Practical Implementation of V-connection power conditioner for 10kW wind power generation

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Abstract- **In this paper, a power conditioner that can generate power into the utility from a 10kW windmill is introduced and developed. This equipment utilized inexpensive diode rectifier plus boost converter in the first stage and V-connection type inverter that has the merit of using high DC voltage in the next stage. The operation of this equipment was verified, the characteristics were evaluated and the practicability was confirmed experimentally. The equipment is deployed with ground fault detection function, and because of the transformer-less utility, it is efficient and has the advantage of generating less loss compared to its counterpart.**

***Keywords*:** **Utility interactive inverter, V-connection inverter, Wind power generation**

I. INTRODUCTION

In recent years, the demand for renewable energy has been increasing due to the increased CO_2 emission and energy problem. Since the wind power along with the solar power can revive natural power resources, the effect to alleviate the energy problem is relatively high.

In wind power generation, large-size windmills (megawatt type) as well as micro type windmills (several hundred watts type) are used. Megawatt type windmill is connected with the commercial power supply. Most of the times, micro windmill has built-in rectifier and the output is DC electric power. For this reason, a DC input power conditioner is needed for connecting a micro windmill to the utility power supply. In case of the windmill of intermediate capacity (which is 10kW in this case), to generate three-phase output, power conditioner of AC input becomes necessary. A rectifier is needed in order to convert this DC electric power required for the utility interactive inverter into the preceding stage of the power conditioner. A PFC rectifier or a diode rectifier plus boost converter is used to serve this purpose in many cases. In the former case in order to perform PFC, it requires good control characteristic but gets complicated and expensive. In the later case, the controllability is bad but it becomes comparatively cheaper. In this case, the utility interactive inverter can use either full bridge type inverter or V-connection type inverter. In the former case, DC link voltage of 350V is necessary where as in the later case 700V DC is required. When windmill voltage is high, the voltage after rectification becomes high. Therefore, compatibility with the type of V connection inverter is good.

In this paper, a power conditioner that can generate power into the utility from a 10kW windmill is introduced and developed. The power conditioner has got two stages. In the first stage, the rectifier unit consists of inexpensive and simple diode rectifier and boost converter and in the 2nd stage the utility interactive inverter unit consists of V-connection inverter with little loss. Moreover, since this power conditioner is designed based on the guidelines of electric equipment technical standard and it does not require the output utility transformer, it has the advantage from loss-wise and cost wise.

II. SYSTEM CONSTRUCTION

2-1 Construction of main circuit

The composition of the main circuit of V-connection power conditioner for wind power generation is shown in Fig. 1. It consists of the rectifier that rectifies the AC output voltage of the windmill, boost converter to boost the DC voltage of the rectifier output and utility interactive inverter to connect it to the utility power supply.

The rectifier consists of 3-phase full bridge diode rectifier, resistance for initial charging, a relay for initial charging, reactor for smoothing, and electrolytic capacitor for smoothing. A microcomputer is not required in the rectifier but control of the relay for initial charging is performed from the microcomputer in V-connection power conditioner. Electrical specification of the rectifier is shown in Table 1.

Table 1 Electrical characteristics of Rectifier

Term	Specification
Circuit System	3-phase bridge rectifier
Input voltage range	0~550V AC
Maximum output current	46A DC
Output voltage range	770V
Smoothing condenser	900 μ F
Protection circuit	Breaker
Others	Initial charge function

