A Study on Photovoltaic/Wind/Diesel Hybrid Power System

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ABSTRACT - In this paper, to solve the defect of stand-alone type power system in a remote area, a hybrid power system with photovoltaic/wind/diesel generators is proposed. A hybrid power system has a power-balanced controller to equilibrate generation power with a given load demand and which is composed of common DC power system. To execute a power-balanced control, a hybrid power system is assumed that all of power generators have the characteristics of an equivalent current-source and load sharing control technique must be needed at the same time. So this paper describes the algorithm of interactive technique for design of a hybrid power system.

1. INTRODUCTION

The stand-alone photovoltaic generation system or diesel generation system has been operated in islands or remote areas for power supplies. However, a stand-alone power system has a defect to extend more energy storage device than hybrid system and a generation power fluctuates as weather condition. Therefore it is required that an interactive photovoltaic/wind/diesel hybrid generation system for mutual compensation of meteorological and regional conditions between individual power generators. When PV/wind hybrid system generates a sufficient power than a load demand, the surplus power is charged to battery bank. On the contrary, in case of an insufficient power, battery system discharges a storage-energy to load. Also, the diesel generator operates on the peak load demand while PV/wind/battery power capacities are insufficient. There are many control methods in hybrid power system. Among several types, control method to guarantee a stable power generation must be adopted, though the fluctuation of output voltage with atmospheric changes. In particular, to connect hybrid generators on DC link, it is a necessary that the technique to operate an individual power system into equivalent current-source. If the controller of current-source type is applied, it has a merit to solve the matter of unbalanced power-sharing in the hybrid system which is controlled by voltage-source method. In this paper, it is proposed that a hybrid generation system has a power-balanced controller to equilibrate generation power with a load demand and it is composed of DC bus-type power systems. And all of power generators in hybrid power system can be equivalent to current-source characteristics. So this paper discusses the algorithm of load-sharing and the structure of power converter in hybrid generation system. And through the results of simulation, the proposed scheme was verified.

2. HYBRID POWER SYSTEM DESCRIPTION

Hybrid power system with DC bus has rectifiers for wind/diesel generators to convert AC into DC voltage as Fig.1. Due to sub-generators are linked to a common DC bus, a surplus power can be charged into battery bank. And when a load demand increase, the storage energy in battery bank can be transfer to a load through inverter system which convert DC into AC voltage. Because this system has a common DC link, it can guarantee the stability of control system without the compensation of phase and magnitude in AC type hybrid system. Especially, because the controller of diesel system is based on charge/discharge status in battery bank, it has a merit to be simple in control structure. But DC bus system has a lower efficiency than AC bus-type generally, due to all generator have rectifiers that convert into DC power. So battery system must have a large storage bank, and that is the defect of a common DC hybrid system.

2.1 Configuration of Hybrid Power System

In this paper, a proposed hybrid power system consists of photovoltaic/wind/diesel generation system, battery bank, inverter system and dump-load for emergency as shown Fig.1. A hybrid system needs the algorithm to operate all of generation systems into equivalent current-source for common DC link. Also as a load demand is varied, whether the surplus power is charged into battery bank or the insufficient power is transferred from battery bank to a load. Therefore battery bank is able to become a based-load or a based-generator as generation-load status. Because battery system must be charged or discharged, so two-quadrant converter is applied for such a operation. On the other hand, wind/diesel system uses AC generator and it needs power-conversion system for rectifying AC into a common DC. Converter which is applied in wind/diesel system must be controlled to keep a maximum power factor in input-terminal. And It has a good current-control characteristic in order to operate as a ideal DC current-source in output-terminal, due to hybrid system can be analyzed as ideal current-source. Using diesel generator in hybrid system, because it is not a turbine generator in daily use but a emergency generator, the spec and life-time of diesel generator is decided by a battery capacities. The output of solar cell array is a DC power, so a boost converter is used in photovoltaic system. Photovoltaic system must be done MPPT (Maximum Power Point Tracking) for maximum output power of solar cell array. To execute MPPT, it

