Exploration and Prospect of intelligent technology for natural gas data acquisition and control system

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Abstract

Verification process for gas flow accurately adjust the actual problem of precision and quality control, research and development for more than a set of suitable for the working conditions of gas source in high-pressure natural gas metering intelligent detection system, the flow control of intelligent controller based on composite algorithm, using the three-dimensional laser scanning and BIM building information model technology to digital reduction verification yard, The industrial application of intelligent verification of natural gas real flow in China is realized. Dynamic processes such as intelligent decision-making, accurate execution and digital perception are completed through the system's independent identification verification task, which greatly improves verification efficiency and verification quality control level.

1. Introduction

As the share of natural gas in China's energy consumption increases year by year, the importance of flowmeter as a handover instrument for natural gas metering trade becomes increasingly prominent, and the demand for flowmeter verification increases year by year. The Nanjing Metrology Research Center of the West-east Gas Transmission Branch of The State Petroleum and Natural Gas Pipeline Group Co., LTD manages the nanjing branch and Guangzhou branch of the national oil and natural gas large flow measurement stations and the wuhan inspection point. Up to now, it has verified and calibrated more than 12 000 flowmeters for multinational and cross-border enterprises such as China and Russia, Central Asia, China and Myanmar and Hong Kong branch lines, as well as many domestic pipeline enterprises, gas companies and flowmeter manufacturers.

Metrological verification of natural gas station is the system in a special kind of gas transmission pipeline station, its process is complex, involving ten core unit, including in and out of the stand pipes, filtration separation devices, pressure adjusting devices, measurement standard devices, check the same at all levels, flow control devices, the nitrogen purging system, truncation of emergency system, safety instrument system and vent sewer system, etc. Each part of the process pipeline in the station is connected with each other to form a complete hydraulic system. Verification process involves many complicated operations, such as technological flow conduction, inlet flat pressure and pressure regulation, verification pipeline switch, flow regulation, verification flow state stability, verification parameter settings, verification process result and certificate result judgment and processing. These operations need to be completed manually step by step, especially pressure, flow regulation needs verification personnel with years of work experience for control valve action control. As verification personnel by manual operation of DCS system by adjusting the parameters of the test of proficiency ascension space is smaller and smaller, and verification process for high flow precision control requirements, it is necessary to use intelligent means to improve test speed and accuracy in the system, to further ensure the safety work of the scene, alleviate the pressure of the test, especially improve verification process control to ensure accurate measurement precision.

National west-east gas pipeline network group company nanjing qualitative research center to promote the innovation in intelligence engineering, focusing on restricting gas verification process flow accurately adjust the actual problem of precision and quality control, collection of intelligence research, and actively explore the artificial intelligence[1-3] and so on big data analysis technology[4-6] is introduced into gas field of metrological verification, accurate presentation. Amplification According to the combination of regulated target flow rate and verification pipeline pressure, the intelligent controller of flow regulation based on compound algorithm is established. The simulation model describing flow change rule is established by using real-time datas. The 3d laser scanning and BIM building information model technology are used to carry out digital restoration of verification station. Implementation of the technology, equipment and operation mechanism of the real describe synchronization and simulation, verification of domestic gas solid flow is implemented for industrialization, broke through the traditional manual switching process, the manual verification process mode of the operating system, through system identification verification tasks independently, complete intelligent decision-making and accurate execution, digital perception, such as dynamic process, The verification efficiency and verification quality control level are greatly improved, and the realization path suitable for intelligent distribution control of the station is explored, which makes a successful practice for the construction of intelligent pipelines.

