Subaru Project: Analysis Of Field Test Results For Stabilization Of 30.6MW Wind Farm With Energy Storage

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1. Introduction

The SUBARU PROJECT provides wind power stabilization by using an energy storage system connected to a large scale wind farm. The target is to stabilize the fluctuation of power output of wind farm in short term range of several seconds to several tens of minutes. Field test started in January 5th, 2005 and it is going to operate until January 2008. The VRB system was installed at Tomamae Wind Villa wind farm on the HOKKAIDO island. Wind Villa farm consists of 19 wind-turbine generators, and the total installed capacity is 30,600 kW. The selected battery rating is 4,000kW$_{ac}$ for 90minitues (6,000 kWh), otherwise 6,000kW$_{ac}$ for 20minutes. We have verified effectiveness of each developed control systems (i.e. State of charge feed back control system (SOC-FB), Time Constant Shift Control system (Variable time constant control system), and Battery bank control system). Now we are verifying Integrated Control that consists of the three control systems and long-term operation test. This paper presents analysis results of field test data about SOC-FB control, Time Constant Shift Control, Battery Bank control, and also present the result of Integrated Control.

2. Analysis results of field test data about SOC-FB

The State of charge feed back control was developed to keep the battery SOC within its normal operating range. The smoothing control system, which provides wind power stabilization, requires the battery to be frequently charged and discharged. Unless controlled, this operation, plus losses from the battery and inverter, can completely discharge the battery. Consequently, a method of control to keep the battery SOC within its normal operating range is required for continuous operation. The battery output and SOC are controlled by feedback from the SOC measured directly at the VRB monitor cell.(Fig. 1).

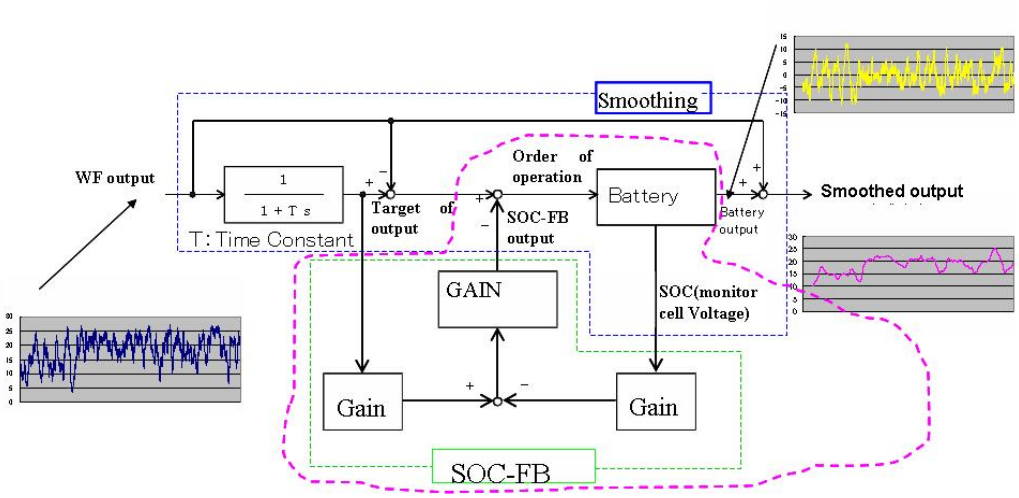

Fig.1: Smoothing Control and State Of Charge Feed back Control

The results showed that the case with State of Charge Feed Back control could keep the battery SOC within its normal range for continuous operation. Otherwise, the case without the SOC-FB control couldn't maintain the battery SOC within its normal range (Fig. 2). With regard to a smoothing performance, the case with the SOC-FB control had a same performance index as the case without the SOC-FB control (Fig. 3). Here, smoothing time constants in Fig. 1 and 2 are parameters to determine a smoothing performance. SOC-FB Control actually keeps SOC within its normal range for continuous operation. Smoothing performance with SOC-FB is almost same as that without SOC. Smoothing performance ratio is defined in Fig. 4.