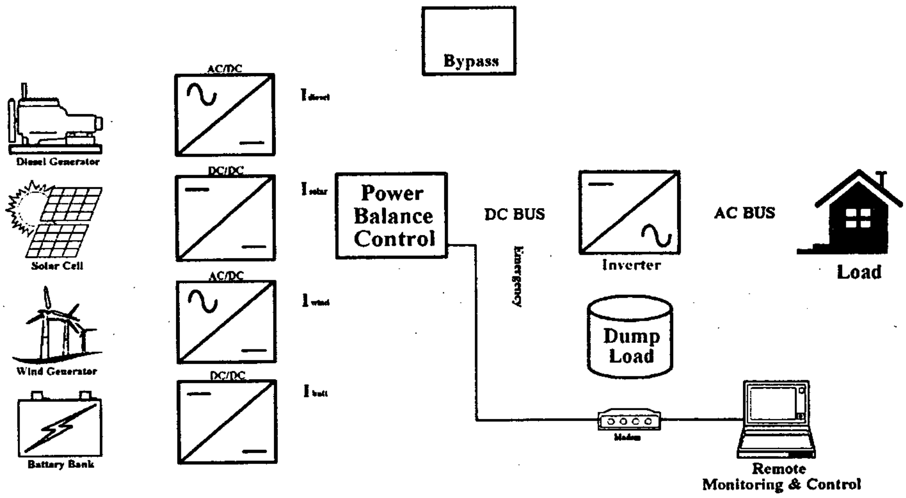

Fig 1. Configuration of Hybrid power system with common DC bus.

performs both of input voltage control and the averaging-current control at the same time. Then photovoltaic system which is connected common DC link can be assumed a equivalent current-source. Also it is an essential that a remote monitoring and control systems for a efficient management of hybrid power system and these are composed of data acquisition system, DB system for analysis of acquired-data and remote communication system as PSTN and RS422.

The AC power of alternator systems is transferred to common DC link through power conversion device. In case the control method with DC voltage-source is applied, .DC voltage of output-terminal in converter must be equal between generator systems for parallel operation exactly. Efficiency of system decreases in a parallel operation of common voltage-source mode, as output fluctuations are exceeded. According to weather condition, photovoltaic /wind system has a fluctuant output-power characteristic each other. So DC/DC converter in hybrid system needs another algorithm for parallel operation. Because the charge and discharge control of battery which is a storage component of surplus energy operates on a constant current-control method, so there is no consistency with voltage-source control method. Improving a defect of voltage-source DC system, this paper proposes a hybrid power system with current–source as shown Fig. 1. In figure 1, each current-source I_{wind} , I_{diesel} , I_{solar} , I_{batt} means the modeling of PV/wind/diesel and battery output. Also, because a load power must be transferred by AC voltage-source, a voltage type inverter is adopted for DC/AC conversion. Therefore hybrid system is divided into DC current-source and AC voltage-source. That is the main technique that a balanced-power operates between different type systems in hybrid generation. Equation (1) shows the relation of power flow when a balanced-power operates.

$$V_{inv} \cdot I_L = V_C \cdot (I_{diesel} + I_{wind} + I_{solar} + I_{batt}) \qquad (1)$$

When an unbalanced-power deviation occurs in a hybrid system, it brings a common DC voltage to fluctuation, because a common DC system is controlled by current-source as eq.(1). To equilibrate generation power with a given load demand, as a load require, the capacities of generator must be controlled to compensate the deviation rapidly. But the response time of generators are so slower than a load variation. So battery system operates as a buffer between generators and load. Especially, battery system operate as not only a current-source but also a load by two-quadrant operation. But when emergency occurs in static inverter system, it is impossible that all powers from generators can't be charged into battery bank. To prevent DC link voltage rising, the limit value of voltage was set up. And then if the voltage increases rapidly by an unbalanced power, battery system breaks the rising voltage with a connecting dump-load in the common DC link. Because proposed hybrid power system controls the output of generator with a demanded-value of current sharing each other. The parallel algorithm in voltage-source mode controller and power deviation compensating controller for regulating voltage phase and its magnitude in the AC parallel operation are not needed. Therefore it has an advantage to be consistent in control structure regardless of varied-generation output and varied-load demand through overall hybrid system.

3. CONTROL METHOD OF HYBRID POWER SYSTEM

Fig 2 shows overall circuit of hybrid power system. It consists of two boost converters and a two-quadrant converter. PV system uses boost converter to control the input-voltage of converter for MPPT operation. Wind system is composed of rectifier for AC to DC conversion and boost converter for input-current control. Also, to perform the charge and discharge current control of battery system, it is adopted that two-quadrant DC/DC converter. To remove the circulating-current between wind and PV power system, free-wheeling diode is used in boost converter respectively.