2. Natural gas metering intelligent verification system

National west-east gas pipeline network group company technical team based on Internet of things technology and intelligent algorithm, developed a set of suitable for many working conditions of gas source of high-pressure natural gas in the intelligent detection system, breaking the original communication barriers, make the data transfer from bottom to top, issued instructions from top to bottom, between system implements data acquisition, storage, calculation, analysis and control of Internet sharing. Verification tasks issued by intelligent calibration system and trigger the system to work together, the scene equipment acquisition offices shall need to import the data and database, the intelligent controller and the real process system of digital twin body actively search for the required data in the database, through calculation and analysis of instruction form submit intelligent calibration system optimal control strategy, The system can control the whole process of on-site process adjustment and verification independently (Figure 1).

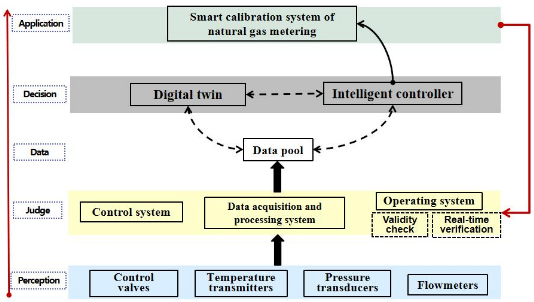

Figure 1: Schematic diagram of data and instructions of integrated and interconnected multi-systems of natural gas metering intelligent verification system

As the core of the intelligent verification system, the intelligent controller performs model training based on more than 10 000*454 sets of historical data, performs model verification based on more than 5 000*454 sets of data, changes BP neural network parameters through independent learning, and constantly modifies to adapt to new control requirements. At present, the intelligent controller model has covered the various working condition, can according to need to carry out the verification flow meter diameter, maximum flow point, accuracy grades, and automatically adapt to the current working condition, independent adjustment and reasoning selection process and regulating valve combination, independent decision-making multichannel flow regulating valve opening, according to the result of adjusting feedback constant optimization of independent learning.

3. Digital twins

3.1 Hydraulic simulation of verification working conditions

With gas flow meter verification organization process piping within the station complex and highly integrated structure, different size for different detected flowmeter verification process and checked the flow point, combined with the on-site verification process, by setting at both ends, to simulate the boundary conditions of constant pressure by adjusting the hydraulic simulation model to adjust the valve opening and ball valve switch, The hydraulic simulation was carried out after the field flow reached the flow point to master the verification process of the flow meter with different diameters, valve opening and hydraulic characteristics of the flow point.

3.1.1 Hydraulic simulation model

According to the function of natural gas metering station, the pipelines in the station are divided into intake filter pressure regulating area, standard device area, verification platform area and flow regulating valve group area, and each area is equivalent to different zoning models. The inlet filtration and pressure regulating area, standard device area and verification platform area are unified into one area, which functions as process switching. For the area of the regulating valve, as another sub-zone, the role is to adjust the flow through the verification platform. Through the parallel connection of the two partitions, a simplified model of the whole hydraulic simulation is constructed. For each sub-zone, in order to make the simplified model achieve the speed of calculation and meet the requirements of calculation accuracy, pipelines and valves in each region need to be combined according to the characteristics of the technological process in each region (Figure 2).

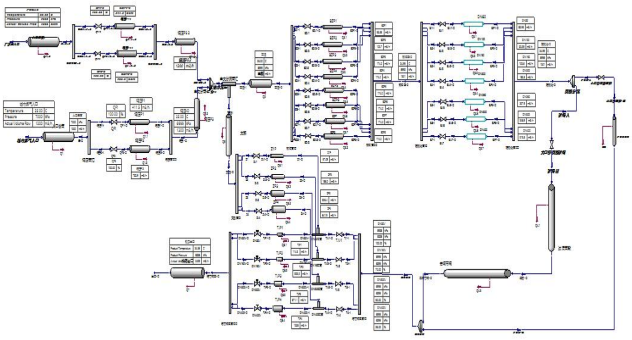

Figure 2: Hydraulic simulation of flow meter verification condition

Of the existing historical data on the spot, through the key switch state of the valve have standard flowmeter and verification of the same process, and by calculating the friction coefficient under different process, to calculate the flow of traffic in real time with the compare, if more than a certain value before or did not record the working process, friction coefficient is obtained by using the direct real time and storage, To improve the accuracy of online simulation.