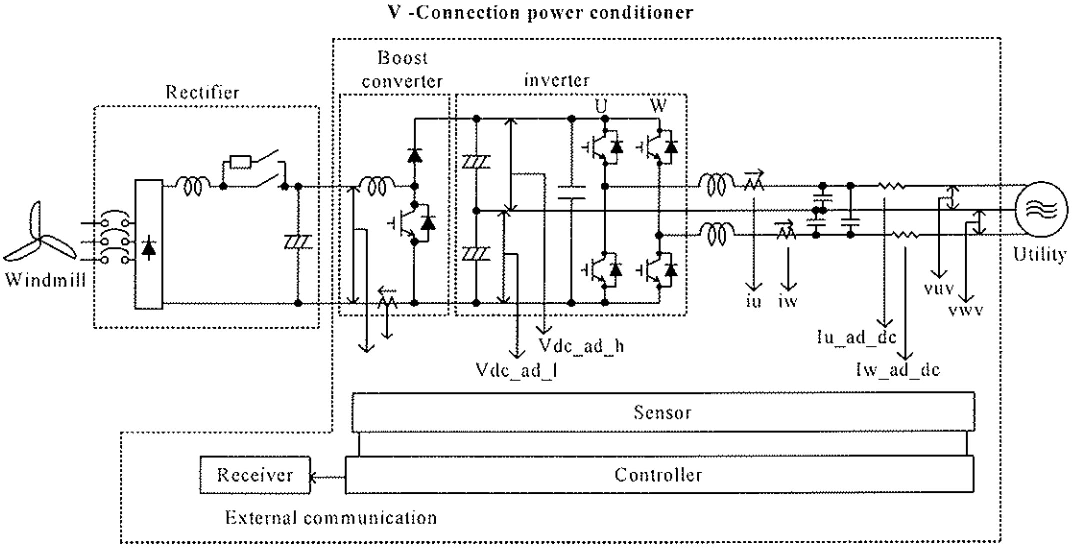

Fig.1 Block diagram of the complete V-connection power conditioner

The DC link voltage of V-connection type power conditioner should be twice of that of the full bridge type inverter. Therefore it is required to install the boost chopper circuit. Electrical specification of boost converter section is shown in Table 2.

Table 2 Boost converter electrical characteristics

Term	Specification
Circuit System	Boost chopper Non-isolated DC-DC converter
Input voltage operating range	100~700V
Input capacity	11.5kW
Rated input voltage range	330V DC
Maximum input current	46A
Switching frequency	15kHz
Main circuit element	IGBT 1200V
Control system	MPPT control

Inverter unit consists of u, w-phase main circuit elements, snubber capacitor, and smoothing capacitor. V-phase is in the middle potential of the DC link voltage. By connecting the smoothing capacitor in series, that potential is used. Therefore, compared with a 3-phase full bridge inverter, the capacity of the smoothing capacitor becomes large in V-connection inverter. Voltage sensors detect the upper DC link voltage (Vdc_ad_h)、lower DC link voltage (Vdc_ad_l). In order to make output voltage balance, Vdc_ad_h and Vdc_ad_l are controlled equally. Though it is necessary to control the boost chopper by detecting the DC link voltage, Vdc_ad_h + Vdc_ad_l is calculated internally in the microcontroller and consequently the voltage sensor for detecting the DC link voltage is not required. Electrical specification of the inverter section is shown in Table 3.

Table 3 Inverter specifications

Term	Specification
Circuit system	3-phase V-connection method
Rated AC output capacity	10kW/10kVA
Rated DC input voltage	770V DC
Rated AC output voltage	200 Vrms±10%
Rated AC output current	30 Arms
Switching frequency	15kHz
Main circuit element	IGBT
Detection	Input voltage, output voltage (Vuv and Vvw), Output current (Iu, Iw)

In the past, 3-phase commercial transformer was often connected between the system and the utility. It is possible to make the system transformer-less by protecting and detecting the DC current component of each phase. This has been achieved in this device. It is indispensable to detect the DC current component of AC current to make it transformerless, and in the present equipment DC component detection was done using shunt resistance, detection circuit and was judged using software. A 3-phase commercial transformer was used in the device earlier. Therefore it was not necessary to consider the detection time of the DC current component. To conform to the electric and technological equipment standard, this product had to shorten the detection time. In the present equipment, the detection of DC component is accomplished using hardware and consequently the detection time has been shortened.

2-2 Construction of control circuit

Considering the development efficiency of software and hardware, the microcomputer SH7047 of Renesas Technology was used. The control circuit has the PWM output carried in the microcomputer, digital output, and digital input function. In addition, the hardware protection function and the control power supply monitoring function are included. Protection of hardware is implemented using PLD. Latch, filter, and the gate block function are also implemented in PLD.

The analog data used inside the microcomputer are transmitted to the personal computer using the SCI function of the microcomputer. The transmitted data are used as measurement data.

