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Wind-solar Complementary Controller Design of Round frame Wind generators

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Abstract. A new-type wind-solar complementary controller applied to round frame wind generators was designed and realized. This wind generator could realize real-time adjustment of paddle angle according to wind power so as to reach high safety and sustainable power generation effect even under a hurricane. The controller was integrated with a stepping motor driver. Integral separation PID control algorithm was used to drive stepping motor and adjust paddle angle so as to realize closed-loop control of generator velocity. Three-phase charging method was used to realize three-phase charging of storage battery so as to effectively lengthen its service life. MPPT algorithm was used to realize wind-solar complementary maximum power point tracking, thus improving the controller efficiency. STM32F103RBT6 chip-based wind-solar complementary controller was designed to complete controller hardware design and software programming. The system prototype was fabricated and experimented, and the experiment indicated that this controller could realize generator velocity control and battery charging-discharging functions with high efficiency and steady and reliable operation.

1. Introduction

Wind energy and solar energy are renewable energy sources enjoying extensive application, and compared with traditional fossil energy, they are characterized by extensive distribution, cyclic utilization and no pollution, etc. [1]. New-type wind driven generators and wind-solar complementary power generation equipment are under rapid development.[2-3] Round frame wind generator is a kind of mini-type wind generator with external round frame structure. Unique round frame structure can ensure high safety of the generator and reduce personal injuries caused by paddle rupture under high-velocity revolution. Paddle of this wind generator can windward angle through the stepping motor driving mechanism. Under a high wind velocity, it will reduce windward angle in order to lower generator velocity. When the wind velocity is low, it adjusts the paddle to the optimal angle so as to ensure maximum power generating efficiency. Wind-solar complementary controller for a round frame wind generator is a core control component of this type of generator, completing real-time adjustment of paddle angle, battery charging and discharging, current/voltage monitoring and protection, man-machine interaction, remote monitoring and other functions. Hardware and software design of the wind-solar complementary controller was conducted in this paper, a prototype was fabricated and experimented, and the experiment indicated that the controller featured steady and reliable operation with high efficiency.

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2. Hardware design

2.1. Overall scheme design

The wind-solar complementary controller takes round frame wind generator and solar photovoltaic cell panel as the energy supply system. Figure 1 shows the overall design block diagram of the system. Output voltage of wind generator, after three-phase rectification, acts upon Buck-Boost inverter together with output voltage of solar panels. After output current and voltage of solar panel and wind generator experience Analog-digital conversion, MPPT algorithm is used to generate PWM impulse control MOSFET switch and regulate MOSFET switching signal so as to realize maximum power tracking of photovoltaic battery and wind generator. Three-phase charging method is used to charge 24V/200Ah lead-acid battery. C-phase voltage of wind generator, after shaping and opto-coupler isolation, is input into the STM32 controller to realize wind generator velocity detection. When the generator velocity is lower than 750RPM, paddle angle is kept at 35°. When the velocity exceeds 750RPM, stepping motor rotates, and paddle is driven to reduce windward angle and lower the generator velocity. Integral separation PID algorithm is used to realize closed loop of wind generator velocity.

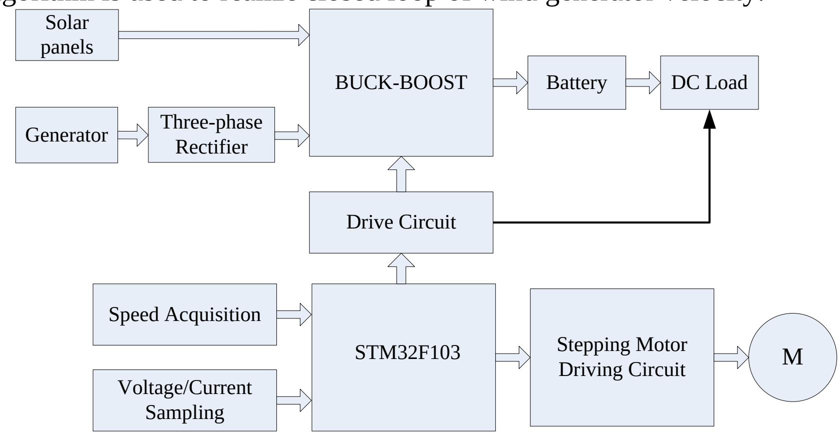

Figure 1. Overall design block diagram

2.2. Main control chip

Main control chip of the wind-solar complementary controller is the core of the whole control system, which mainly completes measurement of generator velocity and closed-loop PID control algorithm of generator velocity, generates stepping motor-driven sequence signals, acquires current and voltage of photovoltaic panel and generator and charging and discharging current and voltage of the lead-acid battery, outputs PWM signal and controls MOSFET on-off so as to realize MPPT algorithm. STM32F103RBT6 is selected as the main control chip of this controller.