In addition to modifying parameters directly, the study also classifies or conducts sensitivity analysis on pipelines first to reduce the amount that needs to be modified, and then makes group modification to make the simulation of the model more accurate. Friction coefficient sensitivity coefficient method is used for correction of node pressure or flow more "sensitive" pipeline, by adjusting the sensitive pipeline friction coefficient, according to certain rules for grouping pipe friction coefficient correction method, can greatly reduce the number of optimization variables, to make changes to the working condition of a wide range of possible online simulation.

According to the mass conservation equation, momentum conservation equation and energy conservation equation, the relationship between the flow velocity, density, temperature, pressure and elevation of the pipeline used to describe the flow of natural gas in the verification station is established and calculated according to Equation (1) :

$$\begin{aligned}
&\frac{\partial\rho}{\partial t}+\frac{\partial(\rho u_x)}{\partial x}+\frac{\partial(\rho u_y)}{\partial y}+\frac{\partial(\rho u_z)}{\partial z}=0\\
&\frac{D}{Dt}\iiint_{\tau_0}\rho v d\tau_0=\iiint_{\tau_0}\rho f d\tau_0+\iint_{A_0}p_n dA_0\\
&\left(\frac{\partial h}{\partial T}\right)_P\frac{d_T}{d_x}+\left(\frac{\partial h}{\partial p}\right)_T\frac{d_P}{d_x}+v\frac{d_v}{d_x}+g\frac{d_s}{d_x}=-\frac{d_Q}{d_x}
\end{aligned} \tag{1}$$

To facilitate the calculation of equivalent friction coefficient of pipe model is set up, make the following assumptions: (1) selection of DCS system collected flow point, in the field devices without action, flow change small flow over a period of time as a steady point, namely the gas within the test stand steady flow in the pipeline, pipe flow and pressure in the just position function, does not change with time and change; (2) Since the natural gas verification station is generally small in area and has relevant shading, the flow of natural gas in the pipeline is assumed to be isothermal flow, so the influence of energy equation is not considered; (3) The fluctuation of the pipeline is not large enough for the horizontal pipeline, that is, ds = 0. In practice, volume flow under standard reference conditions is used. Considering the local resistance, the gas equation P= ρ ZRT is substituted into the above equations to simplify the inverse calculation of friction coefficient:

$$Q=C_0\sqrt{\frac{(p_Q^2-p_Z^2)D^5}{\lambda Z\Delta_* TL}} \tag{2}$$

Where, Q is the volume flow rate (m^3/s) under the working reference condition (p_0 =1.01325×10^5Pa, T_0=293.15K); p_Q is the inlet pressure, Pa; p_Z is outlet pressure, Pa; D is the pipe inner diameter, m; λ is hydraulic friction coefficient; Z is the compression factor of natural gas pipeline transportation conditions (average pressure and average temperature). Δ* is the relative density of natural gas; T is the gas transmission temperature, T=273.15+t, is the average temperature of the gas transmission pipe, ℃; L is the length of the pipe segment, m.

$$\lambda=\frac{0.009407}{\sqrt[3]{D}} \tag{3}$$

3.1.2 Identification of multi-valve parallel flow coefficient

Valve flow coefficient is a measure of regulating valve flow ability index, often used as the selection of the diameter of the regulating valve and the study of the internal structure of the valve, judge the factors affecting the stability of the valve. The flow coefficient of valve is the key parameter of valve process simulation in order to build and simulate the model that can match the field working condition. For the flow control pipeline in the station containing the regulating valve, the regulating valve can be treated as a local resistance element in the simulation, so the identification of the flow coefficient of the regulating valve is transformed into the identification of local friction resistance, so as to improve the accuracy of the simulation.

