A DATA ANALYSIS SYSTEM FOR THERMAL ENERGY LOSS IN ELECTRICAL AUTOMATION MANAGEMENT

by

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In order to achieve data analysis of thermal energy loss for electrical automation management, the author proposes a Broyden Fletcher Goldfarb Shanno (BFGS) trust region algorithm based thermal energy loss calculation method for the integrated energy system of electricity and gas, the BFGS trust region algorithm is utilized to obtain the thermal energy loss distribution of natural gas system, which is not highly dependent on the initial value, this solves the problem of non-convergence in power flow calculation when using the Newton method for calculation. The experimental results show that the relative errors of natural gas system node pressure, pipe-line flow and power system node voltage and phase angle calculated by Newton's method and BFGS trust region algorithm are within $1 \cdot 10^{-4}$, within the allowable range, which verifies the correctness of the calculation results of the method described by the author. It has been proven that the BFGS trust region algorithm can achieve data analysis of thermal energy loss for electrical automation management.

Key words: *integrated energy system, power system, natural gas system, calculation of thermal energy loss, BFGS trust region algorithm*

Introduction

In recent years, the composition and structure of the energy used in our country's production have been constantly changing with the times, and the energy structure used in the construction process is constantly being optimized and adjusted, in China's energy production structure in 2019, the highest proportion of raw coal in total energy production was 68.8%, crude-oil 6.9%, natural gas 5.9%, and other forms of energy such as wind power, hydro power, and nuclear power 18.4% [1]. In terms of the power supply structure for electricity consumption, the national installed capacity of generators in 2019 was 2010.66 GW, an increase of 5.8% compared to the end of last year. Among them, the installed capacity of solar power generation grew the fastest at 204.68 GW, with a growth rate of 17.4%, followed by the growth of grid connected wind turbines at 210.05 GW, with a growth rate of 14.0%, and the assembled capacity of thermal power and water motors at 1190.55 GW and 356.40 GW, with growth rates of 4.1% and 1.1%, respectively [2]. The country is undertaking the historical task of energy transformation and environmental protection, and the following two approaches can help better achieve this historical task: Firstly, fully tap into the potential of fossil energy and improve its utilization rate. The second is to appropriately increase the proportion of renewable energy in use and gradually achieve cleaner production. The proposal of the electric thermal integrated energy

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system is in line with this development trend. In the integrated energy system of electricity and heat, the power grid and regional heating network are combined through coupling modules [3]. The more coupling parts there are, the closer the connection between the two networks becomes, achieving the flow and conversion of energy in different networks. This combined operation mode of electricity and heat considers the complementary nature between electricity and heat energy, achieving multi-level energy utilization, improving energy utilization efficiency, and greatly enhancing the safety and flexibility of system operation. Moreover, as a stable and reliable energy supply system, this integrated energy system of electricity and heat can adapt to the output of renewable energy, by optimizing the output of coupling modules to address the uncertainty of renewable energy and improve the utilization rate of renewable energy.

The mismatch between electric thermal power output and load in the system is more likely to occur, resulting in energy waste. With the development of technology, the emergence of some new types of electrothermal coupling devices, such as electric heat pumps, has provided a solution this phenomenon [4]. Electric heat pumps can be driven by electricity, using electricity to enhance external energy such as air heat, water source heat, and geothermal energy before heating, in this process, the heat pump serves as both the load of the power system and the heat source of the thermal system, demonstrating its excellent electric heating power regulation performance. At the same time, throughout this entire process, the input energy of the electric pump is electrical energy, while the output heating energy is the sum of the input electrical energy and the collected external energy, reflecting the excellent energy-saving and environmental protection characteristics of the electric pump, in line with the national goal of low carbon and green development [5]. Therefore, in order to reduce the total operating cost of the system and achieve construction, it is necessary to identify the heat pump of the integrated thermal power plant and to propose an effective method for the correct preparation of the unit output and pump heat. The goal of saving energy and protecting the environment: energy saving and environmental protection. Energy is the country's economy. Today's global goal is sustainable use of electricity. The energy flow is distributed between the combined electric power system, electric power system (EPS), and natural gas system (NGS), and the interaction of the two EPS has led to education.

