Research on Substation Protection Measurement and Control Integrated Configuration Device Based on SoC Chip

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Abstract: Aiming at the development status of relay protection in intelligent substation, an integrated configuration device of substation protection measurement and control based on SoC chip is proposed. SoC chip integrates dual-core ARM Cortex-A9 and FPGA, which makes full use of the powerful data interaction ability of FPGA and dual-core CPU and realizes the basic function of substation protection and interval measurement and control. With the high integration advantage of SoC chip, it simplifies the hardware plug-in of the device and realizes high integration of substation protection measurement and control functions on a single device.

1. Introduction

The existing intelligent substation protection measurement and control devices are generally composed of multi-CPU plug-ins, in which dual CPU protection function is generally implemented by DSP, and management plug-ins are generally achieved by CPU with real-time operating system. In addition, in order to process SV and GOOSE data, a communication plug-in is needed. Moreover, if the device integrates measurement and control functions, it also need another one plug-in. The structure of the whole device is multi-CPU, consequently, the complexity and power consumption of the device are higher than those of the traditional micro-computer protection device, which reduces the reliability of the device in long-term operation. What’s more, the increase of the complexity of the CPU system is accompanied by the decrease of data processing capacity and the increase of protection action delay.

Benefited from the development of chip technology, the original single components including CPU, DSP, and FPGA can be integrated into one chip, which is called SoC (system on chip). SoC integrates dual-core CPU processors and traditional FPGA functions. The FPGA has powerful parallel computing capabilities and both dual-core CPUs can perform logic operations or high-speed control. Obviously, the birth of Soc chip has provided strong support for the technological development of traditional industrial control, intelligent security, power system and other fields [1,3].

In this paper, an integrated device of substation protection measurement and control based on SOC is proposed. The integrated configuration of protection measurement and control functions of the whole substation is realized by using highly integrated chip technology and the system architecture of the whole substation is optimized. Besides, the function of total station protection and interval measurement and control is realized by using a single device.
2. Configuration scheme of substation protection measurement and control function

In smart substation, all the interval acquisition devices are independent. After the time synchronization of the whole substation acquisition system is completed, the protected area includes the substation and all the lines adjacent to the substation [4-7].

2.1. Functional configuration of integrated device for substation protection measurement and control

The functions of the integrated device of total substation protection, measurement and control are divided into protection function and measurement and control function.

1) The protection function includes:
   a) Line Protection: multiple line protection can be configured, which include three-section phase to earth distance protection, three-section phase to phase distance protection, directional earth fault overcurrent protection, automatic reclosure and overload.
   b) Transformer Overload Protection: According to the transformer configuration. The main transformer overload intertripping module collects three-phase current at the high-voltage side of a single main transformer, monitors the main transformer load status on the basis of reasonable distribution of the main transformer load, and adopts the solution of "five-stage and one-round" intertripping to prevent the main transformer from overloading operation on the premise of maintaining the important load as far as possible.
   c) Simple Busbar Protection: The middle and low voltage side busbar of substations with 110kV or lower voltage levels are not equipped with independent bus bar protection. In order to accelerate the removal of the faults of the middle and low voltage side busbar, the device is equipped with simple busbar protection at the middle and low voltage side busbar. The device is equipped with small power supply action input signal and locking input signal for each bus bar. When there are external faults in busbar area (feeder faults, etc.), the relevant protection device can send simple busbar signal, simple busbar protection does not operate. When there are faults in bus area, there is no lock-in signal. And simple busbar protection can quickly remove main transformer low-side circuit breaker and then remove faults after inducing fault current. At the same time, some measures have been taken to distinguish the branch busbar fault from the parallel busbar fault when the low voltage side of transformer is running in parallel.
   d) Underfrequency Protection: Underfrequency in power systems is caused by an increase of the active power in the load or by a decrease of the generated active power. Other incidents like power system disconnection, generator failure may also cause underfrequency. Underfrequency protection function can be used to detect underfrequencies in the power system, shed load and decouple power systems.
   e) Backup Power Automatic Switch: 7 power supplies are designed according to 3 transformers and 4 lines. When less than 7 power supplies participate in the standby auto-switching logic, some power supplies can be shut down through the corresponding soft-pressing board so that they do not participate in the standby auto-switching logic.
   f) Breaker Failure Protection: The main and important function of Breaker Failure Protection is to provide backup tripping in case of when the circuit breaker is failed to operate. It can monitors the tripping of the associated circuit breaker and in a short time trip local and adjacent circuit breakers and ensure stable operation of the entire power grid to prevent equipment in power system from seriously damaged.

