Research on Rural Distribution Network Reactive Power Dynamic Monitoring and Auto-Compensation System

Xiujie Zheng[1], Jianbo Yi[2,*] and Qian Wang[1]

[1]Chengdu College of University of Electronic Science and Technology of China, Chengdu, China

[2]School of Energy Science and Engineering, University of Electronic Science and Technology of China, Chengdu, China

[*]Corresponding author

Abstract—This paper proposes a novel reactive power dynamic monitoring and auto-compensation system for rural distribution network. The proposed system employs advanced reactive power measurement, Data Transfer Unit (DTU) and hybrid network communication. The technology based on Internet and General Packet Radio Service (GPRS) to achieve remote data exchange between control center and each distributed reactive power compensation equipment. Then the developed scheduling software in control center server will quick compute the best scheme of reactive power compensation according to the upload data and dispatch switching command by reverse communication pathway to implement dynamic reactive power compensation. Finally, the application test validates that the proposed system has good performance in reactive power dynamic monitoring and auto-compensation, and effectively guarantees the power quality in rural distribution network at the same time.

Keywords-component; rural distribution network; reactive power auto-compensation; GPRS

I. INTRODUCTION

The rural distribution network is a great important link of the power supply in power system. Its operation and management tasks will effect power quality and security directly. With the increasing and expanding distributed feeders and diversified loads in most rural distribution network, the issues of excessive active power loss, reduction of power factor and voltage level happened in rural distributed feeders become worthy of attention. Especially, increasing penetration of photovoltaic (PV) and wind generators, as well as increasing peak load demand, has resulted in poor voltage profile for some distribution network [1]. The integration of smart grid technologies along with improved feeder monitoring capabilities have led to a renewed focus on voltage and reactive power control on power distribution systems. Economic and operational benefits result from effectively managing the voltage profile and feeder power factor. In [2], the research focus on the way of fixing high-voltage capacitor on the 10kV branch line and integrating the controller of the capacitor with the protective device of circuit breakers on the branch line. Then a peak load management scheme for rural area is presented in [3], which methodology is for determining the best location for the non-embedded generators as well as the number of generators required to alleviate network problems. While monitoring, control, and communications technologies are rapidly evolving, many application researches have been proposed to improve the power quality of distributed feeders and the real-time operation management level of rural distribution network. In [4], a novel management tool is proposed to manage the distribution voltage profile and reactive power flow to achieve economic and operational benefits. Also the power should be restored in a reasonable amount of time, which in [5] emphasizes the significance of an appropriate switch placement strategy and reserve power planning. This paper proposes a methodology to analyze the costs of different reserve power strategies and to optimize the reserve power arrangements.

There are many challenges particularly regarding electricity supply to rural and remote areas in the developing world. In such countries, potential customers in developing areas have a limited knowledge of modern energy services and uses [6]. Now, some electric power companies of rural areas have installed many kinds of devices and systems supporting distribution automation systems (DAS) to improve the network structure and reinforcing management [7]. This typical management is presented in [8, 9], which integrate with the advanced communication with GPRS network and feeder measurement technology based on AMI. This system can monitor the operating situation and status of breakers, detect and locate the fault of the feeders and help realizing the advanced distribution operation, such as improve power quality, loss detection and state estimation. An improved power distribution management is viewed in [10] to improve intelligence level of the rural 400V power distribution grid, which employ ARM-LINUX based intelligent measurement terminal and mobile (GPRS/CDMA/3G/4G) network to transfer grid parameters and other information. An improved TS algorithm is put forward on the condition that reactive power compensation location and capacity to realize reactive power optimization have been identified in rural distribution lines [11]. Paper [12] presents combining with PLC and GPRS module to realize digital bidirectional communication in 35kV, 10kV and 380V distribution network. With the development of information technology and smart grid, an application research in India where supply is sporadic or highly interrupted is presented in [13], which proposes Microgrid Control Center (MGCC) using low-cost PIC controller which handles the load

management based on dynamic or scheduled inputs to improve the power quality at the tail-end of the grid-connected network.

