Design of RMT-Based IOC Redundancy at the RCPI Experimental Platform in TMSR (Postprint)

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Abstract

In the RCPI (rod control and position indication) system prototype of the TMSR (Thorium Molten Salt Reactor) project, EPICS (Experimental Physics and Industrial Control System) was adopted as the instrumentation and control software platform. To ensure long-term operation, high availability, and system safety, the RMT (redundancy monitor task) software package for Input/Output Controller (IOC) redundancy was employed, and the driver for redundancy control was implemented. Testing demonstrates that the system can achieve rapid IOC redundancy switch-over and ensure long-term stable operation of the IOC.

Full Text

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The Design of RMT-Based IOC Redundancy at RCPI Experimental Platform in TMSR*

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Abstract: In the RCPI (rod control and position indication) system prototype of the TMSR (Thorium Molten Salt Reactor) project, EPICS (Experimental

Physics and Industrial Control System) was adopted as the instrumentation and control software platform. To meet the requirements of long-term operation, high availability, and system safety, the RMT (redundancy monitor task) software package for Input/Output Controller (IOC) redundancy was employed, and the driver for redundancy control was implemented. Tests demonstrate that the system can achieve rapid IOC redundancy switch-over and ensure stable long-term IOC operation.

Keywords: Redundancy monitor task, EPICS, Thorium Molten Salt Reactor, Rod control and position indication
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INTRODUCTION

II. Hardware Architecture

The instrumentation and control (I&C) system serves as the nerve center for reactor operation and monitoring, making its safety and reliability critical. The controller hardware platform for the RCPI (rod control and position indication) system prototype of the TMSR (Thorium Molten Salt Reactor) project [1] is based on the Advanced Telecom Computing Architecture (ATCA), which can achieve 99.999% availability [2]. While the hardware provides high availability, the system software plays a decisive role in the overall availability of the entire system. Building a distributed redundant system is an effective solution to improve system availability.

EPICS, which is based on a standard server/client model and offers high performance and multi-platform support, is used worldwide to create distributed soft real-time control systems [3, 4]. The basic components of EPICS are the Input/Output Controller (IOC), the Operator Interface (OPI), and Channel Access (CA) [5, 6]. EPICS was adopted in the International Thermonuclear Experimental Reactor (ITER) system in 2011 [7].

Due to the high-availability requirements of the instrumentation and control (I&C) software platform for a nuclear reactor [8], the RMT (redundancy monitor task) software package, originally developed at DESY (Deutsches Elektronen Synchrotron) [9, 10], was adopted for the IOC redundancy solution. The RMT package required modification and driver implementation for redundancy control. In this paper, a redundant IOC system communicating with a PLC (programmable logic controller) is designed, and the performance of the EPICS redundant IOC is tested.

An overview of the EPICS-based RCPI system hardware architecture is shown in Fig. 1 [Figure 1: see original paper]. It consists of a pair of IOCs communicating with a remote PLC via network. The upper-level computer system of the platform consists of two ATCA blade computers running the Linux operating system, EPICS components, and the RMT software package.

Fig. 1. Hardware architecture of the redundant ATCA/IOC in RCPI system.

The redundant ATCA/IOC pair shares two network connections: a public/global network and a private network. Both are used for monitoring the health state of each unit. The private network connection is used to synchronize the backup to the primary, while the global/public network is used to communicate data from the primary to any other network clients requiring the data. The lower-level device of the platform is an ABB AC-800M PLC component, which controls or monitors rod operation and communicates with the IOCs via LAN.

III. Software Component

The RMT software components [10] for implementing IOC redundancy mainly include: the RMT main program, the data-synchronization component CCE (Continuous Control Exec), and the SNL (state notation language) Executive. The purpose of SNL Executive redundancy is to keep the state programs of the primary and backup synchronized and to select the node on which they execute. Since there are no state programs in our system, the SNL Executive is not used and this module was deleted during package optimization.