Literature review

In the 21st century, when consumption, safety and environmental issues are growing, the country adheres to the national policy of environmental protection and environmental protection, actively renews the form of construction of the industry, *Energy Development Strategy*, *Energy Development Electricity power* and special documents such as *Energy Technology Revolution and Innovation Action Plan* [6]. As the economy and society continue to develop, important changes are taking place in the types of energy production and use. In this context, learning about the cooperation and efficiency of energy use It is a prerequisite for using our energy resources and creating a clean, low carbon, safe and economical environment. At present, a large amount of research has been conducted both domestically and internationally on the optimal thermal energy loss of integrated energy systems [7].

Uzair *et al*. [8] introduces efficient and low cost rooftop PV solar panels that can be maintained, monitored, and provided with technology. Compared to IoT-based PV systems, configure different public spaces at any location from a predefined list. However, existing IoT systems can only monitor and control PV panels or only detect certain defects (heat, dust, *etc.*). One of the most powerful uses of electricity for an electric or any electric car is to heat a house in cold weather. Hemmati *et al*. [9] to improve design co-operation:

- building heating using electrical energy between thermal protection and heat engine,
- operation of multiple electrical conductors during charging, and
- exhaust gas ignition fuel after thermal control to reduce catalyst loss.

To this end, a design model for heating and power transmission optimization has been developed and tested using multiple test data for plug-in hybrid vehicles.

Amani *et al*. [10] aims to assess the feasibility and design of zero-energy buildings in cold, semi-arid climates. In this study, advanced solar building technology and energy reduction technology were used to increase energy efficiency. The research project is a 100 m house with four residents in a cold and dry climate in northeast Iran. For thermal testing, weather data such as temperature, daylight, wind, precipitation, and hourly sunshine are provided by weather stations in the area. DesignBuilder software is used for building testing and energy analysis, while PVsyst software is used for modelling and evaluating the performance of renewable energy systems.

At present, the Newton method is mostly used for calculating the thermal energy loss of the integrated energy system of electricity and gas in research. Considering that EPS adopts the flat start method (with voltage amplitude and phase angle initial values selected as 1.0 p.u. and 0°, respectively), most power flow calculations can converge. However, NGS often uses engineering experience to select initial values for calculation, and there is no suitable method to address the shortcomings of Newton's method calculation. In response to the aforementioned issues, the author proposes a thermal energy loss calculation method based on the BFGS trust region algorithm, convert the problem of solving the distribution of NGS thermal energy loss into an unconstrained optimization problem, and use the BFGS trust region algorithm to solve this problem. The global convergence ability of the algorithm effectively solves the initial value selection problem in NGS thermal energy loss calculation, and applies this algorithm to the thermal energy loss calculation of a comprehensive energy system composed of EPS and NGS. The applicability of the method proposed by the author was verified through two numerical examples composed of a 19 node electricity gas integrated energy system.

Data analysis of thermal energy loss

Steady-state modelling of IES with electricity and gas

- *The EPS power flow equation*: The author adopts a classic AC power flow model, whose node power expression is shown:

$$
\begin{aligned}
P &= Re\left(U\left(YU\right)^{*}\right) \\
Q &= Im\left(U\left(YU\right)^{*}\right)
\end{aligned}
\tag{1}
$$

- *The NGS steady-state model*: The NGS includes gas pipe-lines, compressors, natural gas nodes, gas sources, and loads. Considering the similarities between NGS and EPS in many aspects, energy is transported from the supply side to the user end through a transmission path. All satisfy Kirchhoff's law*, etc.* We can refer to the modelling method of EPS and compare the node pressure in NGS to the node voltage in EPS, using it as the main state variable for calculating thermal energy loss in NGS [11]. The flow equation of the gas pipe-line (with nodes m and n at both ends of the pipe-line):