According to the above analysis, the feasible solution of power quality and reliability in rural distribution network is necessary to establish a real-time monitoring and reactive power compensating system based on modern communication and data acquisition technology. This paper will propose a novel reactive power dynamic monitoring and auto-compensation system for rural distribution network. The proposed system employs advanced reactive power measurement, DTU and hybrid network communication technology based on Internet and GPRS to achieve real-time data exchange between control center in scheduling room and each compensation devices. The organization of this paper is as follows. The system structure is proposed in Section II. Some key technologies closely related to application system are described and implemented in Section III. System testing and discussions results of application system are shown in Section IV and the conclusions are summarized in Section V.

II. SYSTEM DESIGN

In this paper, the designed dynamic monitoring and auto-compensation system uses GPRS-DTU as its wireless communication terminal. This scheme is able to realize the conversion of serial data to IP data, and then design the developed client application software as center of monitoring and management of reactive power in rural distribution network. The communication link of designed system employs GPRS wireless network as its remote communication support between Data Transfer Unit and client application software.

A. System Structure Design

Figure I shows the system structure designed in three parts, including job site, communication network and control center. The job site is a composite of lots of distributed power feeder lines, huge number of reactive power compensation equipments and many matched DTU devices. In each reactive power compensation point, matched DTU conducts collecting the information of feeder's power factor and publishing switching instruction to compensation equipment using serial commutation. DTU is a wireless terminal device used to transfer serial data into IP data or to convert IP data into serial data through wireless communication network. Real-time data from job site are gathered and transported through serial lines and DTU communication terminal. From the reverse direction of data flow, switching commands sent by sever of dispatching center through internet fed back to compensation equipment which work in the capacitor group graded switching mode.
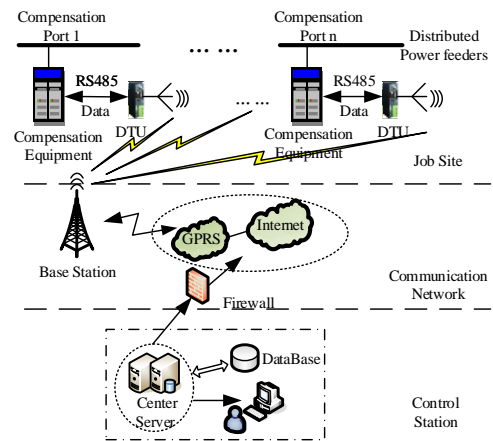

FIGURE I. STRUCTURE OF THE PROPOSED SYSTEM

The second part is the communication network. GPRS + Internet communication mode is employed to form a network data transmission system. GPRS-DTU terminal units connect Internet using GPRS network, and its signals sent forward by GPRS mobile service network. The main advantages of GPRS data service are to have high data transfer rates and maintain link online permanently. Although the transmission rate of the 3G/4G data service is better than the GPRS, analyzing from the national conditions, especially in small towns and remote rural areas there have not yet covered by 3G/4G, so the GPRS service for data transmission in this system is more feasible. Control center server connects to Internet via dedicated line, which can access the DTU terminal finally through network programming technology.

The third part is the control center, which main function is to monitor the data communication and the running states of distributed power feeder lines. The control center also provide data sending, receiving, processing and display services, so that the dispatcher working in the control center can real-time monitor the reactive power shortage in each distributed power feeders, then publish compensation commands through communication feedback loop of dynamic IP in DTU terminal.

B. System Function Design

According to the actual needs of reactive power monitoring and remote auto-compensation control for distributed power feeders, there are three core functions in the designed system: supervision and control station, information transmission platform, and compensation client. Shown in Figure II, the entire system utilizes mode of Client/Server (C/S), furthermore the system employs the synchronous remote database access (RDA) and compressing data transmission two kinds of technologies to achieve data exchange between client and server. The core function of supervision and control station is to implement reactive power and capacitor switch states monitoring of distributed power feeders, as well as reactive power shortage computing, measurement and control data communication with compensation equipment controller in real time. The interactive application interface of supervision and

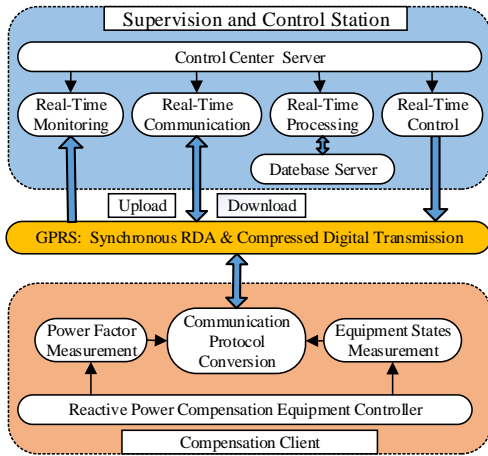control station is exploited by VC++, SQL server database technology and data decompression technology.

