RESEARCH ARTICLE

Multi-objective load dispatching and monitoring analysis of main pollution sources for power energy conservation and environmental protection

Li Zhang[1, 2, *], Baozhong Qu[1], Qingzhi Zhu[1], Heng Wu[1, 2]

[1]Henan Polytechnic Institute, [2]Henan Flexible Manufacturing Engineering Research Center, Nanyang, Henan, China

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At the same time as the rapid growth of the global economy, excessive production has led to serious pollution of water sources and the environment, endangering health and sustainable development of the environment. Realizing the informatization of environmental supervision and the intelligent supervision of pollution sources has become an urgent environmental challenge. In this study, in order to solve the problem of intelligent supervision of pollution sources, an energy-saving and environmentally friendly multi-objective load scheduling method was designed by using multi-objective load dispatching, incorporating environmental factors into power system operation to reduce pollution emissions. The main pollution sources were detected and analyzed. The demand analysis of pollution source online monitoring system was carried out from the perspective of software engineering. According to B/S architecture, the system was divided into corresponding functional modules with the idea of modularization. The system architecture encompassed data collection, transmission, alarm systems, data processing, and centralized control. This integrated approach aided in achieving sustainability in power system operations and environmental protection, offering an effective solution for online monitoring and pollution source management. The results showed that the power system dispatching administrator could view the historical alarm information through the alarm statistics and analysis function and carry out alarm statistics according to different needs. This study provided effective help for the analysis of power system business flow, network operation, and equipment performance.

Keywords: environment; protection; load dispatch; monitor; analysis.

[*]**Corresponding author:** Li Zhang, Henan Polytechnic Institute, Nanyang 473000, Henan, China. Email: Zhangli4211828@163.com.

Introduction

In recent years, the world's rapid economic growth has led to a corresponding increase in environmental pollution, posing significant challenges to sustainable development and global well-being [1]. The adverse effects of pollution on both human health and the environment have become pressing issues that demand effective solutions. In this context, the need for comprehensive strategies that promote energy conservation and environmental protection have become paramount [2]. China, like many other nations, has experienced substantial economic growth, resulting in increased industrialization and urbanization. However, this growth has also led to a surge in environmental pollution with various sources emitting pollutants into the air and water systems. Traditional regulatory approaches have proven inadequate to address the multifaceted challenges posed by a diverse array of pollution sources scattered throughout the country. The lack of continuous and accurate monitoring systems further compounds the difficulties in managing and mitigating pollution effectively [3]. To ensure sustainable development and protect human health, it has become imperative to establish robust and advanced systems for real-time monitoring and management of pollution sources [4]. These systems must combine state-of-the-art information technology with environmental protection efforts, enabling the effective supervision, and control of pollution sources [5]. Only through the integration of advanced technologies, we can accelerate the establishment of an online pollution source monitoring and monitoring system and achieve environmental supervision informatization and pollution source monitoring automation [6, 7]. The global challenge of increasing the demands of energy and environmental pollution necessitates urgent solutions. In light of the pressing environmental challenges, this study proposed a novel approach for energy conservation and environmental protection through a multi-objective load dispatching method that prioritized energy conservation and environmental protection by integrating environmental considerations into the load dispatching process, aiming to maximize energy efficiency while minimizing pollution emissions from power generation and industry. Unlike conventional methods which often focus solely on optimizing energy consumption and power distribution [8, 9], our proposed method uniquely incorporated environmental protection as a primary objective. By considering environmental factors in the load dispatching process, the system could effectively reduce pollution emissions from power generation and other industrial processes while ensuring efficient energy utilization [10]. The multi-objective load dispatching method further integrated an online monitoring system for pollution sources, enabling real-time data collection, analysis, and decision-making. This real-time approach empowered environmental managers and power system dispatchers to proactively respond to pollution events, optimize load distribution, and minimize the environmental impact of power generation [11]. By forming a seamless interaction between the monitoring and dispatching components, the system provided an innovative solution for balancing energy conservation, power distribution, and environmental protection [12, 13]. The results of this study would promote sustainable energy practices, enhancing environmental protection, and contributing to public health and environmental well-being.