STM32F103RBT6 is a 32-bit microcontroller with ARM Cortex-M3 core promoted by ST Corporation. With monocyclic hardware multiplier and divider, it has strong antijamming capability with the highest operating velocity reaching 90DMIPS and operating main frequency is 72MHz. It uses improved-type high-performance RISC CPU core with Harvard architecture. It has been specially optimized for C-language compiling. Enhancement-mode instruction set is used with powerful DSP support. This chip has abundant external equipment, including 2-way 12bit AD converter, 7-channel DMA controller, 7 multifunctional timers and 9 communication interfaces. This chip has 20KB SRAM and 64KBFlash memorizers. Multi-aspect evaluation of main control chip of this controller can satisfy system requirements.

2.3. Buck-boost main circuit

A Buck-Boost circuit is designed as shown in Figure 2. Buck circuit consists of MOSFET switching tubes Q1 and Q4, power inductance L1, power diode D2 and capacitors C16 and C12. Boost circuit consists of MOSFET switching tubes Q1 and Q5, power inductance L1, power diode D2 and capacitors C16 and C12. Under Buck pattern, Q1 and Q4 inputs PWM waves with polarity complementation, and

Q5 is cut off. Under Boost pattern, Q1 is started, Q4 is cut off and Q5 on-off is controlled by PWM switching signal. N channel high-power field-effect tube IRFP260 is selected as power switching element, where ID (cont) = 46 A and VDSS = 200 V, integrated with rapid backward diode. Inductance value is 330μH, and two 470μF/35V aluminum electrolytic capacitors are in parallel connection for filtering. DSE160-06A fast recovery diode is used as power diode D2.

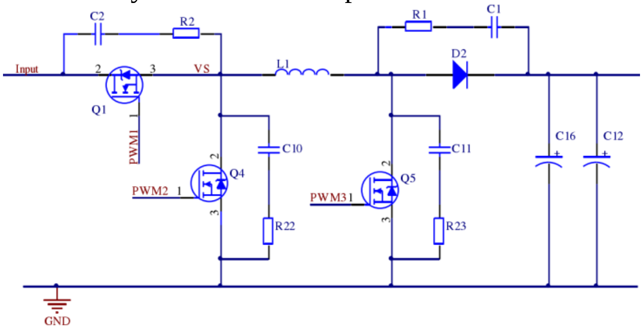

Figure 2. Buck-Boost circuit

2.4. Stepping Motor control circuit

Two-phase four-wire 57-step motor is used as stepping motor for paddle angle control with rated voltage of 24V, rated current of 2A, torque of 0.93N.m and stepping angle of 1.8°. Dual H-bridge drive circuits are designed to drive phase A and phase B windings. Each H-bridge circuit consists of 4 MOSFETs to control their On-Off operation, and they can generate forward winding current and reverse winding current. MOSFET device is IRFB3607 with working voltage of 75V and maximum breakover current of 80A. 4 IR2103 chips are used to realize driving of dual H-bridge circuits. IR2103 is a half-bridge driver used to drive MOSFET and IGBT devices, dead time is set inside to ensure safety of upper and lower half-bridge tubes, compatible 3.3V, 5V and 15V voltage logics are input, and switching time is as short as 150ns. Figure 3 shows phase A half-bridge drive circuit, the controller outputs the commutating-phase logic level to IR2103 input end, and output end generates MOSFET drive signal with complementary 1Y_H and 1Y_L. R141 and D31 constitute the gate driven bootstrap circuit.