$$
f_{m,n} = k_{mn} D_{mn} \sqrt{D_{mn} (L_{gm}^2 - L_{gn}^2)} \tag{2}
$$

$$D_{mn} = \begin{cases} +1 & L_{gm} - L_{gn} \geq 0 \\ -1 & L_{gm} - L_{gn} < 0 \end{cases} \tag{3}$$

where L_{gm} and L_{gn} [Pa] are the pressures of nodes m and n, k_{mn} – the constant, related to the parameters of the pipe-line itself, f_{mn} [m^3 per hour] – the pipe-line flow rate, and D_{mn} – the direction of gas-flow. Natural gas may experience flow loss during pipe-line transmission [12]. In order to compensate for the loss, NGS will configure a certain number of compression stations to increase the transmission pressure inside the pipe-line through internal compressors. However, this process will consume additional energy [13]. The formula for the consumed natural gas-flow rate is shown in eqs. (5) and (6):

$$H_c = B_c f_c \left[\left(\frac{L_{gm}}{L_{gn}} \right)^{Zc} - 1 \right] \tag{4}$$

$$\tau_c = a + \beta H_c + \gamma H_c^2 \tag{5}$$

where c is the compressor, f_c [m^3 per hour] – the flow rate through the compressor, H_c [MW] – the power consumed by the compressor, B_c, Z_c are the compressor parameter, τ_c – the flow rate consumed by the compressor, and a, β, γ – the efficiency constant of the compressor [14].

– Mathematical modelling of coupling links

Gas turbine: The gas turbine consumes natural gas from NGS to generate electrical energy, which is transmitted to EPS [15]. When calculating the thermal energy loss of the electric gas integrated energy system, think of it as the power supply in EPS and the gas load in NGS. The steady-state mathematical model:

$$P_i = \mu\left(f_j\right) f_j H = C_1 f_j^3 + C_2 f_j^2 + C_3 f_j \tag{6}$$

where f_j [m^3 per hour] is the gas-flow rate obtained from natural gas node j and P_i [MW] – the electrical power output to the connected node i in EPS, [16].

Compressor: There are also electric driven compressors in addition gas driven ones. The latter obtains electrical energy from EPS and plays the role of power load in calculations [17]. This article adopts an electric drive type and models it mathematically:

$$P_c^m = H_c \left(\frac{0.7457}{10^5} \right) \tag{7}$$

where P_c^m [MW] is the equivalent electrical load of the compressor in EPS.

Calculation of thermal energy loss in electric gas systems based on BFGS trust region algorithm

– *Mathematical model for calculating thermal energy loss in electric gas system*:

$$\begin{gathered} f_e\left(P_e, Q_e, V, \theta\right) = 0 \\ f_g\left(L_g, f\right) = 0 \end{gathered} \tag{8}$$

where f_e, f_g are the equations of the power system and the vector equations of the NGS, respectively, and P_e, Q_e, V, and θ represents the active power, reactive power. The aforementioned two equations exchange thermal energy losses through coupling links [18].

– *Application of BFGS trust region algorithm in thermal energy loss calculation of natural gas subsystem*: The trust region algorithm is a numerical method for solving non-linear optimization problems, transforming the optimization problem into a simple local optimization problem. The key is to define a search range at the current iteration point and find a suitable step size within this range.

It can be seen from eq. (8) that the essence of heat loss calculation of natural gas subsystem is to solve a set of non-linear equations [19]. The solution of the equation system can be transformed into an unconstrained optimization problem:

$$\begin{gathered}\min h(x)=\frac{1}{2}\|F(x)\|^2 \\ x=\left[L_{g1},L_{g2},...,L_{gn}\right]\end{gathered} \tag{9}$$

