Abstract: The Reactive Power & Voltage Real Time Monitoring System (RPVRTMS) had been developed on the information and database of the Supervisory Control And Data Acquisition (SCADA), Load Management System (LM), Distribution Management System (DMS) to help the relative person to know the system reactive power flow on time, the voltage deviation at the main monitoring point and the operation manner of the reactive power equipments and the voltage regulation equipments. Thus the relative operator can enhance their operation management and take the optimal measures to improve the voltage quality and reduce the line loss of the system. The Monitoring system consists of the following eight modulars and main functions: management of reactive power equipments and voltage regulation equipments, operation management of reactive power and voltages, statistics of allowable Voltage deviation acceptance ratio, statistics of power factor, load management of the network and, system reactive power flow monitoring, intelligent analysis, compile statistical report etc.. The Monitoring system had shown their good results in help the operator to manage the voltage level and reactive power flow under the optimal condition since the system put into operation.

Keywords: Reactive Power, voltage; real-time; monitoring

1. Posing of Problem

In order to improve the reactive power and voltage real-time monitoring of the power distribution network, we have developed a special system to serve this purpose. The idea is that, by using existent real-time data resources of the systems for SCADA, DMS, etc. of all power supply bureaus, the seamless interconnection and effective integration of the systems for SCADA, DMS, etc. and management information system (MIS) of the enterprises are implemented. In this way, a secondary development is effected in the MIS of the enterprises thus forming a relatively independent reactive power and voltage regulating monitoring system (RPVRTMS) of power distribution networks to realize data resources sharing and comprehensive utilization.

The aim of the development of the reactive power and voltage real-time monitoring system (RPVRTMS) of power distribution networks is as follows:

(1) To carry out the secondary development into the data and reports needed by reactive voltage managing personnel by using related reactive power and voltage real-time information and data in all automation systems;
(2) To realize the real-time monitoring of voltage values and reactive voltage regulation equipment at main monitoring points;
(3) To realize the computerized management of the entire process according to the requirements of the reactive voltage management.

The relationship between the reactive power and voltage-regulating monitoring system of power distribution networks and existent automation systems can be denoted in Fig. 1.

![Fig. 1 Relationship between RPVRTMS and existent automation systems](image)

2. System environment and developing tools

Considering the fact that it is necessary to employ existent software and hardware resources of MIS of current power supply enterprises to reduce the input of funds, we have chosen the following system environment as follows while designing and developing the system. The software development is ORACLE 8 or ORACLE 8i. The network environment is the local net work that supports the TCP/IP protocol. The front-end customer’s machine is one operating using WINDOWS 98/2000/XP with the customer’s end software installed. The system is completely configured in the existent operating environment of MIS of enterprises. Except for the input needed for developing the software, it is not necessary to put in any additional funds for software and hardware. In the system, the software is worked out by integrating C/S with B/S structures. The customer’s end of the C/S structure is developed with powerbuilder 8.0. The web page of the B/S structure is developed with JSP. The graph space is developed with VB. The data transmitting and receiving program is realized with VC++.

3. Design of system function modules

In terms of the management requirements, the reactive power and voltage real-time monitoring of power networks is split into 8 management modules, that is, modules for system management, reactive power and voltage regulation management, reactive voltage operation management, allowable voltage deviation acceptance ratio statistics, network load management and power factor statistics, system power flow distribution diagram, intelligent analysis, and statistical reports. The block diagram of the system is...
shown in Fig. 2.

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Fig. 2. Function modules of the system

4. Major technical difficult points and solutions

4.1 In order to get the real-time data needed by the system, it is needed for the system to acquire the data from other systems like SCADA, DMS, LM, etc. But as all the other systems have their own safety and protection requirements, it is impossible for this system to directly access the data from the databases of other systems. As a result, we have specially developed a multi-route message request transmitting and receiving program that follows the TCP/IP protocol. The program is used to receive, in a centralized way, the real-time data transmitted from other systems to assure the seamless interconnection and effective integration of other systems with MIS of enterprises. The main idea is that the message format and content are united; a data-transmitting program is designed in the light of the requirements on respective safety and protection in other systems; a message request transmitting and receiving program is designed in the system. In the system, a message to request to transmit data is sent over to other systems as needed. Other systems send over real-time data message according to the request message. After receiving the data message, the system writes the data into the database.