2) Measurement and control functions: with multiple intervals of measurement and control functions, including:
   a) Acquisition of AC volume: All important telemetry information of interval unit can be provided, including three-phase current, bus voltage, line voltage, frequency, active and reactive power, apparent power, power factor, etc. The device can also provide up to 13 harmonic measurements.
   b) DC measurement: Supporting 20-way DC measurement.
   c) Telemetry information acquisition: The device can provide 16 hard contacts for telemetry information input, and each input can set the anti-jitter time separately. It also supports 144 GOOSE single point telemetry information input acquisition and 17 GOOSE double point telemetry information.
d) Remote control and logic locking function: The device supports 17 remote control output: one circuit breaker remote control output, four isolation knife gate remote control output, four ground knife remote control output, eight standby remote control exit. The device can be remotely controlled through the graphical interface. Under the main wiring graphics display, the switch or the knife gate can be selected by using the mobile key, and the password can be input by pressing the function key to confirm. Apart from the remote control of circuit breaker, each remote control of the device has the function of logical blocking, which can be set by five preventive control words, that is, each remote control can be set as "blocking" or "non-blocking".

e) Synchronization closing function: The synchronization function of the device is used for the synchronization of hand closing and teleclosing, which can realize the synchronization output of a line. The device can be connected with any phase voltage and line voltage, and can set the synchronization voltage phase at the interface. The device "hand contract synchronization " input provides GOOSE input and hard contact input, which can collect GOOSE input signal sent by intelligent terminal, and can also realize synchronous closing by installing switching operation handles on protection measurement and control screen. The synchronization phase can be set up separately.

2.2. Characteristic analysis of integrated device for substation protection measurement and control

The biggest difference between the protection function of substation protection measurement and control integrated device and conventional protection device is the configuration of backup protection.

The first characteristic of backup protection is the adaptation. Traditional backup protection is the backup protection of a single component, which does not need to consider the operation mode and wiring form of the system, but the new principle of backup protection needs to consider the network topology. Taking the protection of double-circuit line between stations as an example, if the main protection is not moving, the backup protection action is needed for the terminal fault of the one-circuit line. Traditionally, both the two circuit lines in distance section II will trip, resulting in the loss of contact between the two stations and expanding the scope of the accident. However, the back-up protection of double-circuit line based on topological structure analysis can synthesize the information of double-circuit line and only jump one-circuit line, so that the connection between two stations still exists and the scope of accidents is reduced.

The second characteristic of backup protection is to shorten the operation time and improve the stability of the system. Traditional 35kV bus is not specially equipped with bus protection. As a consequence, if bus fault occurs, the transformer backup protection trip is needed to remove the fault. The operation time of transformer backup protection is long and the busbar is damaged more greatly. In backup protection, bus differential protection can be configured to improve the action speed, and simple bus differential protection can be realized by GOOSE command to transfer locking information to improve the response speed to low-voltage bus fault.

3. Hardware design of integrated device for substation protection measurement and control

The SoC chip of the device chooses the Zynq-7000 series of Xilinx Company. And the Zynq-7000 series take dual-core ARM Cortex-A9 of CoreSight technology. Of which highest main frequency can reach 1 GHz and supports single-precision and double-precision floating point. The dedicated and fully customized low-power DSP Slice can provide a performance over 2662 GMAC. It is equipped with 32KB L1 Cache and 512KB L2 Cache. What’s more, it has DDR controller, rich storage interface and peripherals, and interacts with FPGA through AMBA AXI4-Lite bus.

Due to the limitation of hardware resources and CPU processing speed of traditional embedded platform, all basic functions of substations such as lines, transformer, backup power automatic switch and simple busbar can only be realized by adding CPU plug-ins. The integrated device of substation protection measurement and control based on SoC chip utilizes the strong characteristics and high integration advantages of Zynq-7000 series chips, and makes full use of dual-core resources to realize diversified integrated device of protection measurement and control.
The device is comprised of CPU module, communication module and HMI module. CPU module uses 4 cores to achieve all protection functions. HMI module is used to achieve interface display and upper communication functions, and integrate measurement and control functions into HMI module. Communication module is responsible for collecting and processing all SV, GOOSE network data.

Compared with the traditional hardware architecture of microprocessor-based protection, the main advantages are as follows:

1) The number of CPU modules decreases. The existing hardware architecture CPU module have four cores, which is similar to the original protection device with four CPU modules. The reduction of the number of CPU modules greatly decrease the power consumption of the whole device.

2) The schematic diagram of the core CPU processing architecture of traditional microprocessor-based protection is: SV GOOSE network data is parsed by FPGA, and then transferred to CPU by PCIE or LocalBus communication bus. The SoC chip in the existing architecture integrates the function of FPGA. The data is parsed by the chip's FPGA, and then written into the chip's DDR memory by the internal high-speed AXI bus. CPU acquires data directly from memory, and uses AXI protocol to build a dedicated DMA between CPU and FPGA. Through DMA, SV and GOOSE messages can be moved quickly between memory and FPGA, and the speed of data transfer exceeds 6 Gbit/s, which greatly improves the ability of data transfer and processing.

