DCIS INTEGRATION TESTS FOR LUNGMEN NUCLEAR POWER PLANT

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ABSTRACTION

The factory acceptance tests (FAT) for distributed control and information systems (DCIS) of Lungmen nuclear power plant (LMNPP) Units 1& 2 were separately performed by individual suppliers for their supplied scopes. The FAT also included overlap interface tests between the separately supplied scopes, but did not include an overall integration test. There were concerned by the regulator and the public over the lack of an integration test, which was believed to be indispensable to verify the correctness and completeness of a digital system of such large scale ever applied by Taiwan Power Company (Taipower). To address these concerns and enhance confidence in the DCIS, the DCIS integration tests, including reactor water level integration test, reactor pressure integration test, integration test for turbine generator and reactor protection system, integration test for proper plant response to safety and non-safety network equipment failures, and DCIS dynamic integration test, were performed at site during Unit 1 site tests. It is to be noted that these tests were beyond the post construction tests, the pre-operational tests, and the start-up tests, which are the normal industry practice and formally required by the regulator.

A common goal for these integration tests is to verify the capability of the DCIS to transmit signal/data properly across various suppliers' equipment to actuate the final equipment. The methods and principle, the test purpose/test items/acceptance criteria and the test results for these tests are described.

Key Words: LMNPP, DCIS, Integration Test

1 INTRODUCTION

Full digitalized instrument and control systems, designated Distributed Control and Information System (DCIS) for the LMNPP Unit 1&2, were adopted by Taipower. For the DCIS, General Electric Nuclear Energy (GENE) was responsible for the top level design and overall integration; and the detailed design, implementation and equipment supply were in the scope of GENE's sub-contracts-GENE NUMAC, Invensys, GEIS, and DRS in the U.S., and Hitachi in Japan; and those for turbine generator were in the scope of MHI in Japan.

When design and implementation was completed, FATs were performed. The FATs were separately performed by individual suppliers for their supplied scopes and included overlap interface tests between the separately supplied scopes. Although some of GEIS, Hitachi and MHI equipment had been sent to GENE or Invensys for the interface tests, equipment of the major suppliers-NUMAC, Invensys, and DRS had not been put in one location and connected together for an overall integration test.

Lack of a total integration test brought about concerns by the regulator and the public. To address these concerns and enhance confidence in the DCIS, the DCIS integration tests were performed at site during Unit 1 site tests. These DCIS integration tests were beyond the post construction tests, the pre-operational tests, and the start-up tests, which are the normal industry practice and formal required by the regulator.

2 THE DCIS INTEGRATION TESTS

In planning and preparation for the DCIS integration tests at Lungmen site, studies had been made by Taipower on relevant information collected from the test items of final integration test in Japanese's ABWR, consultation with WANO Tokyo Center on their experience during their technical support mission to the site in August 2009, the abnormal events encountered during the preoperational tests on LMNPP Unit 1, and the digital I & C dynamic transient test performed by Toshiba on KK6 NPP in Japan. Finally, the following DCIS integration tests were decided:

1. Reactor water level integration test
2. Reactor pressure integration test
3. Integration test for turbine generator (T/B) and reactor protection system(RPS)
4. Integration test for proper plant response to safety and non-safety networks equipment failures
5. DCIS dynamic integration test

A common goal for these tests is to verify the capability of the DCIS to transmit signal/data properly across various suppliers' equipment to actuate the final equipment. The methods and principle, the test purpose/test items/acceptance criteria and the test results for these tests are described below.

2.1 Test Methods and Principle (for tests as applicable)

1. For the reactor water level integration test, actual measured ascending/descending reactor

water level signals were used; for the reactor pressure integration test, actual measured ascending reactor pressures were used; but for other tests simulated signals for water level or pressure at different stages were used as needed.

2. The final or terminal equipment (such as pumps, control rods, etc.) was not actuated during the tests, and only signals arriving/readily available for actuating/initiating of the equipment were verified.

