HITACHI INVERTER

SJ/L100/300 SERIES

PID CONTROL

USERS' GUIDE

After reading this manual, keep it for future reference

HITACHI

Hitachi America, Ltd.

HAL100PID

CONTENTS

1. OVERVIEW

SJ100/L100 series inverters have an integrated PID control function as standard. They can be used for controls, such as constant flow control for fan & pump applications, and they have the following features.

- **Target signal** can be given not only by the digital operator but also by an external digital signal, which can be set to 16 different targets. Furthermore, it can also be given by an analog input signal (0 - 10V or 4 - 20mA).
- **Feedback signal** can be given to SJ100/L100 by analog voltage input (10V max.)or by analog current input (20mA max.).
- For the **feedback signal**, the performance area can be defined individually. For example 0 - 5V, 4 - 20mA or others.
- Using a **scale conversion** function, you can get actual values of target value and/or feedback value for air flows, water flows or temperature on the display.

Please read this guide book to use the convenient PID function of the SJ100/L100 series inverters correctly and without any trouble.

2. PID CONTROL ON SJ100/L100

2-1 PID Control

" P " in PID stands for **P**roportional, " I " for **I**ntegral, and " D " for **D**ifferential. The combination of these controls is called PID control. PID control is widely used in various fields, such as the process control of air flow, water flow, pressure, temperature and others. It controls the output frequency of the inverter according to PID calculation, which is based on the **deviation** between target and feedback. The inverter adjusts its output frequency to correct the deviation. This control block diagram is shown in Fig. 2-1 below.

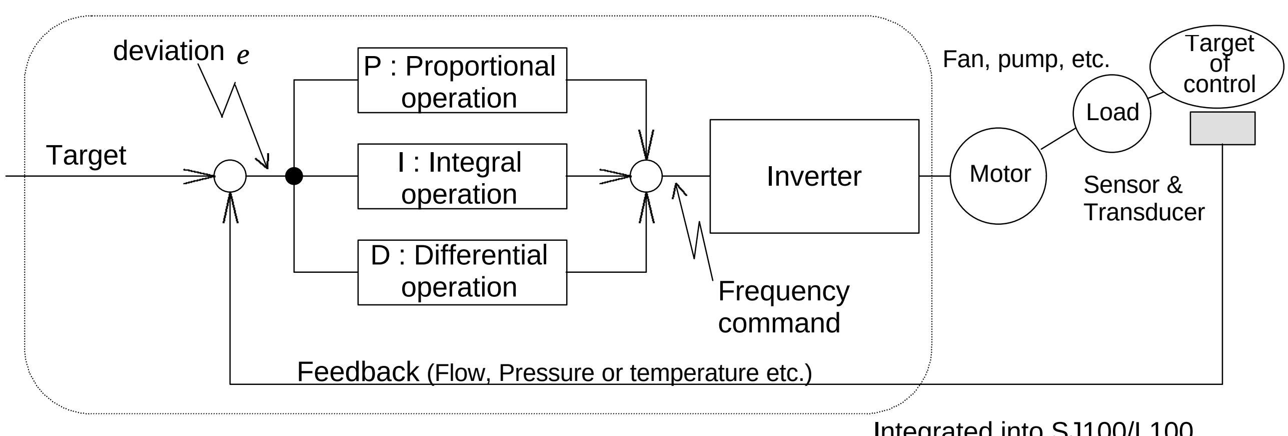


Fig. 2-1 PID Control block diagram

SJ100/L100 series inverters have integrated PID control, which is indicated by the dotted line in Fig. 2-1.
You can use PID control by setting a target value and providing a feedback signal.
The example in Fig. 2-2 shows a connection diagram for ventilation flow control in a fan application.

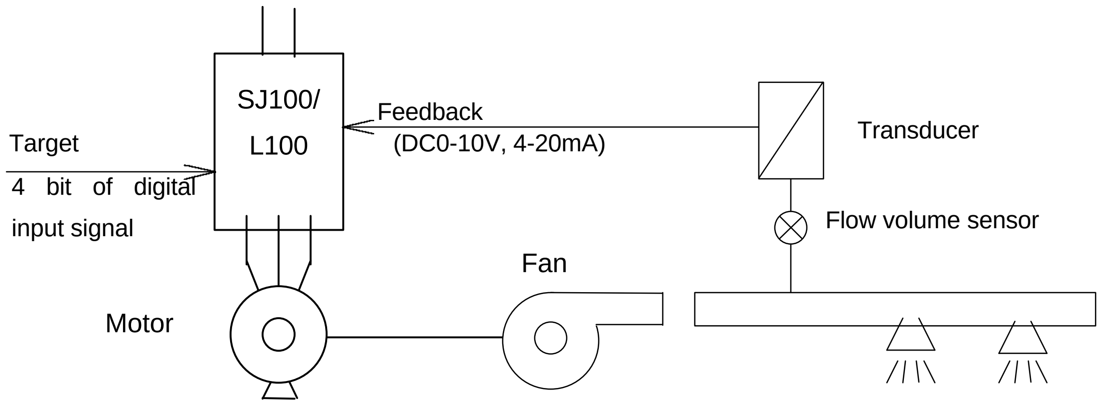
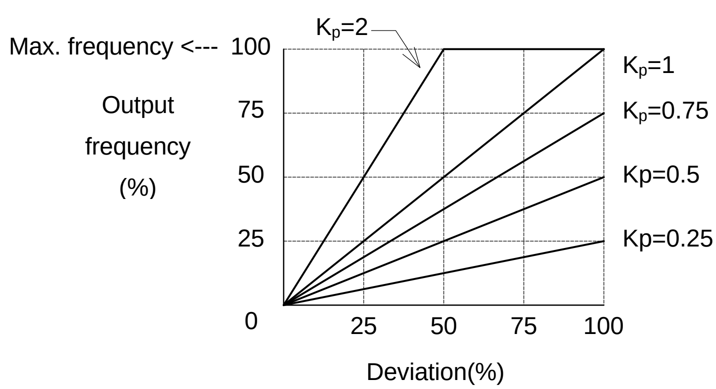