The non-linear trust region model of eq. (9) can be expressed:

$$\begin{gathered}\min g\left(d_k\right)=\frac{1}{2}\left\|F(x)_k\right\|^2+z_k^T d_k+\frac{1}{2}\left(d_k\right)^T d_k B_k \\ s.t.\left\|d_k\right\| \le \Delta_k\end{gathered} \tag{10}$$

where k is the number of iterations, d_k – the based detection step length, $g(d_k)$ – the objective function of the trust region subproblem, z_1^T – the current iteration point x_1. Gradient of

$$\left[\frac{\partial h\left(x_k\right)}{\partial p_{g1}},\frac{\partial h\left(x_k\right)}{\partial p_{g2}},\frac{\partial h\left(x_k\right)}{\partial p_{gn}}\right]$$

and B_k – the Positive-definite matrix, it is the approximate matrix produced by the BFGS formula correction:

$$B_{k+1}=\begin{cases}B_k-\dfrac{B_k d_k\left(d_k\right)^T B_k}{\left(d_k\right)^T B_k d_k}+\dfrac{y_k\left(y_k\right)^T}{\left(y_k\right)^T d_k} & r_k \ge \eta_1 \\ B_k & r_k<\eta_1\end{cases} \tag{11}$$

where $y_k = z_{k+1} - z_k$, B_k is the the Positive-definite matrix (B_0 represents the initial Positive-definite matrix when $k = 0$, and is the identity matrix), η_1 – the iterative success discrimination coefficient, and $0 < \eta_1 < 1$.

Here are the steps for calculating the BFCS trust region algorithm:

– Set $k = 0$, given parameter $\Delta 0 > 0$, calculation accuracy $\varepsilon > 0$, trust region correction radius parameter $0 < c_1 \le 1 \le c_2$, $0 < \eta_1 < \eta_2 < 1$.
– Calculate $\|z_k(x_k)\|$. If $\|z_k(x_k)\| \le \varepsilon$, stop iteration, otherwise, proceed to the next step.
– Solve the estimated descent $pred_k(d_k)$ and actual descent $ared_k(d_k)$ of the objective function defined by the trial step size d_k using eq. (10), and the expressions for both are:

$$\begin{gathered}pred_k\left(d_k\right)=g\left(d_k\right)-g(0) \\ ared_k\left(d_k\right)=h\left(x_k+d_k\right)-h\left(x_k\right)\end{gathered} \tag{12}$$

– Define the ratio r_k between the two.

Experimental results and analysis

Example parameters

The 19 node electricity gas integrated energy system consists of an IEEE 13 node system and a 6 node NGS, see fig. 1: the GB represents the node of the NGS, the EB is the power system node, the GB1 is the reference node for NGS, and the EB1 is the reference node for the power system. The compressor in the coupling part adopts a voltage compressor, which is connected to EB1. The gas turbine is connected to EB9 and GB6, and the author uses electricity to calculate the distribution of thermal energy loss in the electrical system.

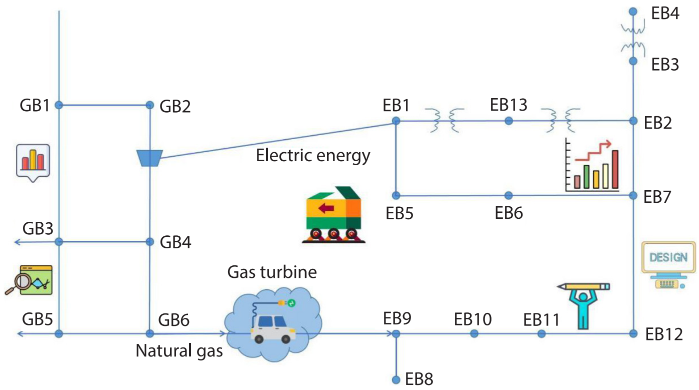

Figure 1. Example structure diagram of electricity-gas integrated energy system

Example simulation results

In MATLAB, the calculation program of thermal energy loss of the electricity gas integrated energy system based on the BFGS trust region algorithm and the conventional Newton's method method is compiled, respectively, the initial parameter setting of the algorithm described by the author is B0 set to identity matrix (6 × 6) $\Delta_{max} = 2$, $\Delta_0 = 1$, $\eta_1 = 0.01$, $\eta_2 = 075$, $c_1 = 0.5$, $c_2 = 2$, and $\varepsilon = 10^{-3}$ [20]. The voltage rating of the power plant is shown at the nominal value, and the power value is taken as 69 kV. To confirm the accuracy of the calculated results of the model described by the author, a comparison of the calculated results of the model and Newton's formula. The model can be seen from the data in fig. 2. The comparison of the calculation results of the subsystem pipe-line flow is shown in fig. 3, the calculation results of the node pressure amplitude of the power subsystem are shown in fig. 4, and the calculation results of the pressure phase angle of the node of the power subsystem are shown in fig. 5. The relative errors of NGS nodal pressure, pipe-line flow, nodal voltage and phase angle calculated by Newton's model and BFGS confidence region algorithm are within $1 \cdot 10^{-4}$, which are all within the tolerance limits. accuracy of calculation of the results of the model defined by the author.

