Accuracy Improvement in Sizing Control Valves Using Neural Network

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Abstract: Given the effect of control valves` performance on product quality in various industries, selection of the right size of control valve is critical. Determining the optimal size of control valves depends on some variables whose values are not accurately available and generally approximately are specified using sizing software. The current research proposed a new method for more accurate estimation of control valve variables and enhancing accuracy in valve sizing using neural network. The proposed method depends on neural network capabilities in the approximation of functions and curve fitting. The proposed method was programmed and implemented in the graphical environment of MATLAB graphical user interface (GUI) as the SIZING software and was finally examined using a case study of ISA75.01.01 Standard.

Keywords: Control valve, Neural network, Sizing, MATLAB GUI

1. Introduction

Today, as the last element of the control loop, control valve has a significant and critical role in various industries and it has a direct effect on the product quality. Moreover, the proper selection and operation of a control valve has significant effects on the operational and maintenance costs of the process units.

Control valves` sizing is the most significant part in selecting a control valve. Credible manufacturers deal with sizing control valves according to the process information, common standards, and their experiences, where the sizes obtained in similar conditions sometimes differ.

According to the explanations above and the direct effect of control valves` performance on the quality and quantity of products manufactured in various industries, the purpose of this study was to present a method to optimize the sizing process and to model it using MATLAB.

Basics of control valves` sizing:

ISA75.01.01 or IEC60534-2-1 is the internationally accepted base for control valve sizing, based on which and their experiences as well, various manufacturers have designed computational software. This standard includes fluid flow equations in control valves applied to compressible fluids (gases) and incompressible fluids (liquids and water). The equations related to incompressible fluids are based on Newton's hydrodynamic equations, determined according to Reynolds number, turbulence or laminar of the fluid, based on which the corresponding formulas are used.

Major definitionss

C_V: According to the definition, C_V is the volume of water at 60 ° F in US gallons that passes through the valve within 1 minute at a constant pressure drop 1 PSI.

Sizing control valve is the proper determination of Cv for passing a certain value of fluid from the control valve under specified process conditions.

Parameters effective in determining control valve sizing:

There are two sets of parameters and input data in sizing the control valves. Some of the parameters correspond to the process of fluid characteristics, including flow rate (Q), inlet pressure (P1), outlet pressure (P2), fluid temperature (T), volume mass, and so on. This set of parameters is exclusively related to the process of fluid characteristics and process of design conditions.

The second part of the parameters corresponds to the structural properties and designing control valve, which varies from one manufacturer to another. Moreover, these parameters are a function of the degree of control valve openness, and the control valve manufacturers measure their values in finite points and present them in tables, the most significant ones of which are:

1. F_L (Liquid pressure recovery factor): It is the control-fluid recovery pressure. This factor calculates the effect of the internal geometry of the control valve on its capacity under flow obstruction conditions.

2. X_T (Pressure differential ratio factor): It is the ratio of the pressure difference of a control valve without connectors at either end.

3. F_d: (Valve style modifier): It is the ratio of the diameter of a flow passage in the control valve to the total flow passage diameter of the flow.

The values of these parameters are measured and determined according to IEC 60534-2-3 standard.

Computational formulas

As the computational formulas presented in the standard differ for compressible and incompressible fluids and for turbulent and laminar flows, the rest of the current research was used to understand the proposed method of incompressible fluid formula in turbulent flows. The stated method can be generalized to all states and the provided software can be used for all modes.

The equations for incompressible fluids in turbulent flows are as follows:

$$C_V = \frac{Q}{N_1 F_P \sqrt{\frac{\Delta P_{SIZING}}{\rho_1/\rho_0}}} \qquad (1)$$

$$\Delta P_{SIZING} = \begin{cases} P1 - P2 & if \quad \Delta P < \Delta P_{Chocked} \\ \Delta P_{Chocked} & if \quad \Delta P \geq \Delta P_{Chocked} \end{cases}$$

$$\Delta P_{Chocked} = \left(\frac{F_{LP}}{F_P}\right)^2 \cdot (P_1 - F_P P_V)$$

$$F_F = 0 \cdot 96 - 0 \cdot 28\sqrt{\frac{P_V}{P_c}}$$

$$F_P = \frac{1}{\sqrt{1 + \frac{\Sigma\zeta}{N_2}\left(\frac{\boldsymbol{C_V}}{d^2}\right)^2}}$$

$$\Sigma\zeta = \zeta_1 + \zeta_2 + \zeta_{B1} - \zeta_{B2}$$

$$\zeta_B = 1 - \left(\frac{d}{D}\right)^4$$

$$\zeta_1 = 0 \cdot 5\left[1 - \left(\frac{d}{D_1}\right)^2\right]^2$$

$$\zeta_2 = 1 \cdot 5\left[1 - \left(\frac{d}{D_2}\right)^2\right]^2$$

$$F_{LP} = \frac{F_L}{\sqrt{1 + \frac{F_L^2}{N_2}(\sum \zeta_1)\left(\frac{\boldsymbol{C_V}}{d^2}\right)^2}}$$

* The explanations of all parameters in ISA75.01.01 standard are given in the symbols table.

Problem solving algorithm

As is seen, given that the determinants of C_V like F_P and ΔP_{SIZING} are directly or indirectly a function of the value of C_V, the above equation should be solved based on numerical computation methods and iteration-based approaches. All sizing software uses duplicate methods one way or another.