Based on the flow coefficient of valve, the least square method is used to fit the relation between the total flow rate and the opening degree of each parallel valve in the case of multiple valves in parallel, and the flow coefficient of each regulating valve is identified. Then, the identified flow coefficients are brought into the hydraulic simulation model to verify the accuracy of the identified flow coefficients.

For regulating valves with equal percentage characteristics, the flow coefficient of valves with different opening degrees is calculated according to Formula (4) :

$$C_v(x)=\frac{C_{v0}}{e^{3.488}-1}e^{3.488x}-\frac{C_{v0}}{e^{3.488}-1} \qquad (4)$$

The flow rate of gas through the valve is calculated according to Formula (5) and (6) :

$$Q=Q_1+Q_2+Q_3=(k_1C_{v1}+k_2C_{v2}+k_3C_{v3})N\sqrt{\frac{(p_1^2-p_2^2)}{ZGT}} \qquad (5)$$

$$\frac{Q}{N\sqrt{(p_1^2-p_2^2)/ZGT}}=A_1e^{3.488FR1}+A_2e^{3.488FR2}+A_3e^{3.488FR3}+B \qquad (6)$$

Where in, Q is the total volume flow through the parallel valve in standard state; Z is the compressibility coefficient at upstream temperature and average pressure; G is the proportion of natural gas relative to air; T is the upstream temperature, K; p_1 inlet pressure, p_2 outlet pressure; N Unit conversion coefficient. The value is 0.0346. C_v is the flow coefficient when fully open.

The pressure of inlet and outlet valve, flow rate in standard state, inlet temperature, compression factor and relative density required for formula fitting were obtained by establishing the model. For the obtained data, the least square method is used to fit according to the above formula, so as to identify the flow coefficient of multiple regulating valves when they are fully open, and the flow coefficient obtained by fitting is used to calculate the physical parameters of regulating valves in the hydraulic simulation model. Here, taking three regulating valves as examples, the established hydraulic simulation model (the flow coefficients when the three valves are fully open are 100, 200 and 300 from top to bottom), the flow calculated by the hydraulic simulation model, the actual flow and the identified flow coefficients of each valve when the valves are fully open are as follows:

Table 1 Actual and fitted flow coefficients of each valve

control valve	The actual flow coefficient	the flow coefficient fitted by the formula	error
FV1	100	100.1436	0.1%
FV2	200	202.1789	1.08%
FV3	300	303.2987	1.09%

The flow coefficient of the valve is directly fitted by the formula of the data extracted from the hydraulic simulation. The calculated flow is basically consistent with that of the hydraulic simulation, and the error between the fitted flow coefficient and the actual set flow coefficient is about 1%.

3.2 Digital twin platforms

Digital twin is a virtual model of physical entities created digitally, which uses data to simulate the behavior of physical entities in the real environment, and adds or expands new capabilities for physical entities through virtual and real interaction feedback, data fusion analysis, decision iteration optimization and other means. As a kind of technology that makes full use of model, data and intelligence and integrates multi-disciplines, digital twin is oriented to the process of product life cycle, plays the role of bridge and link between the physical world and the information world, and provides more real-time, efficient and intelligent service. It has good effect in the application of process detection.

According to process pipeline layout, equipment technical parameters and operating condition data, the intelligent verification system synchronously develops corresponding "digital twin platform", in order to realize the real description and synchronous simulation of field process, equipment and operating mechanism. Is like a mirror, the role of digital twin and control the flow of the process system form state synchronization mapped to the model, the visual image to the digital simulation was carried out on the test run, it had the effect of simulation validation tool before execution, intelligent controller calculates control strategy, must be to digital twin platform for simulation and iterative operation, To ensure that the output results meet the verification requirements can be issued and executed. The digital twin platform can also be corrected through the later operation data, such as the characteristics of different types of valves under different pressure differences, the actual pressure loss of each pipe segment, etc., to achieve continuous optimization of simulation accuracy, and can also be used to find small deviations in the process system, prompting the technical personnel to check the cause. At the same time, through the DCS system set up over limit protection, overspeed protection, overpressure protection, flow regulation protection, valve interlock, valve control, pressure difference and prevent process interruption DCS safety chain logic, to ensure the intelligent verification process process system safe and stable operation (Figure 3).

