

HF Controls

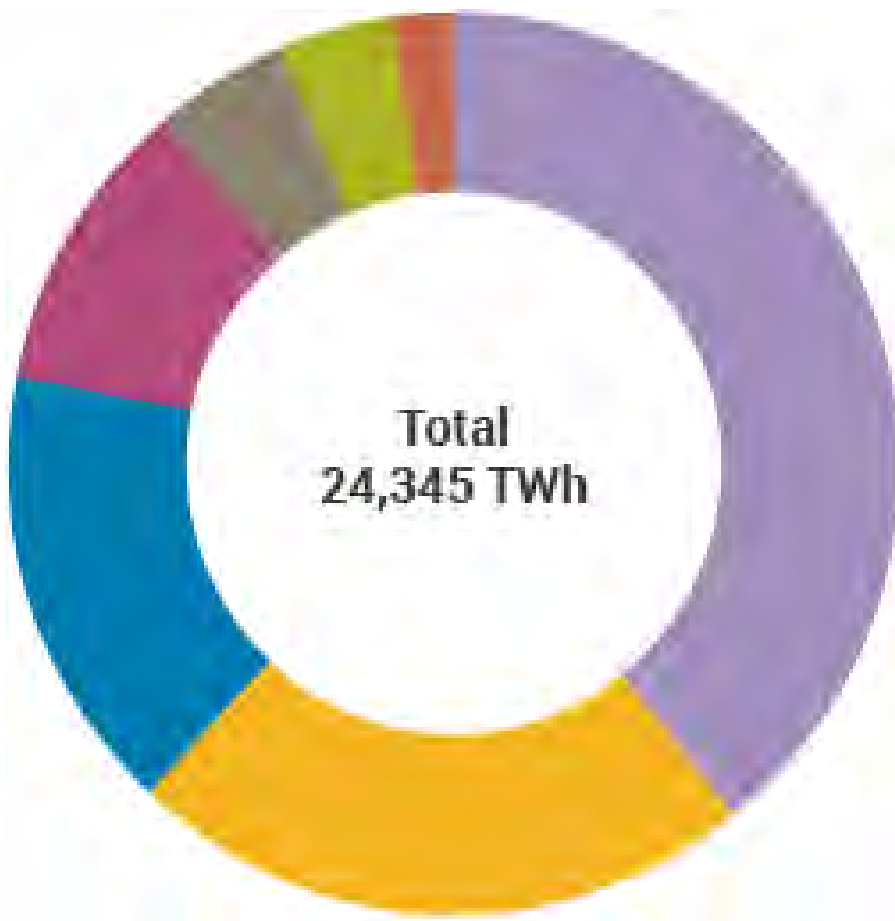
# Digital I&C Design & Implementation for NPPs

Steve Yang, and Allen Hsu  
Doosan HF Controls Corp.  
October 8, 2018



**Innovation Leadership Service**

# World and USA Electricity Generation



- 39.3% Coal
- 22.9% Gas
- 16.0% Hydro
- 10.6% Nuclear
- 4.9% Solar, Wind, Geothermal & Tidal
- 4.1% Oil
- 2.2% Other

- US Electricity Gen**
- ❖ 35% Gas
  - ❖ 30% Coal
  - ❖ 20% Nuclear
  - ❖ 6% Hydro
  - ❖ 6% Wind
  - ❖ 3% Fuel/Solar

Source: IEA Electricity Information 2017

# World Nuclear Power & Reactors

COUNTRY	NUCLEAR ELECTRICITY GENERATION 2017		REACTORS OPERABLE		REACTORS UNDER CONSTRUCTION		REACTORS PLANNED	
	TWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross
<u>USA</u>	805	20	98	99,221	2	2500	14	3100
<u>France</u>	379.1	71.6	58	63,130	1	1750	0	0
<u>China</u>	247.5	3.9	43	40,733	15	15,217	43	50,900
<u>Russia</u>	187.5	17.8	37	28,961	6	4889	25	27,135
<u>Korea (South)</u>	141.1	27.1	24	22,505	4	5600	1	1400
<u>Canada</u>	96	14.6	19	13,553	0	0	2	1500
<u>Ukraine</u>	85.6	55.1	15	13,107	0	0	2	1,900
<u>United Kingdom</u>	63.9	19.3	15	8883	0	0	11	15,600
<u>India</u>	34.9	3.2	22	6219	7	5400	14	10,500

- ❖ Around 11% of the world's electricity from nuclear energy.
- ❖ There are about 450 nuclear power reactors.
- ❖ About 60 more reactors are under construction, equivalent to 16% of existing capacity.
- ❖ An additional 150-160 are planned, equivalent to nearly half of existing capacity.

Based on World Nuclear Association (September 2018)  
<http://www.world-nuclear.org>

# I&C Systems in Nuclear Power Plants

- I&C systems, the nervous system of a nuclear power plant, monitor all aspects of the plant's health and help respond with the care and adjustments needed.
- Nuclear power plants rely on I&C systems for protection, control, supervision and monitoring.
- Digital I&C systems - based on computers, microprocessors or programmable digital devices including FPGA. Analog systems will gradually become obsolete.
- About 40% of the world's operating reactors (~450) have been modernized to include at least some digital I&C systems.
- All new nuclear power plants are being designed with integrated digital I&C systems as the backbone of protection, controls, alarms, and display and monitoring.
- A typical NPP unit has approximately 4,000 sensors and detectors and 5,000 km of I&C cables.
- For a typical PWR, the total mass of I&C related components is on the order of 1,000 tons, which makes the I&C system one of the heaviest and most extensive non-building structures.

# Advantages of Digital I&C

- Digital I&C potentially improves plant safety, reliability, and availability.
- Improves operations with system self-diagnostics, automated testing, enhanced redundancy and more system operation/performance information.
- Addresses the ever increasing obsolescence of analog systems.
- Communication systems for data and information transfer through wires, and fiber optics using digital data protocols, offers ease of maintenance and trouble-shooting efficiency.
- Human-system interfaces provide information and allow interaction with plant operating personnel with improved human ergonomics.
- The US NRC is committed to licensing digital technology in safety system applications. (<https://www.nrc.gov>)

# Challenges in the Digital I&C

- In nuclear power plants, digital technology has been adopted more slowly, especially for safety I&C systems.
- Nuclear industry has an inherently conservative approach to safety, and substantial effort is required.
- Issues to Address:
  - ✓ Common mode failure,
  - ✓ Cyber security,
  - ✓ Emerging technologies,
  - ✓ Engineers skills set on digital I&C, and
  - ✓ Training of plant operators.