Fig. 2-2 Wiring example for flow control application

(1) P : Proportional Control

This controls the output frequency so that output frequency and deviation have a proportional relation. The coefficient of deviation and output frequency (expressed in %) is called **Proportional Gain (K_p)**. This parameter can be set under function [A71].

Fig. 2-3 shows the relationship between deviation and output frequency. If you set a high value of K_p, the response of the system to a rapid change in deviation is fast. However, if K_p is too high, the system can become unstable.



$$0.2 \le Kp \le 5.0$$

Fig. 2-3 Relation between deviation and output frequency of SJ100/L100

100% of output frequency of above figure is equivalent to maximum output frequency.
K_p can be chosen between 0.2 and 5.0 in function [A71].

(2) I: Integral Control

This is a control to correct the output frequency by integrating the deviation. In the case of proportional adjustment, a large deviation will result in a large output frequency adjustment, but if the deviation is small, then the resulting adjustment of output frequency will also be small. However, you cannot make the deviation zero. Integral performance compensates this problem.

Integral correction of output frequency is performed by accumulating the deviation over time, so that eventually, the deviation is brought to zero. **Integration Gain (K_i)** is a coefficient that determines how often the deviation is to be integrated. The reciprocal of integration gain is **Integration Time Constant (T_i : T_i=1/K_i)**.

> You must set the integration time constant (T_i) on the SJ100/L100 inverter. You can set the time between 0.5 second and 150 seconds. When " 0.0 " seconds is set, NO integral control will be performed.

(3) D : Differential Control

This is a control to correct the output frequency by differentiating the deviation. Since P control is based on the current deviation and I control is based on the past deviation, there will always be a delay in the control system. Differential control compensates for this problem.

Differential correction of the output frequency is performed in proportion to the **rate of change** of the deviation. Therefore, D control corrects the output frequency rapidly when there is a rapid change in the deviation. **Differentiation Gain (K_d)** is a coefficient to determine how often the deviation is to be differentiated.

> You can set Kd between 0 and 100. Gain is (Fmax / 10) * set value of [A74] versus change in deviation per second.

(4) PID Control

PID control is a combined Proportional, Integral and Differential control. You can achieve the best control by adjusting the three factors, P-gain, I-gain and D-gain. Smooth control may be achieved without any hunting by **P-control**; you can correct steady-state deviation by **I-control**; and by **D-control,** you can achieve a quick response to sudden disturbances which can influence the feedback value. A large deviation can be suppressed by P-control. A small deviation can be corrected by I-control.

(Note) Since D-control is performed based on the differentiation of deviation, it is a very sensitive control. Therefore, it may also react to extraneous signals and noise, and can easily lead to unstable system control. D-control is not normally required for the control of processes such as flow, pressure and temperature.

2-2 PID Gain Adjustments & Control Characteristics

The optimal gain factors of PID vary from condition to condition, and from system to system. That means it is necessary to set those parameters by taking into account the individual control characteristics of your particular system. The following are the characteristics that are required for a good PID control:

- Stable performance
- Quick response
- Small steady-state deviation

You adjust each parameter K_p, T_i and K_d inside the stable performance area. Generally, when you increase each gain (K_p, K_i, K_d) parameter (= decrease Integration time : T_i), you can obtain quick response. But if you increase them too much, the control will be unstable, because the feedback value is continuously increasing and decreasing, which leads to an oscillation of the control. In the worst case the system is led to a divergence mode. (Refer to Fig. 2-4)

Following are the procedures to adjust each parameter.