Mathematical algorithm for calculating flow coefficient (Cv) in ISA-75.01.01 standard

First step

Function flow is defined as follows:

$$Functionflow(Cv) = Q - C_v N_1 F_P \sqrt{\frac{\Delta P_{SIZING}}{\rho_1/\rho_0}}$$

Cvlow=0

In the above function, Q value is equal to the flow passing through the control valve and among the problem information.

Now the flow coefficient Cv has to be calculated so that the result of the above function becomes zero.

Second step

Determining the lower limit of the flow coefficient (Cvlow)
As the minimum fluid passage is zero, the lower limit of the flow coefficient is considered to be zero.
Cvlow = 0

Third step

Determining Cvupper upper limit
The followings are specified in accordance with the limitations set out in the standard.

$$C_{Upper} = Min \begin{cases} 0 \cdot 99d^2 \sqrt{-\dfrac{N_2}{\sum \zeta}} \\ 0 \cdot 075 d^2 N_{18} \end{cases}$$

Fourth step

The value of the function flow (Cv) is calculated for both the upper and lower limits of the flow coefficient. If the symbol of the calculated values is opposite, it shows that Function flow (Cv) = 0 at [Cvlow,Cvupper] range has at least one answer. Moreover, as function flow (Cv) is strongly ascending in the given range, we will have only one answer. If the values have the same symbols, it means that the above equation does not have an answer and the selected valve cannot pass the flow coefficient and its size should increase.

Fifth step

The average upper bound (Cvupper) and lower bound (Cvlow) of the flow coefficient are calculated (Cvmid). Given that, the parameters (F_{dmid}, F_{Lmid}, X_{Tmid}, Functionflow (Cvmid) are calculated and if the algebraic value of Functionflow (Cvmid) has the same mark with Functionflow (Cvupper), the value of Cvupper would be equal to Cvmid; otherwise, Cvlow would be considered Cvlid.

Sixth step

The previous step is repeated until the following condition is reached:

$$\left| C_{Upper} - C_{Lower} \right| \leq \varepsilon$$

Indeed, by subtracting ε, the accuracy needed to reach the appropriate flow coefficient and the equation response Function flow (Cv) = 0.

Figure 4-1 shows two steps of the algorithm iteration.