4.2. As there is a huge volume of real-time data received from other systems (The data volume per day amounts to as many as hundreds of thousand pieces), the time lasts very long (as long as tens of minutes) and this greatly affects the operating speed of the MIS of the enterprises even in such a large database system as ORACLE if the statistics of the data needed is made during inquiry. For this, we have purposely developed a set of statistical survey program to render all the time- and energy-consuming statistical task to be automatically allocated to be done at one to three o-clock in the early morning when there is the lightest database load. In this, not only is the system performance tremendously raised but the load of the database and network is alleviated as well.

4.3 In order to display the real-time power flow diagram of the system and makes it easy for the customer to edit, manage and operate various diagrams, the system has developed special graph control software. The graph control software has two working states, i.e., editing state and display state. When in the editing state, in addition to editing basic graphs, the customer is also able to define sub-diagrams, which will help him to work out special power network diagrams. Importantly, the customer is enabled to define the real-time data and statistical data to be displayed at the designated position thus causing the graphs and data to be connected closely. Finally, graph elements and data objects defined by the customer can be stored in the database. When displaying the state, the operations such as graph enlargement, contraction and wandering, etc. can be made without deformation, which makes it easy for the customer to view and analyze the data.

5. Main functions of the system

5.1. System parameter maintenance

System parameter maintenance is an important component of the system, which is an interface for the setting of all important parameters, and management and maintenance of the off-line data, i.e., equipment desk account and daily defects and the basis on which to carry out normal operation. The system maintenance also covers off-line data input and some other essential functions to increase the flexibility, adaptability and safety for the customer.

5.2. Reactive power and voltage equipment management

The reactive power and voltage equipment management is separated into two parts – equipment desk account and device defects. The main goal is to work out a set of complete materials associated with the part of reactive voltage management and to deepen the management. This will help professional managerial personnel to be greatly informed of the present situation of the equipment under his jurisdiction, replace and transform the used equipment in a planned and step-by-step way, and the operation state of the equipment made by various manufacturers, thus supplying dependable information about type choice and ordering of equipment.

The equipment desk account and equipment defects category include the desk account and equipment defects records of loaded voltage-regulation capacitors of the substation, desk account and equipment defects records of reactors of the substation, desk account and equipment defects records of automatic voltage-regulation control devices of the substation, desk account and equipment defects records of 10KV line reactive compensation parallel capacitors, desk account and equipment defects records of 380V low-voltage inaction dynamic compensation boxes, desk account and equipment defects records of capacitors of the customer, and desk account and equipment defects records of statistical-type voltage monitor.

There are abundant inquiry functions in the desk account and equipment defects module, in which the statistics and enquiry can be made by using the conditions or combined conditions concerning equipment types and defects types, manufacturers, production dates, commissioning dates, etc. In addition, relevant statistical reports can be printed. An example of a desk account of the capacitors at the substation is indicated in Fig. 3.
The reactive power and voltage operation management module is used to make recording and statistics of the operation of reactive equipment. The data is derived from the real-time information of the SCADA system. The recording and statistics can be made respectively in light of the types of various equipment. The recording is made concerning the change before and after the shifting of the main transformer loaded voltage-regulation switch, before and after the ON/OFF operation of the capacitor (reactor), reactive power, power factor and bus voltage on the sides of the main transformer, the daily and accumulative statistic times of the loaded voltage-regulation switch shifting of the main transformer, the ON/OFF times of the capacitor (reactor). From the recording, the managerial personnel are able to monitor if the reactive power and voltage-regulation equipment effect the voltage regulation as required in order to take timely actions to enhance the system voltage acceptance ratio and power factor and meanwhile help production and managerial personnel to timely shoot the trouble existing in reactive equipment and voltage-regulation operation and protect the reactive power and voltage-regulation equipment from damages resulting from improper operation. Fig. 4 denotes an example of the inquiry of the operation of the load voltage-regulation switch.

5.4. Voltage deviation monitoring module

The voltage deviation-monitoring module is mainly employed to conduct real-time monitoring of the voltage deviation of subordinate units and main monitoring points of the power network. The data comes mainly from real-time systems like SCADA, LM, DMS, etc. The 380V (220V) customer end voltage data is derived from the monitored data of voltage monitors at the voltage monitoring points. In the module, the integrating and processing of the data are carried out and the real-time monitoring of the voltage deviation at main monitoring points of the power network is effected according to requirements of voltage management. The main functions are as follows:

5.4.1. Statistical functions: To convert transient values of the voltage monitored at main monitoring points of all the systems into statistical values, categorize and summarize them as required and make statistics of the daily (monthly, quarterly or yearly) allowable voltage deviation acceptance ratio, ratio close to the upper limit, ratio close to the lower limit, allowable deviation acceptance ratio of voltage of various types at monitoring points of all grass-root units, allowable acceptance ratio of the voltage of all grades, allowable voltage acceptance ratio of the buses on the sides of all the substations, and allowable voltage acceptance ratio of monitoring points.