Materials and Methods

This study introduced the system architecture design, security design, and specific implementation functions. The functions of equipment at all levels were as follows that the system was responsible for receiving information, in which the lower-level equipment sent data to the upper-level in a one-way manner as the sampling equipment sending data to the data acquisition instrument that grouped and integrated the received data and sent it to the database server *via* the public network in a unified format. The monitoring data acquisition subsystem in the online monitoring and monitoring system realized the functions of decentralized monitoring, centralized receiving, unified coding, and centralized sending, and had the function of informing the alarm subsystem of excessive data [14-16]. The alarm subsystem uniformly managed the access equipment in the system, realized the monitoring and fault location of all alarm network elements in the network, analyzed and processed the corresponding fault and abnormal network status information, and had the functions of classifying, statistics, and guiding the analysis of real-time and historical data.

Overall Architecture of the System

The online monitoring system adopted the method mode of unified deployment, distributed realization, and centralized control [17-19],

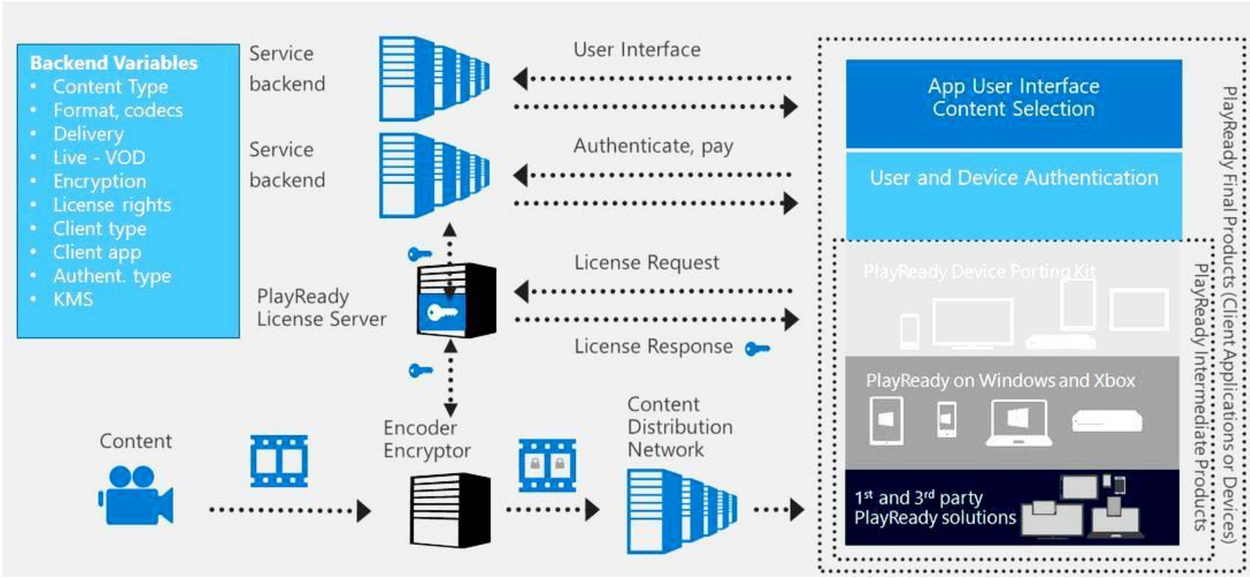

Figure 1. System architecture diagram.