FIGURE II. SYSTEM FUNCTION MODULES DESIGN

The information transmission platform is used to deal with the deficiency of information communication interaction in traditional reactive power compensation. GPRS-DTU module is connected to compensation equipment via RS-485 serial line, so the information interaction between GPRS-DTU module and compensation equipment is a two-way process. Once GPRS-DTU module is powered up, the connection request is sent to the control center server which must have a fixed IP and connection will be established when dynamic IP is assigned. After that, DTU can transfer data to server by socket connection. These socket connection will be disconnected when transmission is finished, but there are still virtual network connections in order to wait for the next connection. The remote compensation client conducts monitoring power factor of power feeders and power reactive compensation equipment sates and uploading data to the server station in real time using the DTU wireless module. Then the compensation is responsible for executing capacitor switch command according to remote feedback control information downloaded by supervision and control station.

III.   KEY TECHNOLOGIES REALIZATION

A.   Communicaion Flow

To ensure the distrusted power feeders monitoring and reactive power compensation in real time and using efficient manner, it is necessary to build a communication link with strict operating procedures. Figure III is overall function modules and operating process diagram of reactive power compensating and monitoring system, which shows a type of two-way communication flow between the compensation equipment controllers and control center server.

In order to achieve mutual communication in each part of the whole system, socket the communication mechanism is used, which is a relatively simple network program implementation, and is a bridge for connecting the application and network drivers. Through socket connection, the relationship between GPRS-DTU terminal and the control center server can be established reliably.
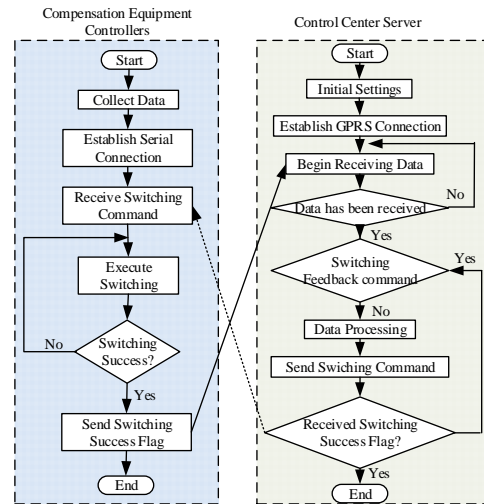

FIGURE III. COMMUNICATION FLOW OF THE SYSTEM

Field compensation equipment gathers power parameters, and sends these data to the control center server through the established GPRS connection while listening/monitoring server control commands. Once receive commands from the server, field compensation equipment will switch capacitor banks automatically, and feedback to the server at the same time. The received data will be processed by algorithms of the server, which can guide on-site equipment operation by the operator of control center.

B.   GPRS Communicaion Stragedy

The GPRS communication interface flow of the server-side is shown in Figure IV. On the server side, power parameters are bound together with monitor interface components, so that SQL Server database can store received power parameters and some secondary data such as loss of distribution lines, loss of power and other data can be calculated from these primary data. Operator can visually check and compare historical data or trend curves and other observed parameters by interactive monitoring interface.
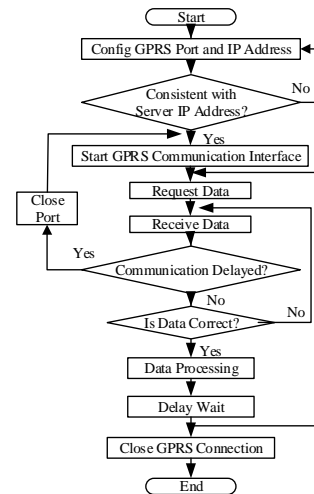

FIGURE IV. GPRS COMMUNICATION INTERFACE FLOW

The system uses some Chinese company's compensation device which model is LBZWB and the communication protocol use R485 as its serial communication interface, which Baud rate is 57600bps, 8 data bits, 1 stop bit and no check digit.

