CONTROL DESIGN AND PERFORMANCE ANALYSIS OF A GRID INTERACTIVE WIND/PV/BESS HYBRID SYSTEM

Seulki KIM
K.E.R.I. [1] – Korea
blksheep@keri.re.kr

Jinhong JEON
K.E.R.I. – Korea
jhjeon@keri.re.kr

Changhee CHO
K.E.R.I. – Korea
chcho@keri.re.kr

Jongbo AHN
K.E.R.I. – Korea
jbahn@keri.re.kr

ABSTRACT

A multifunctional grid-interfaced hybrid system, composed of PV array, wind turbine and BESS, is proposed. The proposed system may operate in multi-operation modes, normal operation, power dispatching, and power averaging, according to coordinate control of the BESS and grid inverter. PV array and wind turbine are individually controlled to operate at the maximum power point. The BESS operates as an energy buffer to flexibly shift the generation from the renewable energy sources without excessively frequent shifts between battery charging and discharging. A grid interface inverter regulates the generated power injection into the grid. Simulation results demonstrate control performance of the proposed system during its operation modes.

INTRODUCTION

Most renewable energy sourced generation systems are weak in stable and sustainable power supply since the sources are mostly dependent on weather conditions. However, it has been reported that in weak grids, the wind and solar hybrid system is more reliable than a single wind or PV system since solar and wind conditions have complementary profiles. Grid interface of the hybrid system with battery storage may improve system stability and practicality [1-2]. This paper proposes a grid interactive hybrid system with a PV array and a wind turbine as power sources, and battery as energy storage. The principle of the system and power control strategies are described and dynamic performance is analyzed.

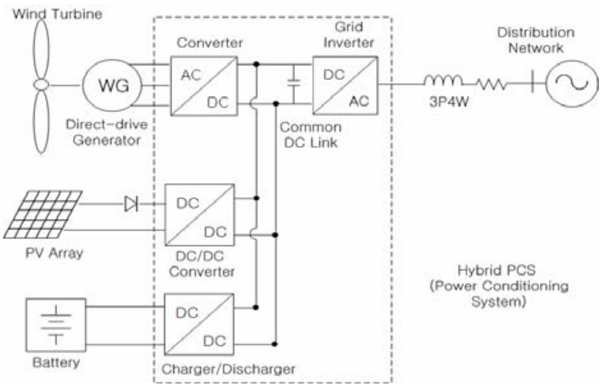

Fig. 1. Proposed grid interactive hybrid system

1. Korea Electrotechnology Research Institute

Fig. 1 presents the configuration of the proposed hybrid system. The system includes a wind turbine generator, a PV array, battery storage, a common dc link, and a power conditioning system. The operation modes of the proposed system include normal operation, power dispatching, and power smoothing. PSCAD/EMTDC simulations are presented to analyzed and demonstrate the control performance during various operating conditions.

POWER CONTROL OF THE PROPOSED SYSTEM

The proposed system has various operation modes such as normal operation, dispatching operation and power smoothing. Table I summarizes power control schemes for various modes.

Table 1. Power control schemes for operation modes

	Wind	PV	BESS	Grid Inv.
Normal	Variable speed control	Max. Power Point Tracking (MPPT)	Stop	Constant V_{dc}
Dispatching			V_{dc} control within Specific Range	Dispatched power
Averaging				Averaged power

- Normal operation: the hybrid system penetrates as much power into the grid as the PV array and wind turbine generate. BESS does not operate.
- Power dispatching: the hybrid system generates the power dispatched by a utility operator or commanded by a user for purpose of utility demand management such as peak load shaving and active load control.
- Power averaging: the hybrid system mitigates fluctuating power generated from the PV array and wind turbine, and injects more stable (less fluctuating) power output into the grid.