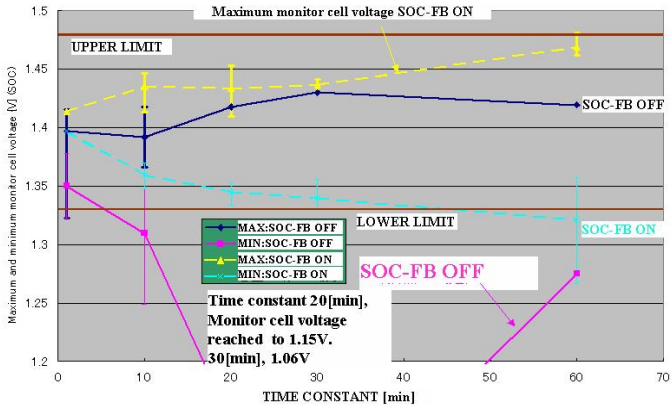

Fig.2: Maximum and minimum monitor cell voltage (Test result of SOC-FB control)

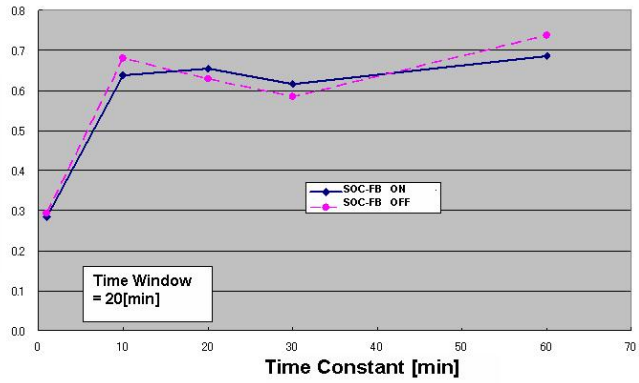

Fig.3: Smoothing performance (Test result of SOC-FB control)

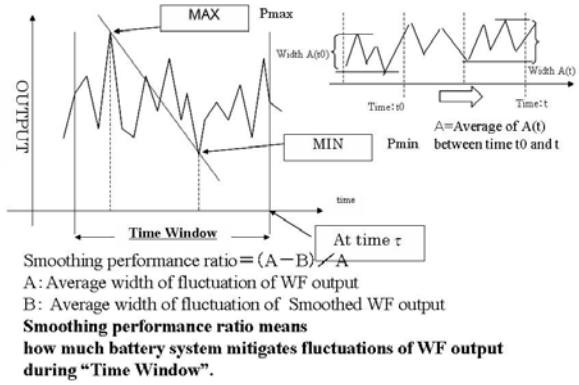

Fig.4: Definition of smoothing performance

3. Analysis results of field test data about Battery Bank Control

Battery Bank Control is adopted to reduce power loss of auxiliary equipment by stopping the operation of some battery banks when wind farm output is low. Signals of wind farm output pass through the first order lag function, and enter the Bank control as the signal for control (Fig 5). Parameters of this control are the value of a time constant of the first order lag function T3, the delay timer T2 for reducing the number of banks and a table for changing number of banks. Parameter sets for field test is shown in Table 1. When the signal of bank control becomes more than X0, first bank begins to operate. Second bank starts at X1, Third one at X2, Fourth one at X3. This control increases output of each battery bank as a result of reducing the number of operating bank (Fig. 6). This implies that, as the side effect, the Bank Control boosts the opportunity that the output of battery is limited by its rating power and is unable to hold expected stabilizing (See Fig. 7, We called this as "the order of over the kW capacity"). So, it is in the conflicting relation with the purpose of the bank control

system and the smoothing performance. To reduce loss or to keep smoothing performance, that is user's choice. For example, small WF output season (At Tomamae site in summer), We can use the parameter to reduce loss. In other season, It has better to start early for smoothing performance.