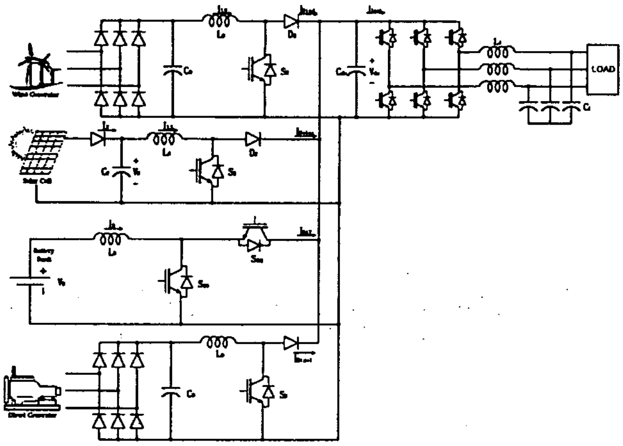

Fig 2. Overall schematic of hybrid power system.

But, due to free-wheeling diode in the terminal of wind/PV system, it is difficult that current-sharing control in proportion to power generation capacities, when it operates on constant-voltage control in the terminal of converter. Therefore in this paper, proposed hybrid power system adopts the input-current control algorithm of power converter for maximum power transfer.

3.1 Control of Wind Power System

It is needed that the algorithm to estimate generation capacity for maximum power transfer operation of wind generation system, although there is variation of load or fluctuation of wind-generator. At any given wind speed, torque vs. rotor speed curves can be easily converted into curves of current vs. speed. In the current-speed plane, as the wind speed changes, the point of maximum power transfer point moves along a curve.

$$I_w^* = k_w \cdot \omega^\alpha \tag{2}$$

where k_w and α are constants that depend on the wind turbine. Therefore, the reference value of input current of wind-generator converter can be calculated form eq (x) whenever the actual value of the rotor speed ω id known. This can be derived form measuring the generator rectified output voltage V_w and current I_w, as it can be written.

$$\omega = \frac{V_w + k_r \cdot I_w}{k_e - k_l \cdot I_w} \tag{3}$$

Where k_r, k_e and k_r are coefficients of speed-rectified value. If wind system operates with the reference value (I_w^*) of input current, maximum power always can be transferred to load. And because power system has a current-source characteristic, it is independent of load or generation capacity. A current control equation in wind power converter is followed as below.

$$V_{con\_w} = (I_w^* - I_w) \cdot (K_{pi} + \frac{K_{ii}}{s}) + V_w \tag{4}$$

Where V_{con_w} : Switching-voltage in converter (Wind)

V_w : Converter input voltage

I_w^* : Reference inductor current

I_w : Inductor current

3.2 Control of Photovoltaic Power System

In the case of DC/DC converter in PV system, MPPT algorithm is adopted to derive a maximum output from PV cells. Due to the characteristics of solar cell, as a maximum power is varied by illumination and temperature, the maximum power point voltage of solar cells are fluctuated simultaneously. Therefore output voltage of solar cells must be controlled through current-control of inductor by switching. For such a operation, it is needed that input voltage varied-control of boost converter and this voltage is in reverse-proportion to flowing current in inductor. The solar cell, it has a characteristic of current-source, so if it is controlled by MPPT method in input stage of converter, it can transfers maximum power to load regardless of output-terminal voltage of boost converter. Also Perturbation and Observation (P&O) method and Incremental Conductance (IncCond) method are applied for MPPT algorithm of PV system generally. In practical, to control the input-terminal of converter, it is needed that the method of control with negative closed-transfer function in reverse-proportion to inductor current. And as Fig 3, an averaging current-mode control method must be used. Assuming that converter consist of major voltage and minor current controller, these equations can be represented as following .

$$V_{con\_S} = (I_{Ls}^* - I_{Ls}) \cdot (K_{pi} + \frac{K_{ii}}{s}) + V_S \tag{5}$$

Where V_{con_S} : Switching-voltage in converter (Solar)

V_S : Converter input voltage

I_{Ls}^* : Reference inductor current

I_{Ls} : Inductor current

$$I_{Ls}^* = -(V_S^* - V_S) \cdot (K_{pv} + \frac{K_{iv}}{s}) + I_S \tag{6}$$

Where V_S^* : MPPT reference voltage point

I_S : Solar cell output current

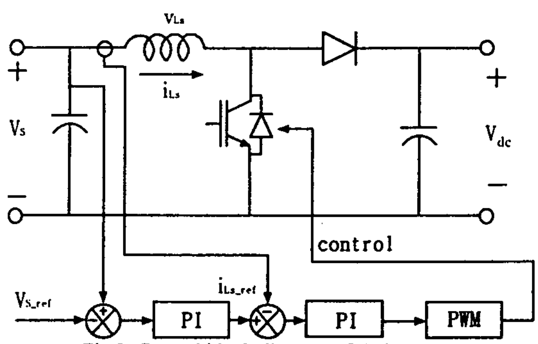

Fig 3. Control block diagram of PV system.