Fig. 2 presents the power control schematic of the power conditioning system of the proposed hybrid system. The controller of the wind-side converter consists of a wind turbine speed controller and a current controller. The upper level controller regulates the active and reactive power, P_W and Q_W, of the wind generator and outputs the *d-* and *q-* axis current commands, $i^*_{w\_dq}$, at which the lower level current controller regulates the wind generator current. The PV converter regulates the array voltage V_{PV} at the reference voltage V_{PV}^* commanded by the MPPT controller and boosts it to the level of common dc voltage. Error between the ordered and real voltage is processed through the voltage controller into the ordered current i_{PV}*, which is followed by the array current i_{PV}. A dc-dc converter for BESS should be capable of controlling the battery current i_{BESS} in both directions. So the BESS converter should be a type of a buck-booster, which may operate in buck mode for battery charging and in boost mode for battery discharging. The BESS mode controller determines whether to charge or discharge battery storage and outputs the common dc voltage command, V^*_{dc}. The voltage and current controllers have the same structure as those for PV converter. A grid inverter injects the power from the individual components into the distribution network. A controller structure of the grid inverter is basically identical to that of the wind-side converter.

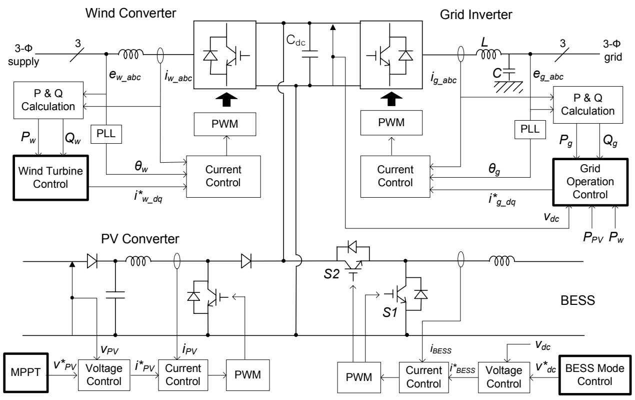

Fig. 2. Control schematic of the proposed system

Wind Turbine Control

Basic concept of wind turbine control is to obtain the maximum energy by optimizing the turbine rotating speed under varying wind speed and minimize the rating of the wind converter by regulating reactive power generation at zero. The maximum power can be described by equations (1) and (2). The η is an efficiency factor that accounts for loss in the generator and converter [3].

$$P_M^{MAX} = \frac{1}{2}\pi\rho R^5 \frac{C_P^{MAX}}{\lambda_{OPT}^3}\omega_M^{\ 3} \tag{1}$$

$$P_{ref} = \eta P_M^{MAX} \tag{2}$$

PV Array Control

For efficient operation a PV array should operate near at the peak point of V-P curve. Various MPPT techniques have been proposed. The incremental conductance (IndCond) method [4] was implemented in this study.

BESS Control

BESS is controlled such that the common dc voltage should not violate the specified upper and lower limits by being charged or discharged. There are two reasons for such BESS control. First, common dc link voltage over an adequate level is required for the wind converter and grid interface inverter. Secondly, it is intended to prevent the battery storage from excessively repeating mode shifts between charging and discharging by keeping the common dc voltage not constant but variable within a certain range. Excessively high charging and discharging frequency might result in shortening life expectancy of battery. Fig. 3 presents BESS operation mode control.

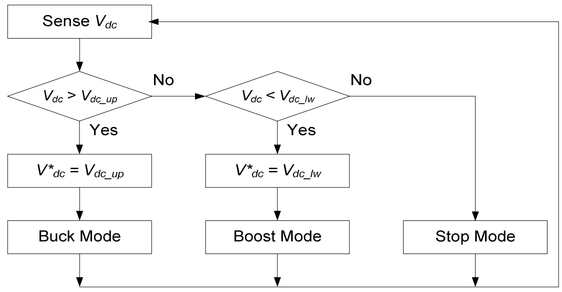

Fig. 3. Battery Operation Mode Control

Grid Inverter Control

Power controller of the grid interface inverter is divided as follows.

- Normal operation mode: the common dc voltage is regu lated at a constant value. Fig. 4 presents the voltage con troller in normal mode for power regulation.

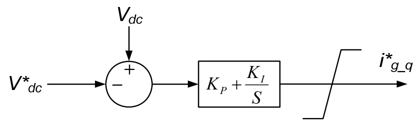

Fig. 4. Power controller for normal operation mode

- Power dispatching mode: the power controller regulates real power injection into the network at a value dispatc hed by a user or an operator as shown in fig. 5.