# Doosan Heavy Industries & Construction (Doosan)

EPC BG



Power Service BG



Turbine/Generator BG



Nuclear BG



Water BG



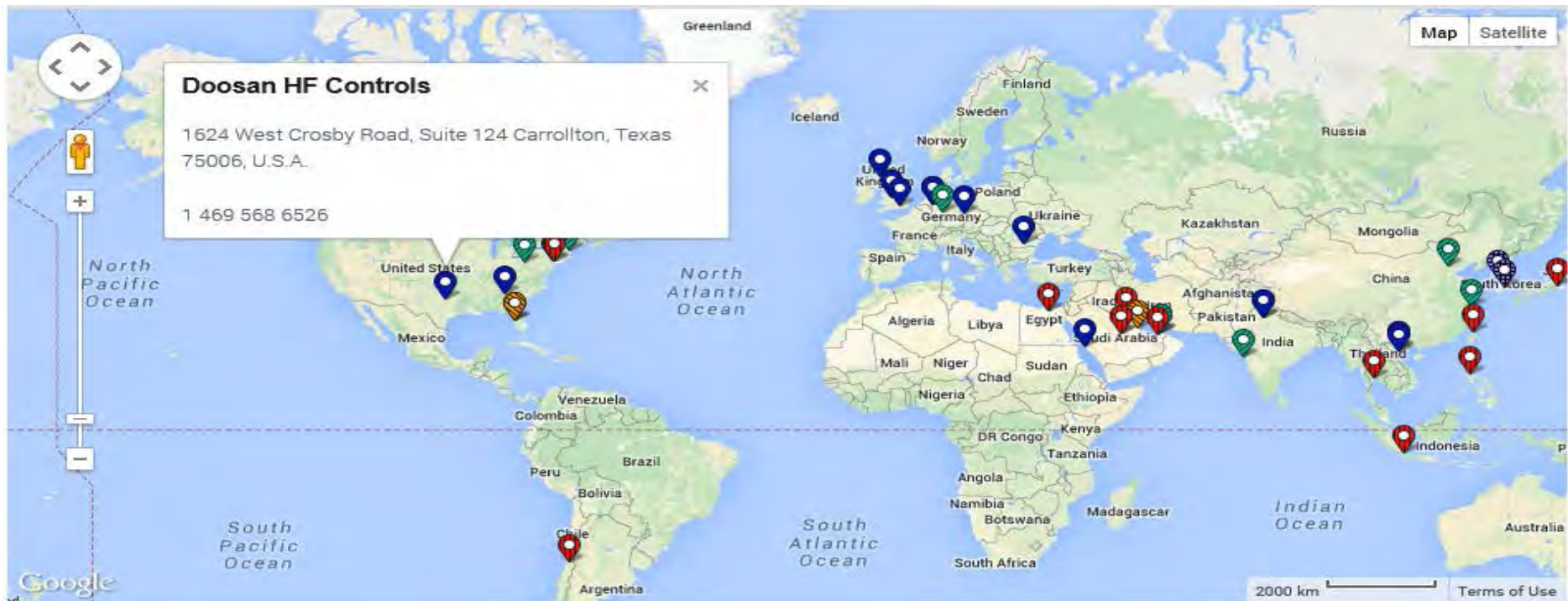
C&F BG



# Doosan HF Controls (HFC)

## Doosan Worldwide Today

At Doosan, our global network of sales, engineering, and production plants is building tomorrow, today. Our presence in key markets worldwide enables us to deliver world-class turnkey power and water solutions to customers virtually anywhere on the planet.



- All
- Headquarter
- Sales
- Office
- Subsidiary
- R&D Center



# Snapshot of Doosan HF Controls

## Overview

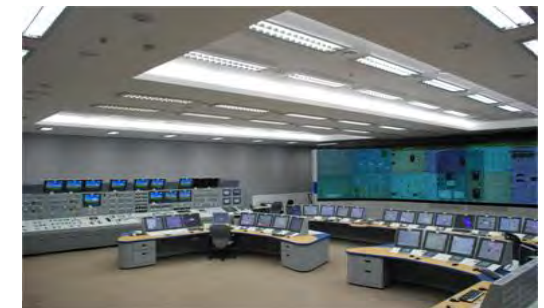
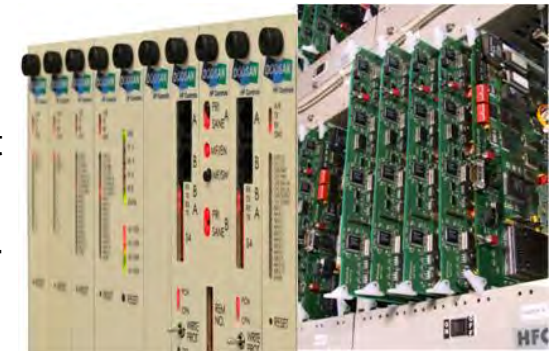
- Address : 1624, West Crosby Carrollton, TX 75006, USA
- Toll Free: 1-866-501-9954
- Fax: 469-568-6589
- Web [www.HFControls.com](http://www.HFControls.com)

## Business Line

- Designing and manufacturing **Nuclear Power Plant safety class 1E/ non-class 1E distributed control systems (DCS)**
- Designing and manufacturing plant control system and boiler management system for fossil power plant
- Provide certified safety control system for various industries such as petrochemical and chemical plants.

