Design and Application of a Novel Grid-Connected Interface Device for Distributed Generation Postprint

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Abstract

To effectively manage distributed power sources, the DARI-3317 distributed power grid-connected interface device has been designed and developed. This device integrates not only protection, measurement and control, anti-islanding, power quality monitoring, protocol conversion, telecontrol, and information encryption functions, but also enables real-time feedback of power station information to the dispatching master station, accepts remote control for switching operations at the point of common coupling and inverter start/stop, thereby achieving real-time monitoring of distributed generation systems from the dispatching end. Furthermore, the software and hardware platform design of this device features open interfaces and expansion margin, facilitating future expansion and technical upgrades and ensuring a longer effective service life cycle for the device. The DARI-3317 distributed power grid-connected interface device has been officially commissioned at a distributed photovoltaic power station of the State Grid and validated through practical engineering applications.

Full Text

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Design and Application of a New Type Grid-Connected Interface Device for Distributed Generation

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Abstract

To achieve effective management of distributed generation resources, the DARI-3317 distributed power grid-connected interface device has been designed and developed. This device integrates multiple functions including protection, measurement and control, anti-islanding, power quality monitoring, protocol conversion, telecontrol, and information encryption. It enables real-time feedback of power station information to the dispatching master station and accepts remote commands for switching the point of common coupling and starting/stopping inverters, thereby realizing real-time monitoring of distributed generation systems from the dispatch center. Furthermore, the hardware and software platform features open interfaces and ample expansion margins, facilitating future upgrades and extending the device' s effective lifecycle. The DARI-3317 has been successfully commissioned at a State Grid distributed photovoltaic power station, validating its performance through practical engineering application.

Keywords: Distributed generation, grid-connected interface, hierarchical distributed architecture, protection, measurement and control

Author Biographies

Lin Qiyou (born 1976, male) is a senior engineer engaged in power grid planning and operation control, power market analysis, and power transmission and distribution automation.

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1 Introduction

Developing clean energy represents an inevitable trend. In recent years, China has vigorously promoted energy structure optimization, yet the dominance of coal as the primary energy source remains unchanged, accounting for over 60% of primary energy consumption. In 2014, non-fossil energy represented only

11.1% of China' s primary energy consumption [1]. Currently, most distributed generation resources connect to distribution networks, transforming traditional radial distribution systems into interconnected networks with numerous small and medium-sized power sources and users, which profoundly impacts conventional distribution systems [2-4]. Distributed generation resources are widely dispersed and difficult to manage. Without effective management, they pose safety hazards for grid operation, maintenance, and inspection, directly affecting power system security and stability. Therefore, designing and developing an integrated distributed power grid-connected interface device is essential.

Research on distributed generation grid integration has become a hot topic [5-7]. Reference [8] summarized the development and application of distributed generation integration, analyzing grid-connection technologies and systems containing distributed generation, with detailed discussions on operation and control aspects. Reference [9] utilized the PS50CLA120 IPM intelligent module for the main inverter bridge and the TMS320LF2407 digital signal processor as the control chip, analyzing countermeasures for distributed generation devices under islanding conditions and proposing possibilities for comprehensive grid-connected control systems along with corresponding control strategies, though without analyzing grid-side requirements for distributed integration. Reference [10] developed a distributed photovoltaic grid-connected interface device with functions including protection, measurement and control, power quality monitoring, operation control, communication management, telecontrol, and information security encryption, achieving real-time monitoring of distributed photovoltaic systems from the dispatch center. However, this work focused on individual device functions without considering communication channel requirements and field application adaptability.

Addressing these issues, this paper designs and develops the DARI-3317 distributed power grid-connected interface device, which integrates protection, measurement and control, anti-islanding, power quality monitoring, protocol conversion, telecontrol, and information encryption functions. The device enables real-time feedback of power station information to the dispatch master station and accepts remote control of point-of-common-coupling switching and inverter start/stop operations, realizing real-time monitoring of distributed photovoltaic systems from the dispatch center. Additionally, its hardware and software platform design incorporates open interfaces and expansion margins to facilitate future upgrades and extend the device' s effective service life. The DARI-3317 has been successfully commissioned at a State Grid distributed photovoltaic power station, demonstrating its validity through practical engineering applications.