3.3 Control of Battery Charge/Discharge System

A DC/DC converter in the Wind/PV generation system, because it works by the algorithm of maximum power transfer with current-source characteristic, it is not able to control output-terminal voltage in converter. Therefore it is required that peripheral system to support a balanced power between load and generation systems. In this system, it is applied battery charge/discharge system to use the two-quadrant converter like fig 2. Because the battery system has the characteristic of bi-directional power flow, it has a ability to perform a balanced-power between generation systems and a given load in DC bus. A balanced-power equation of battery system is given by

$$V_{dc} \cdot I_{Load} = V_{dc} \cdot (I_{Solar} + I_{Wind} + I_{BAT} + I_{Diesel}) \quad (7)$$

$$V_B \cdot I_B = V_{dc} \cdot I_{BAT} \quad (8)$$

In special, this system is composed of a current controller and the voltage controller of output-terminal. The control-equation structure is followed as below.

$$V_{con\_B} = (I_B^* - I_B) \cdot (K_{pi} + \frac{K_{ii}}{s}) + V_B \quad (9)$$

Where V_{con_B} : Switching-voltage in converter (Battery)

V_B : Battery-cell voltage

I_B^* : Reference inductor current

I_B : Inductor current

$$I_B^* = (V_{dc}^* - V_{dc}) \cdot (K_{pv} + \frac{K_{iv}}{s}) + \frac{V_{dc}}{V_B}(I_{Load} - I_{Wind} - I_{Solar} - I_{Disel}) \quad (10)$$

Where V_{dc}^* : DC bus reference voltage

V_{dc} : DC bus voltage

I_{Load} : Load current

I_{Wind} : Wind system current

I_{Solar} : PV system current

I_{Disel} : Diesel system current

Assuming that the battery system operates with the value of reference DC voltage for balanced-power control, if there is an unbalanced-power between generation power and required-power in load, so that the error of dc voltage occurs. Therefore battery system is able to compensate a unbalanced-power by charging or discharging with current in proportion to DC voltage's error.

4. SIMULATION

The proposed algorithm of hybrid power system is verified through computer simulation. Simulation parameters are shown as table 1, and simulation conditions for transient characteristic of systems are shown as table 2.

Table 1. Simulation parameters.

Parameters	Value
C_{dc}	9900 [uF]
C_S	9900 [uF]
L_S	3.7 [mH]
L_W	2 [mH]
L_B	2 [mH]
V_{dc}	600 [V]
V_B	230 [V]
T_S	100 [us]
Rated-load	50 [kW]
Solar cell maximum output	10 [kW]
Solar MPPT voltage	252 [V]
Solar MPPT current	41.6 [A]
Wind-Gen. maximum output	40 [kVA]
Wind-Gen. rated voltage	380 [V]

Table 2. Simulation conditions.

Generation power	Condition 1	Condition 2
P_{solar} [kW]	10	10
P_{wind} [kW]	20	25 → 5
P_{bat} [kW]	-20 → 20 (Charge) (Discharge)	-5 → 15 (Charge) (Discharge)
P_{load} [kW]	10 → 50	30

Fig 4 is shown that simulation schematic for hybrid power system. In this paper, without inverter in load-side, the interactive-operation of PV/Wind/Battery hybrid system are applied through DC common load.

Fig 5 shows the result of simulation condition 1. Filtered-current waveforms of output-terminal in hybrid system are shown, when DC load is changed from 10[kW] to 50[kW]. When the load is a 10[kW] capacity, it is shown that battery system operates on charge-mode. Also when hybrid system operates on a rated-load, PV/Wind system has a insufficient generation capacities than load demand. So the battery system is changed charge-mode into discharge-mode to compensate lacking power. Fig 6 represents that DC bus voltage has a fast transient response, when load is changed suddenly. And it is shown that although the load is varied, PV/wind generation systems carry on maximum power transfer operation, due to the current-source control method.

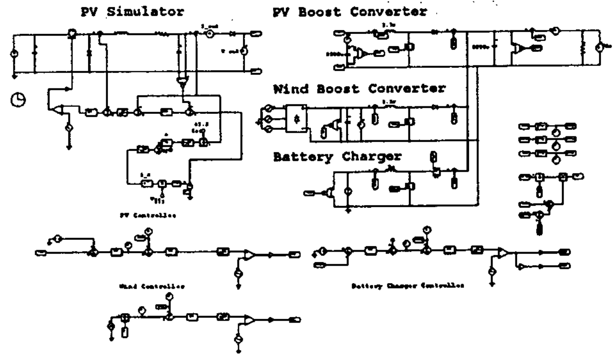

Fig 4. Simulation schematic of hybrid power system.