2.2 Test Purpose/Test Items/Acceptance Criteria

2.2.1 Reactor water level integration test

2.2.1.1 Test purpose

This test is to verify the plant design requirements being met when the actual reactor water level reaches the individual set-point conditions of the reactor water level instruments. Specifically, it is to be verified that signals can be correctly transmitted from the reactor water level instruments, across systems, across platforms, to circuits, contacts of various systems/equipment; and that when the actual reactor water level reaches the set-points, all relevant systems/equipment, displays, and alarms can be indicated/actuated/initiated in conformity with the plant design.

2.2.1.2 Test items

Verify correct indications, alarms and equipment actuations at reactor water levels L-8, L-3, L-2, L-1.5 and L-1.

2.2.1.3 Test methods

Before the test, the condenser water/feed-water systems are operated to establish normal reactor water level (L-4~L-7), then the systems are operated for the reactor water to reach the desired levels for the test. During the test, the reactor water clean up system (RWCU) is started to remove the impurities in the reactor water and discharge the excess water.

The reactor water level is raised to L-8 and statuses of test items for L-8 are checked. Then, the reactor water level is lowered to L-3 using the blow down valve and bottom drain valve of RWCU system, and statuses of test items for L-3 are checked. Step by step, lower the reactor water level to L-2, L-1.5, and L-1 and sequentially confirm correct actuation of systems/components/ instruments at each water level.

2.2.1.4 Acceptance criteria

When the reactor water level reaches each level set-point, it can be confirmed that the tripping or isolating signals are delivered to the related systems to initiate the valves isolation and equipment tripping. For instance, when reactor water level reaches level L-8, the main turbine, feed-water pump turbine and the electric feed-water pumps are tripped, and the steam supply valves of reactor core isolation cooling (RCIC) system and the injection valves of high pressure core flooder (HPCF) system are closed.

2.2.1.5 Test results review and conclusions

It took about 15 hours to complete the whole test. Test results were reviewed and concluded as following:

1. Temperature compensation for reactor water level instruments

   It is to be noted that the test was preceded with the reactor water under normal temperature and pressure, and there are five level instruments with different measurement and indication ranges, i.e., narrow range, wide range, fuel zone, shutdown injection and reactor well. During the test, readings recorded of the instruments were inconsistent among these instruments. After temperature compensation calculations, it was confirmed that the indicated values in the test record of the reactor water level instruments were correct under the test conditions.

2. Test record review and evaluation

   In this test, there were 12 cases as exceptions. Causes were to avoid impact of the test water level, a status change was manually initiated by the operator and to establish the test conditions (Normal→Trip), a variety of status changes were initiated, etc. After the review and evaluation, the test results were found to meet design requirements and acceptance criteria.

3. Conclusions from the test results

   A. Each water level instrument had adequate water level range and correct displays.

   B. The logic was correct that implemented actuation of the relevant systems/equipment initiated by the reactor water level instruments.

   C. Actions and responses from the related systems were verified to meet expectations, and test results met acceptance criteria.

2.2.2 Reactor pressure integration test

2.2.2.1 Test purpose

This test is to verify the plant design requirements being met when the actual reactor pressure reaches the individual set-point conditions of the pressure instruments, Specifically, it is to be verified that signals can be correctly transmitted from the reactor pressure instruments, across systems, across platforms, to circuits, contacts of various systems/equipment; and that when the actual reactor pressure reaches the set-points, all relevant systems/equipment, displays, and alarms can be indicated/actuated/initiated in conformity with the plant design.