Table 1: Battery bank control parameters

Case No	BK0-1	BK1-1	BK2-1	BK0-2	BK1-2	BK2-2
LPF time constant for signal T3[min]	5	5	5	30	30	30
Delay time for stop T2[min]	5	5	5	0	0	0
X0 (MW) 1 bank	1.5	1.5	1.5	1.5	1.5	1.5
X1 (MW) 2banks	3	3	3	3	3	3
X2 (MW) 3banks	4.5	6	6	4.5	6	6
X3 (MW) 4banks	6	10.5	13.5	6	10.5	13.5

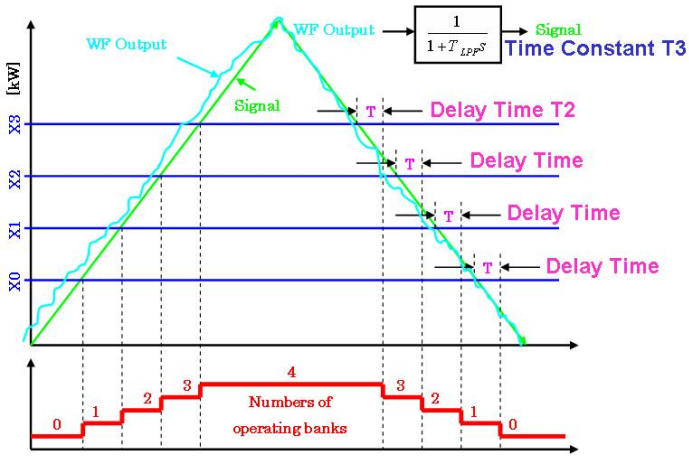

Fig.5: battery Bank Control

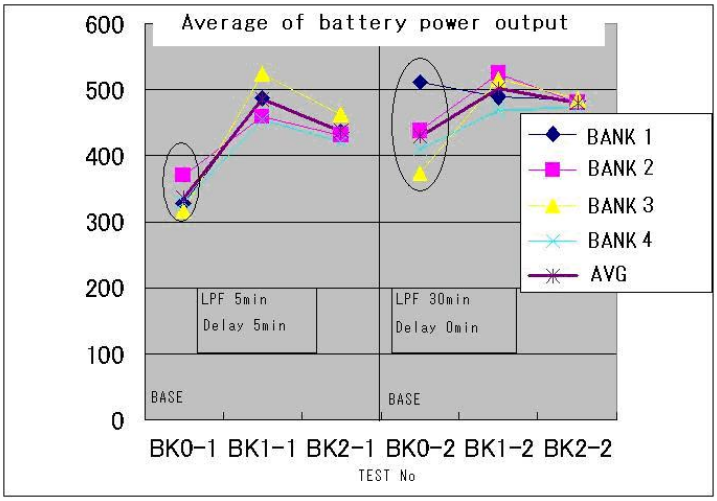

Fig.6: Average of battery power output (test result of bank control system)

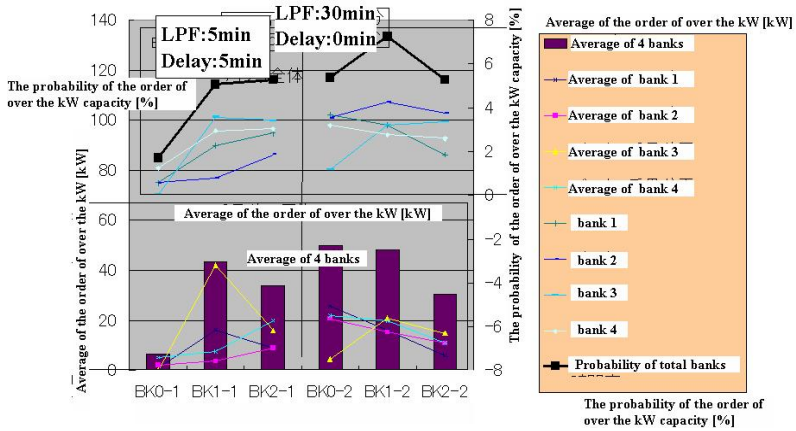

Fig.7: The probability of the order of over the kW capacity (test result of bank control system)

4. Analysis results of field test data about Time Constant Shift Control

Especially in times of large wind fluctuations, a large differential develops between the targeted wind farm output that is set by the smoothing control system and the actual wind farm power output. To fix this problem, Time Constant Shift Control changes the smoothing time constant value in accordance with battery output to continue stabilizing wind power or to restart stabilizing as soon as possible (Fig.8). Parameter sets for field test is shown in Table 2. Time Constant Shift Control system can relax the order of over the kW capacity (Fig 9), and can improve the smoothing performance as the result of reducing the order of over the kW capacity (Fig.10).

