CONTROLLER FOR 1KW-5KW WIND-SOLAR HYBRID GENERATION SYSTEMS

Mao Meiqin[1], Su Jianhui[1], Liuchen Chang[1,2], Zhang Guorong[1], Zhou Yuzhu[1]

1. Research Center for Photovoltaic System Engineering, MOE,
Hefei University of Technology
Hefei, Anhui Province 230009 China
2. Department of Electrical and Computer Engineering
University of New Brunswick, Fredericton
New Brunswick, Canada E3B 5A3
mmao@unb.ca

ABSTRACT

In the districts where solar energy and wind energy are naturally complementary, the application of wind-solar hybrid generation systems (WSHGS) can reduce the storage capacity of batteries and the total cost of the system compared with stand-alone PV or wind generation system. This paper presents a cost-effect controller system for 1kW to 5kW WSHGS with low DC voltage input (24V DC or 48V DC) and high output AC sine wave voltage (220V AC). This controller system includes features as follows: 1) PWM chopping technology in charging control of batteries, which can make wind turbine and solar array operate at maximum power point so that the overall system efficiency can be improved greatly. 2) Constant voltage and limited current two-loops control of battery charge, which can make batteries in float charging state, enhance the cycle rate and prolong the life of the batteries. 3) SPWM conversion with front-end high frequency DC-DC modules in parallel and special microchip control IC with high performance-cost, which can accomplish sine wave output voltage with high reliability and high load efficiency.

Index Terms— wind energy, solar energy, controller, Power electronics, load sharing

1. INTRODUCTION

In the districts where solar energy and wind energy are naturally complementary, the application of wind-solar hybrid generation systems (WSHGS) can reduce the capacity of batteries and the total cost of the system compared with stand-alone PV or wind generation systems. But efficient and reliable operation of WSHGS largely depends on control strategies of the controller. There are some drawbacks as follows in current controllers for small-scale WSHGSs :

1) The charging voltage is controlled by using voltage hysteresis comparison (that is, two points control). In that case, batteries may not be charged to full state even though wind energy and solar energy are sufficient, which will shorten the cycle number of batteries.
2) The Output voltage of most inverters used now is square wave, which has devastating effect on inverters because of rushing current caused by condensive loads. In addition to that, harmonics in square wave output voltage will make the efficiency of the load lower.
3) Solar array and wind turbine can not operate at maximum power point, which will give rise to a great deal of energy loss.

To improve the performances of current controller in WSHGS, the following technologies are discussed in this paper and adopted in 1kW to 5kW prototypes :

1) PWM chopping technology in charging control of batteries, which can make wind turbine and solar array operate at maximum power point so that the overall system efficiency can be improved greatly.
2) Constant voltage and limited current two-loops control of battery charge, which can make batteries in float charging state, enhance the cycle rate and prolong the life of the batteries.
3) SPWM conversion with front-end high frequency DC-DC modules in parallel and special microchip control IC with high performance-cost, which can accomplish sine wave output voltage with high reliability and high load efficiency.

2. SYSTEM CONFIGURATION OF WSHGS

The configuration of 1kW-5kW stand-alone WSHGSs proposed in this paper is shown in Fig.1. In these systems,

The paper is supported by the Grant Project of GEF/WB / NDRC (PRC.) (CG-2005-029)

CCECE/CCGEI May 5-7 2008 Niagara Falls. Canada
978-1-4244-1643-1/08/$25.00

the battery voltage levels usually cover 24V DC or 48V DC. Therefore, a high frequency DC-DC stage is used to boost the lower voltage of battery to higher DC voltage (350V). And two controllers are used : the controller1 is designed to

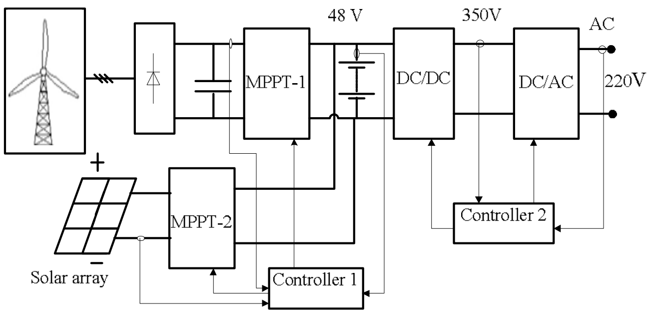


Fig. 1 Configuration of stand- alone WSHGS

make wind turbine and solar array operate at their maximum power point (MPPT) respectively and the battery charged and discharged at high efficiency; controller 2 for high frequency DC-DC boost and inverter control.

