

## Research Article

### Study of Constant Voltage Control on Small Steam Generator Based on PID Algorithm

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**Abstract:** The object of this study is a kind of 3 kW small steam generator, which can recover waste heat through making use of 0.1~0.3 MPa steam. This can exploit secondary energy efficiently. The electricity generated can be commonly used as factory lighting, heating, fan and emergency power supply. But the generation voltage of the existed steam turbine is instable, especially when the steam pressure and the load of the generator changes suddenly. This can pose a threat to electrical safety and greatly limit the market of small steam generator. In this study, PID control algorithm is used to control the amount of steam into the turbine of generator system. And the closed-loop control system can make a real-time feedback regulation to the steam, so that the generator voltage can be stable. The user's electrical safety requirements are satisfied as well.

**Keywords:** PID algorithm, secondary energy, steam generation

#### INTRODUCTION

Because of convenient, compact and flexible, economical and durable, small steam generator will enter the mainstream market of factories and home emergency backup energy. The small steam generator is composed by the steam:

- Regulating valve
- The steam pipe
- A turbine
- The exhaust duct
- A belt
- The generator
- The encoder
- The control cabinet
- The rack
- Turbine, generator, ratio control cabinet and rack are shown in Fig. 1

Exhaust of combustion plants or other heating ways go into a turbine through the pipeline and the regulating valve, promoting the turbine wheel to a high speed rotation. The output shaft of the turbine and the input shaft of the generator transmit the power through the belt so that it can drive the generator to generate electric power. As the factory exhaust pressure is sometimes beyond the needed size, sometimes below it and changes of generator power load lead to differences in generator speed, which makes the speed of the turbine and generator change and result in instability of the generator power voltage. So that the generator

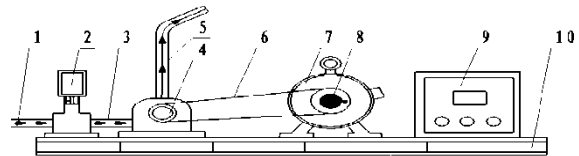


Fig. 1: Diagram of small steam generator

voltage is strictly controlled at 220V around, we have designed a set of closed-loop feedback control system which used PID control to correct the deviation of the output signal in real-time, in order to reach a constant voltage power.

In order to change waste into treasure, save energy, the related idea emerged and the research products are proposed. If the developed products can be promoted to the market, the study will make a big difference on contribution to economy and environmental protection.

#### LITERATURE REVIEW

Environmental protection is one of China's basic national policies. In order to promote the scientific development of the environmental protection cause and speed up the resource-saving and environment-friendly society during the "12<sup>th</sup> Five-Year, Hebei University of Technology and an enterprise launched this green project. Many thermal power plants, chemical plants, metallurgical plants and automobile manufacturing industry have a lot of steam emissions. But few of enterprises make use of the energy. Large amount of energy were wasted. The purpose of this study is to improve the utilization of energy and protect

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environment. The research products are still in a shortage state in the market.

### HARDWARE DESIGN

**Theory of design:** The speed data of the generator output shaft is collected by the encoder and the data is inputted to internal PLC by the PLC high-speed counter. PID operation output an analog output voltage to the valve after inputting the actual speed of generator and given 220V speed. The size of the voltage determines the opening valve of the proportional control valve, which can control the amount of the steam turbine inlet. The steam flow rate is stable in every unit time. It can ensure a constant turbine and generator speed and further stability of the generator output voltage.

**The choice of core controller:** The control system requires an analog output, so I select small Siemens S7-200 series of CPU224XP PLC with two input analog and one output analog, which also contain a 14-channel digital input amount and a 10-channel digital output (Cui, 2007; He and Wu, 2011; Siemens (China) Co., Ltd., 2004). The count pulse frequency reach to 100 kHz using one high-speed counter.

**The choice of encoder:** The encoder, which is called Teen Pu TEP-S38G-300BM-C526 incremental encoder, will input count pulse to high-speed counter of the PLC, high speed counter HSC1 of the PLC choose to the mode 0, that is, the internal control counter mode in the direction of one-way up/down.