Table 2: parameter sets for field test about Time Constant Shift Control

	BASE	TC1-1	TC1-2	TC1-3	TC2-2	TC3-1
Z1[kW]	-	1,350	1,200	1050	1,200	1,350
Time Constant T1[min]	30	30	30	30	30	30
Time Constant T2[min]	30	5	5	5	1	5

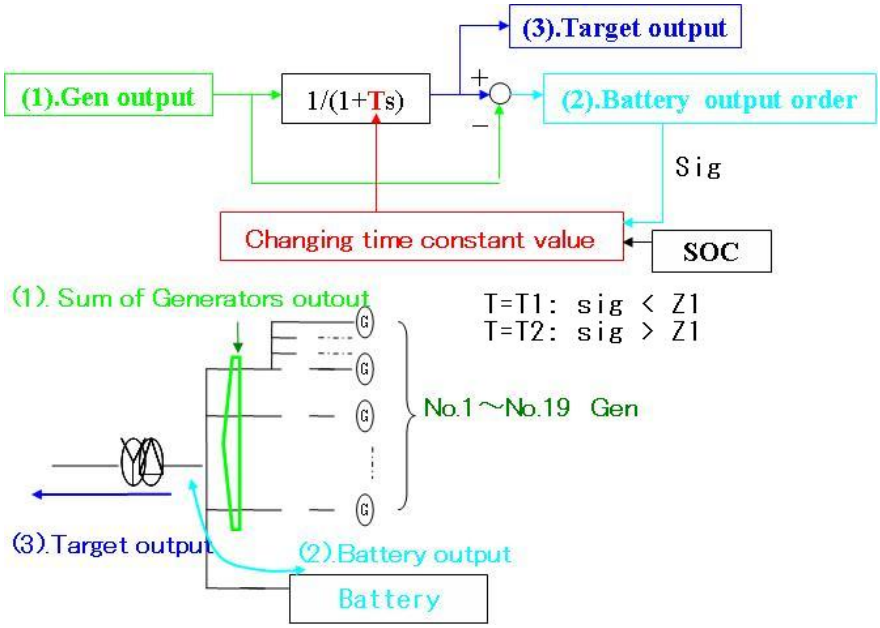

Fig.8: Time Constant Shift Control

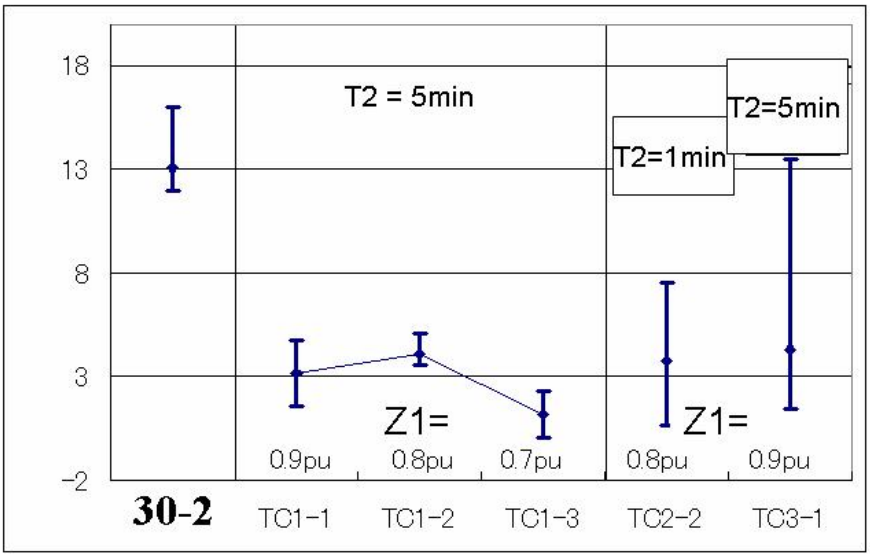

Fig.9: The probability of the order of over the kW capacity (Time Constant Shift Control)