5.4.2. Monitoring functions: The real-time monitoring of the voltage deviation of main monitoring of the power network is conducted. When the network is operating with the voltage deviation above the upper limit or below the lower limit, an alarming signal will be given out requiring the operators to make timely voltage regulation.

5.4.3 Inquiry functions: The inquiry can be made as per units, types of monitoring points, substations, voltage grades, time intervals, and comprehensive conditions. In Fig. 5 is shown an example of a monthly inquiry of the allowable voltage acceptance ratio of a low-voltage network.
5.5. Power network load management and power factor statistics

The power network load management and power factor statistical module is mainly used to carry out the real-time monitoring of the reactive power equilibrium at the network interface. The data originates from such real-time systems as SCADA, LM, DMS and remote meter readings of power, etc. In the module, integration or processing of the data is made in terms of the requirements of reactive power management. This forms the long-circle historical recording, thus accumulating raw data for the reasonable layout of the system reactive equipment, network loss theoretical calculation, and network reactive optimizing calculation. The statistics of the inquiry contents is as follows:

5.5.1. The network-wide reactive load and power factor under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of network-wide power peak, normal or valley electricity amount, total electricity amount and corresponding power factor.

5.5.2. The regional reactive load and power factor under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of regional power peak, normal or valley electricity amount, total electricity amount and corresponding power factor.

5.5.3. The active load, reactive load and power factor for all voltage grades in the power network under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of regional power peak, normal or valley electricity amount, total electricity amount and corresponding power factor.

5.5.4. The active load, reactive load and power factor of the general meter at three (two) sides of the main transformer in all substations under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of regional power peak, normal or valley electricity amount, total electricity amount and corresponding power factor at three (two) sides of the main transformer in all substations under the network-wide maximum (minimum) active load per day (month, quarter, or year).

5.5.5. The active load, reactive load and power factor of all 35KV-110KV lines under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of regional power peak, normal or valley electricity amount, total electricity amount and corresponding power factor of all 35KV-110KV lines under the network-wide maximum (minimum) active load per day (month, quarter, or year).

5.5.6. The active load, reactive load and power factor of all power customers under the network-wide maximum (minimum) active load per day (month, quarter, or year); presence (absence) of regional power peak, normal or valley electricity amount, total electricity amount and corresponding power factor of all the power customers under the network-wide maximum (minimum) active load per day (month, quarter, or year).

An example of inquiry of the power factor on the three sides of the main transformer is denoted in the following. The electricity amount data is from the remote meter reading system of electricity amount. An example of the statistical power factors at the three sides of the main transformer is indicated in Fig. 6.

5.7. Intelligent analysis

By using the operation of the reactive equipment and the statistical results of the data of all kinds, the comprehensive analysis and logic judgment are made according to the principle of local reactive equilibrium, voltage priority and adverse voltage regulation. Combined with the power network operation form, the network voltage regulating program is provided. The person on duty is able to conduct the voltage and reactive power regulating in terms of recommended program. This has overcome the drawbacks such as the frequent actions of comprehensive voltage-regulating equipment and non timely of manual voltage regulating, etc. The module also has the functions like reactive check, determination of reactive compensation...
capacity of the substations and lines. In Fig. 7 is shown a diagram indicating that the capacitor, through intelligent analysis, should be put into operation at a substation of a certain subsidiary of the Shaanxi Provincial Power Company.

Fig. 7 Intelligent analysis diagram – Ancun substation
Note: Reactive power compensation needed, please put capacitor I into operation

5.8. Network reactive power flow distribution diagram
In order to make real-time monitoring of the distribution power cross the network and enable the managerial personnel to clearly view the reactive power flow of the system, the system has designed the network reactive power flow monitoring module as per the management requirements. The values of the network active and reactive power flow and the voltage of monitoring points are from the SCADA system, and the active and reactive power amount are derived from the remote electricity amount meter-reading system. Within the module, the data is integrated and processed into the data needed by the reactive voltage management. The contents to be monitored consist mainly of the following: drawing the network real-time active and reactive power flow distribution diagrams according to voltage grades; drawing the real-time power factor distribution diagrams at all monitoring points across the network according to voltage grades; making real-time display of the bus voltage at all substations according to voltage grades; drawing of the daily (monthly, quarterly, or yearly) distribution diagrams for active and reactive electricity amount, power factor, voltage acceptance ratio, etc. according to voltage grades. Fig. 8 shows an example of the voltage values at all monitoring points of the Xianyang Network.