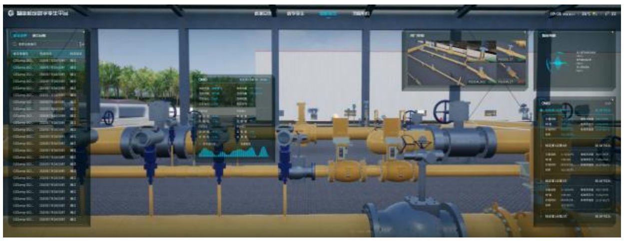

Figure 3: Actual diagram of auxiliary simulation verification of digital twin platform for intelligent verification of natural gas metering

4. Intelligent controller based on neural network

BP neural network is one of the most widely used neural network models. Its basic principle is to continuously modify the network weights and thresholds to make the error function descend along the negative gradient direction and approach the expected value through the training of sample data. BP neural network can learn a large number of input-output mode mappings without revealing the mathematical equations describing the mappings in advance, the topology of neural network model is shown in Figure 4.

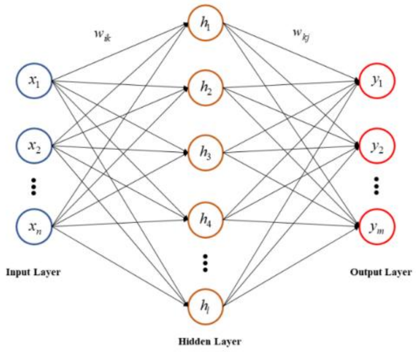

Figure 4: Topology of neural network model

BP algorithm consists of two processes: forward propagation of data stream and back propagation of error signal. In forward propagation, the propagation direction is from the input layer to the hidden layer and then to the output layer, and the state of neurons in each layer only affects neurons in the next layer. Suppose the input layer of BP neural network has n nodes, the hidden layer has L nodes, and the output has M nodes. The weight between the input layer and the hidden layer is w_{ik}, and the weight between the hidden layer and the output layer is w_{kj}. The transfer function of the hidden layer is f_1, and that of the output layer is f_2, so the output of the node of the hidden layer is:

$$h_k = f_1\left(\sum_{i=1}^{n} w_{ik} x_i\right) \quad k = 1,2,3,\ldots,l \tag{7}$$

The output of node of output layer is:

$$y_j = f_2\left(\sum_{k=1}^{l} w_{kj} h_k\right) \quad j = 1,2,3,\ldots,m \tag{8}$$

BP neural network has completed the approximate mapping of n- dimensional vector to m- dimensional vector. If the desired output is not obtained at the output layer, the reverse propagation process of error signal is turned. Suppose p learning samples, denoted as X_1, X_2... , X_q,... X_p, The q_{th} sample is substituted into the network to obtain a set of output Y^q, $Y^q = \left[y_1^q, y_2^q, \ldots, y_m^q\right]$. Using the square error function, the error of the q_{th} sample is obtained:

$$E_q = \frac{1}{2}\sum_{j=1}^{m}\left(t_j^q - y_j^q\right)^2 \tag{9}$$

Where, is the expected output. For P learning samples, the global error is:

$$E = \frac{1}{2}\sum_{q=1}^{p}\sum_{j=1}^{m}\left(t_j^q - y_j^q\right)^2 = \sum_{q=1}^{p} E_q \tag{10}$$

The cumulative error BP algorithm is adopted to adjust the weight w_{kj}, so that the global error E becomes smaller, namely:

$$\Delta w_{kj} = -\eta\frac{\partial E}{\partial w_{kj}} = -\eta\frac{\partial}{\partial w_{kj}}\left(\sum_{q=1}^{p} E_q\right) = \sum_{q=1}^{p}\left(-\eta\frac{\partial E_q}{\partial w_{kj}}\right) \tag{11}$$