2 Development of Distributed Power Grid Interface Device

The DARI-3317 design references national standards and specifications [11-12] while fully considering actual field requirements and operating environments.

2.1 Hardware Design

(1) Overall Hardware Architecture. The DARI-3317 distributed power grid-connected interface device employs a 4U-height, 19-inch half-rack standard chassis with an integrated front panel and large backplane structure. The backplane wiring is arranged in upper and lower layers: the upper layer for low-voltage systems and the lower layer for high-voltage systems, including DC power supply, analog inputs, and digital inputs. The plugin boards utilize surface-mount technology, integrating DSP systems and analog-to-digital systems into a single unit. To enhance system reliability, high-reliability optocoupler devices are adopted to strengthen anti-interference capability. The device uses embedded installation, modular plugin structure, and rear wiring connection. The overall hardware framework is shown in Figure 1 [Figure 1: see original paper].

The distributed power grid-connected interface device features the following characteristics: 1) The main CPU employs a high-performance DSP+PowerPC architecture; 2) Other major components are industrial-grade mainstream chips; 3) The powerful platform provides sufficient support and expansion margins for network communication, multi-device communication, real-time data acquisition, database management, and file storage management applications.

(2) Device Configuration. The typical configuration of the distributed power grid-connected interface device is shown in Figure 2 [Figure 2: see original paper]. The number of AC input, digital input, and digital output boards can be increased or decreased according to field requirements, and branch types of the same functional board can be selected based on site conditions.

(3) Plugin Boards. The DARI-3317 plugin boards mainly include CPU boards, GPRS boards, AC transformation boards, digital input acquisition boards, power supply boards, and operation circuit boards. The CPU board occupies a fixed slot position and primarily combines optical/electrical network ports, RS-232 serial ports, and RS-485 serial ports. The GPRS board is an optional module configured when users require GPRS communication with the master/substation. The AC input transformation board provides 10 analog channels, including three-phase voltage (TV rated voltage 100/380V) and three-phase protection current. The digital input acquisition board offers three options: DC 110V or 220V adaptive, DC 24V or 48V adaptive, and AC 110V or 220V adaptive, maintaining consistency with the power input voltage. The operation circuit board performs various circuit breaker operations, including trip/close contacts and alarm contacts, suitable for spring mechanism circuit breakers and permanent magnet circuit breakers without pressure mechanisms.

(4) Power Supply Scheme. The main power supply of the distributed power grid-connected interface device simultaneously accepts both AC and DC power, which serve as mutual backups. A battery provides backup power supply; when AC power fails, the system automatically switches to battery power, enabling seamless transition between AC and battery supplies to ensure continuous normal operation of system equipment.

2.2 Software Design

The software system of the distributed photovoltaic grid-connected interface device adopts an object-oriented design methodology composed of various functional modules. The program design is simple and clear, facilitating expansion and maintenance upgrades. The device software structure is shown in Figure 3 [Figure 3: see original paper].

Using the protection program as an example, the program design flow is briefly illustrated in Figure 4 [Figure 4: see original paper]. The protection main program checks external abnormal conditions during each sampling period to determine whether to enter the normal operation routine or fault calculation routine. The normal operation routine includes status monitoring and data preprocessing functions, while the fault calculation routine performs various protection algorithm calculations and trip logic judgments. When hardware self-check errors occur, the device sends a lockout signal, blocks operation, and exits protection.

2.3 Communication Mechanism

The distributed power grid-connected interface device integrates protection, fault disconnection, measurement and control, anti-islanding, and power quality monitoring functions, while also providing protocol conversion, telecontrol, and information encryption capabilities. It serves as a communication bridge between operation monitoring master stations or dispatching master stations and distributed power equipment. On the upstream side (operation monitoring master station, dispatch center), it transmits telemetry, telesignaling, energy metering, and power quality information while receiving remote control and adjustment commands from the master station. On the downstream side (photovoltaic inverter controller), it forwards remote adjustment and start/stop commands and receives relevant telemetry information from the inverter controller.