The command frame format for reading real-time data includes upstream and downstream frames. The two formats of upstream and downstream are consistent in Figure V (a) and (b), which can be divided into three parts: The header, the core data and the tail. In Figure V (a), the head of frame Consists of 2 bytes representing initial symbol, address symbol, control symbol and all the byte numbers from the control domain to the checksum. The core data part includes 5 groups of data, which is voltage, current, active power, reactive power and power factor of distributed feeders before and after control. Each item

contains two bytes represented in sixteen decimal, the high byte is in front and the low byte is in the back. When center server receiving data, center server need to verify the correctness of data by comparing the data of each frame start character and checksum of the data stream, then parse the data and extract useful information. The uploaded data of distributed feeders will be displayed on the monitor interface after data parsing completed. Further data processing such as estimating power factor and line loss power will help to determine compensation parameters according to Figure V (c), then the generated control command of capacitor switching in each distrusted feeders will be sent to each reactive power compensation controller. All of these designs realize the advanced automation of rural power distribution line monitoring and compensation.

(a) Upstream

Byte Number	Contents
0	68H(Start Character)
1	L
2	L(Repeat)
3	68H(Repeat)
4	Control Field (c)
5	Address Field (a)
Variable-length User Data	Type Identification
	Varistructure Qualifier
	Transmission Reason
	Public Address of Application Service Data Unit
	Function Type
	Information Number
	Information Element Set
1 byte	Checksum
1 byte	16H(End Character)

(b) Downstream

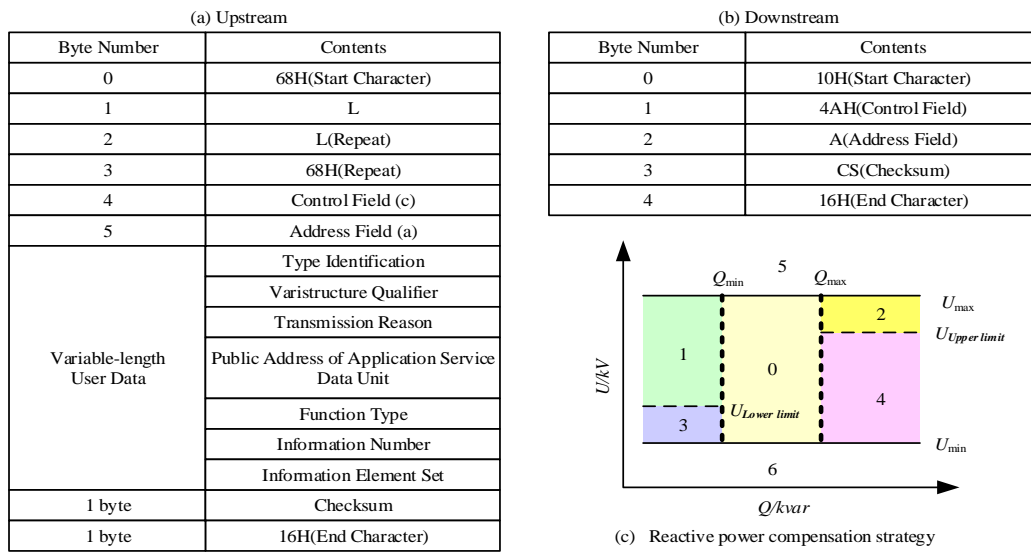| Byte Number	Contents
0	10H(Start Character)
1	4AH(Control Field)
2	A(Address Field)
3	CS(Checksum)
4	16H(End Character)

(c) Reactive power compensation strategy

FIGURE V. (A) IS UPSTREAM DATA FRAME FORMAT, (B) IS DOWNSTREAM COMMAND FRAME FORMAT AND (C) IS THE CONTROL STRATEGY MAP OF REACTIVE POWER COMPENSATION

IV. APPLICATION TEST

The rural distribution network reactive power dynamic monitoring and auto-compensation system is presented in the above description. To illustrate the application of the above system and test its validity and reliability, the proposed system is tested and applied in Sichuan Electric Power Company Jianyang Power Supply Bureau.