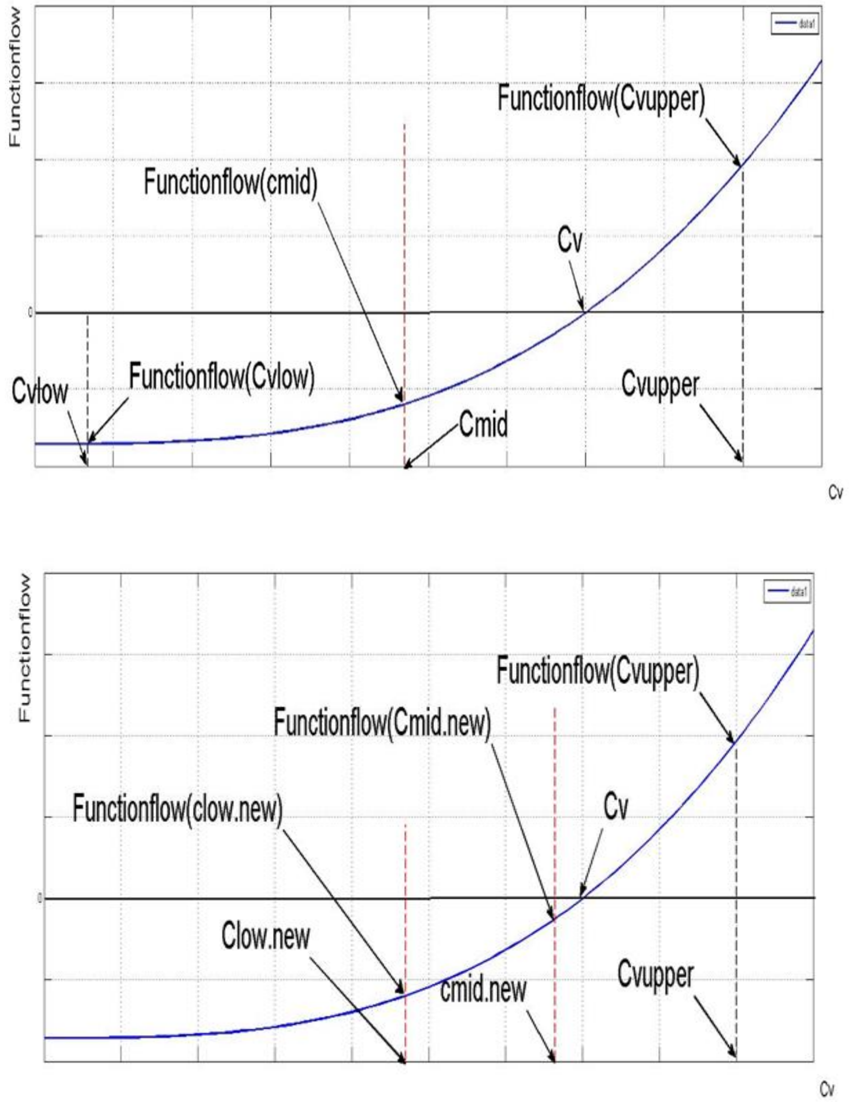
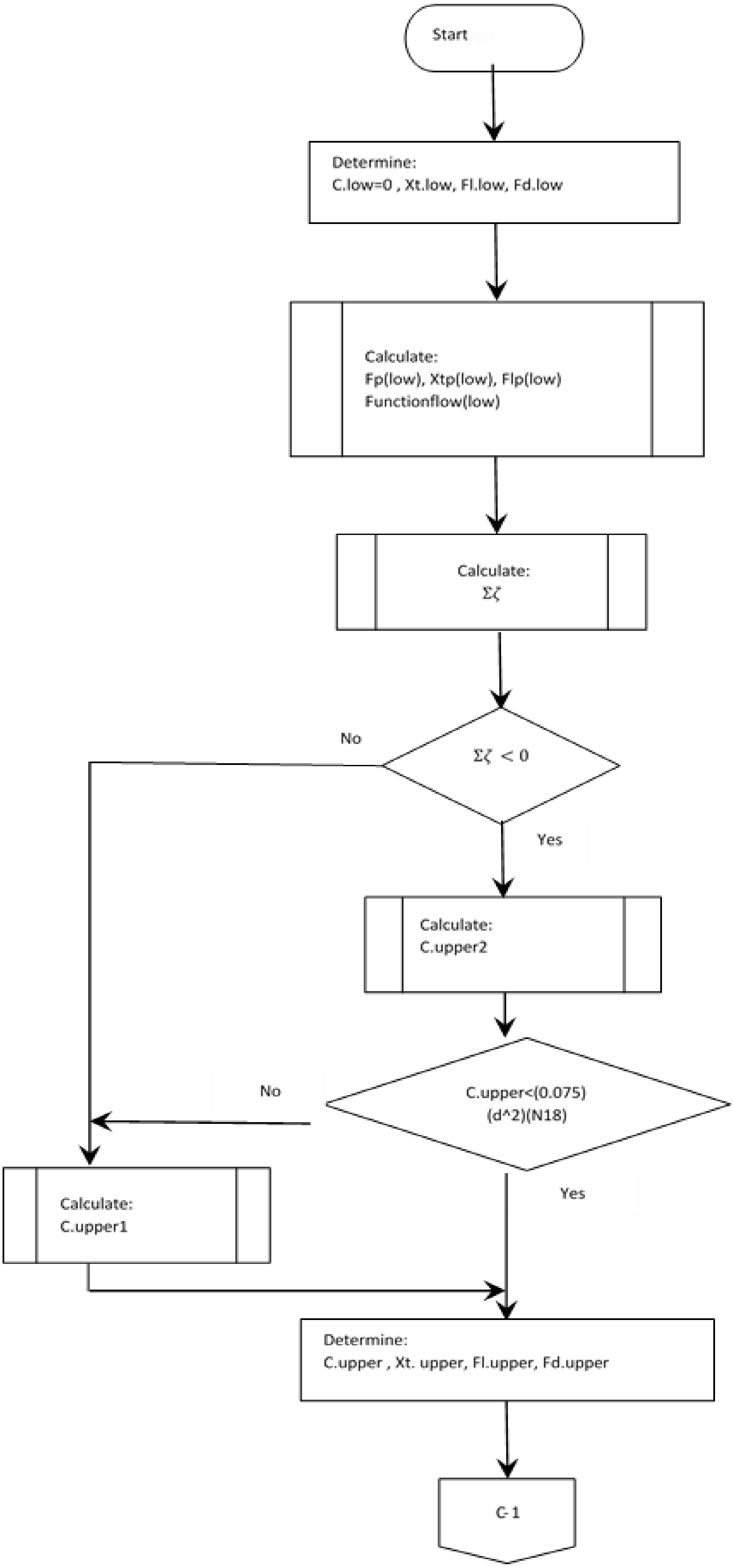


Figure 1: Two steps of iteration of flow-coefficient calculation algorithm


Start
Determine:
C.low=0 , Xt.low, Fl.low, Fd.low
Calculate:
Fp(low), Xtp(low), Flp(low)
Functionflow(low)
Calculate:
Σζ
No
Σζ < 0
Yes
Calculate:
C.upper2
No
C.upper<(0.075)
(d^2)(N18)
Yes
Calculate:
C.upper1
Determine:
C.upper , Xt. upper, Fl.upper, Fd.upper
C-1

