \left[\exp\left(\frac{q}{kT_c A} \frac{v_{\text{pv}}}{n_s} \right) - 1 \right]. \end{aligned} \tag{5}$$

Based on (5), it is evident that the power delivered by the PV array is a function of insulation level at any given temperature.

Since the inverter employed in the PV system of this paper is of current-source type, the power-versus-current characteristic of the PV array has to be examined. Fig. 2 illustrates the power-versus-current characteristic of the PV array based on the parameters listed in the Appendix for insulation levels of 0.25, 0.5, and 1 kW/m. Fig. 2 shows that can be maximized by control of, based on an MPPT strategy.

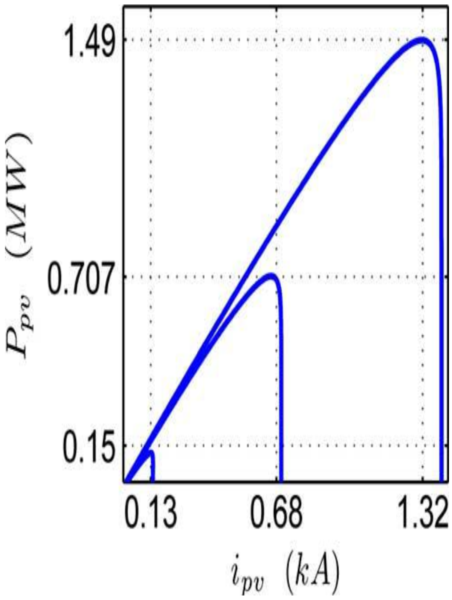


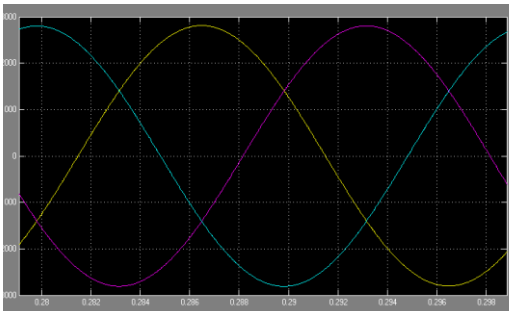
Fig. 3. – Characteristic of a PV array for s=0.25,0.5, and 1 kW/m .

SIMULATION RESULTS

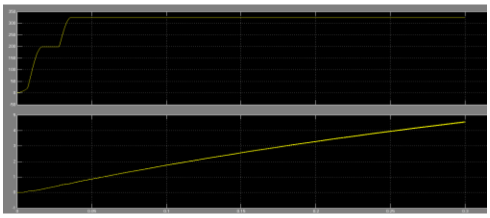
Simulation is performed using MATLAB/SIMULINK software. Simulink library files include inbuilt models of many electrical and electronics components and devices such as diodes, MOSFETS, capacitors, inductors, motors, power supplies and so on. The circuit components are connected as per design without error, parameters of all components are configured as per requirement and simulation is performed.

WAVEFORMS

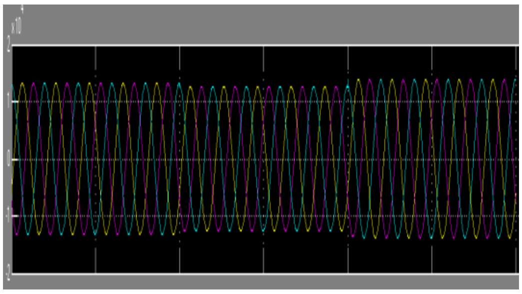
a) Grid side voltages



Solar & Wind output



Grid injected voltages



CONCLUSION

The disadvantage of PV and wind power generation is their unstable power output, which can impact negatively on utility-and micro-grid operations. One means of solving this problem is to integrate PVGS and WPGS with a BESS. For such hybrid generation systems, control strategies for efficient power dispatch need to be developed. Therefore, in this paper, a novel SOC-based control strategy for smoothing the output fluctuation of a WP and PV hybrid generation system has been proposed.

Additionally, the SOC feedback control strategy and the real-time power allocation method for timely regulation of battery power and energy are presented. Simulation results demonstrate that the proposed control strategy can manage BESS power and SOC within a specified target region while smoothing PVGS and WPGS outputs.

At present, how to control the SOC of the energy storage system is an ongoing research topic. We also need to combine the characteristics of the battery, and do further research and exploration. From the present research results, it can be seen that by using the proposed control method, the SOC of each battery energy storage unit can gradually move toward 50% with the increase of control time although the initial SOC of the energy storage unit is different. It is also considered that this con-trol method can make the storage unit share the load as consistently as possible, so as to achieve the effect of extending the service life of the energy storage system and, therefore, can delay the accelerated decay of the battery performance. More-over, it should be noted that some filtering on the BESS charge and discharge power have been achieved by using a power fluctuation rate constraint as the smoothing control target to prevent excessive excursions to "chase down" every PV or wind power output fluctuation. In addition, this paper was mainly focused on the control strategies of BESS and smoothing based on battery capacity established conditions. Another significant issue is the means by which an appropriate battery capacity for this application is to be determined. The power control strategies for large-scale wind/PV/BESS hybrid power systems taking into account the optimum capacity of BESS and battery aging will be discussed in the near future combined with smoothing control application of wind and PV power generations.

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