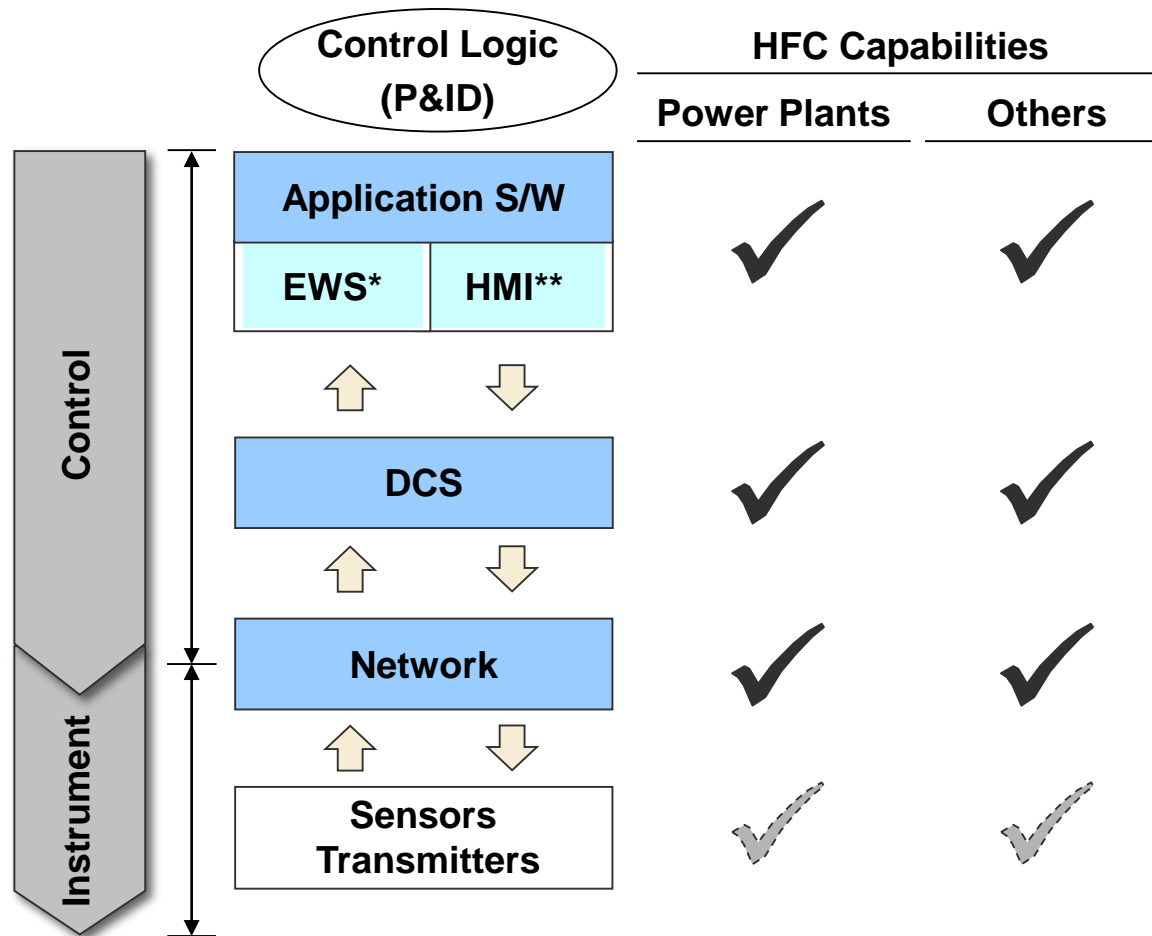
## Accomplishments

- **Over 500+ plant control system installations worldwide**
  - Thousands of digital controllers and I/Os installed in nuclear power plant
  - Field proven plant control I&C product lines including both nuclear and non-nuclear applications



# Capability of I&C Engineering and Design

HFC is capable of handling I&C engineering from system and component design to manufacturing and implementation



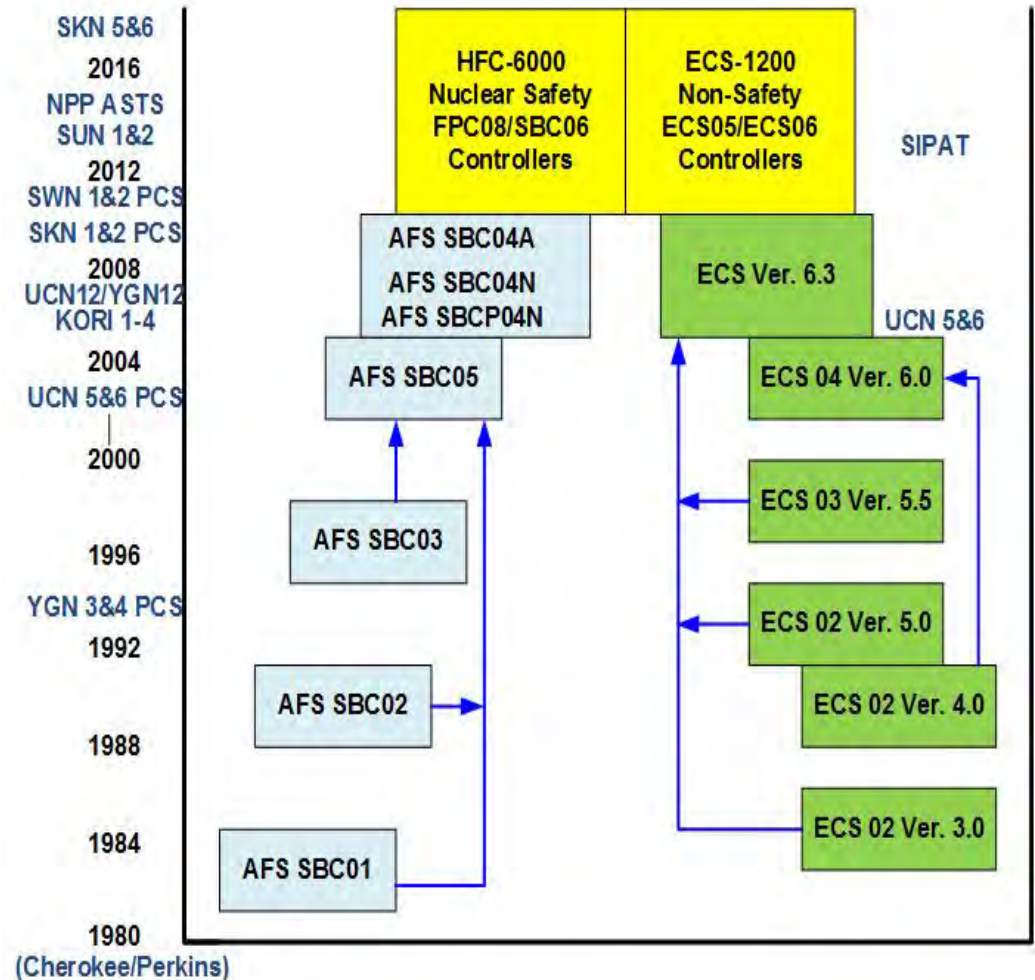
✓ : Design & Manufacturing  
 ✎ : Procurement

## Entire power plant I&C System Integration

- Human Factor Engineering, Human Machine Interface and Programming Tools
- NPP/TPP I&C Product Line Design & Development
- Hardware and Software Qualification Testing and System Integrity Analysis
- Integration, Testing and Software V&V program
- Qualification Hardware system design, engineering and integration
- **NQA-1 Nuclear Safety Manufacturing Facility and Dedicated Resources**

# HFC Product Lines Evolution

- ❖ Established as Forney Engineering Company (subsidiary of Foster Wheeler) in 1961 as a supplier of fossil plant I&C
- ❖ Formed Doosan HF Controls Corporation in 2000
- ❖ Entered the Nuclear I&C market in 1979 with Duke Power Cherokee 1&2 and Perkins 1&2 projects
- ❖ Nuclear I&C System Supplier for Nuclear Safety Class 1E and Non Class 1E Systems in nuclear power plants includes Plant Control System for Korean YGN 3&4, UCN 5&6, Kori 1,2,3&4, SKN 1&2, SWN 1&2, YGN 1&2, UCN 1&2, SHN 1&2, SKN 5&6, ASCO NPP in Spain and Qingshang NPP in China.
- ❖ More than 500+ I&C Safety System installations world wide. After the operation of SKN 1&2 (2010) and SWN 1&2 (2012), Doosan HF Controls installations over 10,000 modernized digital controllers to nuclear power plants.