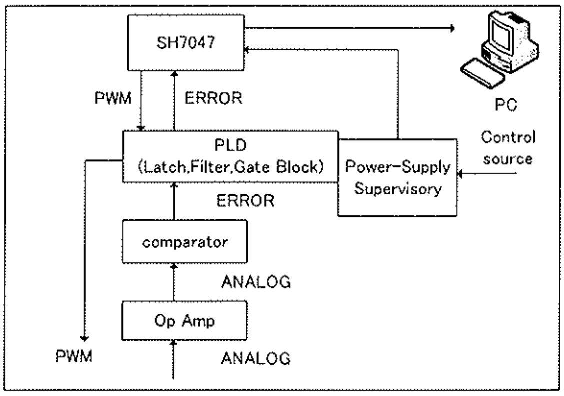

Fig. 2 Construction of control circuit

2-3 External I/F

The external display consists of the display by the console panel and the display by LED. The console panel communicates using the SCI function of the microcomputer mounted in the control board. Starting and stop operation of the equipment are performed using the switch of the console panel. Console panel displays the state of operation, error condition etc. in written form. Operation, stop and error signal are also displayed by LEDs other than the console panel.

2-4 Characteristics

The utility interactive inverter has utilized V-connection inverter system. Although the electrolytic capacitor of V-connection inverter requires high withstand voltage of 700V, since IGBT of two arms can be constituted from four, components count has been reduced compared to normal 3-phase inverter. There is also a merit that can lessen the high frequency leak current which leaks from the grounding floating capacity of a windmill.

Since a three-phase utility interactive inverter can be composed of 2 arms, it decreases the number of components in the circuit. In addition, as compared to three-phase inverter, V-connection inverter has an advantage that can reduce the high frequency leakage current that leaks from the earth stray capacitance of the windmill because the switching is not done at high frequency.

Table 4 Comparison of V-connection inverter and normal 3-phase inverter

Term	V-connection power conditioner	3-phase inverter
Current sensor	Two	Two
DC section voltage sensor	Two	Two
Main circuit element	4 arms	6 arms
Output filter	Two	Three
Component count	Few	More
Noise	Less high frequency leakage current	More high frequency leakage current

III. CONTROL BLOCK

3-1 DC section control

V-connection power conditioner is connected to the utility without transformer. For that reason it is necessary to control the DC component of the current. In the equipment, the DC component of the current is being controlled to make zero. DC component current becomes unable to flow by the fact that the upper DC link voltage (Vdc_ad_h) and lower DC link voltage (Vdc_ad_l) become equal. In direct-current part control, the control to make the difference of Vdc_ad_h and Vdc_ad_l to zero is also added. Control block diagram of the DC section is shown in Fig 3.

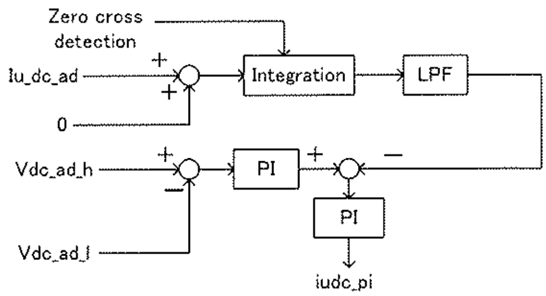

Fig 3 Block diagram of DC section

3-2 D-axis current control

d-axis current is controlled by calculating it from u-phase ac current iu, w-phase ac current, iw with respect to reference value. The instruction value is calculated from the MPPT control.

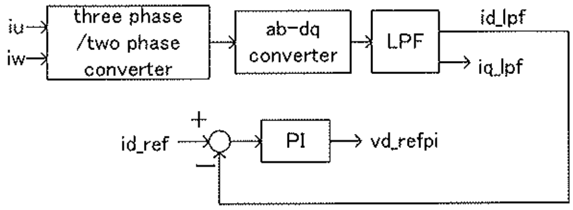

Fig 4 Block diagram of d-axis current control

The detection of the current of d axis is calculated from the voltages vuv and vwv between system lines. Details are shown in Fig.5.

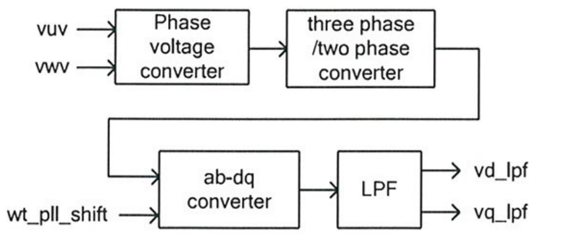

Fig. 5 d-axis current detection

3-3 Modulation factor

The instruction value is computed from d-axis current, q-axis current, AC current, and DC -current. Fig. 6 shows the control block of the modulation factor.