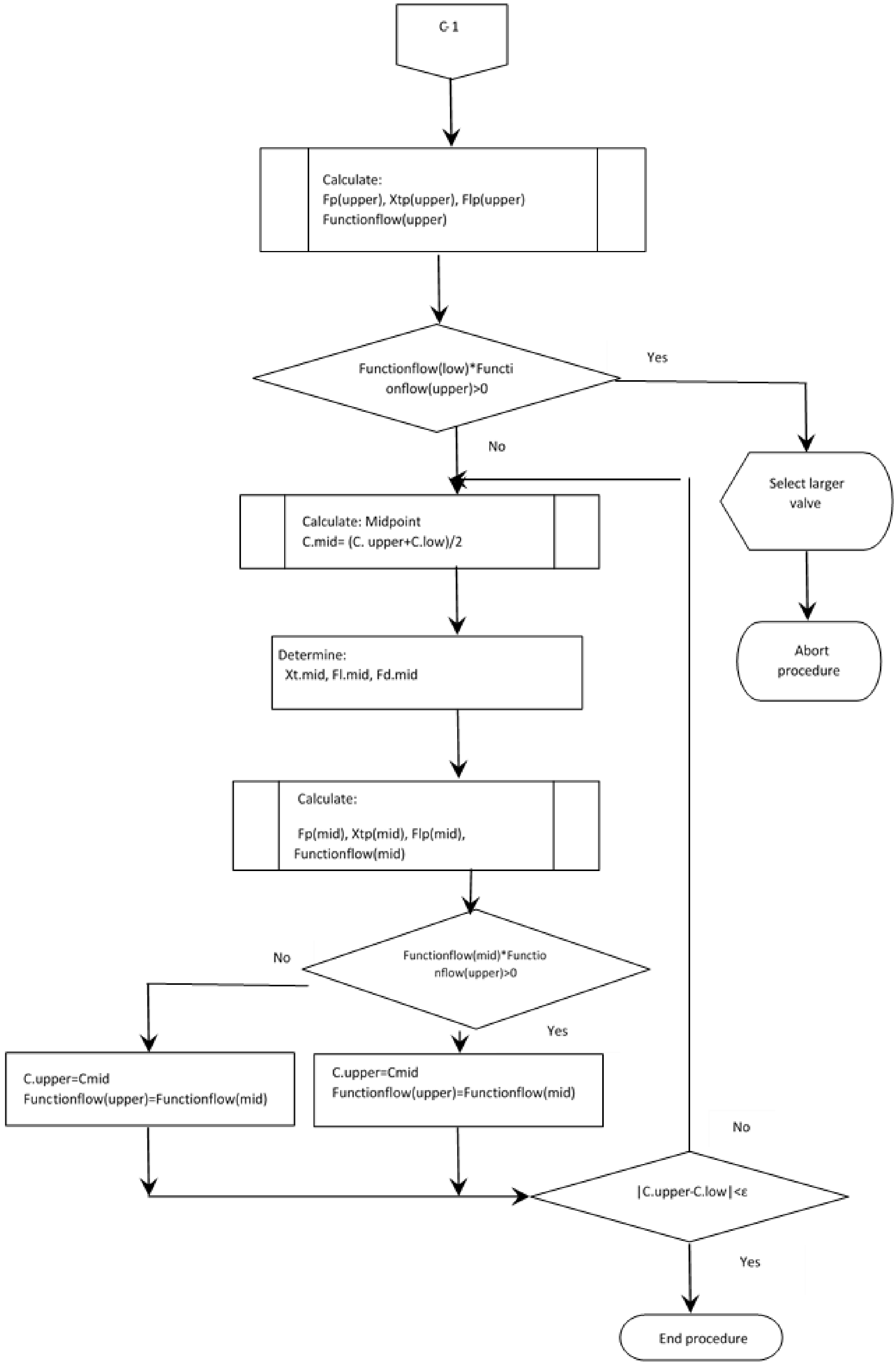
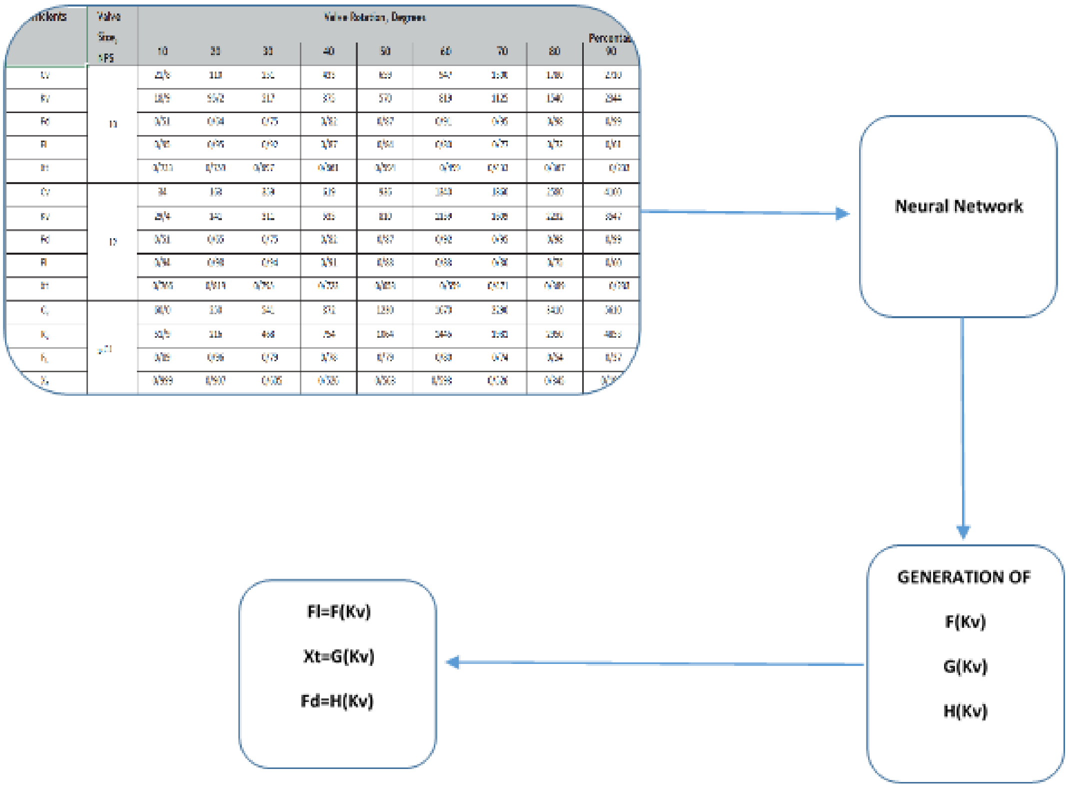