Fig. 8 Example of the voltage values at all monitoring points of the Xianyang Network
Note: Title of window: Reactive power and voltage management system – [110KV real-time power flow diagram]

5.9. Reports management
According to management requirements, 30-plus comprehensive statistic reports of various categories are worked out by using statistic data. There are five main categories – equipment desk account report, reactive power and voltage operation report, voltage acceptance ratio statistic report, power factor statistic report, and comprehensive statistic report. This can meet the requirements of reactive power and voltage management of the network, making it possible to realize penless office work of the reactive power and voltage management work. Fig. 9 denotes a statistic report of the allowable voltage deviation acceptance ratio of the Xianyang Power Supply Bureau in September 2002.

Fig. 9 Statistic report of the allowable voltage deviation acceptance ratio of the Xianyang Power Supply Bureau in September 2002
Note: Title of window: Reactive power and voltage management system – [Report management]

6. Application results of system
At the beginning of 2002 when the system was put into
use in a certain subsidiary of the Xianyang Power Supply Bureau, good results were obtained that can be summarized as follows:

6.1. The work of voltage deviation real-time monitoring and allowable voltage deviation acceptance ratio statistics at more than 200 voltage monitoring points across the power network was put into use. This helps to timely adjust the system voltage in terms of monitoring and statistic information resulting in an increase of one percentage point of the bureau-wide comprehensive allowable voltage deviation acceptance ratio when compared to the period prior to the application of the system.

6.2. The real-time monitoring of the reactive power and voltage-regulation equipment was realized, which guides the operating personnel to timely adjust the voltage as needed by the system. The line loss rate of the power network was lowered to a large degree when compared to the previous period before the system was put into operation. In the period from January to October, 2002, the 35kV-110kV line loss rate was lowered by 0.52 percentage point compared to the same period last year. When compared to the line loss rate index last year, 15 million kWh electricity amount was saved, which means a saving of 6 million yuan when converted into RMB (people’s currency).

6.3 The reactive power and voltage management level was raised, realizing the data sharing and integration of all the automatic systems and the computerization of the entire process of the specialized management of voltage reactive power. The system also helps to reduce the labor intensity of managerial personnel. The statistic work volume that was carried out by 7 to 8 persons for five days each month is now done by computers automatically. Moreover, the former monthly statistics is turned into the current real-time one with additional abundant inquiry functions so as to provide a large amount of raw data for the network safe production and operation and management.

6.4. The application of the system makes it possible to carry out all-round monitoring of voltage deviation and to save a great amount of hardware investment. From statistics, the Xianyang Power Supply Bureau has saved more than 200 voltage monitoring meters, which is equal to a saving of 0.6 million yuan (RMB). With the consecutive improvement and application of the system, it is possible to replace step by step the comprehensive control and voltage regulating devices, which means an additional saving of 1.4 million yuan (RMB).

The investment in the software and hardware is about 0.7 million yuan. The investment can be returned after the application of more than a month. So it results in a good economic result.

7. Conclusions

The development and application of the system has made it possible for the monitoring and managerial work of the voltage and reactive power of the power network to enter into a stage from the simple monitoring statistics to the systematic and comprehensive assessment so that the data of all the application layers can be shared and applied, the efficiency can be increased and the establishment, regulating and control of the reactive equipment can be reliably supported by the practical data. With the expansion of the functions of the system, the real-time monitoring and statistic operation of the network line losses, real-time theoretical calculation of the network line loss, the network reactive optimizing theoretical calculation, etc. can be effected step by step. However, the network reactive voltage management work is of a larger domain. With the intensification of the serves for customers, it is necessary to put into consideration a number of such electric power indexes as harmonic wave, three-phase unbalance, voltage fluctuation transient change, voltage drop, etc. when supplying qualified power to customers apart from the index of voltage deviation. As a result, it is needed to put into the system the monitoring of the above new indexes when making its further improvement to enable the functions of the system to be bettered incessantly.