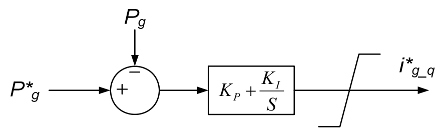

Fig. 5. Power controller for dispatching mode

- Power averaging mode: a sum of power from the wind and solar sources is averaged by a low pass filter and specified as the real power command. Fig. 6 presents the power controller for power averaging mode.

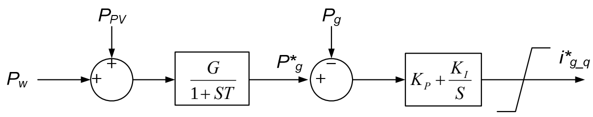

Fig. 6. Power controller for power averaging mode

SIMULATION RESULTS

The proposed hybrid system was simulated to validate its control performance. A 30kW wind/PV/BESS hybrid system was considered. System parameters used in the simulation study are shown in APPENDIX. A wind turbine, PV array and battery storage were represented by models in the literatures [5-6].

Control Performance of the Hybrid System

The hybrid system was in power dispatching mode and a real power command was set to 16kW. Fig. 7 presents the wind system response to a given wind speed condition. The power coefficient of the wind turbine was maintained at the maximum value of 0.44, which indicated that the maximum power control was well performed. Fig. 8 presents MPPT performance. The curves are power versus voltage curves of the PV array for various solar conditions, and the dots are array operation points. The PV array was operating very close to the peak points under the varying solar condition. Fig. 9 presents the BESS control performance. The common dc voltage was maintained between the upper (760V) and lower (720V) limits, which did not cause excessive mode shifts in BESS. Fig. 10 presents real power generation curves of the hybrid system and its component systems.