**The choice of regulating valve:** We choose Nanjing Ji Zhi De Zhi travel electric valve ZDLP-16C, which the opening degree of stroke range from 0 to 25 mm. The larger the value is, the greater the corresponding of adjusting the degree of the opening valve is and the more the gas flow through the control valve within a unit time. The size 0-25 mm of the opening degree can be controlled by DC1-5V proportionally. Siemens PLC analog output is DC0-10V voltage signal corresponding to the output data 0-32000, to output DC1-5V voltage and output data can set to 3200-16000. I/O allocation table of PLC are showed as Table 1.

Table 1: I/O allocation table of PLC

Input	Project	Output	Project
I0.0	Knob/automatic position	Q 0.0	Status indicator
I0.1	Knob/manual position	Q 0.1	Power switch of valve
I0.6	High-speed counter pulse	Q 0.2	Alarm light
I0.7	High-speed counter direction	V	Analog voltage output
I1.0	High-speed counter reset		
I1.1	High-speed counter start		

### SOFTWARE DESIGN

**PID control process:** PID control algorithm is shown in Fig. 2.

**Detailed PID control process:** This is a PID closed-loop control system, the encoder detect the generator speed  $V(t)$ , compare with the generator speed setting value  $V$  after AD converter in a internal high-speed counter of the PLC. Generated deviation is carried out the PID calculation. The result PID operation produced is a control voltage signal of adjusting the valve opening degree through the DA converter and the degree of opening determines the rotational speed of the turbine. So the rotational speed of the generator can approach to the given value of the generator speed. When the generator speed reaches the set value, the output voltage of the generator can also be constant (Tao *et al.*, 1998; Mr. Lee *et al.*, 2001).

**PID control mathematical model:** The PID Control mathematical model is seen in the formula (1):

$$M_n = K_c * e_n + K_i * e_n + M_X + K_d * (e_n - e_{n-1}) \quad (1)$$

Output = Proportional term + integral term + differential term

where,

$M_n$  = In n sampling time, PID loop output value calculated

$K_c$  = PID loop gain

$e_n$  = The deviation in the n sampling instants

$e_{n-1}$  = In the n-1-sampling moment deviation (deviation of the preceding paragraph)

$K_i$  = Proportional constant of the integral term

$M_X$  = Integral sum

$K_d$  = Proportional constant of the differential term

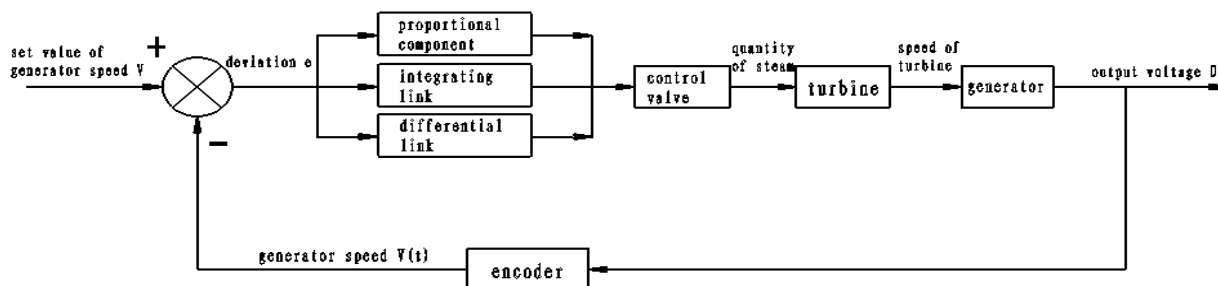


Fig. 2: Schematic diagram of PID algorithm

The three parameters the PID control is the proportional gain  $K_c$ , integral coefficient  $K_i$ , differential coefficient  $K_d$ . In addition, the affect that sampling time  $T_s$  acts on the characteristics of the control system is also very significant.

**Proportional gain  $K_c$ :** When there is a deviation  $e$  between the Process output Values (PV) and set-point SP, the proportion of links will make deviation  $e$  decrease. The size of the proportional gain determines the proportion of links' functional capacity. The larger  $K_c$  is, the more sensitively system responses and adjusts. But at the same time over shoot or oscillation will occur. The proportional component itself can not eliminate the static deviation and the single ratio control cannot guarantee the accuracy of the control.