(1) After changing target,	response is slow	--- **Increase P-gain (K_p)**
	response is quick but unstable	--- **Decrease P-gain (K_p)**
(2) Target and feedback	do not become equal	--- **Decrease Integration time (T_i)**
	become equal after unstable vibration	--- **Increase Integration time (T_i)**
(3) Even after increasing Kp,	response is still slow	--- **Increase D-gain (K_d)**
	it is still unstable	--- **Decrease D-gain (K_d)**

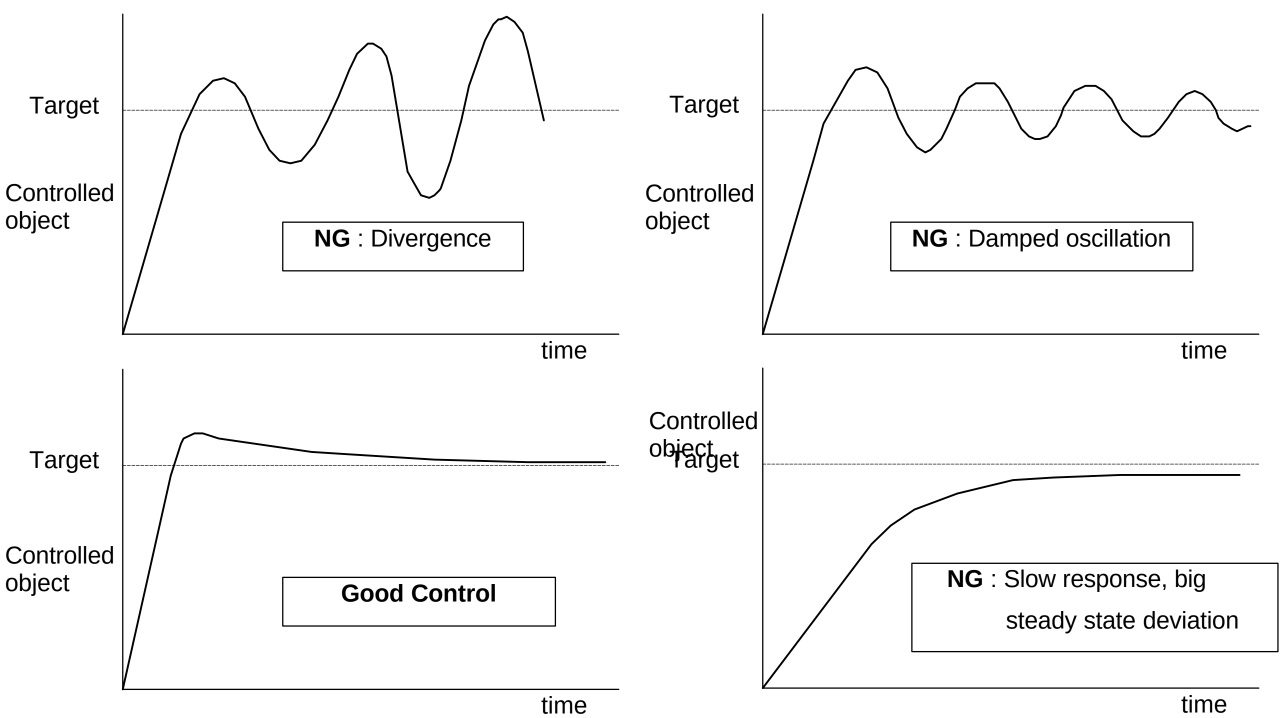


Fig. 2-4 Example of good control and bad control (in case of step response)

3. HOW TO USE

3-1 Structure & Parameters

(1) Control Mode Integrated operator A71 : 00 / 01

DOP, DRW F43 : PID SW ON / OFF

SJ100/L100 series inverters feature the following two control modes:

- **Frequency control mode**
- **PID control mode**

These can be selected by " PID function selection (A71) " .

Frequency control mode is the typical control mode of standard frequency inverters which enables you to give a frequency command to the inverter from either the operator panel, or by analog voltage or current, or by 4 bit digital command from the control terminals.

In the PID control mode, an output frequency is set automatically such that the deviation between target value and feedback value approaches zero.

(2) Parameters

Fig. 3-1 shows the relation between control block diagram of PID control and each parameter. Function numbers shown in the figure are based on the commands from the integrated operator of the inverter.