2.2.2.2 Test items

1. 7.58～7.93 MPaG: Test for initiation signal for safety relief valve (SRV) relief function
2. 7.608 MPaG: Test for initiation signals for anticipated transient without scram (ATWS)

and ATWS-recirculation pump trip (RPT)

3. 7.24 MPaG: Test for initiation signal for reactor scram
4. 3.955 MPaG: Test for related signals for MSIV close and RPS scram
5. 3 MPaG: Test for permissive open signal for low pressure injection valve in low pressure flooder (LPFL)
6. 0.87 MPaG: Test for initiation signal for reactor high pressure LDI valve of residual heat removal (RHR)/RWCU

2.2.2.3 Acceptance Criteria

1. Initiation signals for related pumps and valves are verified correct
2. Initiation signal for relief function of SRV is verified correct
3. Initiation signals for ATWS and ATWS-RPT related systems are verified correct
4. Initiation signal for reactor scram is verified correct

2.2.2.4 Test results review and conclusions

Records taken for the test were reviewed and evaluated. Test results were found to meet the design requirements and acceptance criteria.

2.2.3 Integration test for turbine generator (T/G) and reactor protection system

2.2.3.1. Test purpose

To verify signal communication being in compliance with design requirements among reactor recirculation flow control system (RFCS (C81), TMR network), main turbine electronic fluid control system (N32, MHI network), RPS (C71, NUMAC network), and rod control and information system (RCIS (C11), Hitachi network).

2.2.3.2 Test items

1. Fast load winddown (FLWD)
2. Reactor scram caused by overspeed protection control (OPC) event

2.2.3.3 Test method

1. A fast load winddown signal is initiated manually from the FLWD switch of H11-PL-1701 panel.
2. Reactor power is simulated at more than 40%, when an OPC event occurs and the turbine control valves (TCV or GV) are fast closing; if

   A. the turbine bypass valves (BPV) open, and it will not cause a reactor scram.

   B. the turbine bypass valves (BPV) fail to open, and this causes a dramatic increase of the reactor pressure, resulting in reactor scram.

2.2.3.4 Acceptance Criteria

1. Confirm the signals and equipment are initiated as follows:

   A. Recirculation internal pump (RIP) runback (C81 GEIS)

B. Selected control rods run in (SCRRI) initiation (C11 Hitachi)

C. SCRRI is initiated in (C11 Hitachi), Generator circuit breaker (GCB) opens after 50 seconds

2. Confirm reactor scram signal (C71-RPS)

2.2.3.5 Test results review and conclusions

Records taken for the test were reviewed and evaluated. Test results met the design requirements and acceptance criteria.

2.2.4 Integration test for proper plant response to safety and non-safety networks equipment failures

2.2.4.1 Test purpose

1. Verify plant responses meeting expectations upon DCIS safety and non-safety network equipment and components failures.
2. Upon DCIS equipment and components failures, confirm the plant can provide abnormal alarms and take appropriate contingency measures.

2.2.4.2 Test items

1. Upon failure of DRS Division II (Safety), verify the signals of other network layers being displayed properly.
2. Upon failure of Invensys (Non-safety) network, verify the plant safe shutdown being executable.
3. Verify remote shutdown system (RSS) being operable and able to provide proper displays upon failures of Invensys network and DRS Division II.
4. Upon failure of DRS Division II, verify RPS and other fail safe features operating properly.

2.2.4.3 Acceptance Criteria

1. Systems and signals, other than those of DRS Division II, which are assumed in failed condition in the test, can operate properly.
2. Upon failure of Invensys network to operate and display, DRS can execute safe plant shutdown.
3. Upon failures of Invensys network and DRS Division II, remote shutdown system (RSS) Division II can be operated and provide proper displays.
4. Upon failure of DRS Division II, RPS and other fail safe design can work properly.

2.2.4.4 Test Results

All test results met acceptance criteria.

2.2.5 DCIS dynamic integration test

In preparation for this test, Taipower found experience of Toshiba in performing the digital I&C dynamic transient test for KK6 NPP valuable for reference. Thanks to this precedent case, Taipower was able to develop and proceed with the test as described below:

2.2.5.1. Test purpose

To verify the Lungmen DCIS being able to correctly execute complete plant safety functions, when subjected to simulated composite accidents scenarios, which are based on the hypothetical design basis events listed in Chapter 15, Accident and Analysis, of the Lungmen final safety analysis report (FSAR), and which would lead up to a dynamic transient process.