which included monitoring and acquisition system, data transmission system, over standard alarm and fault alarm system, data processing and analysis system, geographic information system, and centralized control system. The system was composed of at least three levels, and the connection mode remained unchanged, but hardware equipment could be deleted and added according to the number of discharge outlets and monitoring points. The first level was set in the sewage discharge unit, which mainly completed the collection, temporary storage, and remote data transmission of sewage and waste gas detection data such as sewage flow, chemical oxygen demand (COD), pH, SO_2, and flue gas density [20]. Camera equipment was used to monitor the operation of pollution prevention facilities and key sewage outlets, compress, and temporarily store image information to realize remote data transmission. The second level was transmission network and database, which was composed of network equipment and database server, which was responsible for regular or real-time transmission of information sent from monitoring points, storing data in the database, and processing a large amount of data received. It mainly included the functions of data recording, remote operation and control, alarm recording, data report, multiple data output modes, realizing data sharing, printing, projection, network data exchange. The third level was Weifang Environmental Protection Monitoring Center located in Weifang city, Shandong, China, which could extract information from monitoring points, exchange information with them, and exchange information with provincial or national monitoring information centers. The system architecture was shown in Figure 1.

Functions to be realized by each layer

The subsystems were layered as follows. According to business logic, the acquisition layer included monitoring and acquisition system and alarm system. The transmission layer included the data transmission management system. Data processing layer included data processing and analysis system and geographic information system. The monitoring layer included the centralized control system. The data acquisition function provided automatic and manual data acquisition modes, which could read the equipment information, monitoring data, operating parameters, working status, and images on the pollution source online monitoring device safely and reliably at fixed time or in real

Table 1. Detection indicators of continuous monitoring system for waste gas pollution sources.

Monitoring items		Assessment indicators
Gaseous pollutant	Accuracy	When SO_2 in flue gas was measured by reference method and NOx emission concentration was ≤ 20 μmol/mol, the absolute error should not exceed ≤ 6 μmol/mol. When it was 20 μmol/mol - ≤ 250 μmol/mol, the relative error should not exceed ±20%. When it was 20 μmol/mol, the relative accuracy was ≤ 15%. When the emission concentration of other gaseous pollutants in the flue gas was measured by reference method, the relative accuracy was ≤ 15%.
Current Speed	Relative error	When the flow rate was > 10 m/s, it should not exceed ±10%. When the flow rate was ≤ 10 m/s, it should not exceed 12%.
Temperature	Absolute error	Not more than ± 3℃
Oxygen content	Relative accuracy	≤15%

time, and enter the classification database, realize real-time display of monitored data and effective monitoring of the operation of instruments and equipment, and ensure the high reliability, timeliness, security, and other requirements of data transmission. If the monitored data exceeded the established standard, the online monitor would display an exception and send a monitoring alarm signal to the data acquisition instrument. The subsequent operation was no different from the general monitoring data until the two types of data were written to different data tables when they were written to the database. The abnormal display would not end until the monitoring terminal processed the alarm signal. If the monitoring equipment failed to effectively monitor the blowdown data, the online monitor would display an exception and send a fault alarm signal to the data acquisition instrument. The processing process was similar to the monitoring alarm. Specific standards were shown in Table 1.
The data processing and analysis unit was connected to the data acquisition instrument at the output end of each line monitor. The data collected and packaged by the data acquisition instrument could be transmitted externally through the network, and the monitoring data could be collected, processed, and stored. The processing operations included filtering and sorting the information and saving the original monitoring information to the database. The data analysis and processing module analyzed the data, returned the analysis results to the control module, made decisions based on the analysis results, conducted appropriate processing, and then transferred them to the display module. The data processing and analysis system aimed to establish a pollution source monitoring database, develop a database management system based on geographic information system (GIS), realize the management of monitoring data query, statistics, report output in different ways, and generate a change process chart or a statistical comparison chart of a pollution monitoring indicator in different periods for the real-time data of the terminal. At the same time, it could cooperate with pollution source information management such as pollution discharge declaration and environmental statistics to provide query and display of pollution source distribution and pollutant discharge.

Detailed system design

The server side included database server, communication server, web server, and GIS server. Clients included PC, video receiving card, plotter, printer, large screen projector. Network communication equipment included switches (routers), hubs, network adapters, network cards, wireless data radio and antennas. Monitoring equipment included various monitoring instruments installed on the cross

Table 2. Used software for the development of system.