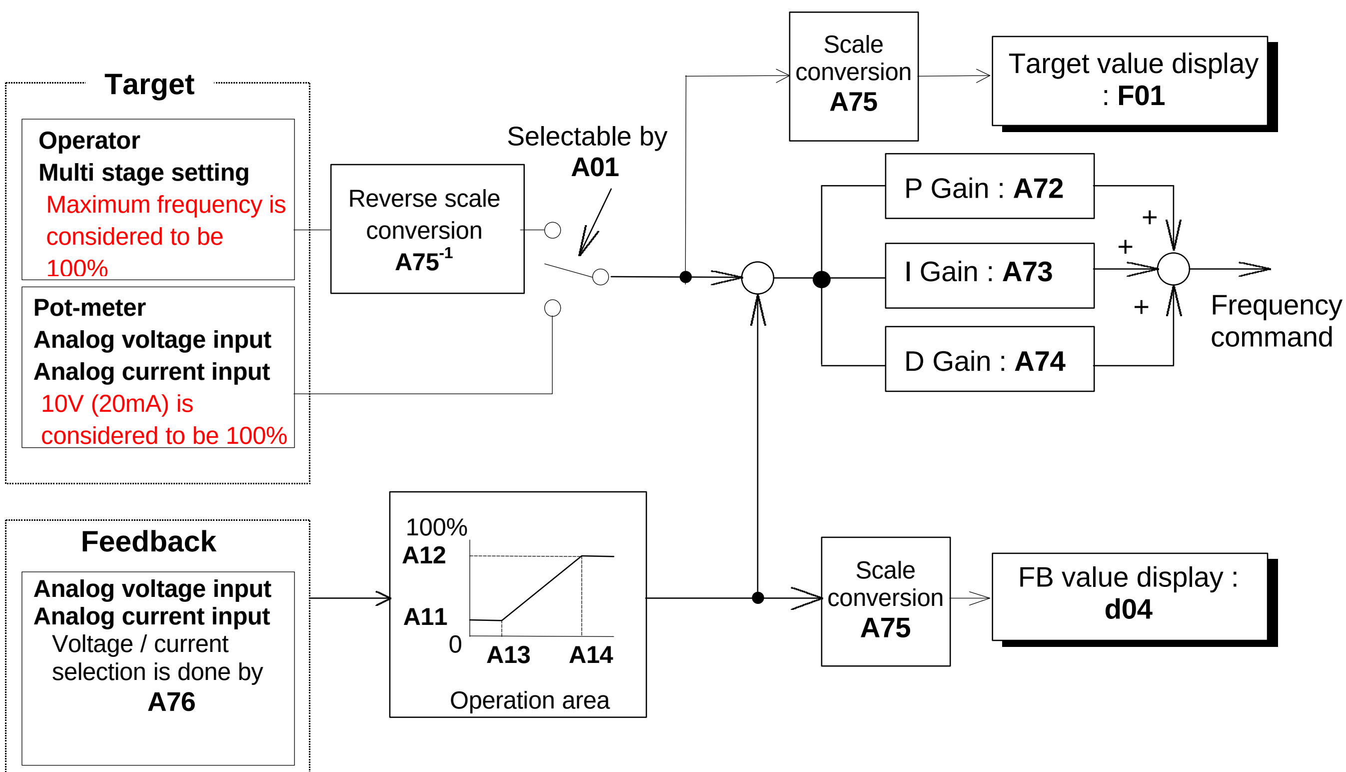


Fig. 3-1 control block diagram of PID control

(3) Deviation Calculation

Every calculation in PID control in the SJ100/L100 is based on “ % ” so that it can be used with various applications and units of measure, such as pressure (N/m^2), flow (m^3/min), temperature (degrees) and so on. For example, comparing target value and feedback value is based on % of target and % of feedback full scale value.

However, there is a useful function called scale conversion function (A75). If you use this function, you can set a target value and/or you can monitor target and feedback value in the actual units of the specific application. Also, there is a **“**active range of PID**”** setting function (A11 - A14), which allows you to define an area based on the feedback signal. Please refer to Fig.3-2 and Fig.3-3 for more detail.

(4) Target Input

Only one source for the target input can be chosen from the following:

- Keypad/Operator (Integrated operator, or DOP, or DRW)
- 4 bits of digital input from the control terminals
- Analog input terminals (O-L terminal or OI-L terminal)

In the case of digital input of the target value from the terminals, it is necessary beforehand to set the required target values in functions A21 to A35. This allows you to define an array of target values. Then you can select the one you require from that array according to the combination of the 4 bits of digital input (binary). This is the same philosophy used for multi-stage speed control in the frequency control mode.

(5) Feedback Input & Setting PID Performance Area

Feedback signals should be given to one of the following units:

- Analog voltage input terminal (O terminal : 10V maximum)
- Analog current input terminal (OI terminal : 20mA maximum)

Select one of them using “Feedback input method selection [A76]”.

This feedback signal can be defined as shown in Fig.3-2 and Fig.3-3 below, so that you can achieve suitable performance for your particular system. The “100%” shown at vertical axis is a maximum value which is based on an internal calculation.