3. CONTROL STRATEGES FOR CONTROLLER1

The battery charging control and converter control are crucial technologies in WSHGS, and their control strategies determine the efficiency, reliability and life span of the hybrid system.

The control strategies for controller1 are as follows:

1) MPPT control strategy
2) Battery energy management strategy

3.1. MPPT Control strategy for wind turbine and solar array

In the system proposed above, the output terminals of DC-DC converters for MPPT are connected to a battery bank. In this case, the output voltage of them are dictated by the instantaneous voltage of the battery banks. So the voltage MPPT control strategies do not work anymore in this system In the paper, the current MPPT control strategies are developed instead, which is described in the following sections.

3.1.1. MPPT Control strategy for wind turbine system

For small-scale wind generator system (say, the rated output power bellow 5kW), the synchronous generator is used. According to the operation theory of wind turbine, the maximum output power of wind generator depends on the optimal tip speed ratio λ opt. In terms of this, the MPPT1 block shown in Fig. 1 is controlled to track the maximum power of wind turbine and the battery charging voltage in such a way :

1) Taking the technique parameters of wind turbine given by the manufacturer to calculate the optimum tip speed of the wind turbine λ_{opt} and the maximum power coefficient C_{pmax} related to the optimum tip speed λ_{opt}.
2) The maximum power is divided by the amplitude of the output voltage of the load side which is obtained by measure module, obtaining a reference current of the buck converter of MPPT1.
3) By comparing the measured current with the reference current of the converter, the PWM signals are acquired. When the measured value is greater than the reference value, the switch is turned off, so the output voltage will get down and the current will also get down to track the reference current. Contrarily, the switch is turned on. The control diagram is showed in Fig2.

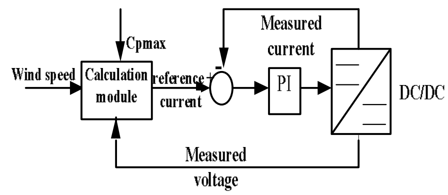


Fig.2 Control diagram of the wind generation system

3.1.2. MPPT control strategy for solar array

The control block of solar generation system is shown in Fig. 3, in which Vcr is the reference voltage of solar array; Vcm the measured voltage of the solar array, Ibr the reference charging current of battery; Ibm the measured charging current of battery; Vbr the reference charging voltage of battery; Vbm the measured charging voltage of battery.

The reference operation voltage of solar array Vcr can be obtained by a calculation module, where the solar array operates at the maximum power point. When the battery voltage Vbrm is lower than the reference charging voltage Vbr, Vb equals to zero, the solar array operation voltage tracks its reference voltage. If Vcm>Vcr, the pulse width of the PWM signal increases produced by PWM generator, and the duty ratio of the switch also increases, so the charging current of the battery increases and Vcm will drop to the reference voltage Vcr adjusted by the control circuit in the end. If Vcm<Vcr, the operation process is just opposite. In that case that the battery voltage Vbm is lower than the reference charging voltage Vbr, the solar array operates at the optimum point in order that the charging current of battery is as high as possible.

Once the charging voltage equals to or goes over the reference charging voltage, Vb will gradually increase. at the moment the operation voltage Vcm of the solar array is determined by Vb and Vcr. The output power of the solar array decreases and the charging current of battery also decreases gradually till the discharging current and the charging current of battery is balanced. The Fig. 4 shows the simulation result of voltage Vs and current Is of battery tank. It can been seen that the charging current is not zero even when the battery voltage has reached the rated voltage level of 24V. So the battery is kept in float charging state, which will make the battery charged fully and prolong the life of the battery.

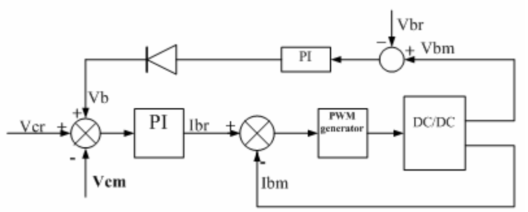


Fig.3 Control diagram of the solar generation system

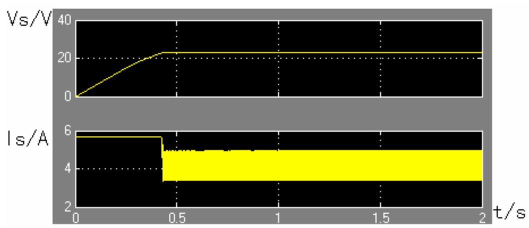


Fig. 4 battery voltage Vs and the charging current Is.