HFC's Nuclear Control System Evolution

# HFC Key Products

HF Controls has **unique position** to provide both nuclear safety and non-safety equipment

## Product Name

## Features

## Application

### HFC-6000 (Evolved from AFS-1000)



- Nuclear safety class 1E qualified
- Modular Packaging (19"/23" Rack)
- Redundant and Triple Redundant
- DCS and Loop application
- Dedicated CSM & M/A stations
- Nuclear qualified Flat Panel Display
- Superior Response time
- Thousands controllers installed in Nuclear Power Plants

- Nuclear Power Plant Safety
- Turbine Control
- Missions Critical Control
- TÜV SIL-3 Certified



### ECS-1200

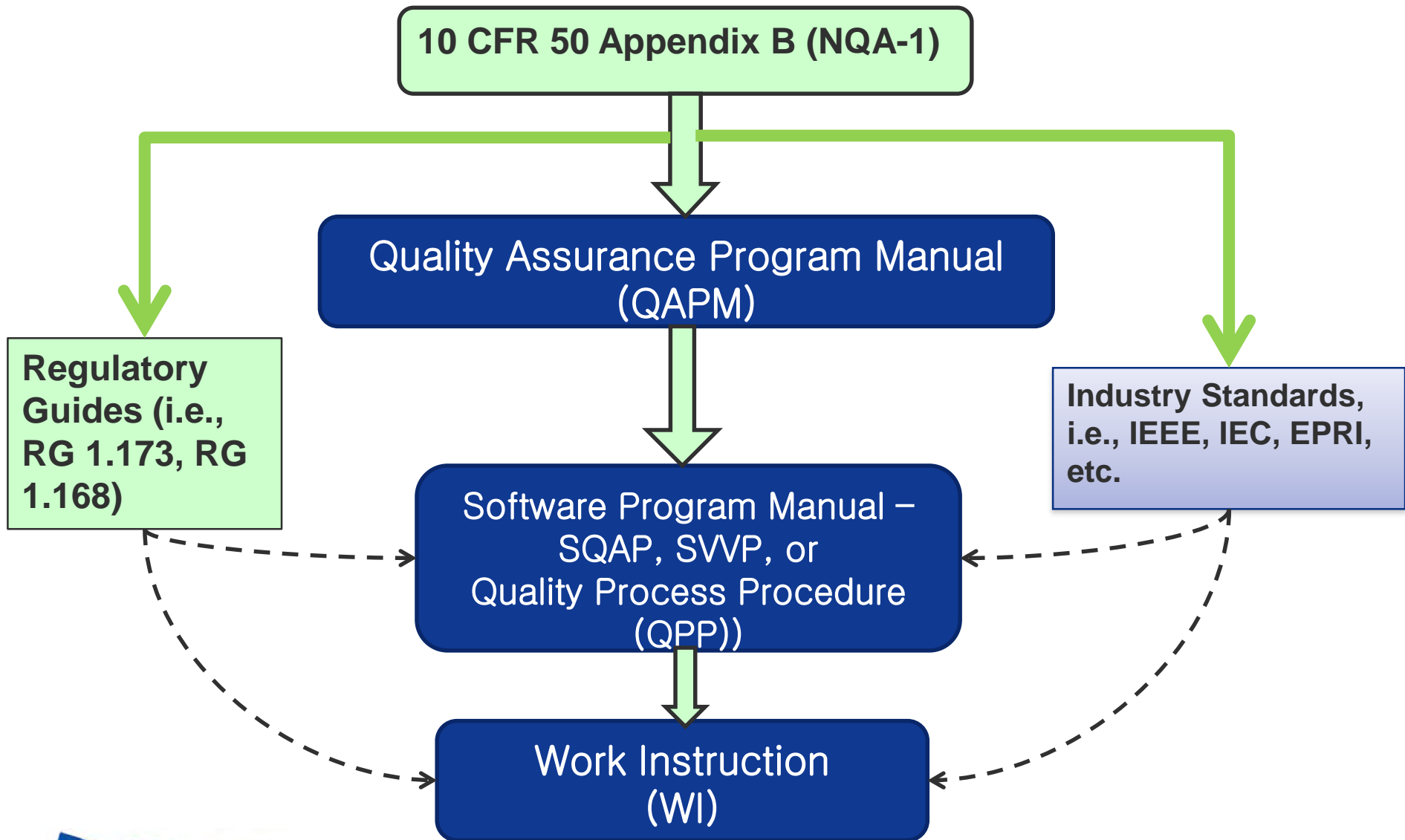


- Scalable DCS Systems (ECS05 / ECS06)
- State-of-Art System Architecture
- Up to 16 microprocessors configurations
- Complete I/O library cards
- Redundant and Triple Redundant applications

- Nuclear Power Plant Non-Safety
- Standard DCS Application
- TÜV SIL Certified



# Quality Assurance Process Hierarchical



# NQA-1 and 10 CFR 50 Appendix B Compliance

**Under 10CFR50 Appendix B, HFC has developed its Quality Assurance Program Manual. HFC has in place many standards, practices, and conventions (in the form of Procedures) and a complex series of information collections, assembly, and analysis steps resulting in the publication of metric data on the Quality System. The following procedures are utilized in the execution and monitoring of the nuclear project:**

- ✓QPP 1.1 Management Review
- ✓QPP 1.2 Organizational Responsibilities
- ✓QPP 2.1 Quality Plans
- ✓QPP 2.2 General Indoctrination and Training
- ✓QPP 3.1 Design Control
- ✓QPP 3.2 System Lifecycle and Verification/Validation Program
- ✓QPP 4.1 Review, Approval and Issuance of Purchase Orders
- ✓QPP 5.1 Review and Approval of Documents
- ✓QPP 6.1 Control and Distribution of Documents
- ✓QPP 7.1 Supplier Selection, Qualification and Re-Evaluation
- ✓QPP 8.1 Identification and Control of Material
- ✓QPP 10.1 Receipt, In-Process and Final inspection
- ✓QPP 14.1 Inspection and Test Status
- ✓QPP 15.1 Nonconformance Control Program
- ✓QPP 16.1 Corrective Action Program
- ✓QPP 17.1 Quality Records
- ✓QPP 18.1 Audits
- ✓QPP 19.1 Contract Review

Any additional information collection/analysis/publication that is to be part of the project will be defined in the PQP, SVVP and SCMP.