Platform classification		Software model	
System software	Server	Windows 2000 Server, Linux	
	Workstation	Windows 2000 Professional (Chinese version)	
Database management software		Oracle9i for windows NT/2000	
GIS software		GIS Analysis software	ArcInfo8.3, Arcview8.3
		GIS Data Engine	ArcSDE8.3
		GIS Displays the published software	MapObject2.2
Develop software		Python 3.11.4	
Other software		Office 2000	

section of the sewage outfall of various enterprises and various monitoring equipment on the pollution control facilities, including online flow meters, online pH meters, COD online monitors, online flue gas monitors, camera guns, processing facility operation recorders and data collectors. The monitoring center system server adopted Linux and used ASP.NET as the development tool. The client adopted Windows XP Professional. The database management adopted SQL Server. ArcInf08.3 was adopted for GIS management. The database server, communication server, and web server used the same configuration with the Intel i9-13900K CPU, 64G memory, NVIDIA RTX3090TI graphics card. The GIS server used China Haida Palm Test World Q5 (China Haida, Shenzhen, Guangdong, China). The details of the software used for the development of the system were listed in Table 2.

The alarm response module integrated the processing functions of several sub modules and played an important role in the processing and control of alarm events. It could obtain event and fault information from various monitoring equipment, network equipment, host equipment, and other subsystems, send it to the data processing and analysis module of the system for relevant processing, connect the geographic information display module, and finally send it to the monitoring center display terminal, and write the alarm information into the database. The alarm response module was responsible for receiving the alarm information from each alarm source, and then sending it to each data processing and analysis module to classify, sort, analyze, and solve the alarm information. At the same time, it was connected to the geographic information display module to display the geographic location of the alarm source on the electronic map. The processed alarm records and original alarm information were sent to the database for storage and to the monitoring center display terminal. According to the system processing flow, the alarm response module was designed into the following three functional sub modules: alarm identification module, integrated management module, and information input module. The function of the alarm identification sub module was to read the basic information of the alarm source, obtain the process name and alarm source number, read the configuration file, obtain the configuration information, create a connection to the database, register with common object request broker architecture (CORBA). The function of the integrated management module was to receive alarm information, conduct preliminary analysis and judgment, and then forward it to the data analysis and processing module and map it to the electronic map. The function of the information entry module was to write the configuration information into the database.

The data summary module was a module that summarized the data in this area within a specified time interval and stored the summary data in the summary database for collection and call by the superior department. Before data summary, the data of the rated operating time of the original equipment of the enterprise needed to be deleted and the pollutant discharge from the daily pollutant discharge table of the enterprise to the monthly pollutant discharge table of the enterprise and the pollutant discharge from the monthly pollutant discharge table of the enterprise to the annual pollutant discharge table of the enterprise were summarized. In the summary process, the daily, monthly, and annual rated operating time of enterprise equipment needed to be set. After enterprise information was summarized, regional pollutant information was summarized. The daily pollution discharge data was summarized, and the original daily pollution discharge data was deleted. The pollutant discharge from the daily pollutant discharge table of the enterprise to the monthly pollutant discharge table of the district and monthly pollution discharge data were also summarized, similarly. The data summary module was also responsible for setting the daily rated running time of the equipment in the area, deleting the information about the rated daily running time of the equipment in the original area, getting the annual rated running time of all enterprises at the same level, inserting the information about the rated running time of the area, and summarizing the daily data of the rated running time of the area. The database centrally stored all kinds of external data and thematic attribute data of pollution sources in the region, and provided management and analysis functions for business data, so that the entire system had query oriented, statistical and analysis-oriented functions. The internal data exchange of the system mainly involved the data exchange between the provincial monitoring center, the municipal monitoring center, and the pollution source enterprises. Data acquisition and exchange were carried out among data acquisition instruments, real-time database, and historical database.