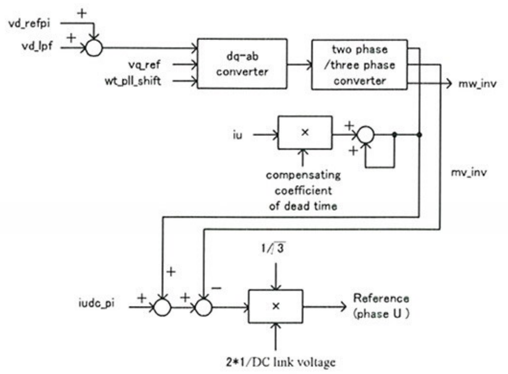

Fig. 6 Control block of modulation factor

3-4 MPPT

In this medium-size windmill, it is not possible to track the maximum power point based on the mountain climbing method. It is because the maximum output of the windmill will be changed, while searching the maximum power. The maximum power point is tracked by using the previous test bench of the windmill. A table of voltage-current characteristic is constructed and from this characteristic and the output voltage of the windmill, the reference current value is determined. Based on this method, MPPT of medium-sized windmill is implemented.

IV. Experimental Results

4-1 AC current waveform

The output current waveform of the utility interactive inverter is shown in Fig. 7.

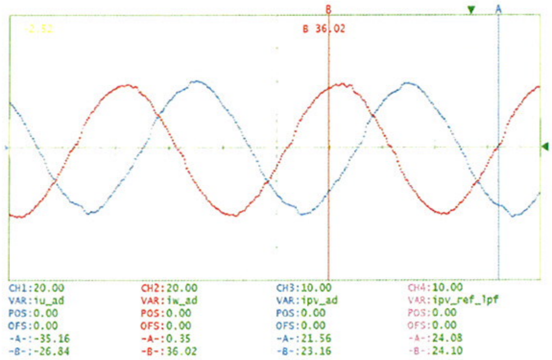

Fig. 7 Output phase current

4-2 Actual Measured efficiency

Fig 8 shows the actual measured efficiency of the V-connection power conditioner.

The efficiency is 90.92% at the rated value. The efficiency is satisfactory at 5 kW and it was 89.96%.

The number of power supply was reduced to one by reconstructing the circuit and making several power supplies to one. In 3-phase full-bridge inverter, at low wind speed, it was not possible to generate power as most of the power of the windmill was consumed by the control power supply. The improvement of that problem was accomplished by lowering the power requirement of the control power supply.

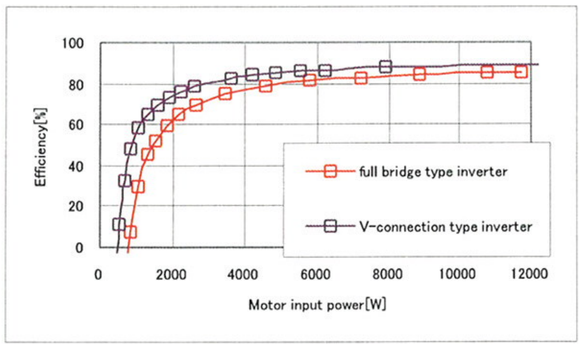

Fig. 8 Variation of efficiency with load

4-3 Static characteristic

The total harmonic distortion is 2.93% and the maximum value of the distortion for individual order is 1.48% (7th order) that satisfies the guideline of the utility interactive inverter system.

Fig. 9 shows the magnitude of different harmonic current components with respect to fundamental component.

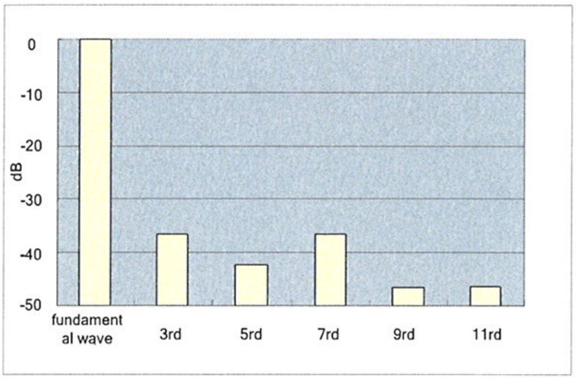

Fig. 9 Harmonic current component with respect to fundamental component

4-4 Deadtime compensation and total harmonic distortion (THD)