# Design Requirements

## 1. Licensing

- (a). *10CFR 50 Appendix A* - The general design criteria for nuclear power plants
- (b). *10CFR 50 Appendix B* - Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
- (c). *RG 1.173-2013* - Developing Software Life Cycle Processes for Digital Computer Software Used in Safety Systems of Nuclear Power Plants

## 2. Industry Standards

- (a). *IEEE-603-1991* - Criteria for Safety Systems for Nuclear Power Generating Stations
- (b). *IEEE-1012-2004* - Software Verification and Validation

## 3. Plant Specific Requirements

- (a). Purchase Order
- (b). Purchase Technical Specifications

# Audits and Certifications

## Key Activities



- Feb. 2002 : KINS\* and KHNP\*\* delegation performed audit on plant control system
- Apr. 2007 : KHNP and KINS performed audit on HFC-6000 and V&V documents
- Nov. 2007: KHNP and KINS performed audit on software V&V  
KHNP annual audit

- ❖ Successfully completed rigorous audits by the Korean Institute of Nuclear Safety and officially reconfirmed its leading position in nuclear I&C market.



- Mar. 2008 : Submitted Topical Reports for HFC-6000 Safety **Control** System
- Sep. 2008 : Received Acceptance Letter from NRC
- Oct/Dec 2009 : Audited by US NRC I&C staff
- Feb. 2010 : Response of formal RAI
- **Apr. 2011 : Acquired SER from NRC**
- **Current : Amendment 2, 3 and 4**

- ❖ Qualified for nuclear safety class 1E equipment in the US;
- ❖ To expect to infiltrate the US retrofit market both for safety and non-safety areas



- Mar. 2007 : Acquired TÜV SIL 1 certificate for DCS product line (ECS-1200)
- Apr. 2009 : Applied Certification for TÜV SIL 3
- Sep. 2009 : Approval of conceptual assessment
- **Sep. 2010 : Acquired TÜV SIL-3 Certification (SBC06)**
- **Sep. 2013 : Acquired TÜV SIL-3 Certification (FPC08)**
- 2018 : Renewed Certifications

- ❖ Qualified to bid for projects that requires SIL 3 safety specifications;
- ❖ To further expand the market share in the petrochemical and turbine control system.



# The Advantage of FPGA Technology

- 1. Field Programmable Gate Arrays (FPGAs) have gained interest for implementing safety I&C applications in nuclear power plants (NPPs).**
- 2. FPGAs, from software perspective, can be made simpler, less reliant on complex software such as operating systems, which should make FPGAs easier to qualify for nuclear safety applications.**
- 3. FPGAs are less vulnerable to cyber attacks when FPGAs implement the I&C systems that do not contain high-level, general purpose software that may be easily subjected to malicious modifications.**
- 4. FPGAs can process separate functions independently and in parallel on the same integrated circuit, which makes FPGAs highly efficient in their performance.**
- 5. FPGA technology has been widely used and proven in the aerospace industry, the telecommunications industry and the general control industry for over 20 years.**

# FPGA-based Application Development Lifecycle

- 1. Development process of FPGA-based application is similar to that of software for microprocessor-based systems.**
- 2. The control system application development starts with system requirements specification.**
- 3. The system requirements are then allocated to the FPGA specific application requirements.**
- 4. FPGA architecture and design specification are then constructed.**
- 5. With the completion of the design, the FPGA implementation is followed. (The specific implementation of FPGA-based applications has its own characteristics.)**
- 6. FPGA-based module level testing is planned and executed.**
- 7. FPGA-based modules are integrated with system for system integration testing and acceptance testing.**

# HFC's FPGA Technology (I) – FPGA as emulator

## A. FPGA as Microprocessor's Emulator

- To emulate the process of current microprocessors and to interpret the execution of CPU processes.
- Existing software of communication networking and control algorithms can be adopted with ease.
- It is suitable for retrofit project.

### Current Status -

- ✓ HFC developed a FPGA version SBC-01Y controllers as the direct replacement for YGN NPP unit 3 & 4. More than 250 of them had been installed successfully at the site since 2009. It uses existing system and application software from old board.
- ✓ SBC-01Y emulates the functions of Intel 8085 microprocessor .

# HFC's FPGA Technology (II) - FPGA Platform

## B. Generic FPGA platform for nuclear safety application

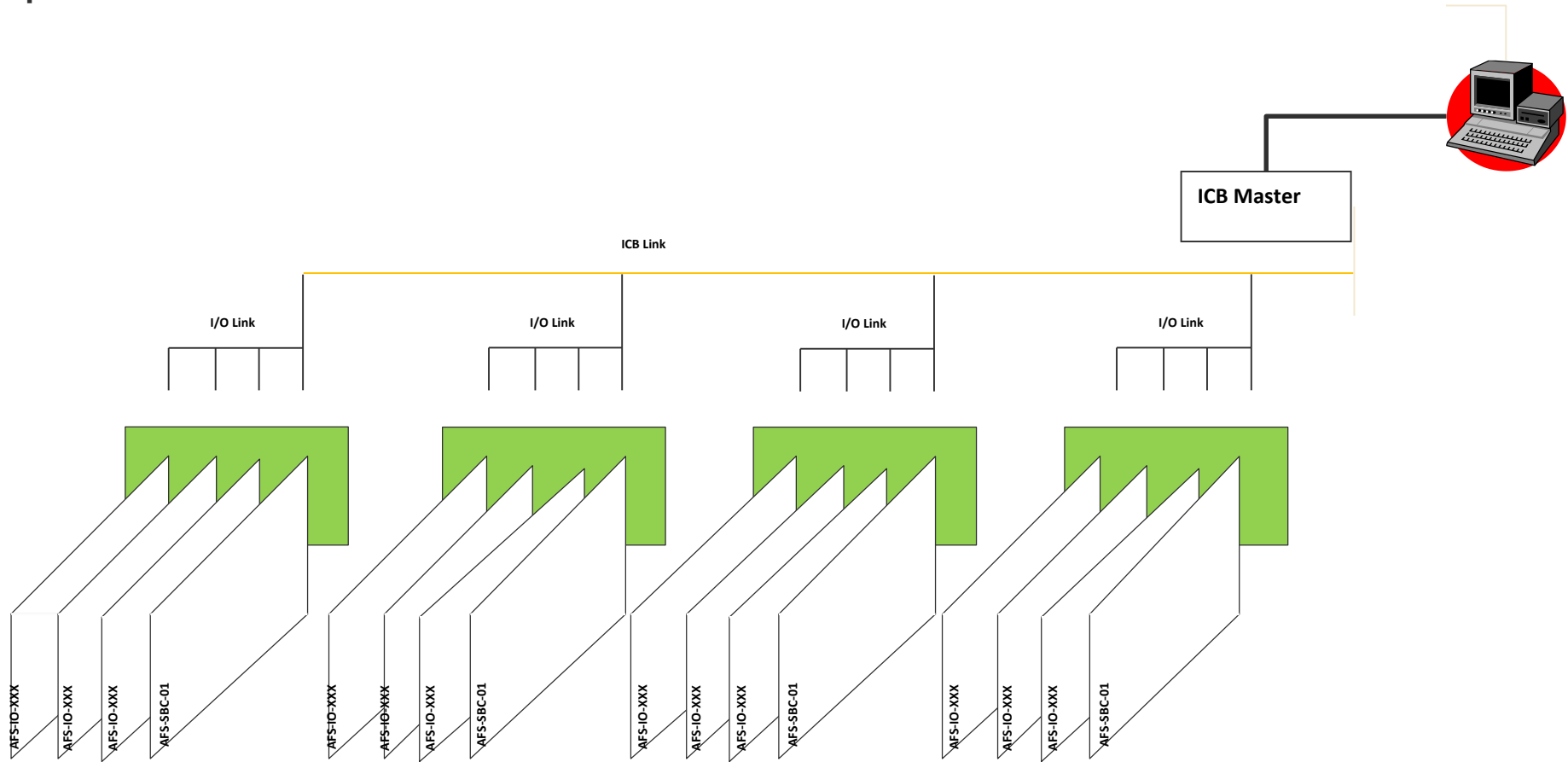
- A generic platform design considers all requirements of nuclear safety I&C (calculation power, response time,...).
- The complexity in the implementation of 100% verification, true parallel processing for heavy analog logics and multiple level communication network.
- Continuous enhancement depends on the maturity of FPGA technology.
- It is suitable for both retrofit and new build applications.