A. RMT

RMT is the core component for realizing EPICS redundant IOCs. It is used to gather and examine the overall condition of the IOC, establish and maintain communications with the partner through the public/global Ethernet and private Ethernet, and control CCE, I/O Driver, Scan Tasks, CA Server, and other components. The software architecture of RMT is shown in Fig. 2 [Figure 2: see original paper].

The main thread of RMT is a state machine that defines six states. The state names and transitions are shown in Fig. 3 [Figure 3: see original paper]. State transitions are determined by information from the configuration file, Primary Redundancy Resources (PRR), and shell commands. The parameters of RMT are set in the configuration file to improve program execution.

The PRRs include the public/global Ethernet, private Ethernet, I/O Driver, CCE, Scan Tasks, CA Server, and others. Shell commands provide a route for operators to change the redundant state of IOCs and to start/stop RMT.

CCE, Device Driver, and other components are controlled by RMT and share the same software interface defined in a header file. RMT calls functions in this interface using an entry table to send commands to a driver instance or to get information from it. Based on information from the configuration file, the driver instance, and the partner, RMT makes decisions about assuming or relinquishing control.

B. CCE

The main task of CCE is to keep the database synchronized between the primary and backup. At CCE initialization, it creates the Traverse Task and Exec Task, and calls the rmtRegister() function to register itself with RMT. The purpose of the Traverse Task is to force a redundant update on every field. After the initial pass, the Traverse Task waits for a signal from the Exec Task to be triggered. The Exec Task attempts to connect to the partner and monitors the TCP connection. It is a state machine whose state is determined by commands from RMT and the state of the connection to the partner. When a connection is established, each unit transitions to the "synching" state. They remain in this state until the master has completed sending a full update to the partner. Then the master and slave transition to the "in sync" state. In this state, the master periodically transfers all fields that have changed.

IV. System Implementation

A. The RCPI System Design

From the RCPI system prototype shown in Fig. 1, ATCA/IOC acts as the controller in the I&C system. Its device support module is a communication driver to the ABB AC-800M PLC employed in the project via the Modbus/TCP protocol. A fixed-size data block that bundles many variables can be transferred; through this method, control commands and measured values can be mapped between PLC variables and IOC Process Variables (PVs) periodically over the network in both directions. For multi-level high-availability insurance for the whole system, both the ATCA/IOC pair and the AC-800M PLC in this prototype system are configured for redundancy, implemented by the PLC vendor. The solution for the PLC pair includes CPU redundancy and channel redundancy. Thus, the PLC pair and IOC pair are independent, and switch-over occurring on either side does not affect the other side.

B. The Design of RMT Driver

Redundancy control makes the running status of the redundant IOC pair change with the RMT state machine. The RMT package provides the same interface in the header file "rmtDrvIf.h". The RMT driver mainly consists of several functions called by the state machine if the redundant state needs to be changed or confirmed for both IOC units. According to engineering needs, functions for the ATCA/IOC device support module are written as follows:

- **start()**: If the redundant state is "MASTER", the state machine calls this function to run the IOC. If this function executes successfully, it returns 0.
- **stop()**: If the redundant state is "SLAVE", RMT calls this function to pause the IOC, and clients cannot search for any Process Variables from this IOC.
- **testIO()**: This function initiates a procedure to test driver access to the I/O. With the result of the testIO() function, the state machine can determine whether the driver state is normal and make state transition decisions. This function is always called when an error occurs in the MASTER IOC. If the test result is OK, the IOC remains in the MASTER state; otherwise, switch-over occurs.

- **getStatus()**: This function periodically returns the status of the device support module of each IOC unit. The state machine can easily check if the I/O driver is healthy. If the driver state is abnormal, RMT can increment a counter or call the testIO() function and determine state transition.