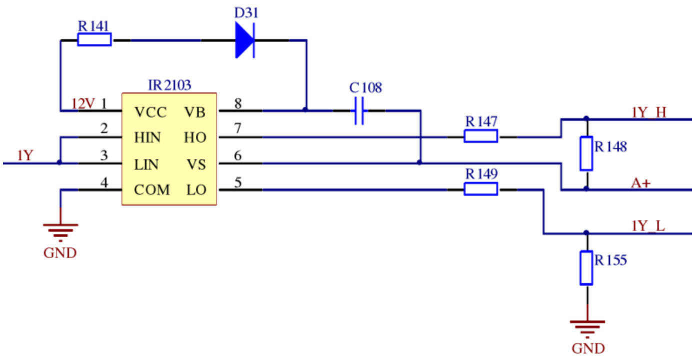

Figure 3. Phase A half-bridge drive circuit

3. Key method

3.1. Closed-loop integral separation PID algorithm for wind generator velocity control

When paddle angle of the wind generator is certain, the higher the wind velocity, the higher the generator velocity. When generator velocity exceeds 750RPM, it can be decelerated by reducing paddle windward angle through the stepping motor. When generator velocity is lower than 750RPM, paddle windward angle should be enlarged. Integral separation PID algorithm is used to control wind generator velocity in the system. Phase-C voltage of the three-phase permanent magnetic wind generator is sent to the host processor after shaping. The host processor conducts real-time calculation of generator velocity and obtains controlled output quantity through integral separation PID algorithm. This output quantity is forward or reverse rotation steps of the stepping motor, and then wind generator velocity control is realized.

Introduction of integration element in the PID control mainly aims at eliminating static error and improving precision. However, when the system is started, finished or set values are increased or reduced by a large margin, integral accumulation of PID operation will be caused within a short time, which results in too large control quantity, large overshooting and even system oscillation, and these are not allowed in the control process. [4] Integral separation PID control algorithm not only keeps integral action and reduces overshooting quantity but also greatly improves the control performance.

Expression of the algorithm is[5]:

$$u(k) = K_P e(k) + aK_I \sum_{i=1} e(i) + K_D[e(k) - e(k-1)] \tag{1}$$

Where α is logic coefficient of the integral term, namely:

$$\alpha = \begin{cases} 1, |e(k)| \le \varepsilon & PID\,Control \\ 0, |e(k)| \ge \varepsilon & PD\ Control \end{cases} \tag{2}$$

ε is set threshold. When the deviation is greater than the threshold, PD control algorithm will be used, or otherwise PID algorithm will be used.

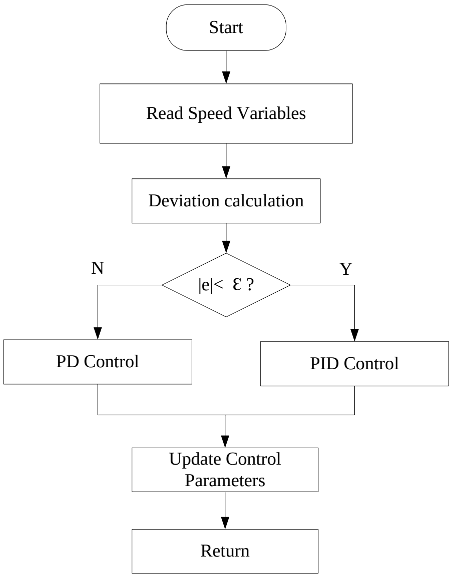

Figure 4. Integral separation PID control algorithm

3.2. Maximum power point tracking (MPPT) algorithm

Utilization rate of electrical energy output by wind power generation and photovoltaic power generation system is not only related to its own characteristics but also is influenced by illumination intensity, temperature, load characteristics, etc. Under different external conditions, draught fan and photovoltaic modules can operate at different and sole maximum power points, so the control method which finds out the optimal working state of wind generator and photovoltaic modules and makes them operate at maximum power points is namely maximum power point tracking (MPPT) technology. [6-8]Perturbation and observation method of output power was used in this paper to obtain maximum power points. When the controller charges the storage battery, its output voltage will be clamped by the storage battery within a certain range, so controller output power is acquired by detecting battery voltage and controller output current. The computing formulas are :

$$\begin{cases} P(n+1) = P(n) + \Delta P \\ \Delta P = U(n+1)I(n+1) - P(n) \end{cases} \tag{3}$$

Where $P(n+1)$ is the current output power; $P(n)$ is the last output power; ΔP is sum of two powers; $U(n+1)$ is the current battery voltage; $I(n+1)$ is the current controller output current. The last controller output power $P(n)$ is calculated, Buck circuit duty ratio β of the controller is enlarged by a certain step length, and the current controller output power $P(n+1)$ is calculated so as to obtain ΔP. If ΔP is positive (namely output power increases after perturbation), β is continuously increased. If ΔP is negative (namely output power reduces after perturbation), then perturbation direction changes and β is reduced, and the control method is shown in Figure 5.