### Approach -

- ✓ *Distributed Loop Control Scheme and Centralized Control scheme.*
- ✓ *Based upon HFC's nuclear safety I&C experiences for nuclear plants, a combination of FPGA version controller (i.e., CPU, Digital, Analog, Special function,...) with onboard I/O has been developed and fitted into HFC-6000 racks.*
- ✓ *The controllers is capable of handling application logics that generated from HFC One-Step automated logic generator.*

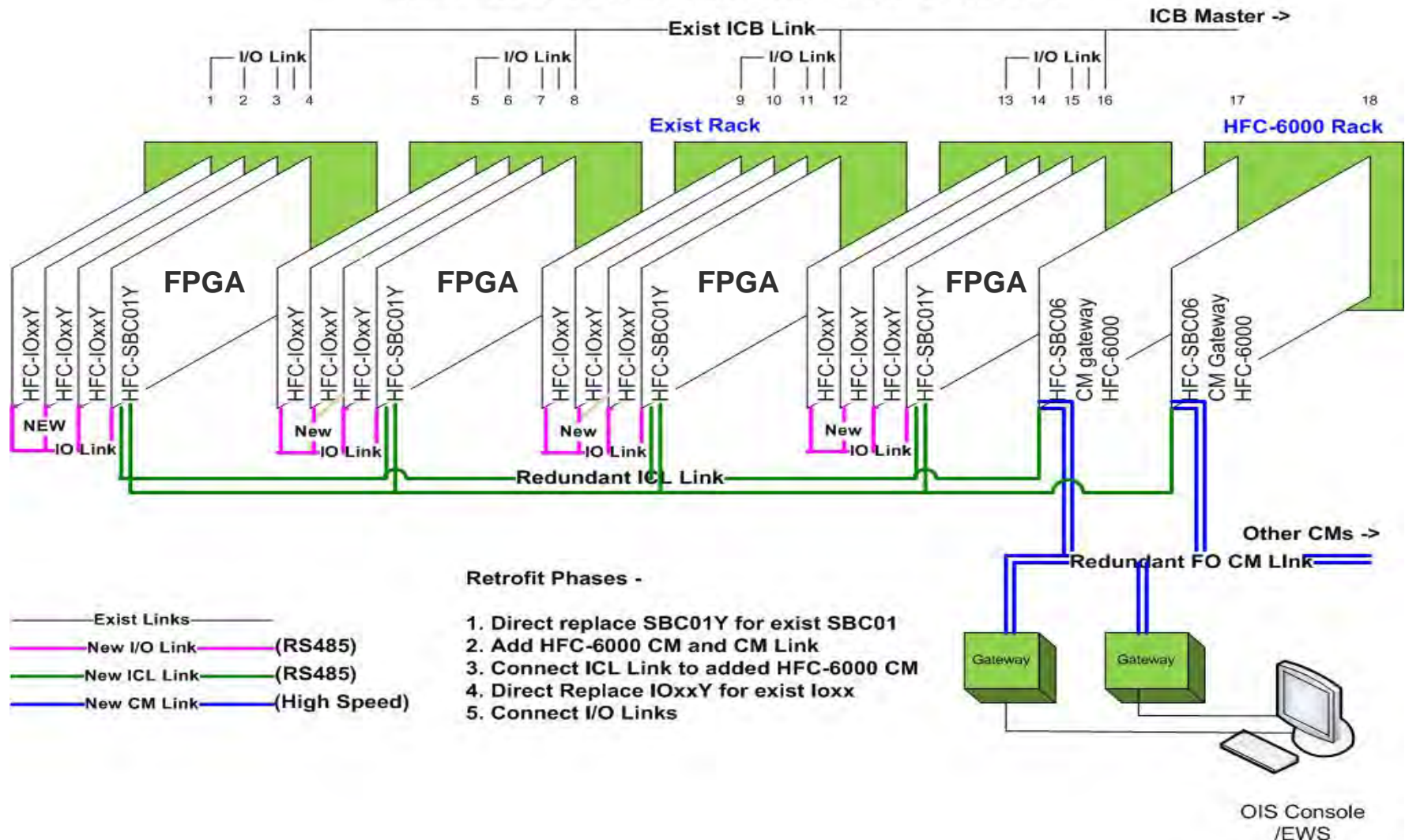
# FPGA version SBC01Y Retrofit at YGN Unit 3 & 4

The existing system configuration where the single loop controller board (AFS SBC-01) was the Intel 8085 Microprocessor-based that is obsolete.