**The integral coefficient  $K_i$ :** For the static deviation that the proportional control cannot eliminate, integral part of the control time is good to eliminate the effect. When the role of integral control and proportional control action output equivalent effect, it is known as the integration time  $T_i$ . The size of the integral time  $T_i$  directly determines the integral element to control the size of the system functions. The greater  $T_i$  is, the smaller the integral control function is. It will take a longer time to eliminate the static deviation. The smaller  $T_i$  is, the greater the integral control function is. But the oscillations decay rate of the control system is slower. The sustained oscillation even cannot reach a

steady state. While Integral part eliminates the static deviation, the dynamic performance of the system performs variation.

**Differential coefficient  $K_d$ :** The differential part improves the dynamic performance of the system. Derivative action may have a predictive control on the next step deviation according to the system of the deviation rate of system. When the role of differential control and proportional control action output equivalent effect, it is known as the integration time  $T_d$ . The bigger  $T_d$  is, the greater the integral control function is. The adjustment time will be shorter. At the same time improving the system dynamic performance, it may also cause sustained oscillation on the system.

**Sampling time  $T_s$ :** The sampling time reflects the reproduction ability of sampling continuous variation signal. Reducing sampling time can guarantee system without distortion in reproduction sampling signal. Meanwhile, the changes of the PLC analog output voltage signal fix the position of the control valve, which is extremely important in a complex control system.

**PLC program preparation:** PID programming uses STEP7-Micro/WIN provided by the PID instruction Wizard, in the menu, you can select Tools>Instruction Wizard, then choose PID instruction in the instruction