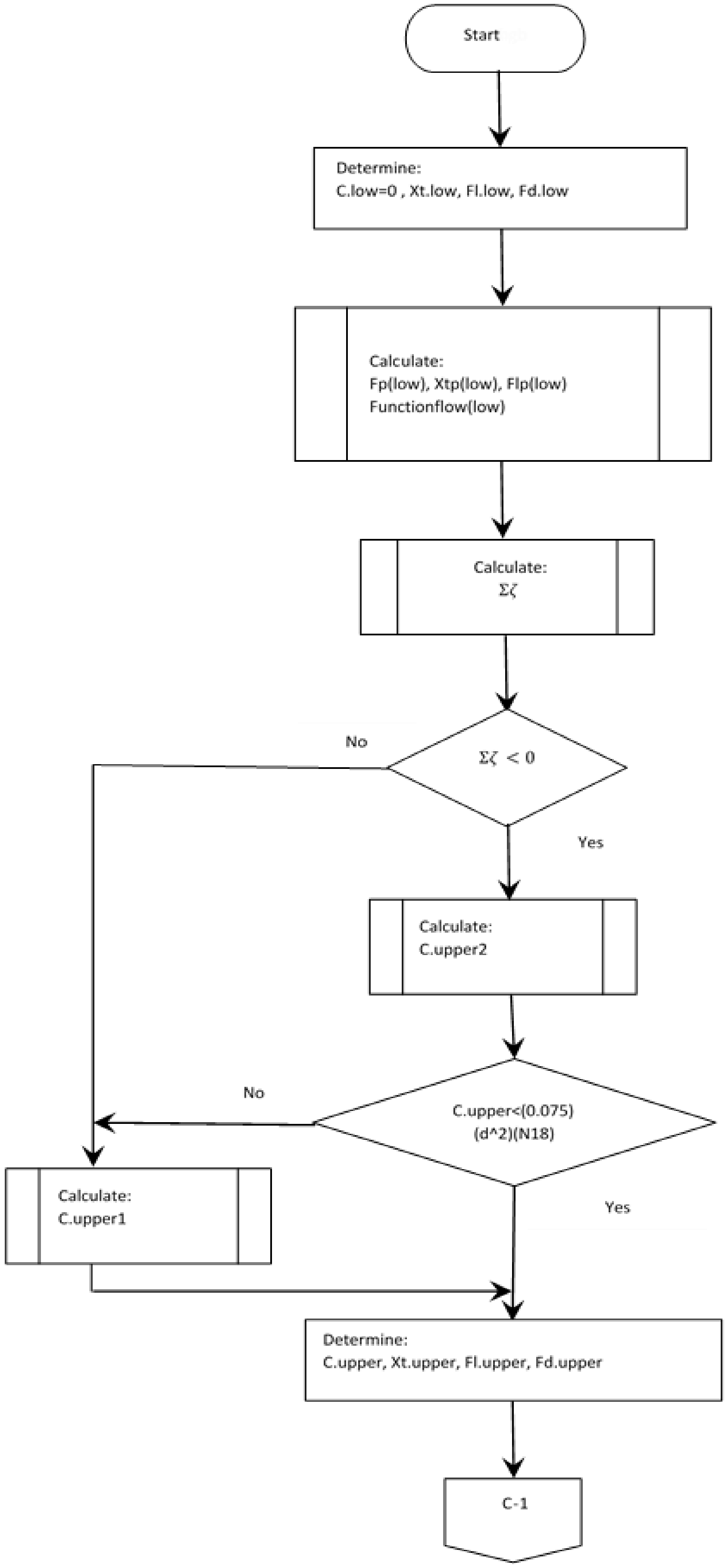
Figure 2: Flowchart of calculating the flow coefficient according to ISA75.01.01 standard

As the values of F_L, X_T and F_d depend on C_V value, a function of the valve openness of the control valve is usually the case in most computational sizing methods for numerical solution of Equation (1) by iterative method to simplify F_L, X_T and F_d values where all stages of the constant iteration algorithm are assumed constant. Ts leads to the loss of accuracy in C_v calculations. In EXAMPLE 5, ANNEX E uses standard ISA75.01.01 to increase the accuracy in iterative algorithm stage and linear interpolation to estimate F_L, X_T and F_d values. In this study, neural network abilities was used in function approximation and curve fitting in estimating F_L, X_T and F_d values in the iterative algorithm.

As F_d, F_l, and X_T values were functions of value (Cv), manufacturers of control valves provided tables for each model of their manufactured valves where the valve openness of F_d, F_l, X_T and Cv were recorded in varying values. These measurements were done according to IEC 60534-2-3 standard. By entering this information as neural network data, one can obtain functions for each of the above parameters by which it shows the value of that parameter in each location with high accuracy.