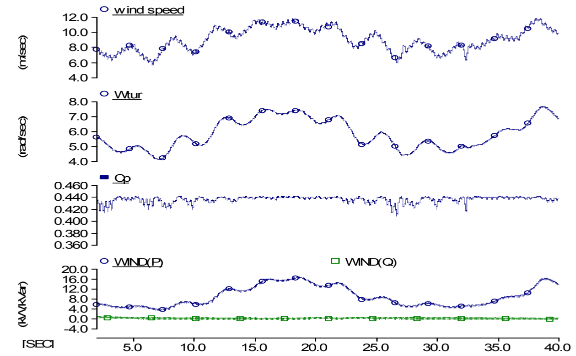

Fig. 7. Wind system performance

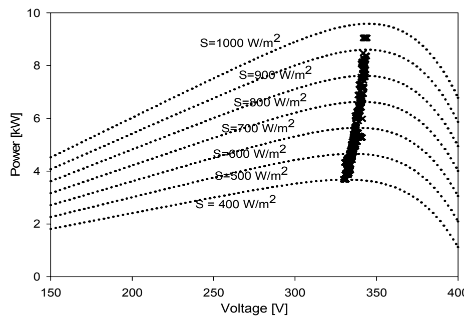

Fig. 8. MPPT performance

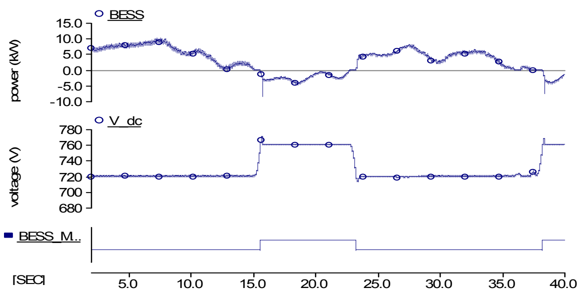

Fig. 9. BESS performance

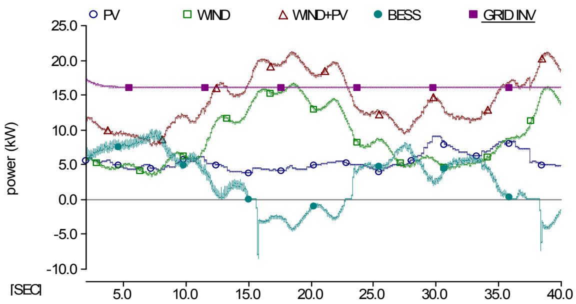

Fig. 10. Power generation of the hybrid system

Hybrid System under Different Operation Modes

The hybrid system under different operation modes was simulated to validate the performance of the proposed system. Fig. 11 presents the simulation result for normal operation mode. The common dc voltage was maintained at 0.72kV and the grid inverter passed all the power from the wind turbine and solar array into the distribution grid. THD of inverter current was reversely proportional to the power injection, since the harmonic component ratio to the fundamental component (60Hz) decreased with the greater output current. Magnitude of PCC voltage showed a variation pattern similar to that of real power injection into the grid. Fig. 12 presents the simulation result of power dispatching mode. The hybrid system was dispatched to generate 20kW and re-dispatched for 10kW at 20 second. The grid inverter injected constant power irrespective of power fluctuations of the wind and PV systems. The dc link voltage was maintained at the upper limit in battery charging mode, and at the lower limit in discharging mode. This BESS operation scheme did not require frequent shifts of the battery operation mode that might give adverse effects on the battery lifecycle.