By compiling the RMT software package in the EPICS environment and writing the redundancy control interface functions for ATCA/IOC called by the state machine, the IOC pair achieves fast switch-over and data synchronization. For any redundancy solution, it is essential that the redundant implementation makes the system more reliable than the non-redundant one, so the risk of RMT package failure or error should be considered and evaluated. The RMT package is configured to start during IOC initialization; it checks the IOC configuration and running status for both IOC units, and the state machine makes decisions regarding unit redundant state. Normally, there is only one active IOC; if the RMT package fails or one connection breaks, the redundant IOC pair will run as a single unit.

V. Redundant Performance Test

Redundant performance testing includes tests for long-term availability and redundancy switch-over interval. The system ran continuously with 198 records in the IOC for about three months. The redundant system demonstrated high availability and safety during switch-over optimization and testing.

IOC redundancy switch-over can be caused by failures, operator commands, or master IOC failures due to ATCA hardware or software problems. The implementation method for redundancy switch-over testing was to set the control rod range to 1400 mm and speed to 30 mm/s, and to obtain rod position in real time by monitoring the rotating transformer through the Control System Studio (CSS) interface on a CA client terminal. Fig. 4(a) [Figure 4: see original paper] shows the IOC redundancy switch-over interval before optimization. The first and second switch-overs were caused by IOC failure, while the third was caused by operator command. The longest switch-over interval was about 8 seconds and was caused by IOC failure.

The curve clearly shows the trace of switch-over caused by IOC failure. The switch-over time from the CSS interface is too long, which is not acceptable for the whole system, but at the IOC layer the redundancy switch-over time is faster. It is speculated that this is a result of the CA timeout management mechanism, so the switch-over optimization mainly focuses on modifying the CA server's beacon period to show server existence to clients, and the client's reconnection period to the server if disconnection occurs. The redundant pair's data synchronization frequency controlled by CCE also increases. The switch-over interval after optimization is shown in Fig. 4(b) [Figure 4: see original paper]. The first five switch-over events were caused by master IOC failure, and the last four events were caused by operator commands. The longest interval shown in Fig. 4(b) is less than 1 second in the CSS client, which is much superior to the result in Fig. 4(a).

VI. Conclusion

ATCA/IOC redundancy in the TMSR RCPI experimental platform has been implemented through modifying and configuring the RMT and CCE modules and writing a redundancy control driver for the IOC support module. The system based on ATCA standard and IOC redundancy has high availability and can quickly achieve IOC switch-over and data synchronization. This IOC redundancy solution provides technical support for EPICS application in future nuclear I&C systems. In the future, we will optimize and test the switching time affected by network environment and data volume increase.

References

[1] Jiang M H, Xu H J, Dai Z M. Bull Chin Acad Sci, 2012, 27: Grenoble, France, 1–4.
[2] PCI Industrial Computers Manufactures Group (PICMG). Advanced TCA. PCIMG 3.0 Short Form Specification, Jan. 2003.
[3] http://www.aps.anl.gov/epics/
[4] Hu Z, Mi Q R, Zhen L F, et al. Nucl Sci Tech, 2014, 02:
[5] Han L, Chen Y, Zhou D, et al. Nucl Tech, 2013, 09: 090603. (in Chinese)
[6] Ding J, Liu S. Nucl Tech, 2006, 05: 380–383. (in Chinese)
[7] Wallander A, Abadie L, Di Maio F, et al. News from ITER controls–A status report. Proceedings of ICALEPCS 2011,
[8] IAEA. Implementing digital instrumentation and control modernization of nuclear power plants. International Atomic Energy Agency, Vienna, 2009.
[9] Kazakov A, Furukawa K, Satoh M, et al. Higher availability with ATCA and redundant IOC. Proceedings of the 5th Annual Meeting of Particle Accelerator Society of Japan and the 33rd Linear Accelerator Meeting in Japan, Aug. 2008.
[10] Clausen M, Liu G, Schoeneburg B, et al. Redundancy for EPICS IOC, Proceedings of ICALEPCS 2007, Knoxville, Tennessee, USA, 158–160.

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