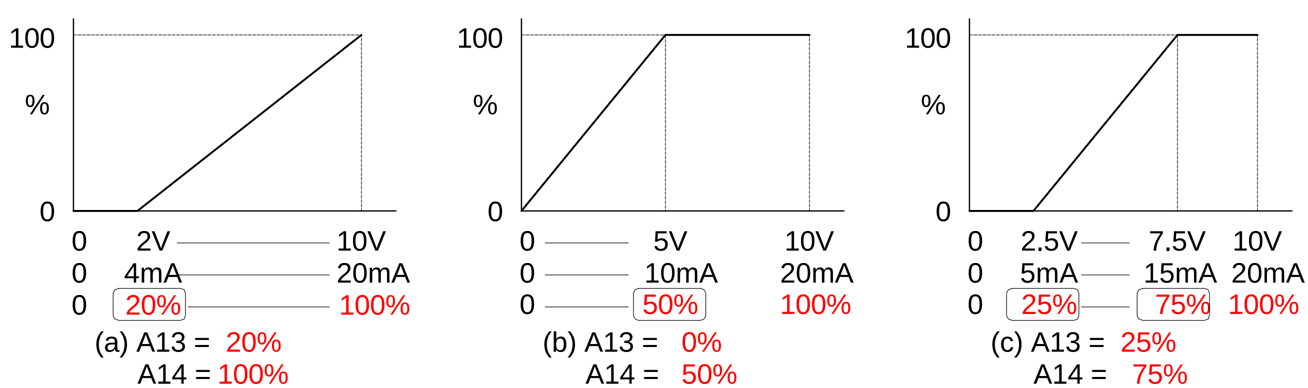


Fig. 3-2 Setting Active Range (A11=0, A12=0 or 100) : Example 1

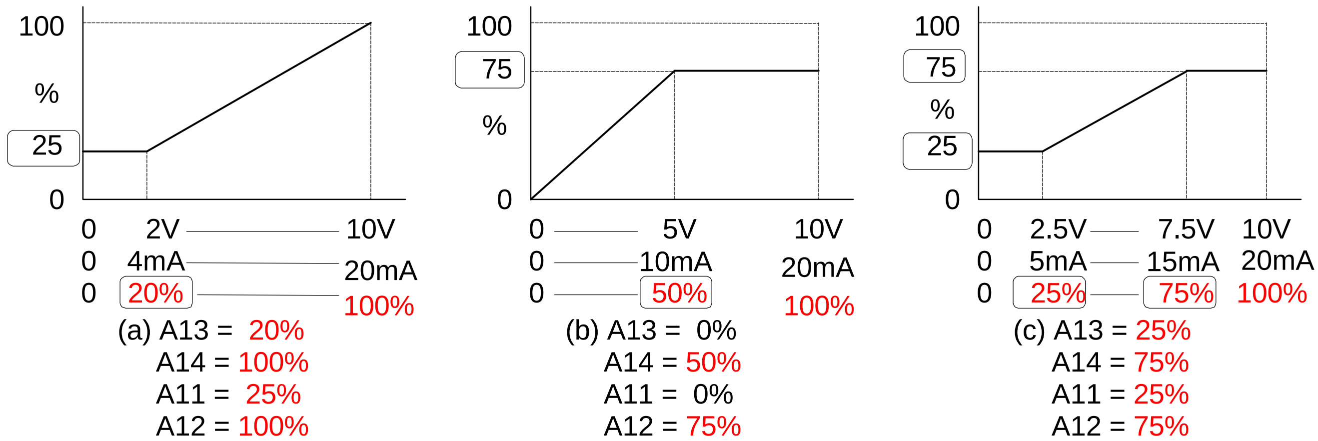


Fig. 3-3 Setting Active Range : Example 2

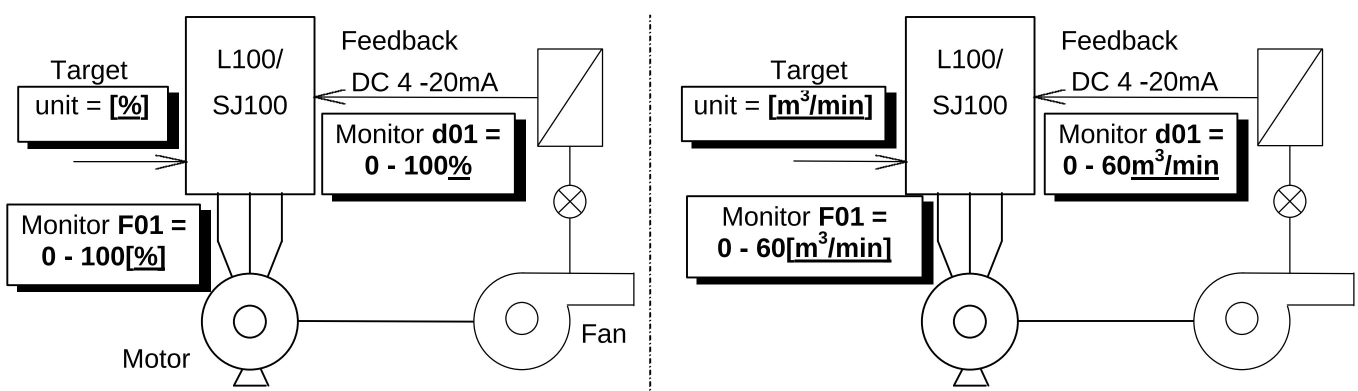
As you can see from Fig 3-3, if you set parameters A11 and A12 other than "0", you should set the target value inside the valid range of the vertical axis. Otherwise it is not possible to achieve stable performance because there is no feedback value. That means the inverter will either output maximum frequency or stop, or it will output lower limit frequency continuously if it is set.

(6) Scale Conversion

Using this function, you can set and display the target value and display the feedback value in the actual units of the process variable. Set the parameters individually relative to 100% of feedback value.

With the factory default setting, the input and display value is based on 0 - 100%.

Example : In case of (a) in Fig.3-3, 20mA of feedback corresponds to **100%** of PID internal calculation. For instance, if actual flow at 20mA of feedback is 60 [m^3/ min], you set the parameter to 0.6 (=60 / 100) in function mode **A75**. Then you can get the actual feedback value on the monitor mode **d04**, and you can also set the target value by actual value of the control system.