The above functions were recalled while calculating CV value in the algorithm and calculations were done accordingly. Using this method, in each iteration of the computational algorithm more realistic values of F_d, F_l, X_T were entered into the computations and as the neural network had higher accuracy in estimating the values compared to the linear interpolation (given the nonlinear nature of the variations), this process lead to increased accuracy in SIZING calculations.


Start
Determine:
C.low=0 , Xt.low, Fl.low, Fd.low
Calculate:
Fp(low), Xtp(low), Flp(low)
Functionflow(low)
Calculate:
Σζ
No
Σζ < 0
Yes
Calculate:
C.upper2
No
C.upper<(0.075)
(d^2)(N18)
Yes
Calculate:
C.upper1
Determine:
C.upper, Xt.upper, Fl.upper, Fd.upper
C-1

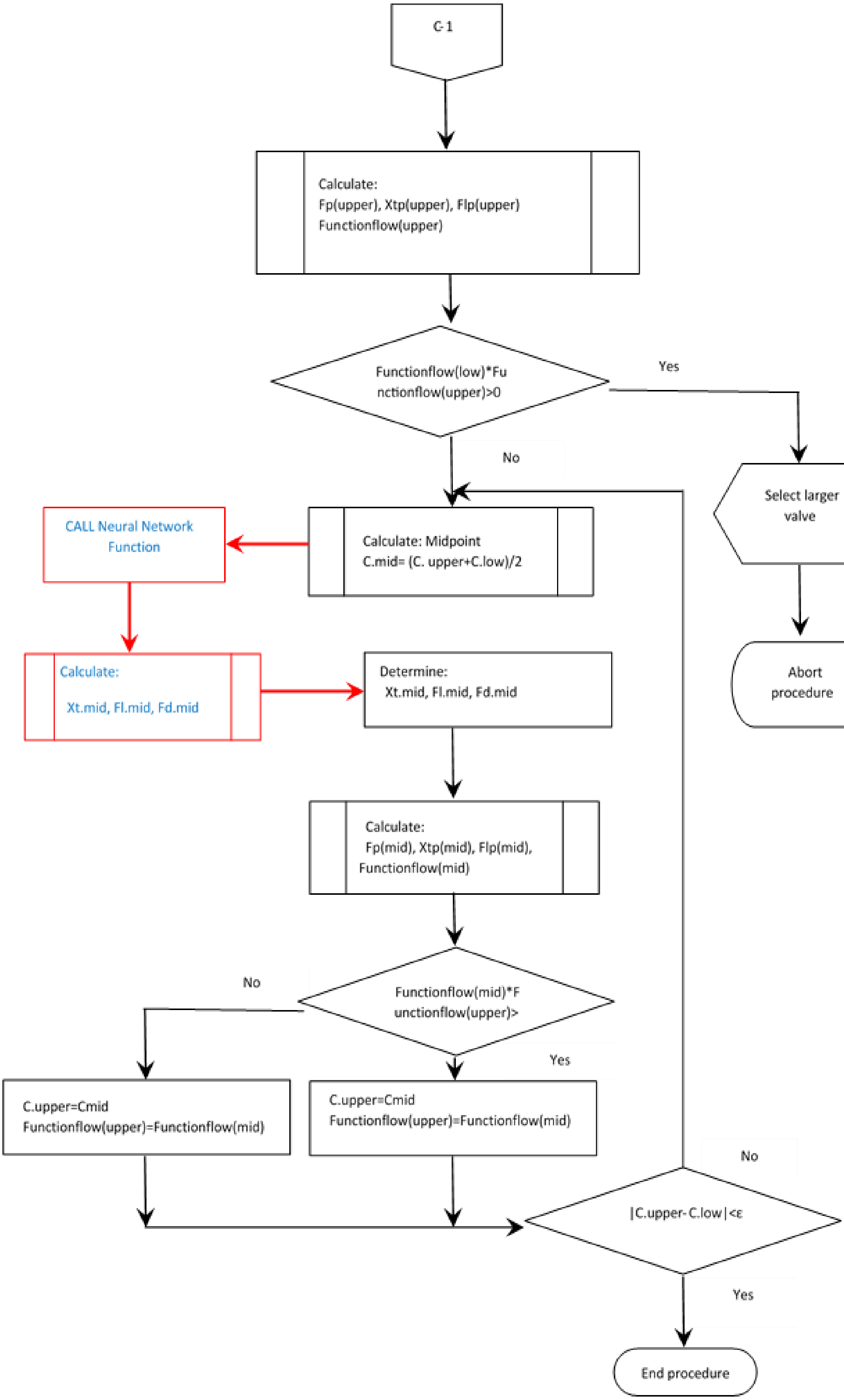


Figure 3: Modified flowchart

Case study

The modified flowchart was programmed using MATLAB and in GUI environment. A case study was conducted to analyze and compare the proposed method with those of conventional methods and the results were analyzed. In doing so, Example 5 of ANNEX E Standard ISA-75-01-01 2012 Edition (last modified) was analyzed.