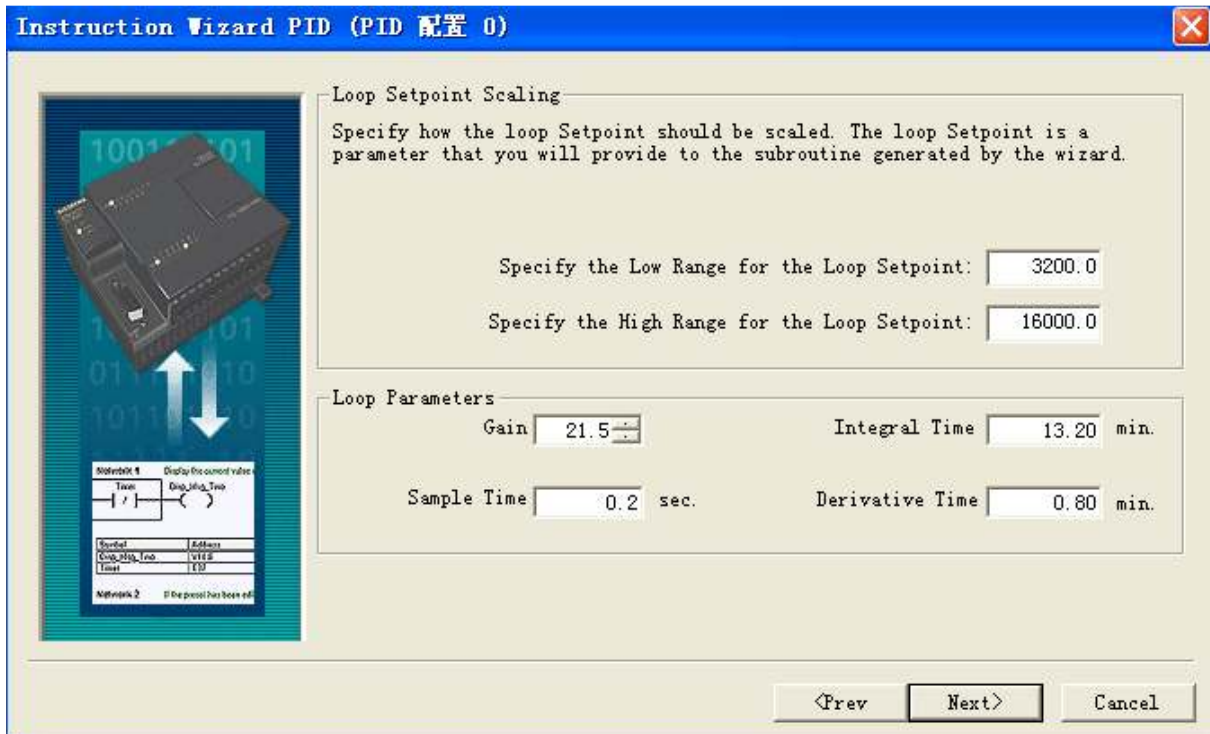


Fig. 3: How to set the loop given value and PID loop key parameters

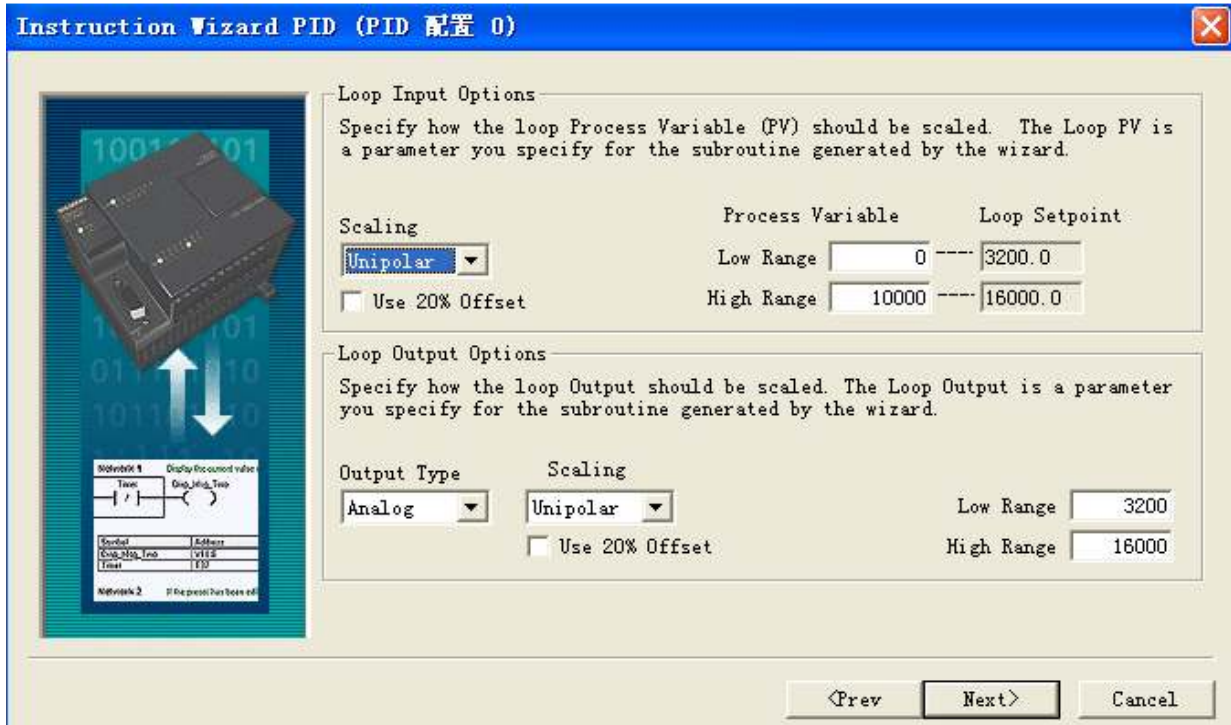


Fig. 4: How to calibrate loop input and output values

Network 1		
initialization of high speed counter HSC1		
LD	SM0.1	
CALL	SBR_0:SBR0	
Symbol	Address	Comment
SBR_0	SBR0	

Network 2		
encoder sampling		
LDN	M0.0	
TON	T32, 100	

Network 3		
encoder sampling		
LD	T32	
CALL	SBR_1:SBR1	
=	M0.0	
Symbol	Address	Comment
SBR_1	SBR1	