3) The communication between CPUs is changed from the original FPGA bus LVDS to the high-speed LVDS point-to-point communication. HMI, data, AD sampling and Goose/SV extension are all connected directly through high-speed point-to-point communication. Consequently, it brings the following advantages: Firstly, the communication rate of each pair of differential lines is increased to 200 Mbps, and the bandwidth is exclusive, which greatly improves the throughput of the internal bus. Secondly, signal integrity and anti-jamming performance are greatly improved compared with the old bus communication. Thirdly, it greatly simplifies the program of FPGA, bus polling and arbitration become unnecessary, and reduces the complexity and program overhead. LVDS bus chip is omitted, fever and cost are reduced, but reliability is improved.

4. Software design of protection measurement and control integrated device

4.1. Design of platform driven guidance software

Zynq-7000 series can be regarded as a dual-core processor with the function of FPGA, so the start-up process of the chip is different from that of conventional FPGA. Zynq effectively utilizes the
resource allocation of on-chip systems. Processor systems (PS) and programmable logic (PL) require PS to complete initialization configuration. And it is actively started from the internal boot storage area (BootROM) or passively started in JTAG mode. The whole boot-up process is divided into three stages:

1) Execute the program in the on-chip ROM. This part of the code is non-modifiable and automatically executed at power-on startup and initializes ARM Cortex-A9. It is also responsible for loading the next stage startup image (FSBL image) into OCM (a 256K RAM on Zynq chip, but it can only use 192K before FSBL runs, so FSBL is less than 192K. 192K).

2) Start the loader (FSBL), which can be controlled by the user's code. The main work is: according to the user configuration, completing the initialization of PS and configure PL to guide the Uboot program’s load in the next stage.

3) Load Uboot, load the operation system, configure the rest of the PL, and return to the user's APP.

4.2. Design of data interaction software

The high-speed data interaction between ARM dual-core and FPGA in Zynq-7000 series chips is accomplished by AXI interface protocol. The AXI bus protocol is implemented through hardware interface in Zynq. The hardware interface includes four GP ports (two GP_Masters, two GP_Slave), four HP ports and one ACP port. And the high-speed data interaction between dual-core ARM and between ARM and FPGA is realized through these nine hardware interfaces. GP_Slave and HP ports are similar in function, because they are all up to FPGA. Since the GP_Slave rate is much lower than the HP port rate, the use of GP_Slave is not considered. The advantage of GP_Master is that A9 can read and write the FPGA directly. The disadvantage of HP port or ACP port is that data can be directly transferred to DDR or OCM without A9. In addition the protocol of handshake between A9 and FPGA is complex. In summary, the major principle is that A9 uses less GP port to interact with the data of the FPGA and more HP port to interact with the data. A9 power-on initialising the FPGA, and A9 real-time requirements of reading and writing operations through the GP port. Other information interaction is realized through HP port and ACP port.

1) data interaction design of Zynq_0

The dual cores of Zynq_0 are protection core and communication core respectively. The data between FPGA and A9 can be exchanged directly through GP port or DDR through HP port. Data on DDR can be accessed by both cores. Hardware and FPGA do not distinguish which core is accessed, but decided by the application program. In order to prevent collision caused by dual-core sharing a GP port, A9_0 is fixed using GP0, A9_1 is fixed using GP1. The two GP ports are distinguished by address partition.

2) Data interaction design of Zynq_1

Zynq_1’s dual-cores are blocking core and management core respectively. A9_0 is blocking core, and it exchanges data with FPGA through OCM. The management and blocking cores each occupy a GP port, which is dedicated to interact data between the management core and the FPGA.
5. Conclusion

In this paper, a substation protection measurement and control integrated device based on SoC chip is studied. Compared with the traditional micro-processor protection device, this device realizes the high integration of substation protection measurement and control functions without adding more CPU plug-ins. The device has the following advantages:

1) Hardware is reliable. Utilizing the advantages of high integration and low power consumption of SoC chip, combined with the powerful data processing ability between dual core of SoC chip and FPGA, the device function achieves the maximum integration.

2) Optimizing the backup protection function. Utilizing the advantage of obtaining the information of the whole station, the function of the backup protection is optimized, and the action time of the backup protection is shortened.

3) Integrating the function of interval measurement and control. On the basis of data centralized sharing, flexibly configuring control, protection, measurement and control function logic, making full use of relevant data of various control, protection, measurement and control functions, and providing strong support for the realization of advanced functions such as on-line analysis and decision-making of substation operation and maintenance, collaborative interaction and so on.

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