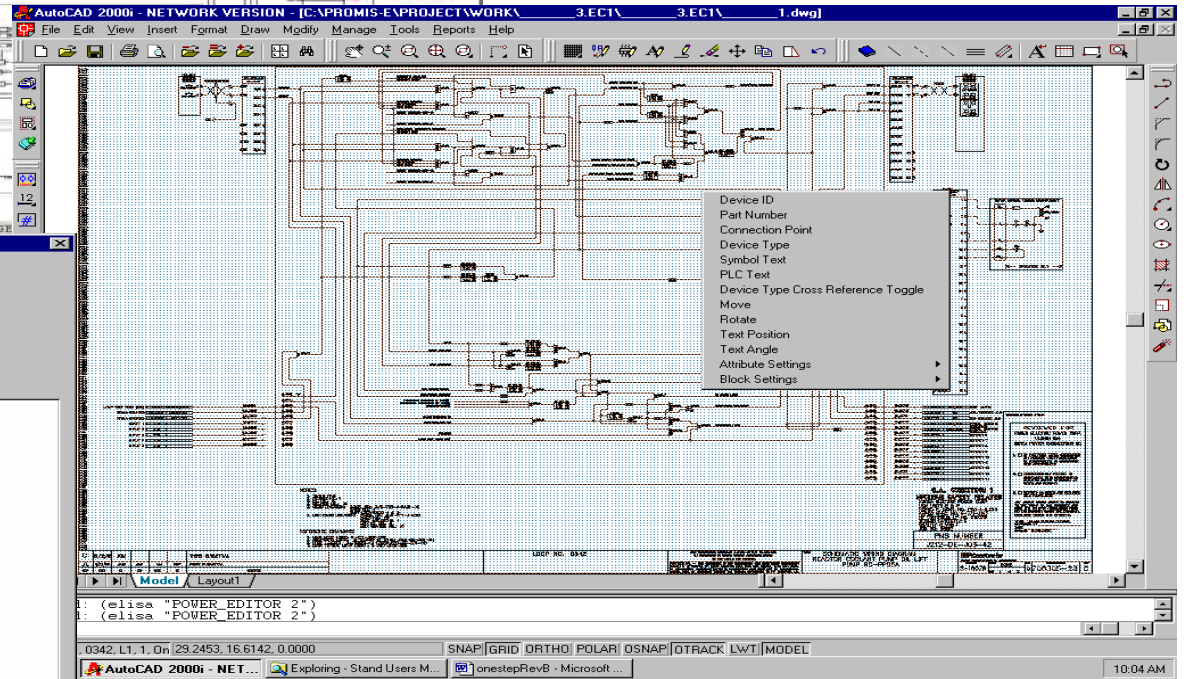
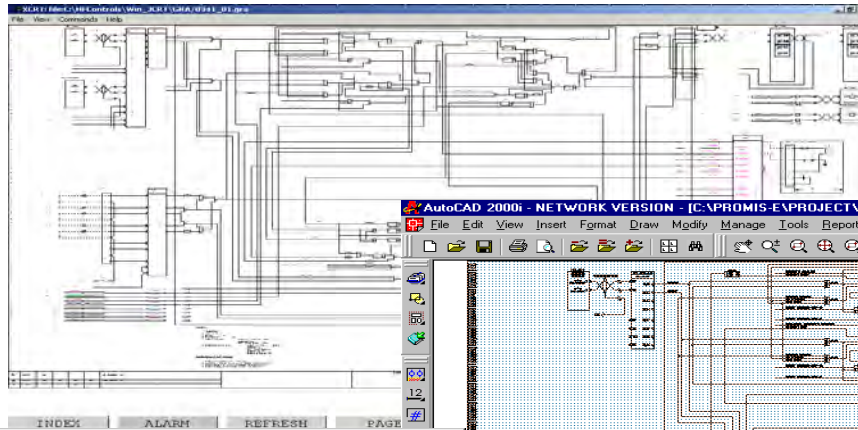
# FPGA version SBC01Y Retrofit at YGN Unit 3 & 4

## HFC-SBC01Y and HFC-IOxxY for YGN 3&4





# Sample Drawings – One-Step



**Select Icon - HFC**  
Exit Edit Settings

Name:  Search...   Symbol  
Description:   Macro

	Angle:	Scale:	Mirror	Maintain Device IDs As Created
Symbol Settings:	0	1.0000	Off	-
Macro Settings:	0	1.0000	-	No

**Standardized Library of Icons**

Analogue logic (basic)  
Digital logic  
J212DEJ11-11  
Kepco\_I/O\_cards  
Kepco\_functional\_I/O\_cards  
Kepco\_logic\_templates

WAN AUTO BLOCK E-1 BL-1	AVERAGING BLOCK AVC BL-7
CONTROLLER WITH SETPOINT & PV S-P-100 BL-2 0-100 % (D)	CHARACTERIZING BLOCK FCO BL-8
CALCULATION BLOCK A-2-1-3-5 BL-6 +/-2+3	DIVIDE BLOCK E-A BL-9
EXTENDED BLOCK MEMORY STORAGE EXT BL-3	HIGH SELECT BLOCK > BL-10
ANALOG INPUT BLOCK AIC BL-4 0-100 %	LOW SELECT BLOCK < BL-11
ANALOG OUTPUT BLOCK AOO BL-5 (D)	LEAD LAG BLOCK LLG BL-12
	DIGITAL HIGH ALARM BLOCK DHA BL-13 HL
	DIGITAL LOW ALARM BLOCK DLA BL-14 LL

Pop Up and Dialog Box Constructions of Control Logics



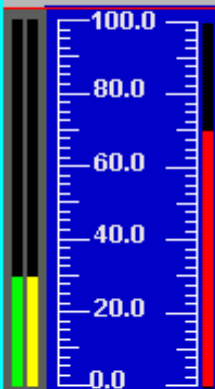
## ➤ Tool V&V Program

As the development of One-Step for microprocessor program, HFC implemented a V&V program for the One-Step tool for FPGA. This program is consistent with the V&V methodologies specified in the IEEE Std 1012-2004. Specific steps are described as follows:

- ✓ Review and Verification of Tool Requirements Specification and Design Implementation
- ✓ Tool Code Review and Walkthrough
- ✓ Tool Code Coverage Testing (complete for all needed logics gates and MACROs)
- ✓ Tool Functional Testing (all logics functions)
- ✓ Tool Timing Simulation Testing (on all required logics)
- ✓ Tool Use in the FPGA Circuitry System Testing (on selected applications, as well as loops logics that have been used in operating NPPs)