Fig. 5: Encoder sampling on the main program

Network 4		
PID operation		
LD	SM0.0	
CALL	PID0_INIT:SBR2, VW0, 5050.0, VW4	
Symbol	Address	Comment
PID0_INIT	SBR2	This PDU was created by the PID formula

Network 5		
PID output segmentation control		
LD	SM0.0	
LPS		
MOVW	VW2, VW6	
+I	VW4, VW6	
AW<=	VW6, 3250	
MOVW	3250, AQW0	
LRD		
AW>	VW6, 3250	
AW<	VW6, 16000	
MOVW	VW6, AQW0	
LFP		
AW>=	VW6, 16000	
MOVW	16000, AQW0	

Fig. 6: PID algorithm and output main program

Wizard window. Now you can set all the parameters of the PID. How to set the loop given value and PID loop key parameters is in Fig. 3.

The calibration of loop input and output value is in Fig. 4.

Encoder sampling on the main program is shown in Fig. 5.

PID algorithm and output main program is shown in Fig. 6.

Main controlling program of Regulating valve and Indicator is shown in Fig. 7.

Initialization of high-speed counter SBR0 is shown in Fig. 8.

Network 6		
power control of control valve: automatically and manually operation		
LD	I0.0	
O	I0.1	
=	Q0.1	

Network 7		
operating light		
LDN	I0.0	
=	Q0.0	

Fig. 7: Main controlling program of regulating valve and Indicator

Encoder sampling subroutine SBR1 is shown in Fig. 9.

```

Network 1
initialization of high speed counter HSC1 subroutine SBR0
LD      SM0.0
MOVW   16#CC, SMB47
HDEF   1, 0
MOVD   16#0, SMD48
HSC    1
MOVW   1500, VW2
    
```

Fig. 8: Initialization of high-speed counter SBR0

```

Network 1
encoder sampling subroutine SBR1
LD      SM0.0
MOVD   HC1, AC0
MOVD   0, SMD48
HSC    1
DTI    AC0, VW0
    
```

Fig. 9: Encoder sampling subroutine SBR1



Fig. 10: PID regulation and control panel

## DEBUG

The detailed debugging method is: firstly, on the base of the sampling time  $T_s$ , adjust ratio gain  $K_c$  from small to large in turn. steered sequentially attempt, when the current value of  $K_c$  is able to make the system response faster, that is, the system becomes steady quickly when the system appears electricity load changes, the integral time  $T_i$  begins to change. Integration time try to increase the dynamic characteristics of the system in descending order. After the system static offset is eliminated to some extent, adjusting the size of the differential time  $T_d$  appropriately, to make the system stronger in anti-interference ability.

In order to observe the curve changes in real-time, we carry out scale transformation on various input and output parameters, such as, transformation of all data to a uniform scale. And the input value (the data collected by the encoder) in the specific variation interval was added given constant, which functions in proper range after Partition between correction. It should output two setting extremums when the value exceeds the range. This improvement eliminates the deviation the control system generated internally.

After test, sudden changes in the load are more apparent than in air pressure (0.1~0.3 Mpa) for power generation voltage stability. The following describes a PID system control effect under the load changes. Figure 10 describes that when generator powers to a 1 kW load the curve is displayed on the PID control panel because of removing the load suddenly. The green line shows set point SP and the red line shows the process variable PV (almost coincides with red line) and the blue line shows the output value of Mn. As shown in the figure. When the load is removed, the rotate speed of the generator has a upward trend (red line up). the PID output value immediately reduce and the opening valve is also reduced, now the generator speed quickly falls back to the position of the setting to ensure a stable voltage output. Voltage floats up and down less than 3 V at 220 V on the multimeter. It will take 3 sec about to re-Back to the steady state. And the output value approaches to be stable after an oscillation curve. The valve opening adjusts to a new degree.

## CONCLUSION

After the commissioning, this control system can meet the requirement of constant voltage power in stability, rapidity and accuracy. Final result is to be able to stability in 220 v deviating 3 v or so in 4 sec. Then added 1000 w bulb load, it restores stability of the output value in 3 sec. And in the process of change, the deviation of the output value is very small. After removing the load, the curve can also restore stability in 3 sec. The technology can be promoted continually in other areas.

## ACKNOWLEDGMENT

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