The data table was mainly used to store the data information in the pollution source monitoring business, including pollution source (enterprise) information, pollution source monitoring point (monitoring equipment) information, pollution source discharge outlet information, and the list of pollution factors to be measured at the pollution source discharge outlet, which included real time data, hourly data, and daily data of pollution discharge of pollution sources, alarm data of pollution discharge of pollution sources, operation status information of pollution treatment equipment of pollution sources, daily operation time information of operation of pollution treatment equipment of pollution sources, system operation log table, system error log table, user information table, user authority table, and list of enterprises under the jurisdiction of users. The data acquisition instrument was associated with the pollution control equipment information table through the enterprise number, which was associated with the pollution control equipment operation time information table through the enterprise number.

After the test phase, the COD online monitoring system was put into normal operation. After two months of trial operation, the COD online monitoring instrument was monitored again, and the main indicators of the instrument were reviewed and verified to ensure the accuracy of the instrument monitoring data.

Results and discussion

According to the relevant technical regulations, the accuracy and reproducibility of the online instrument were rechecked, and the potassium hydrogen phthalate test and the actual wastewater sample comparison test were conducted. The test results were shown in Table 3 and Table 4. The COD online monitoring instruments in the pilot enterprises met national standards and operated stably. A pass rate below 60% signaled pollutant discharges exceeding limits, triggering alarm signals to the pollution control facility management. The prompt adjustment of water quality through dosing measures could be done, which improved upon manual sampling and lab analysis, offering

Table 3. Monitoring results of potassium hydrogen phthalate comparison experiment.

Enterprise name	Number of comparisons (times)	Instrument monitoring value range (mg/L)	Standard value range (mp/L)	Relative error range (%)	Assessment criteria	Pass rate (%)
H Thermoelectric	5	98.9-102.4	100	-0.65-3.63	≤8%	100
L Pulp	5	99.7-101.6	100	-1.08-2.65	≤8%	100

Table 4. Monitoring results of actual wastewater samples.

Enterprise name	Number of comparisons (times)	Total number of samples	Instrument monitoring value range (mg/L)	Standard value range (mp/L)	Relative error range (%)	Assessment criteria	Pass rate (%)
H Thermoelectric	5	17	33.7-89.4	32.5-90.2	-2.98-3.55	25-50%	100
L Pulp	5	17	41.7-93.2	38.1-92.1	-1.47-9.58	25-50%	100

resource savings and real-time sewage quality control. The online monitoring system software must meet design specifications, reflecting instrument functions, serving environmental monitoring and management needs, ensuring integrity, compatibility, and user-friendliness while minimizing resource usage. Data transmission system acceptance included fixed IP addresses, network speeds over 10 Mbps with minimal packet loss and delay, along with timely maintenance. During the system's initial commissioning, equipment failures due to incorrect power supply could occur, often due to voltage issues and transmission line faults. Hence, power-on tests before equipment installation were essential to prevent problems like poor insulation, wrong wiring, and equipment damage. Analyzing and identifying incorrect connections was vital for problem resolution. On the other hand, establishing a specialized maintenance team, enforcing environmental department oversight, clarifying ownership of the data adapter to prevent data transfer issues, promptly investigating system alarms, and reporting to higher authorities for swift resolution were also critical to ensure the efficient operation of the pollution source remote monitoring system.

The system supervised and managed monitoring, network, and storage equipment from various manufacturers in the city's monitoring network and successfully collected data, issued over-standard and fault alarms. Both the data acquisition and alarm response subsystems had been deployed citywide, passing operational tests. Handling nearly 200 million items, it improved pollution source monitoring and management. Insights gained from primary pollution source analysis extended to power systems, promoting sustainable, environmentally responsible energy practices. This framework integrated environmental considerations into power system operation, advanced energy conservation and environmental protection. The research bridged the gap between power systems and environmental concerns, fostered a more sustainable, environmentally conscious energy management approach.

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