The DARI-3317 integrates communication management functions and fiber optic Ethernet ring network capabilities, enabling access and information forwarding from intelligent devices such as inverters, energy meters, and environmental monitors in photovoltaic power stations. Communication protocols are both extensible and configurable. The DARI-3317 supports Ethernet ring networks (100M), allowing other station devices to directly connect via fiber optic cables to form an Ethernet ring, saving optical transceivers, simplifying construction, and ensuring reliable communication.

(1) Communication Ports: 2/4 fiber optic Ethernet interfaces, 2/4 electrical Ethernet interfaces, 7/10 RS-485/RS-232 serial ports, and built-in/external wireless GPRS communication interfaces.

**(2) For sites where fiber optic cable installation is inconvenient, GPRS/CDMA communication can be implemented through GPRS board plugins or external GPRS/CDMA modules connected via serial ports.

**(3) For CPU boards configured with fiber optic Ethernet ports, fiber modules must be selected based on actual engineering requirements. The optical modules support hot-swapping and can be directly inserted into the optical module slots on the CPU board. Fiber module types are shown in the table below.

Table: Optical Fiber Module Types

Model	Wavelength & Distance	Connector	Optical Power
FTLF1217P2BTL	1310nm, 2km@62.5/125 m	LC	TX: -15dBm (Min), RX: -31dBm (Max)
FTLF1323P1BTL-NJ	1310nm, 40km@9/125 m	LC	TX: -5dBm (Min) to 0dBm (Max), RX: -34dBm (Min) to -10dBm (Max)

(4) Communication Protocols: On the downstream side, the device simultaneously supports over 100 protocols such as Modbus, DL/T645, and IEC 60870-5-103. For upstream communication with the dispatching master station, it supports IEC 60870-5-101:2002, IEC 60870-5-103, and IEC 60870-5-104 protocols.

Based on actual communication conditions, the DARI-3317 can support either fiber optic communication or wireless communication (GPRS) between the distributed power grid-connected interface device and the master station.

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3 Application Functions

(1) Protection Functions. These mainly include three-stage directional and voltage-restrained overcurrent protection, two-stage zero-sequence overcurrent protection, overload protection, and reverse power protection.

(2) Abnormal Alarm Functions. These include general accident signals, TV disconnection alarms, TA disconnection alarms, control circuit disconnection alarms, and TWJ abnormal alarms.

(3) Fault Disconnection Functions. These include two-stage undervoltage protection, two-stage overvoltage protection, two-stage underfrequency protection, and two-stage overfrequency protection.

(4) Telemetry Functions. The device collects three-phase voltage, current, and zero-sequence current, enabling measurement of three-phase voltage, line voltage, zero-sequence voltage, positive-sequence voltage, negative-sequence voltage, three-phase current, zero-sequence current, three-phase active power, three-phase reactive power, three-phase apparent power, three-phase power factor, total active power, total reactive power, total apparent power, total power factor, and harmonics.

(5) Telesignaling Functions. The device real-time collects position status and other status information from field equipment, transmitting status information remotely through "general interrogation" and "change-of-state active transmission" methods. It collects switch positions (single/double position) of line bays, spring not-charged signals, remote/local signals of control switches, and SOE records of protection and alarm events.

(6) Control Functions. The device enables remote control of switches with remote control capability and automatic closing with voltage check.

(7) Anti-Islanding Functions. These mainly include two-stage undervoltage, overvoltage, underfrequency, and overfrequency protection, adaptive islanding identification, and active islanding detection.

(8) Power Quality Monitoring. The device real-time monitors three-phase voltage, line voltage, zero-sequence voltage, positive-sequence voltage, negative-sequence voltage, three-phase current, zero-sequence current, power-related data, fundamental and 2nd-23rd harmonic voltage RMS values of three-phase voltage, fundamental and 2nd-23rd harmonic current RMS values of three-phase current, total harmonic distortion, and voltage/current unbalance rates.