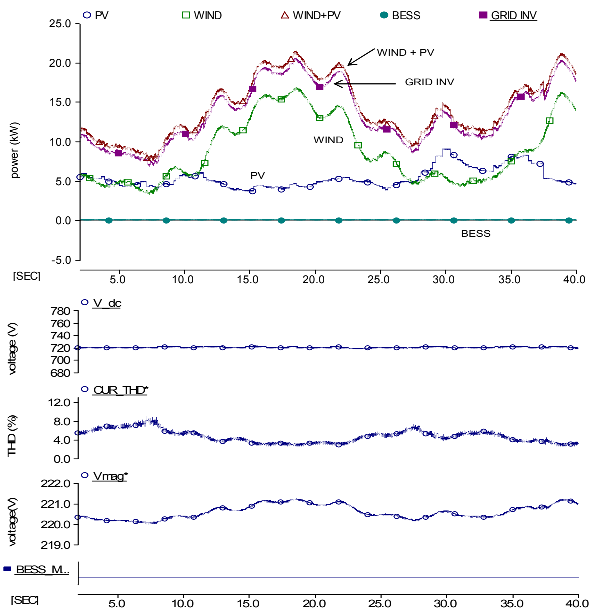

Fig. 11. Results of normal operation mode

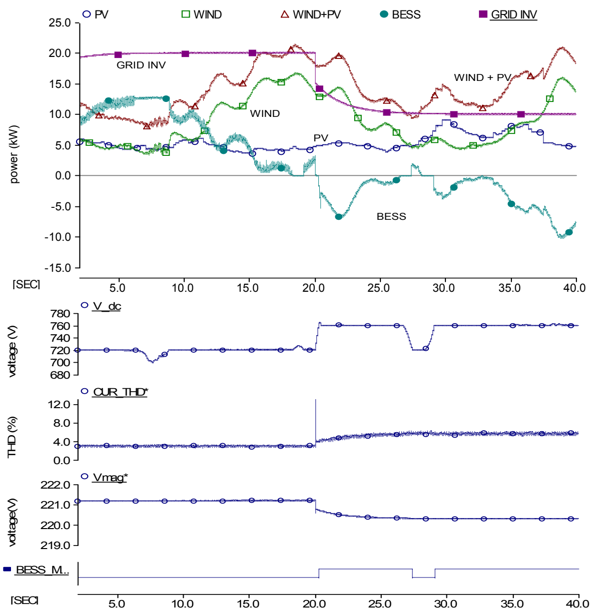

Fig. 12. Results of power dispatching mode

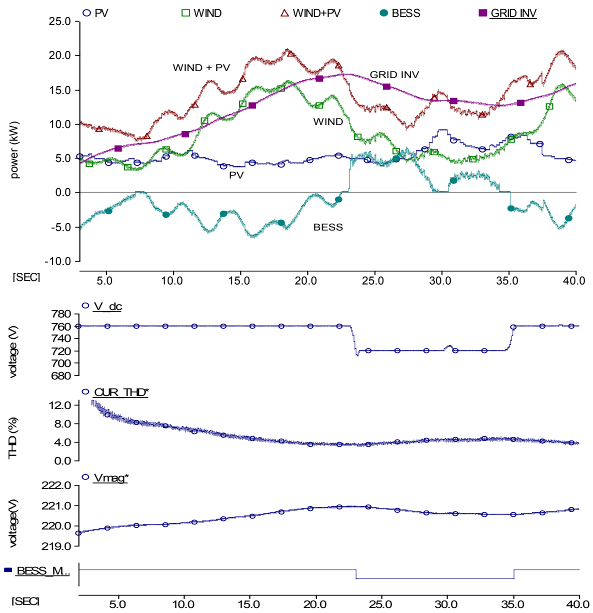

Fig. 13. Results of power averaging mode

Fig. 13 shows the result of power averaging mode. The ordered power was set as low-pass filtering value of the sum of the wind and solar power. Smoothing effect in power injection into grid was clearly seen. Fluctuations in THD of the current and the PCC voltage became smoother. The dc link voltage was controlled between the pre-set limits, which did not require too many battery mode changes.

CONCLUSIONS

A multifunctional grid-connected wind/PV/BESS hybrid system has been proposed. The principle of the proposed system and power control scheme for multi-operation modes were described. PSCAD/EMTDC Simulation results demonstrated that the proposed system was capable of supplying flexible and stable power into grid with coordination control of BESS and a grid interface inverter, and simultaneously maximizing use of the individual renewable energy sources. The proposed system is environmentally-friendly energy sources, and user- or utility-friendly. From the perspective of system economy, however, system engineering including unit sizing, particularly BESS, should be considered in the future work.

REFERENCES

[1] Fernando Valencaga *et al*, 2003, “Power Control of a Sola r/Wind Generation System Without Wind Measurement: A Passivity/Sliding Mode Approach”, *IEEE Trans. Energ y Conversion*, vol. 18, no. 4, 501-507.

[2] Francois Giraud *et al*, 2001, “Steady-State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage”, *IEEE Trans. Energy Conversion*, vol. 16, no. 1, 1-7.

[3] Z. Lubsony, Wind Turbine Operation in Electric Power Systems, Springer-Verlag, Germany, 2003.

[4] Mukund R. Patel, Wind and Solar Power Systems. CRC Press, USA, 1999.

[5] Seul-Ki Kim *et al*, 2004, “Modeling of a Variable Speed Wind Turbine in Dynamic Analysis”, KIEE International Trans. Power Engineering, vol. 4, no. 2.

[6] Minwon Park et al, 2004, "A Novel Real-Time Simulation Technique of Photovoltaic Generation Systems Using RTDS", IEEE Trans. on Energy Conversion, vol. 19, no. 1, 164-169.

APPENDIX

System parameters for simulation study

- Wind turbine (20 kW)

rated wind speed: 12 m/s rated rotor speed: 74 rpm
blade radius: 3.7 m inertia constant: 0.6 s

- Wind generator

rating : 25 kVA pole numbers: 42
rated voltage: 0.3 kV rated current: 27.8 A
basic frequency: 25.9 Hz inertia constant: 0.4 s

- Wind converter

rating : 25 kVA switching freq.: 6.3 kHz
power control: K_p=K_i=2 current control: K_p=20, K_i=500

- PV array (9.5 kW)

open-circuit volt.: 434 V short-circuit cur.: 30.15 A
volt. at max. power: 348 V cur. at max. power: 27.45 A

- PV converter

switching freq.: 10 kHz voltage control: K_p=100, K_i=2
current control: K_p=K_i=100

- BESS converter

switching freq.: 10 kHz voltage control: K_p=0.01, K_i=1
0 current control: K_p=1, K_i=500

- Grid inverter (30kVA)

switching freq.: 6.3 kHz filter: L=6 mH, C=10 uF
power control: K_p=2, K_i=5 current control: K_p=10, K_i=500