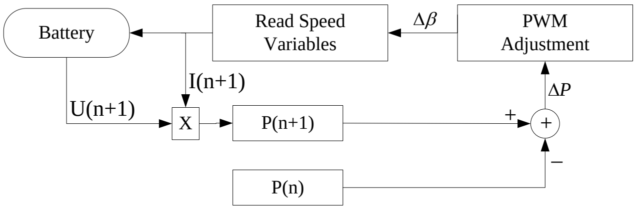

Figure 5. MPPT Algorithm

4. Experimental verification

In order to verify feasibility of the wind-solar complementary controller scheme, a controller prototype was fabricated and an actual experiment was carried out. The controller prototype is shown in Figure 6, which shows real object of round frame wind generator and controller circuit board respectively.

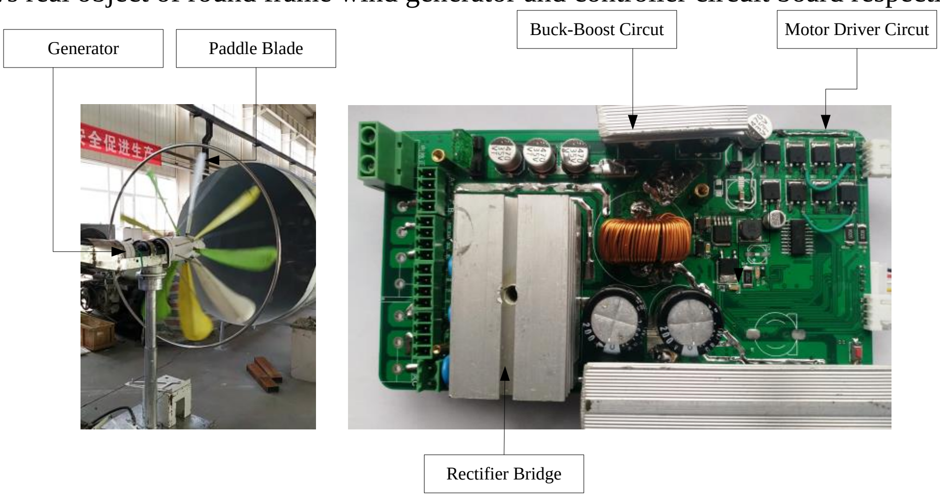

Figure 6. Prototype picture

Self-made small wind tunnel was used in the experiment to generate level-8 wind power to blow towards the round frame wind generator. The controller implements real-time monitoring of generator velocity and uses integral separation PID algorithm to drive the stepping motor and adjust paddle windward angle so as to realize closed-loop generator velocity which is kept at 750rpm. Capacity of storage battery is 24V/200Ah, and three-phase charging method is used to charge the lead-acid battery. The first charging phase is constant current charging and charging current limit is 10A. When voltage rises to 27V, constant voltage charging is adopted. When it rises to 28.8V, float charging voltage is 27.2V. Figure 7 shows measured curves of charging voltage (V) and charging current (A) of the lead-acid battery, where x-coordinate is charging time (min).

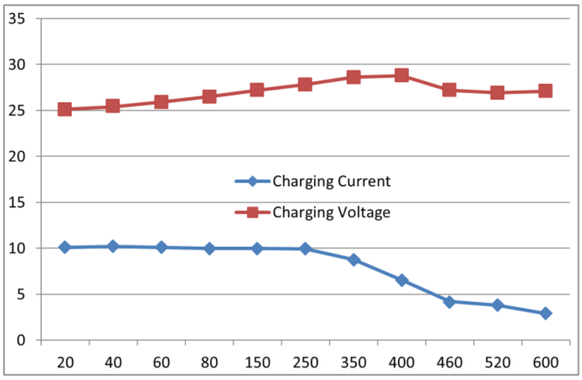

Figure 7. Measured curves

5. Conclusions

Round frame wind generator has a good application prospect by virtue of high safety and possible power generation under both breeze and hurricane conditions. A wind-solar complementary controller was designed in this paper for the round frame wind generator. Closed-loop generator velocity control was realized by detecting generator velocity and using integral separation PID control algorithm. Perturbation and observation MPPT algorithm was used to realize maximum power point tracking of the system. The lead-acid battery was charged using the three-phase charging method. Prototype testing results indicate that this control system is of high control precision and steady operation.

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