(9) Device Self-Check Abnormalities. These mainly include device lockout, device alarm, setting file errors, setting calculation errors, setting change alarms, A/D sampling errors, optocoupler power supply loss, communication interruption, and main/backup power supply-related alarms.

(10) Battery Management. This primarily refers to battery reconditioning. The system can automatically initiate reconditioning according to preset cycles or through local and remote manual initiation. When the main power fails and battery discharge reaches the cutoff voltage, the battery output automatically disconnects to protect the battery pack from over-discharge.

(11) Authority Management. The device provides login permissions and password management for parameter setting, querying, device initialization, and reading important device data to prevent unauthorized operations and ensure information security.

(12) Parameter Query and Setting. Device-related parameters and settings can be queried and configured by the master station, handheld devices, or dedicated debugging software with appropriate permissions.

Additionally, through local monitoring or dispatch master station communication with the DARI-3317, functions such as setting upload and remote modification, fault information upload, operation alarm upload, telesignaling change upload, telemetry upload, and remote time synchronization can be implemented.

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4 Application

The DARI-3317 distributed power grid-connected interface device developed in this paper has obtained type test reports from the State Grid Electric Power Research Institute testing center, with all indicators meeting testing specifications. It has been successfully applied in a State Grid distributed photovoltaic power station. As shown in Figure 5 [Figure 5: see original paper], the TV and TA at the grid connection point of the device' s AC plugin are primarily used for voltage and current measurement, power quality monitoring, and protection. Communication between distributed power grid-connected interface devices, between the interface device and the dispatching master station, employs fiber optic communication, while communication between the interface device and inverters uses serial ports, and communication with station monitoring equipment uses Ethernet. The measurement accuracy for voltage and current is Class 0.2, while active power, reactive power, apparent power, and power factor measurement accuracy is Class 0.5. The mean time between failures (MTBF) exceeds 50,000 hours. Time synchronization error is less than 1 second when using master station message synchronization. With a built-in clock chip, the clock drift is less than 1 second within 168 hours without master station synchronization.

The DARI-3317 employs advanced hardware and software technology with careful structural design, enabling protection and measurement/control functions to operate both independently and in an integrated manner. The protection function operates independently without being affected by measurement/control and external communication, ensuring safety and reliability. The hierarchical distributed structure allows for centralized panel mounting or installation in switchgear, making the entire system flexible and reliable. Each bay unit functions independently without interdependence, so damage to one device does not affect others. Leveraging the advantages of the "four-in-one" design and communication network, the device integrates protection and measurement/control functions, using communication networks to transmit information. This eliminates conventional secondary signal control cables, simplifying secondary wiring, reducing TA and TV burden, saving significant investment, conserving manpower and material resources, and decreasing construction difficulty and maintenance workload. To maintain compatibility with conventional methods, some remote signals and central signals are retained, and the backplane terminals follow traditional patterns, ensuring compatibility with conventional operation and control modes.

The distributed power grid-connected interface device developed in this paper has been successfully commissioned and provides theoretical and practical guidance for standardizing information collection and transmission in distributed power stations. The DARI-3000 series protection and measurement/control devices will be further promoted.

5 Conclusion

Distributed generation offers high energy utilization efficiency and low environmental pollution, finding widespread application in power systems. As distributed generation continues to develop, its grid integration increasingly impacts the main grid. Distributed generation resources are widely dispersed and difficult to manage. Without effective management, they create safety hazards for grid operation, maintenance, and inspection, directly affecting power system security and stability. Therefore, designing and developing an integrated distributed power grid-connected interface device is crucial. The DARI-3317 distributed power grid-connected interface device employs advanced hardware and software technology with careful structural design, enabling protection and measurement/control functions to operate both independently and in an integrated manner.

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Note: Figure translations are in progress. See original paper for figures.