4. DC-DC BOOST MODULES IN PARALLEL

The DC-DC boost stage, used to convert 24V DC or 48V DC to 350 DC, is designed as 1kW module that can dynamically adjust its output current in terms of load current. In this way, 3kW and 5kW system can be derived from the 1kW system with the parallel operation of multi-independent-modules in 1kW. These multiple-independent-power modules can be paralleled such that each module supplies only its proportionate share to total-load current.

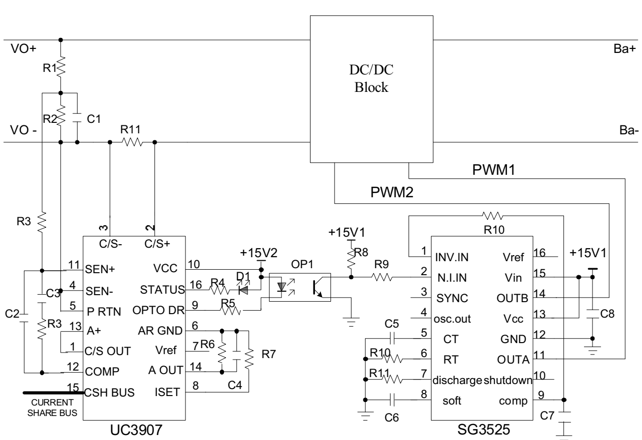


Fig.5 PWM drive and current sharing control

This sharing is accomplished by controlling each module's power stage with a command generated from a voltage-feedback amplifier whose reference can be independently adjusted in response to a common-share-bus voltage. By monitoring the current from each module, the current share bus circuitry determines which paralleled module would normally have the highest output current and, with the designation of this unit as the master, adjusts all the other modules to increase their output current to within 2.5% of that of the master. The 1kW DC-DC stage with load sharing controller UC3907 and PWM controller SG3525 is shown in Fig.5

5. INVERTER CONTROL

5.1. Topology and controller

H-bridge topology is adopted in inverter power stage. The controller is based on 68HC908MR16 microchip to reduce the cost of the system, shown in Fig.6. To meet the needs for dynamic response and robust control requirement, a hybrid control strategy with feed-back and feed-forward control is adopted, shown in Fig.7, in which, U_0 and U_g are instantaneous and reference value of output voltage of the inverter and K_r is the feed-forward transfer function.

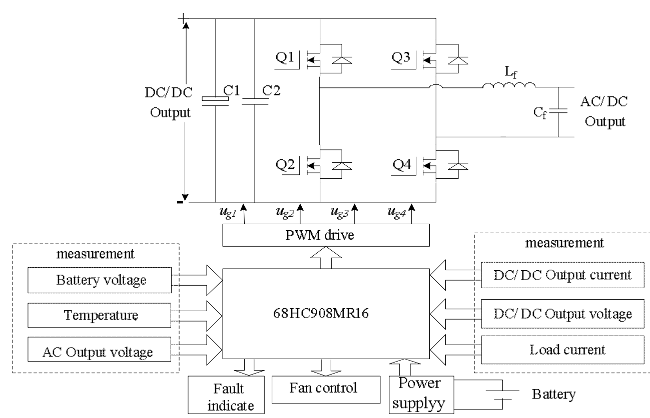


Fig.6 Inverter stage and controller in WSHGS

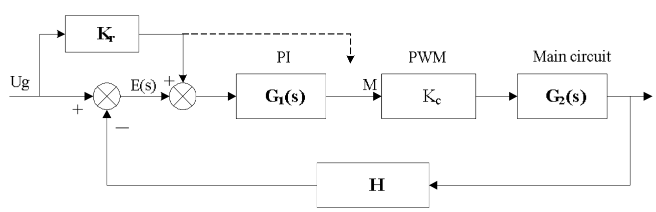
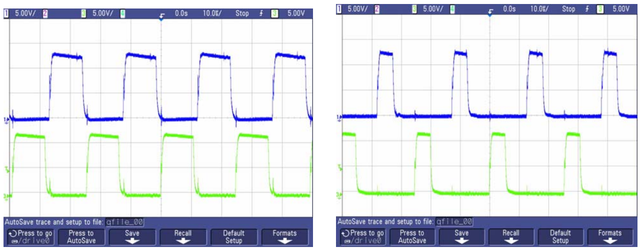


Fig.7 Block diagram of inverter stage

6. EXPERIMENT RESULTS

According to the control strategies above, 1kW, 3kW and 5kW controller prototypes of WSHGS are made. And the drive wave forms of MOSFET of the high frequency DC-DC boost stage in heavy load and light load are shown in Fig.8 (a), (b).