2.2.5.2 Test scope

All safety systems, all safety and non-safety networks, anticipated transient without scram (ATWS) function, and relevant non-safety systems.

2.2.5.3 Test scenarios

The scenarios for the test start with the plant in full power normal operation; then with a series of hypothetical composite accidents breaking out, the plant goes through a dynamic transient process which lasts for as long as 800 seconds. Derived from the hypothetical design basis events as delineated in Chapter 15 of the LMNPP FSAR, these hypothetical composite accidents are listed below:

1. The first accident is the hypothetical design basis event “Inadvertent Closure of One Turbine Control Valve” (Section 15.2.1.2.1 of the FSAR).
2. The second accident is the hypothetical design basis event “Generator Load Rejection with Failure of All Bypass Valves” (Section 15.2.2.1.2.3 of the FSAR).
3. As a result of the second accident, the reactor pressure goes up to reach the set-point of high pressure scram, causing a reactor scram, but the control rods are not fully inserted. This constitutes the third accident.
4. The fourth accident is the hypothetical design basis event “Main steam-line breaks inside containment”(Section 6.3.3.7 of the FSAR), which initiates signals to start RCIC, HPCF, and RHR/LPCF.

2.2.5.4. Test architecture and method

The application software of the test platform adopts relevant test software developed by Labview System and is installed in the industrial personal computers (a total of 8). These are used to provide 36 channels of simulated composite accidents signals, including reactor water level and pressure signals.

The actuating/initiating signals are tracked/recorded by the transient record analyzer (TRA)/sequence of event (SOE) and the historical data recorder (Historian) of the plant computer system (PCS). Items to be tracked/recorded for analysis and reporting include reactor scram, turn on/off of safety/relief valves, start/shutdown of RCIC, HPCF, LPFL, etc. The related terminal equipment (such as pumps, control rods, etc.) is not actuated during the test; only its actuating/initiating signal arriving at the RMUs.

2.2.5.5 Test procedure

1. Test scenarios as listed in Section 2.2.5.3 are used to pre-determine expected check points for equipment actuation/initiation. Expected check points for equipment actuation/initiation are pre-determined as described below:
   A. As the reactor pressure is increasing from normal operating pressure, check point for initiating the test signal for reactor scram: 7.24 MPaG; check point for initiating the test signal for SRV relief function: 7.446~7.796 MPaG; check point for initiating the test signal for ATWS and ATWS-RPT: 7.608 MPaG; and check point for allowing the RHR/LPFL low pressure injection valve to open: as the reactor pressure is decreasing to lower than 2.638 MPaG with reactor water level at L-1
   B. As the reactor water level is decreasing from L-4 (normal operation), check point for initiating RPS: L-3; check point for initiating ECCS: L-2; then to L-1.5 and L-1 sequentially.
2. With the expected check points pre-determined and with continuous reactor level and reactor pressure test signals provided from the signal generators, the profile of these test signals were estimated to last for 800 seconds.
3. As 36 channels of simulated composite accidents signals for test are simultaneously sent out to instrument control cabinets, statuses/data of equipment actuation/initiation, including reactor scram, turn on/off of safety/relief valves, start/shutdown of RCIC, HPCF, LPFL, etc are tracked/recorded/logged by the TRA, SOE and Historian of the PCS. The tracked/recorded data will be evaluated.

2.2.5.6 Test Results

1. The dynamic transient process lasted for 800 seconds as estimated. The reactor water level and reactor pressure profiles during this period were drawn based on the data as tracked/recorded by the TRA, SOE and Historian of the PCS. These profiles were comparable with the test signal profiles matched with each other.
2. In total, there were 256 status changes, at the pre-determined check points, of equipment actuation/initiation tracked/recorded by the TRA, SOE and Historian of the PCS during the test. The 256 status changes, all of which, except for 32 cases, were readily verified correct. For these 32 cases, after further check, it was found that state changes were not required of them during the test, due to, e.g., being prevented/isolated from actuation, etc. In addition, the logic for initiation at the set-point of the reactor water level or pressure was confirmed correct.
3. With the test results, the acceptance criteria were met.