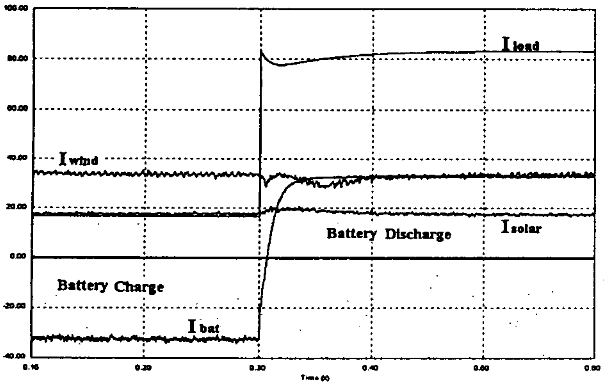

Fig 5. Current waveforms when load is changed from 10[kW] to 50[kW].

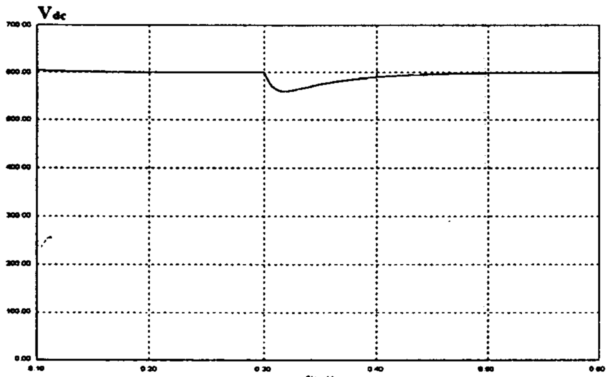

Fig 6. DC bus voltage when load is changed from 10[kW] to 50[kW].

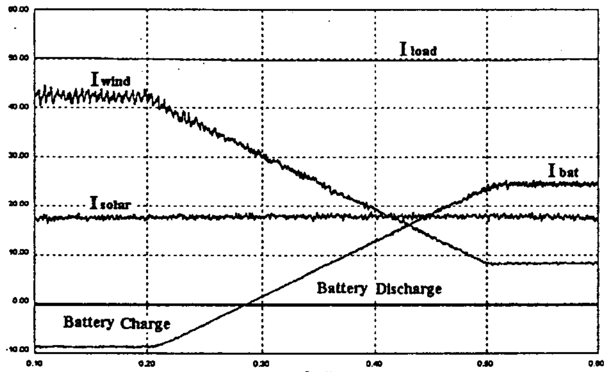

Fig 7. Current waveforms when wind generation output is varied.

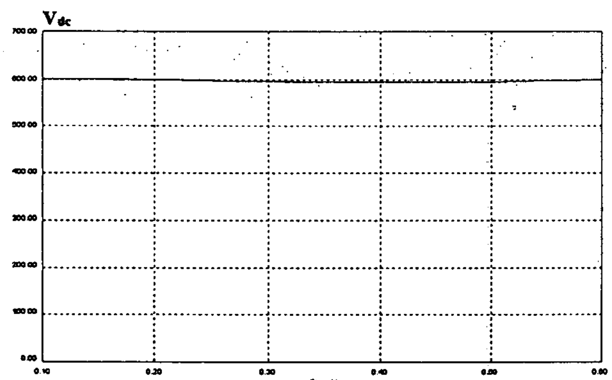

Fig 8. DC bus voltage when wind generation output is varied.

Assumed fixed-load 30[kW], Fig 7. shows the current waveforms of hybrid system, while the output-power of wind generation system is decreased from 25[kW] to 5[kW]. As the output current of wind system is decreased, battery system is reversed from charge to discharge mode. Also Fig 8 is shown that a stable output characteristic of DC bus voltage on previous condition.

5. CONCLUSION

In this paper, it deals with an overall basic-configuration and a control algorithm for photovoltaic/wind/diesel hybrid power system and that is verified by simulation tools. To execute a stable power-balanced control, a hybrid power system is assumed that all of power generators are an equivalent current-source with a common DC link. And the boost converter in PV/wind simulation schematic is controlled to transfer maximum power into a load respectively, and it has a fast transient response with a stable operation. From now on, The research of power factor correction in AC generator must be carried on and the algorithm of proposed hybrid power system will be verified through a experiment

6. ACKNOWLEDGMENTS

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