Where, η is the learning rate, and error signal δ_{yj} is defined as:

$$\delta_{yj} = -\frac{\partial E_q}{\partial S_j} = -\frac{\partial E_q}{\partial y_j}\frac{\partial y_j}{\partial S_j}$$
$$\frac{\partial E_q}{\partial y_j} = \frac{\partial}{\partial y_j}\left[\frac{1}{2}\sum_{j=1}^{m}\left(t_j^q - y_j^q\right)^2\right] = -\sum_{j=1}^{m}\left(t_j^q - y_j^q\right)$$
$$\frac{\partial y_j}{\partial S_j} = f_2'\left(S_j\right) \tag{12}$$

Where, S_j is the net input of node j.
The weight w_{kj} adjustment formula can be obtained from the above formula:

$$\Delta w_{kj} = \sum_{q=1}^{p}\sum_{j=1}^{m}\eta\left(t_j^q - y_j^q\right) f_2'\left(S_j\right) \tag{13}$$

The adjustment of weight w_{ik} is similar to that of w_{kj} , and its adjustment formula is as follows:

$$\Delta w_{ik} = \sum_{q=1}^{p}\sum_{j=1}^{m}\eta\left(t_j^q - y_j^q\right) f_2'\left(S_j\right) w_{kj} f_1'\left(S_k\right) x_i \tag{14}$$

By alternating forward propagation and back propagation, the error function gradient descent strategy is implemented in the weight vector space, and a set of weight vectors are dynamically iterated to minimize the network error function, so as to complete the information extraction and memory process.

After processing the samples, 70% were selected as training data, 15% as verification data, and the remaining 15% as test data for BP neural network training. Through training and modification, the neural network structure is finally determined as a 6-layer network, in which the number of neurons in the hidden layer 4 layer is 20, 50, 40 and 10 respectively. The training result is shown in Figure 5, which takes 6 minutes and 19 seconds. The R value of the neural network is 0.96117, indicating that the fitting effect is good. 3000 points are uniformly selected from the data set to verify the results, and the proposed scheme is basically consistent with the actual scheme, which proves the availability of the neural network controller.

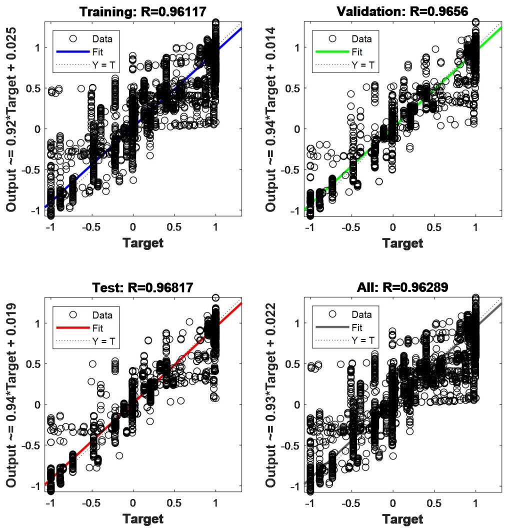

Figure 5: Regression coefficient of control neural network training

5. Conclusion

Done in prediction algorithm for point of forward calculation, combined with the hydraulic simulation model with multiple valve parallel flow coefficient of the identification results and the intelligent controller based on neural network to build valve combination and issued by the site equipment complete control, combined with field data and expert experience upgrading adaptability, intelligent control and regulation of verification to complete the whole process. After data comparison, field deployment and practical application test, the interactive verification accuracy of the optimized hydraulic model is greater than 95%, and the system delay characteristics are effectively predicted. Through the innovation and application research of intelligent flow regulation, the intellectualization, high efficiency, safety and precision of domestic work-level metrological verification are realized.

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