2.2.6 Summary of Test Results

The test results showed that for each test, acceptance criteria were all met. The tests involved a large number of plant systems and suppliers as can be seen in Table 1 (here the systems are represented by the mnemonic codes consisted of an alphabet and two digits, e.g., C71 represents reactor protection system). The tests had demonstrated the integrated capability of the DCIS to transmit signal/data properly across various systems and equipment supplied by different suppliers to actuate the final equipment; and to provide displays, alarms and data logging, etc. needed for proper plant operation.

3 CONCLUSION

To make up for the lack of an integration test during the acceptance tests at the suppliers' factories, so as to address the concerns by the regulator and the public, Taipower had collected relevant information and made studies in planning and preparing for performing the integration tests for the LMNPP DCIS. The DCIS integration tests, as performed at site during Unit 1 site tests, included integration test for reactor water level integration test; reactor pressure integration test; integration test for turbine generator and reactor protection system; integration test for proper plant response to safety and non-safety networks equipment failures; and DCIS dynamic integration test.

The test results of these integration tests showed that the acceptance criteria for each were all met; and that the DCIS was able to function properly among plant systems and equipment supplied by different suppliers. As these tests were performed on the real plant installation, the correctness and completeness of the LMNPP DCIS were essentially verified; especially in the reactor water level integration testing, the test signals were come from the reactor water level sensors through real water level in the reactor, not the simulation signals used in the FAT. Finally, the concerns of the regulator had been addressed.

4 REFERENCE

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Table 1：The table for involved suppliers and the tested systems in 5 DCIS tests

No.	Test Items	DRS Systems	NUMAC Systems	Invensy Systems (Included GEIS)	MHI Systems	Hitachi Systems	The Integration for cross-suppliers
1	Reactor Water Level Integration Test	E51/E22/T43/G31/P21/R21/C73/E11/T41/C61/C41/T31/T22/R13/T63	B21/C71	G51/P24/P52/T40/N22/K11/C91/ B31/C81/C31	N36/N31	C12/C11	Total cross 5 Suppliers for DRS, NUMAC, Invensys (GEIS), MHI, and Hitachi
2	Reactor Pressure Integration test	C41/C61/C73/C74/E11/H23	B21/C51/C71	C91/G31/H11/H23/C81/C31/C85	NA	C12/C11	Total cross 4 Suppliers for DRS, NUMAC, Invensys (GEIS), and Hitachi
3	Integration Test for T/G and Reactor Protection Test	T62/R10/H11	B21/C51/C71	N21/N23/C91/C81/C31/C85	N61/B31/N31/N34/N51/N32/N33	C12	Total cross 5 Suppliers for DRS, NUMAC, Invensys (GEIS), MHI, and Hitachi
4	Integration Test for Proper Plant Response to Safety and Non-safety Networks Equipment Failures	P24/R10/R11/R12/R13/R16/R21T41/T43/T49/T62/H23/E11/E22/E51/G31/H23/T22	B21	N21/T51/T54/N15/C91/H23/N11/N12/N22/N23/P11/P13/P22/P29/P30/T42/R10/R12/C72/F42/G41/G51/H23/K11/K15/P11/P13/P16/P27/P28/P31/P52/P54/C31/B31/C81/C82/C85	N14/N33/N51/N36/N37/N41/N43/N61	C12/C11	Total cross 4 Suppliers for DRS, NUMAC, Invensys (GEIS), and Hitachi
5	DCIS Dynamic Integration Test	C73/C74/C41/E11/E22/E51/K11/T22/T31/T41/T43/T49	C51/C71/B21/T63	G31/G51/T40/C31/C81/C85/C91	NA	C11	Total cross 4 Suppliers for DRS, NUMAC, Invensys (GEIS), and Hitachi