In order to compare the merits of Newton's method and BFGS confidence zone algorithm for calculating thermal energy losses in electrical systems, it is enough to compare the number of iterations and calculate the time required for Newton's method and BFGS confidence zone algorithm. The results are shown in tab. 1.

Compared to Newton's simple method, the use of the BFGS confidence zone algorithm for calculating the integrated energy of electric fuel requires less calculation time and measurement time, and it is known that the model described by the author has good properties.

Table 1. Comparison of the superiority of the two methods

Computing method	Newyton method	BFGS trust region algorithm
Iterations [time]	72	63
Calculation time [ms]	182	153

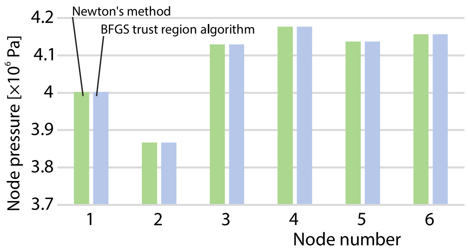

Figure 2. Comparison of the pressure calculation results of the subsystem nodes

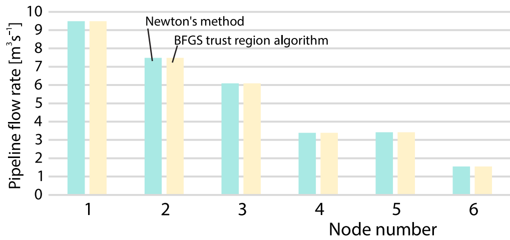

Figure 3. Comparison of the flow calculation results of the subsystem pipe-line

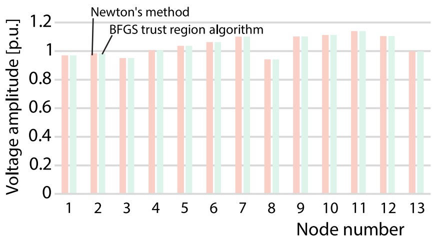

Figure 4. Calculation results of the node pressure amplitude of the power subsystem

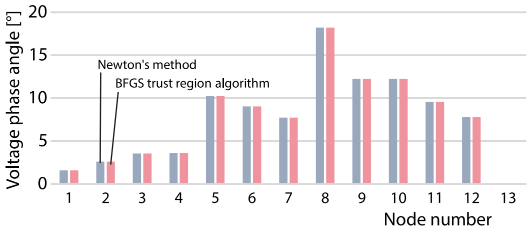

Figure 5. Computing results of node pressure phase angle of power subsystem

Conclusion

The author proposes to use the thermal energy loss based on the BFGS confidence zone algorithm to solve the sensitivity of the simple Newtonian process to the first factor when calculating the gas heat energy loss. When converting the solution of the system of non-linear nodal pressure equations in the gas network into an unconstrained optimization problem, the BFGS confidence region algorithm is used to solve this optimization problem. To verify the validity and effectiveness of the model proposed by the author, the author used two numerical examples. According to the results of the examples: the method proposed by the author has good global properties and can solve the problem of initializing the sensitive cost of Newtonian gas in calculating the thermal energy loss of natural gas. composition of natural gas thermal energy loss calculations. At the same time, it can reduce the number of iterations required for calculation, the calculation time, and improve the calculation performance. When calculating the heat energy loss of the integrated EPS, comparing the distribution of heat energy loss in the system with the use of Newton's method, it is good to confirm the accuracy of the formula proposed by the author, as well as gain profit calculation.

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