(a) Factory setting **(b) A75 = 0.6**

Fig. 3-4 Example of Scale Conversion

3-2 Summary of Parameters for PID Control

On the SJ100/L100 series inverters, the same function numbers are used for both frequency control mode and PID control mode. The function name for each function is based on frequency control mode, which is normally used for general application. Therefore, some functions have misleading explanations in the instruction manual.

To avoid confusion, please find in below Table 3-1 the explanation of function names for frequency control mode and PID control mode.

Table 3-1 Relation between Frequency Control Mode & PID Control Mode

Function No.		Function name	
Integral Operator Display	DOP, DRW	Contents in case of Frequency control mode	Contents in case of PID control mode
D04	Monitor mode	-	PID Feedback monitor
F01	Monitor mode	Output frequency monitor	Target value monitor
A01	Monitor mode	Frequency command origin setting	Target value origin setting
A11	**F31**	External frequency setting START (Unit : Hz)	Feedback value input corresponding % for lower acceptance level (Unit : %)
A12		External frequency setting END (unit : Hz)	Feedback value input corresponding % for upper acceptance level (Unit : %)
A13		External frequency setting START rate (Unit : Hz)	Feedback value of lower acceptance level input (Unit : %)
A14		External frequency setting END rate (unit : Hz)	Feedback value of upper acceptance level input (Unit : %)
A21 - A35	**F11**	Multi-stage Speed 1 - 15 setting	Multi-stage Target 1 - 15 setting
A71	**F39**	-	PID mode selection
A72			P-gain adjustment
A73			I-gain adjustment
A74			D-gain adjustment
A75			Scale conversion ratio setting
A76			Origin of feedback signal selection

3-3 Example of Set Up

(1) Parameter Set Up under Frequency Control Mode

Before driving the system in PID mode, you set up each required parameter under frequency control mode. Pay particular attention to the following items.

- **Acceleration ramp and Deceleration ramp**

The output of the PID calculation (refer to Fig. 3-1) will not immediately be an output frequency of the inverter. The actual output frequency of the inverter will ramp to the calculated output frequency according to the set value of acceleration and deceleration ramps. This means that even if you set high D-gain, the change of the actual output frequency is restricted by the set acceleration and deceleration ramp rates, and this can lead to unstable control.

To achieve overall stable performance of the PID control, in addition to setting the three gain parameters (**A72**, **A73**, **A74**), you should set the acceleration and deceleration ramps to the fastest values the system will allow.

Be sure to re-adjust the PID parameters after you change the acceleration and/or deceleration ramps.

- **Jump Frequency / Range**

The required condition for setting jump frequency is that there should be no change in feedback value when frequency is jumped. If there is a stable control point inside the jump frequency range, there will be a hunting between both ends of the range.

(2) PID Set Up (Target & Feedback)

In PID control mode, the combination of target value and feedback signal sources can be set according to the following table (Table 3-2).

Table 3-2 How to Set Origins for Target and Feedback

		Target Input Source				
		Integral Operator	Multi-stage target (Terminal)	Integral Potentiometer	Analog Voltage input (O-L)	Analog Current input (OI-L)
Feedback Source	Voltage input (O-L : 0-10V)	**A01** = 02 **A76** = 01		**A01** = 00 **A76** = 01	-	**A01** = 01 **A76** = 01
	Current input (OI-L : 4-20mA)	**A01** = 02 **A76** = 00		**A01** = 00 **A76** = 00	**A01** = 01 **A76** = 00	-

(1) It is not possible to set both sources to the same analog input terminal.

(2) The inverter will decelerate to a stop according to the set deceleration ramp rate when a stop command is received while in PID control mode.

(3) Scale Conversion Factor Setting

Set this factor according to your application, e.g. flow, pressure, temperature and so on. For a detailed explanation, please refer to item (6) on page 9.

(4) Target Input by Digital Input Signal

Please refer to the following when changing the target with the digital input signal (4 bit max.).

(a) Input terminal assignment

L100 series inverters have five intelligent input terminals. The SJ100 series have six. Assign **"CF1"**, **"CF2"**, **"CF3"** and **"CF4"** to 4 of the intelligent input terminals. This assignment is done with function numbers **C01** to **C05 (**or **C06** for SJ100**),** which correspond to terminals 1 to 5 (or 6) on the I/O terminal.

(b) Setting each target value

Next, set the required number of targets (up to 16 targets maximum) according to the following table (Table 3-3). Set them using functions **A21** to **A35** which correspond to target 0 to 15. **A20** and **F01** correspond to a target 0. Please note that <u>in case a scale conversion ratio is set, you should set those targets as converted value according to this ratio</u>.

Table 3-3 Multi-stage Target Input (1 : ON, 0 : OFF)

No.	CF4	CF3	CF2	CF1	Referred Target number (Function number to be inputted)
1	0	0	0	0	Target 0 (**A20** or **F01**)
2	0	0	0	1	Target 1 (**A21**)
3	0	0	1	0	Target 2 (**A22**)
4	0	0	1	1	Target 3 (**A23**)
5	0	1	0	0	Target 4 (**A24**)
6	0	1	0	1	Target 5 (**A25**)
7	0	1	1	0	Target 6 (**A26**)
8	0	1	1	1	Target 7 (**A27**)
9	1	0	0	0	Target 8 (**A28**)
10	1	0	0	1	Target 9 (**A29**)
11	1	0	1	0	Target 10 (**A30**)
12	1	0	1	1	Target 11 (**A31**)
13	1	1	0	0	Target 12 (**A32**)
14	1	1	0	1	Target 13 (**A33**)
15	1	1	1	0	Target 14 (**A34**)
16	1	1	1	1	Target 15 (**A35**)

Note: If you need only 4 targets, you would only use CF1 and CF2.