In this problem, the goal was to find Cv with the following information:

Process information:

Fluid: Unspecified-Incompressible
Density: 780 kg/m3
Vapor pressure: Pv = 4 kPa or 0.004bar
Thermodynamic critical pressure: Pc = 22,120 kPa or 221.2bar
Inlet absolute pressure: P1 =3,550 kPa or 35.5bar
Outlet absolute pressure: P2 = 1310 kPa or 13.1bar
Flow rate: Q = 750 m3/h
Upstream Pipe size: D1 = 154.1 mm or 6.06"
Downstream Pipe size: D1 = 202.7 mm or 7.98"

Control valve information:

Valve style: Butterfly
Valve size: d = 101.6 mm
The relationship between Cv, Fl and angle of control valve openness are given as follows:
Flow Coefficient Data:

ROTATION	0	10	20	30	40	50	60	70	80	90
Cv	0	17.2	50.2	87.8	146	206	285	365	465	521
Fl	0.85	0.85	0.84	0.79	0.75	0.71	0.63	0.58	0.56	0.54

According to the table above and the process data, determining Cv value was the goal of the problem. In doing so, Cv was calculated and compared with three methods.

First method: Assumption of Fl value constant

To this end, Fl value was considered regardless of Cv value and the angle of control valve openness was equal to the value proportional to the maximum valve openness of control 0.54. By replacing other values into the software, we had:

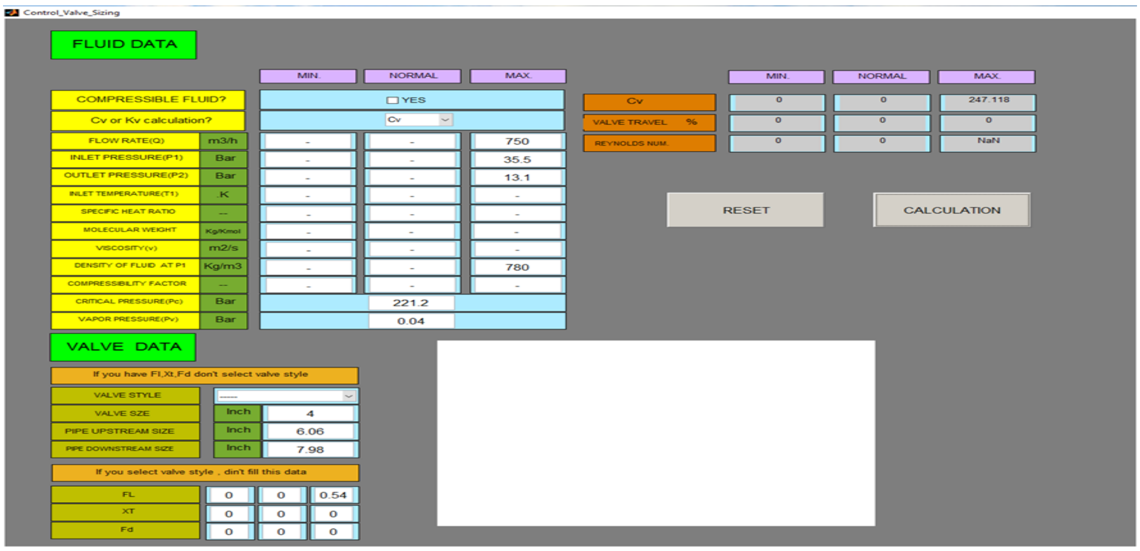


Figure 4: Calculating Cv value with constant Fl

The value obtained in this method was 247.18.

Second method: This method had utilized the iterative algorithm and linear approximation of Fl value according to the values given in the table.

In doing so, according to Table 1, repeated values of different parameters were recorded in each step and after 10 iterations, the obtained value was 183.7.

Table 1: Calculating Cv value by interpolating Fl

Iteration	C_{Lower}	C_{Mid}	C_{Upper}	F_L	F_p	F_{LP}	$\square P_{choked}$	$\square P_{sizing}$	$Flow_{Mid}$
1	0	387	774	0.576	0.848	0.523	1,349	1,349	-431
2	0	194	387	0.718	0.954	0.690	1,856	1,856	-29.4
3	0	96.8	194	0.784	0.988	0.774	2,179	2,179	313
4	96.8	145	194	0.751	0.974	0.732	2,006	2,006	130
5	130	169	194	0.734	0.965	0.711	1,929	1,929	47.3
6	169	181	194	0.726	0.960	0.701	1,892	1,892	8.23
7	181	188	194	0.722	0.957	0.696	1,874	1,874	-10.8
8	181	184	188	0.724	0.958	0.698	1,883	1,883	-1.32
9	181	183	184	0.725	0.959	0.700	1,887	1,887	3.44
10	183	183.7	184	0.725	0.959	0.699	1,885	1,885	1.06

Third method: This method had used neural network in estimating Fl value and openness of control valve angle.

By entering data into software according to the figure, 183.45 value was obtained.