Case 1: server and remote controller communication test. The system that has been put into use contains 1 center sever and 30 remote distributed compensation equipment controllers. Each distributed power feeders at monitoring state, there is 1 upload data package every 10 minutes, unless the voltage of monitored feeders skip over the lower or upper limits like shown in Figure V (c), or its power factor drop to below 0.8. At that situation, the compensation equipment controller will send the real-time monitoring data to center server promptly. When center server receive the upload monitoring data, control command of each feeders reactive power will be generated and issued to corresponding equipment controller with downstream

package. There are 24 hours communication test results shown in Table I.

TABLE I. COMMUNICATION TEST RESULTS BETWEEN CENTER SERVER AND REMOTER CONTROLLERS

Item	Normal upload	U limits trigger	Power factor trigger	Command download
Data package	4320	28	12	86
Success rate	99.2%	100%	91.7%	97.7%

The test results in Table I show that the function design of communication connection between center server and compensation equipment controllers has good performance, while the transmission of monitoring upload and command download data mentioned Internet, mobile network and data protocol has high success rate. In actual test, the phenomenon of the data failed to upload and download appear in GPRS disconnection, because the GPRS service is a very unstable system in actual operation. In the practical application of proposed system, to improve the both sides data transmission

reliability, multiple transmission and retransmission timeout are used to make the communication module performance more perfect.

Case 2: reactive power dynamic compensation test. The compensation equipment distributed in different place adopts the form of fixed compensation + dynamic compensation, which means fixing a base amount of compensation capacity first, and compensating a certain capacity according to the actual needs. The center sever knows the reactive power shortage of each distributed power feeders through monitoring the upload measurement data, and send the switching command to the compensation equipment controller to achieve reactive power balance. The control strategy as shown in Figure V (c), the voltage U and reactive power Q are used as 2 comprehensive discriminant quantities and the control plane is divided into 6 regions. Region 0 represents the voltage and reactive power are of good quality, region 1 and 5 represent higher voltage and need to remove compensation capacity, region 2 and 3 have no control action, region 4 and 6 represent lower voltage and need to switch compensation capacity. In the actual application test, the 35kV power feeders, which compensation equipment is separately installed at the 1/3, 2/3 and end, the 10kV and the 6kV power feeders just installed compensation equipment at the end are selected as monitoring lines. The test results of reactive power compensation effect in different feeders are shown in Table II.

TABLE II. TEST RESULTS OF REACTIVE POWER COMPENSATION EFFECT

Item		Pre Compensation					Post Compensation		
		Voltage kV	*Power factor*	*Shortage Q kVar*	*power loss P kW*	*Compensation Q kVar*	*Voltage kV*	*Power factor*	*power loss P kW*
35kV	1/3	36.1	0.93	4.2	24.2	0	37.6	0.96	2.5
	2/3	34.5	0.88	11.1	55.6	5	35.8	0.95	4.4
	End	32.4	0.81	29.4	148.3	20	34.6	0.94	11.8.
10kV		9.2	0.82	6.9	29.4	6	9.9	0.96	3.5
6kV		5.2	0.84	3.7	10.3	3	6.1	0.98	1.4

The test results in Table II show that the reactive power dynamic monitoring and auto-compensation performance of proposed system has good application effect. After the auto-compensation command executed in each distributed feeders, the power loss of the certain feeder is reduced greatly, meanwhile the end voltage and the power factor of distributed feeder are improved. In practical application, the proposed system can meet the remote control of the on-site compensation equipment. The case 1 results test and verify the system has high stability and reliability, and the case 2 results verify the system for reactive power compensation of distributed feeders has good practical effect. Furthermore, the proposed system will have great application value in rural power grid.

V. CONCLUSIONS

A novel reactive power dynamic monitoring and auto-compensation system for rural distribution network is proposed, which implements remote data exchange between control center and each distributed reactive power compensation equipment with hybrid network communication. In addition, the developed software can achieve the functions of data transmission, data processing and remote compensation capacitors controlling. Finally, the application test validates that the proposed system has good performance in reactive power dynamic monitoring and auto-compensation, and its technical method should be widely used in other remote and mountain areas power grid.

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