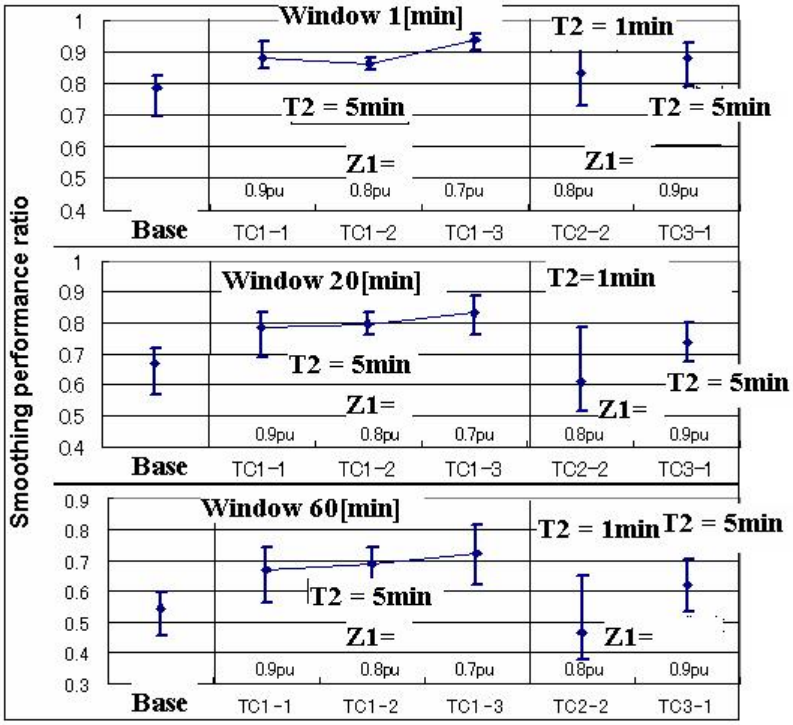

Fig.10: Smoothing performance (Time Constant Shift Control)

5. Integrated Control and Long-term operation test

The Integrated Control that consists of the above mentioned three control systems can relax each side effect that developed control systems have (Fig.11). Parameters of Integrated Control were set to maximize smoothing performance, to hold energy level within battery's kWh capacity, to reduce losses as little as possible and to reduce the order of over the kW capacity as small as possible. SOC-FB was set to use full capacity of the battery. Bank control was set to reduce loss as possible with maximum smoothing performance. Time Constant Shift Control was set to keep SOC, to reduce the order of kW rating over to increase smoothing performance. Soft Start function is minor control in SOC-FB to increase smoothing performance especially at starting bank or changing number of banks.

Because the aspect of the fluctuation of the wind farm output is different at each season, some sets of parameter were determined. For example, in summer, the wind farm output is low and also the fluctuation of the output is usually small. So, a set of parameter was mainly determined to make losses as little as possible (Fig. 12). On the other hand, in winter, the wind farm output is high and also the fluctuation of the output is sometimes too large to keep the operation of stabilizing. So, a set of parameter was determined so that battery output would not limited by its rating power (Fig. 13).