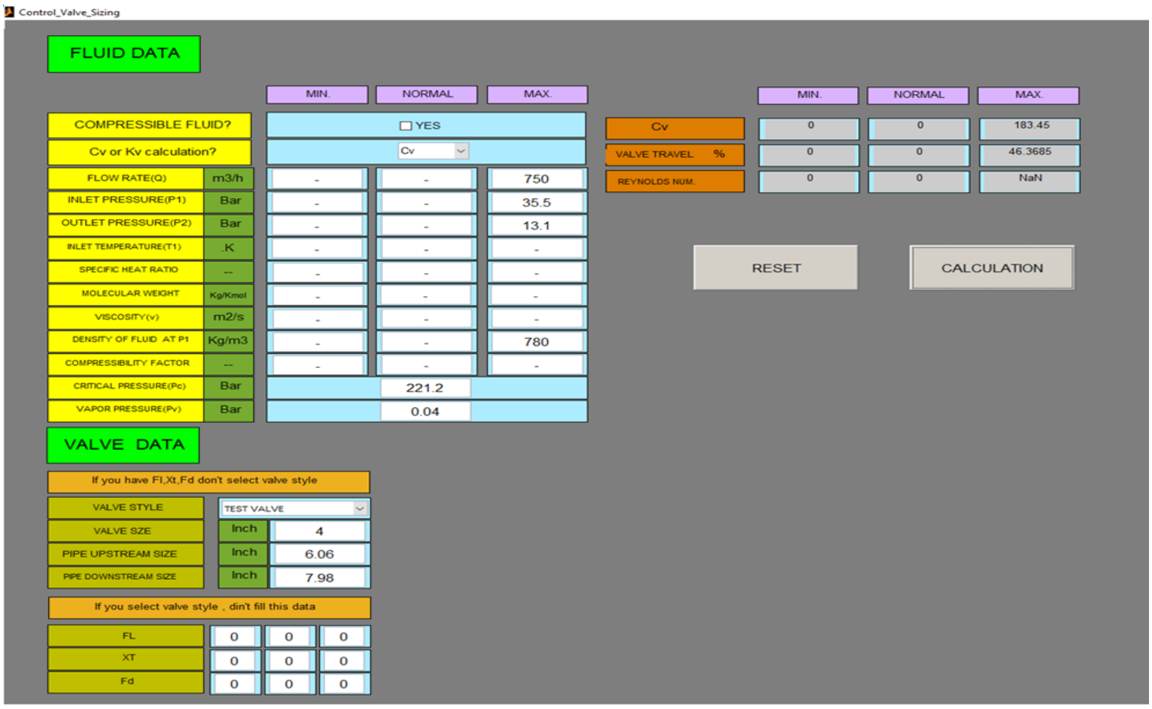


Figure 6-3: Calculating Cv using the neural network

Iteration	C_{Lower}	C_{Mid}	C_{Upper}	F_L	F_p	F_{LP}	$\square P_{choked}$	$\square P_{sizing}$	$Flow_{Mid}$
1	0	387	774	0.5696	0.8482	0.5185	13.2514	13.2514	-419.74

2	0	193	387	0.7195	0.9546	0.6916	18.61	18.61	-30.088
3	0	96.5	193	0.78	0.9880	0.7708	21.57	21.57	315.3
4	96.5	145	193	0.7481	0.9773	.73	19.93	19.93	132.41
5	145	169.3	193	0.7364	0.9647	0.7132	19.38	19.38	46
6	169.3	181.4	193	0.7289	0.9597	0.7032	19.36	19.36	6.4051
7	181.4	187.45	193	0.7244	0.9572	0.6976	18.83	18.83	-12.2707
8	181.4	184.42	187.45	0.7267	0.9585	0.7004	18.93	18.93	-3.037
….	…	…	…	…	…	…	…	…	…
20		183.45		0.7274	0.9589	0.7013	18.9706	18.9706	-0.000092

Since the neural network predicted more accurate values for Fl, Cv value was more accurate.
In Figure 1, Cv-Fl values were compared in linear approximation and neural networks.

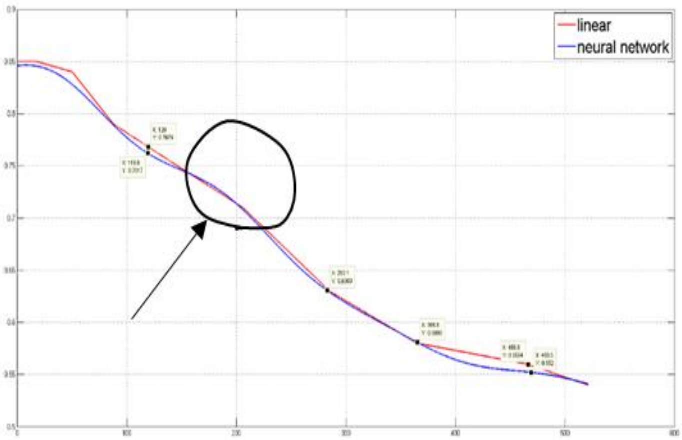


Diagram 1: Comparison of Fl in linear interpolation and neural network modes

As is seen in the figure, the values of Fl for the linear state and the neural network were close to each other in the specified range. Thus, the value difference in the obtained Cv was small. It is clear that at intervals where Fl value had greater difference for the linear state and the neural network, the difference between the CVs obtained from these two methods was more and in some cases led to a change in control valve size.

2. Discussion and Conclusion

As the sizing of control valves completely depends on the structural variables of the control valve, the more precise selection of these variables will bring about increased accuracy in determining the size of the control valve. As the values of these variables are measured by manufacturers at finite points, accuracy in predicting values at other points is critical. The common method in predicting the values is using linear interpolation. This study introduced neural network as an optimal method in estimating values given its intrinsic capability in curve fitting and predicting function values, which can have a more accurate prediction compared to other methods after training using the given points and thus determining the control valve size with greater accuracy. As a follow up study, it is recommended that sizing calculations be conducted at one of the companies producing valves using the presented software and the parameters of the control valves manufactured be tested and measured according to the requirements of IEC 60534-2-3 Standard to compare the capability of this method with other common methods a follow-up study.

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