(5) PID Mode Selection

Set PID mode selection **A71** to **"01"**. You can also set this function first.

3-4 Example of Each Gain Adjustment (K_p & T_i)

- Check the response of feedback signal or the output frequency of the inverter when making a step change in the target. (Please refer to Fig. 2-4)
- Use an oscilloscope or other measuring equipment to observe the waveform of the feedback value or output frequency of the inverter (frequency monitor).
- Prepare two targets that can be changed by digital input signal in advance, so that you can change targets with a step change.
- Before proceeding, the control system must be stable.

(1) Adjustment of Proportional Gain (K_p : Function No. A72)

Start driving only with P-control, without I-control and D-control (i.e., set them to ZERO).

First, set a minimal value of P-gain and see how it works. According to the result, increase P-gain gradually. Repeat this procedure until you get good performance. (Alternatively, you set maximum P-gain and observe the performance. If the system is not stable, you set a medium value and see how it works. Repeat this procedure...)

If the performance is unstable, decrease P-gain.

If the steady state deviation is in the acceptable range, you have completed tuning the P-gain.

(2) Adjustment of Integration Time (T_i : Function No. A73) & Readjustment of K_p

Start adjustment by setting minimum integration time. If it is difficult to adjust, try decreasing the P-gain.

In case the deviation does not converge, decrease integration time. If the control becomes unstable at that time, decrease P-gain.

Repeat this procedure to find the suitable parameters.

(Note) In the instruction manual, the description of **A73** function is **"Integration Gain (Ki)"**. But actually this is an **"Integration Time (Ti)",** which is the inverse of gain. Please be aware of this while you set this parameter.

3-5 General Cautions

(1) When you set AVR function **(A81)** to **"DOFF"** (which makes the AVR function invalid while decelerating) with PID control, there is a possibility the motor may exhibit hunting in some applications. This is because the motor repeatedly accelerates and decelerates each time the AVR function operates. This may lead to unstable rotation of the motor.

Solution: Set AVR function ALWAYS OFF in this case.

4. EXAMPLE OF ACTUAL APPLICATION

You can find in this chapter some typical setting examples for actual applications.

4-1 Constant Flow Control

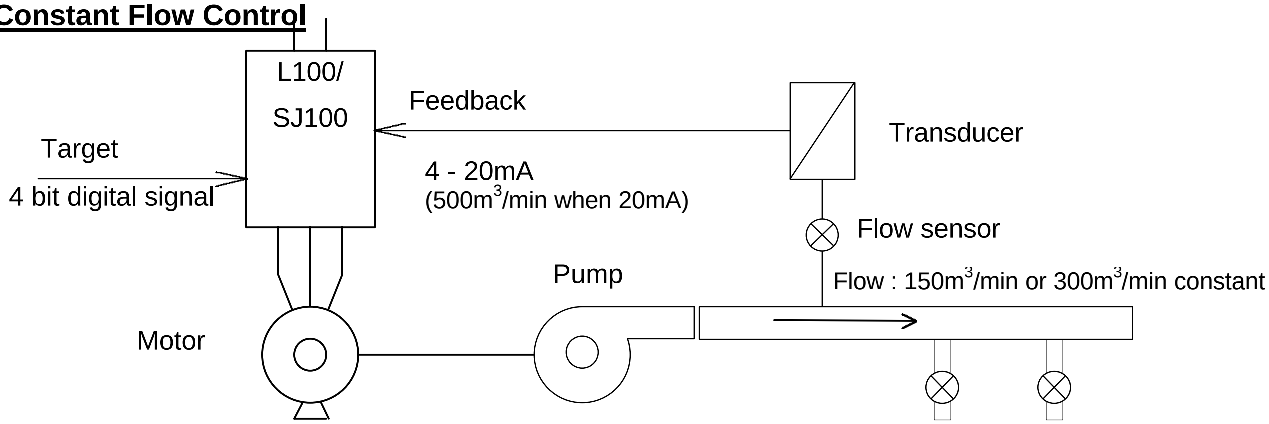
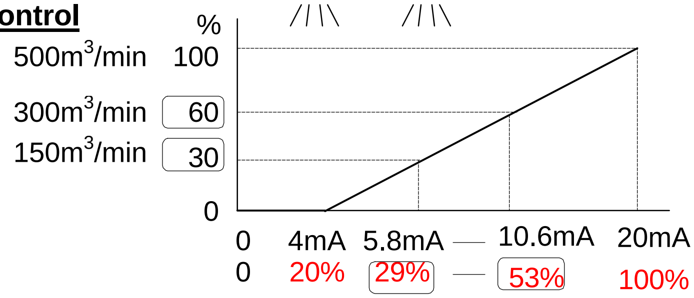