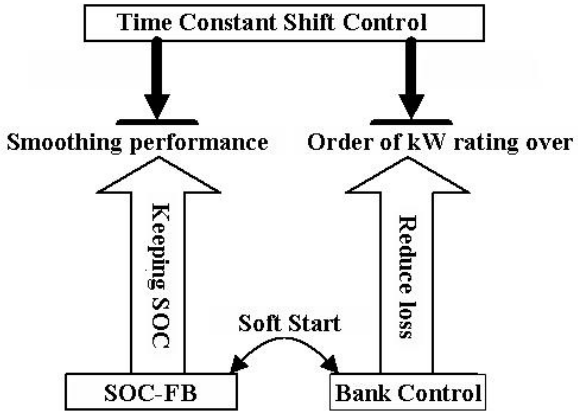

Fig.11: Integrated Control

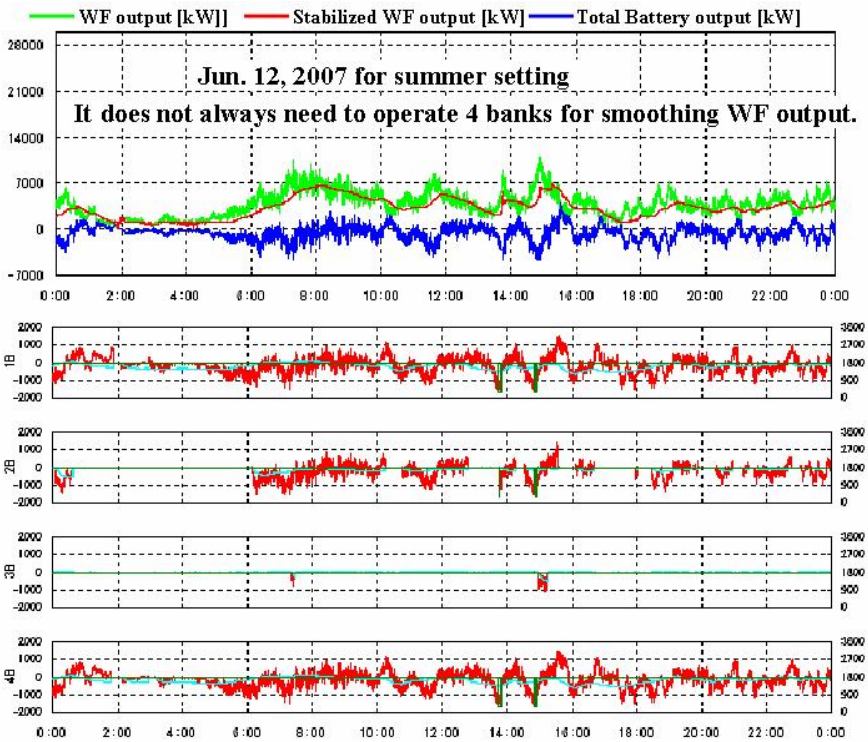

Fig.12: Operating result with Integrated Control (Summer season)

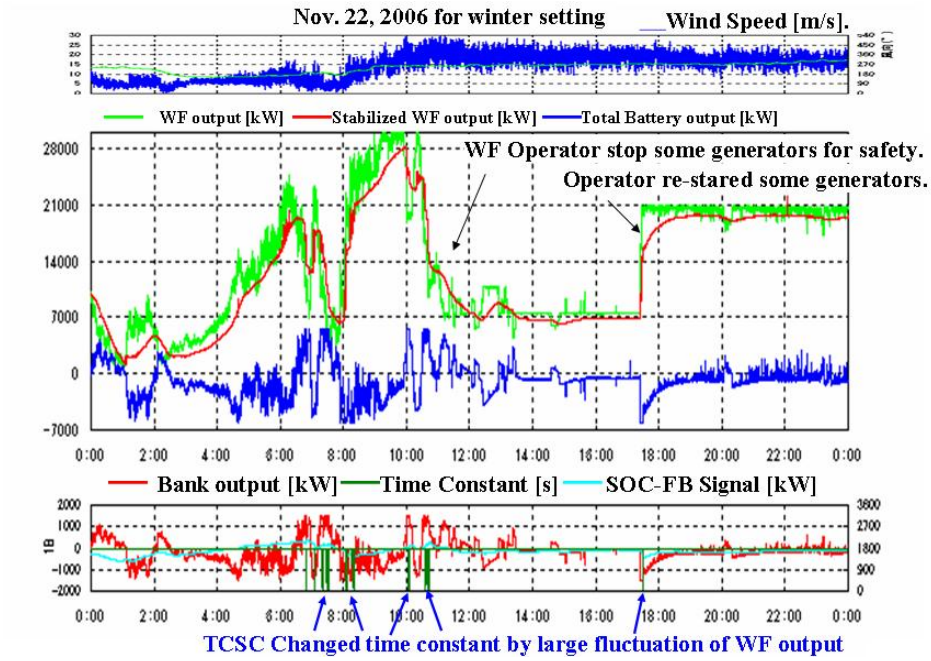

Fig.13: Operating result with Integrated Control (Winter season)

6. Conclusion

Subaru project is to provide the technology of power stabilization by using an energy storage system connected to a large scale wind farm. We have verified effectiveness of each developed control systems, and are going to verify the effectiveness of the result of Integrated Control, and long-term operation test until early 2008. This project is funded by New Energy and Industrial Technology Development Organization (NEDO), a Japanese government agency, through the Electric Power Development Co., Ltd.