(a) (b)

Fig.8 Drive wave forms of MOSFET in heavy load (a) and light load(b) respectively

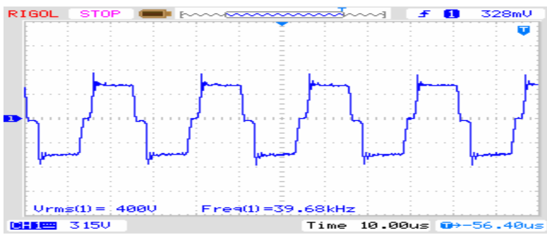


Fig. 9 Output voltage of DC-DC boost in heavy load

The experiment results of output current of DC-DC boost modules in parallel are presented in the table 1. It shows that by the proposed controller shown in Fig.5 , each DC-DC module can balance its output current in proportion to total load currents very well.

Table 1 Output current of DC-DC boost modules in parallel

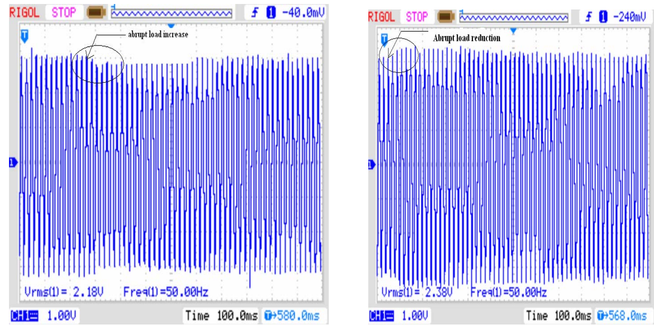
I_M(A) \ I_L(A) module	2.88	5.88	9.11	11.58	14.4
1	0.96	1.88	3.01	3.87	4.90
2	0.95	2.07	2.90	4.10	4.77
3	0.97	1.93	3.02	3.61	4.73

The main performances of the inverter with 5kW resistor load is shown in table 2. All the requirements are met well.

Table 2 Inverter performances with a 5kW load

Index	Design requirements	Measurement
Output voltage	220VAC±5%	220VAC±0.5%
Inverter efficiency	≥95%	≥96.3%
frequency	50Hz±5%	50Hz±2%
THD	<5%	<3%

Fig.10 shows that dynamic output voltage wave of the inverter with sudden 5kW load abrupt increase, while in Fig.11 with 5kW load abrupt decrease.



(a) (b)

Fig.10 Dynamic output voltage of inverter with abrupt load increase (a) and reduction (b)

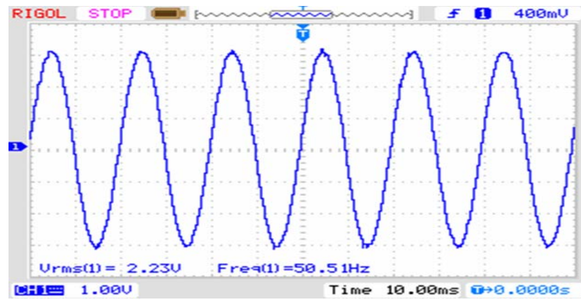


Fig.11 stable output voltage of inverter

7. CONCLUSION

The paper presents control strategies and design scheme for 1kW to 5 kW stand-alone WSHGSs. The simulation and experiment results show that by the proposed control and design scheme, wind turbine and solar array operate at maximum power point and battery bank may be in float charging state, enhancing the cycle rate and prolong the life of batteries. In addition to that, SPWM conversion with front-end high frequency DC-DC modules in parallel and special microchip control IC can accomplish sine wave output voltage with high dynamic and steady performances .

REFERENCE

[1]Bogdan S. Borowy, Ziyad M .Salameh, " Dynamic Response of a Stand-Alone Wind Energy Conversion System With Battery Energy Storage to a wind Gust ", IEEE Transactions on Energy Conversion, Vol.12, NO.1, March 1997.

[2]Sujianhui, Yushijie, Zhaowei, Wumuida, Shenruliang, Hehuiruo, "mathematical model of solar cell for project implement", Journal of Solar Energy (Chinese), Vol 22, NO.4, Oct 2001.