Fig. 4-1 Example of Constant Flow Control

In this case (targets are 150m^3/min & 300m^3/min), the settings would be as follows:



Feedback value range setting

Function Number		Function Name	Input	Remarks
Integrated Operator	DOP, DRW	Under PID Control Mode	Data	
F01	Monitor mode	Target 0	150	Directly input "150 [m^3/min]" because scale conversion ratio is given
A01		Target input origin setting	02	Operator
A11	**F31**	Feedback value input corresponding % for lower acceptable level	0	0%
A12		Feedback value input corresponding % for upper acceptable level	100	100%
A13		Feedback value input for lower acceptable level setting	20	20%
A14		Feedback value input for upper acceptable level setting	100	100%
A21	**F11**	Target 1	300	300 [m^3/min]
A71	**F39**	PID mode selection	01	PID mode ON
A72		P-gain adjustment	-	Depends on each application
A73		I -gain adjustment	-	
A74		D-gain adjustment	-	
A75		PID scale conversion factor setting	5.0	100% when 500 [m^3/min]
A76		Source of feedback signal selection	00	Feedback from OI-L terminal

4-2 Constant Temperature Control

In the case of constant flow control shown in the previous section, output frequency of the inverter increases if the feedback value is smaller than target value, and output frequency of the inverter decreases if the feedback value is bigger than the target value. However, in the case of constant temperature control, this is the opposite. The inverter increases its output frequency to drive a cooling fan much faster when the temperature feedback signal is higher than target temperature, for example. Below you can find an example of how to configure such an application.

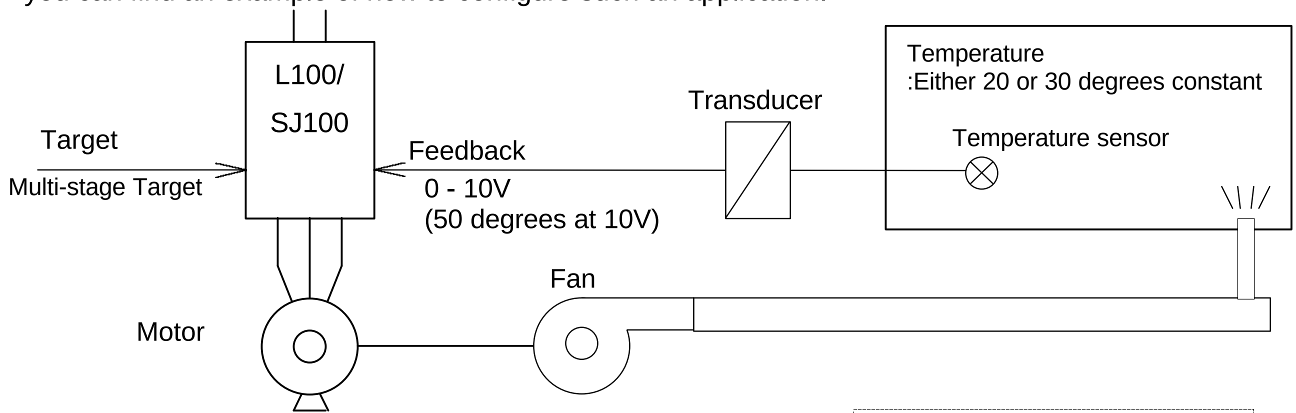
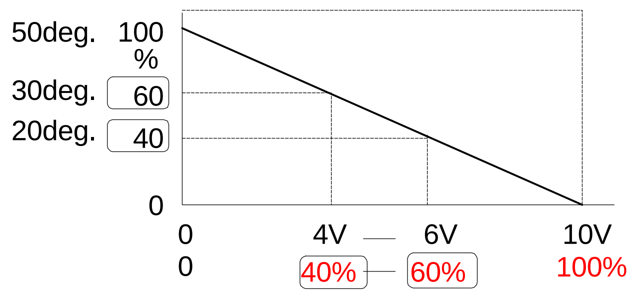


Fig. 4-2 Example of

Constant Temperature Control



Feedback value range setting

In this case (targets are 20 & 30 degrees), the settings would be as follows:

Function Number		Function Name	Input	Remarks
Integrated Operator	DOP, DRW	Under PID Control Mode	Data	
F01	Monitor mode	Target 0	20	Directly input "20 [deg]" because scale conversion ratio is given
A01		Target input origin setting	02	Operator
A11	**F31**	Feedback value input corresponding % for lower acceptance level	100	100%
A12		Feedback value input corresponding % for upper acceptance level	0	0%
A13		Feedback value input for lower acceptance level setting	0	0%
A14		Feedback value input for upper acceptance level setting	100	100%
A21	**F11**	Target 1	30	30 deg
A71	**F39**	PID mode selection	01	PID Mode ON
A72		P-gain adjustment	-	Depends on each application
A73		I -gain adjustment	-	
A74		D-gain adjustment	-	
A75		PID scale conversion ratio setting	0.5	100% when 50 [deg]
A76		Origin of feedback signal selection	01	Feedback from OI-L terminal

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