FD FAN A  
CTRL  
VANES

EUNIT001



0,AG,3

P 30.097

S 30.0

O 69.901

AUTO

LOCAL

E C S

MODE: ACTIVE

BLOCK TYPE: PID

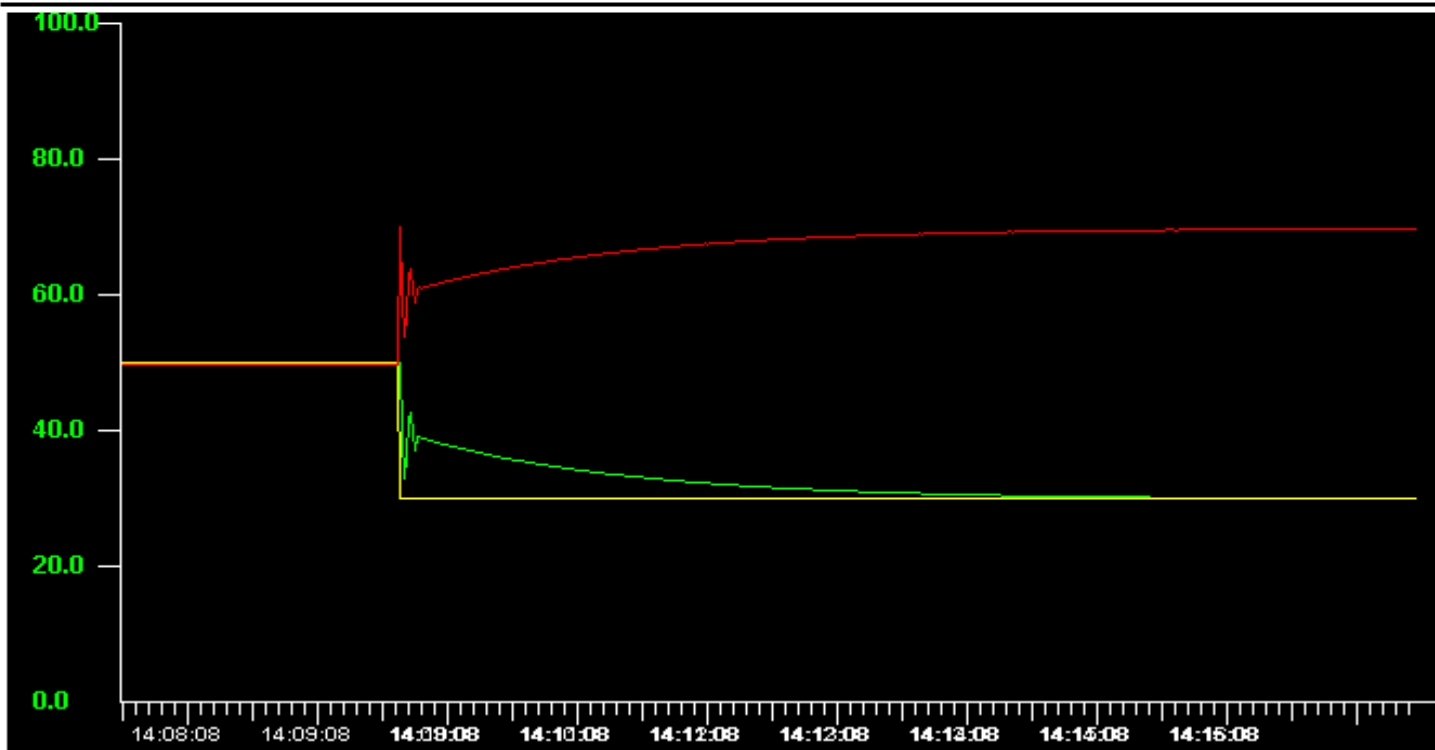
REMOTE: 0

STR: 0

FREQ: 0

PHASE: 0

BLOCK: 3



DYNAMIC GAIN

NaN

DISABLE

NL GAIN

0.0

GAIN

1.0

TAUI

100.0

TAUD

0.0

PRIMARY TUNING

HIGH ALARM 0.0 DISABLE

LOW ALARM 0.0 DISABLE

RATE ALARM 0.0 DISABLE

ALARM DEADBAND 0.0

DEVIATION ALARM DISABLE

HIGH OUTPUT CLAMP 100.0 DISABLE

LOW OUTPUT CLAMP 0.0 DISABLE

HIGH TRIGGER 0.0 DISABLE

LOW TRIGGER 0.0 DISABLE

REVERSE

NO SP INIT

PROP FROM ERROR

INDEX

ALARM

REFRESH

PAGE

BACK

RETURN

COPY

EXE

# Summaries and Conclusion

- **About 40% of the world's operating reactors (~450) have been modernized to include at least some digital I&C systems; new builds are adopting digital I&C.**
- **Digital I&C will stay because of its benefits. However, there are challenges.**
- **FPGA offers some advantages where Microprocessors may not have.**
- **Doosan HFC uses FPGA to emulate obsolete microprocessors as well as I&C platform for safety applications.**
- **High confidence and reliability in digital I&C design & implementation can be obtained:**
  - ✓ **Following acceptable lifecycle process in the design,**
  - ✓ **Generating/adopting I&C architecture complying with digital I&C fundamental design principles, and**
  - ✓ **Performing rigorous V&V work.**

# Thanks and Enjoy Your Time In Dallas!

## Dallas Sightseeing Guide:

1. <https://www.youtube.com/watch?v=Kt7lpqdbNgA>
2. [https://www.google.com/destination/map/topsights?q=dallas+sightseeing&site=search&output=search&dest\\_mid=/m/0f2rq&sa=X&ved=0ahUKEwit7ono1crdAhWC14MKHbKIC9sQ69EBCEooADAA#trifp=skpm%3D/m/0ct4dp](https://www.google.com/destination/map/topsights?q=dallas+sightseeing&site=search&output=search&dest_mid=/m/0f2rq&sa=X&ved=0ahUKEwit7ono1crdAhWC14MKHbKIC9sQ69EBCEooADAA#trifp=skpm%3D/m/0ct4dp)



# Thanks and Enjoy Your Time In Dallas!

## 1. Reunion Tower

Landmark observation deck featuring light shows, 360-degree city views, 2 restaurants & a gift shop.

## 2. The Dallas Arboretum and Botanical Gardens

70-acre botanical garden set on White Rock Lake with frequent concerts, special exhibits & classes.

## 3. The Sixth Floor Museum at Dealey Plaza

Comprehensive exhibits on John F. Kennedy's presidency & assassination at site of the sniper's nest.

## 4. The Dallas World Aquarium

Replica habitats containing exotic birds, mammals & fish are open for public tours & private events.

## 5. Dallas Museum Of Art

Arts District anchor with an encyclopedic collection spanning ancient times to the present.

## 6. George W. Bush Presidential Center

Museum housing the archives of the George W. Bush presidency, 43,000 gifts & a replica Oval Office

## 7. ....