It was possible to confirm the guideline of utility interactive inverter by implementing deadtime compensation for Total harmonic distortion. Fig. 10 shows the total harmonic distortion with respect to deadtime compensation value. Deadtime compensation is not effective during light load. Since the deadtime compensation is calculated based on the output current, the compensation is small when the output current is small and consequently the compensation is not effective. It is necessary to investigate the method to improve the total harmonic distortion during light load. The most improved THD was obtained the compensation value was 10. From Fig. 10 it can be observed that the improvement of total harmonic distortion is not possible even by increasing the deadtime compensation value. It is possible to get the sufficient and efficient result by making the deadtime compensation value most appropriate. This time the most suitable deadtime compensation value was obtained from the experimental result. Now it is necessary to find the appropriate deadtime value from design point of view.

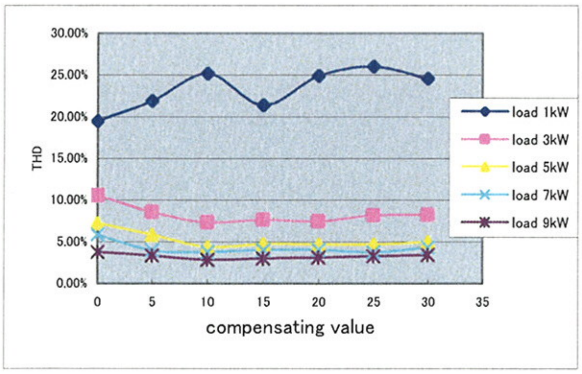

Fig. 10 Variation of THD with compensation value

4-5 Appearance

Outward appearance of the equipment and actual windmill are shown in figures 11 and 12 respectively. The height of the windmill is 9.2m and the wing diameter is 4.5m. This equipment being called horizontal axis type windmill aims at the range effect of the wind and increases the power generation efficiency. Because of this, it becomes the special windmill which has the wing framework. The equipment is divided into rectifier unit and PCS unit. The input/output breaker and the diode bridge of the system are loaded in rectifier unit. The rectifier unit has the joint box function and having this structure it can also be used as a power conditioner for solar power.

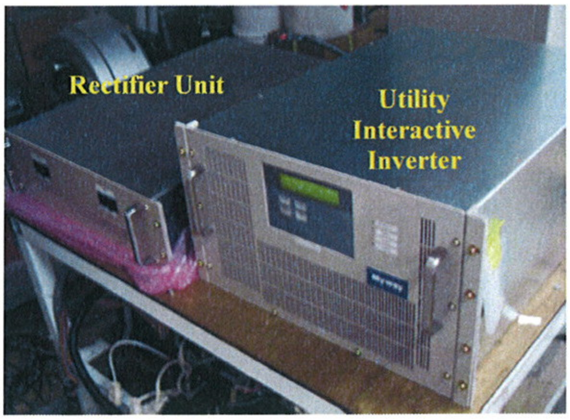

Fig. 11 System picture

Fig. 12 Windmill (Courtesy: GH Craft)

V. CONCLUSIONS

As mentioned earlier, in this paper, a power conditioner was developed and examined for 10 kW windmills.

This equipment utilized inexpensive diode rectifier plus boost converter in the first stage and V-connection type inverter that has the merit of using high DC voltage in the next stage. The operation of this equipment was verified, the characteristics were evaluated and the practicability was confirmed experimentally. The equipment is equipped with the DC component detection function of the electric technical equipment standard. Furthermore, the equipment is deployed with ground fault detection function, and because of the transformer-less utility, it is efficient and has the advantage of generating less loss compared to its counterpart.

As compared with normal 3-phase inverter, V-connection inverter has less components and it was possible to reduce the overall cost. Furthermore, in order to reduce cost, there are challenges such as standardization of the substrate and reconsideration of mechanism design.

Other method of efficiency improvement such as variation of voltage using DC link voltage control with respect to load will be considered. In order to improve the efficiency further, it is required to replace the diode rectification by the PWM rectification in the rectifier. The voltage controlled by the direct current link voltage control is devised as other efficiency improvement methods and the changeability method is devised by the load.

In future, the power conditioner will be evaluated by connecting it with the actual windmill.

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