KSTAR Integrated Control System

October 22, 2012

Mikyung Park
Introduction

• KSTAR Project
• Operation and Experiments
KSTAR Project

◆ KSTAR - Korea Superconducting Tokamak Advanced Research
◆ Mission -
Development of a steady-state-capable advanced superconducting tokamak to establish the scientific and technological base for an attractive fusion reactor as a future energy source.
◆ History-
1995: Project launched
1998: Construction started
2007: Completion of Assembly
2008: Achievement of the 1st plasma
2012: 5th Campaign

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major radius, $R_0$ / Minor radius, $a$</td>
<td>1.8 m / 0.5 m</td>
</tr>
<tr>
<td>Elongation, $\kappa$ / Triangularity, $\delta$</td>
<td>2.0 / 0.8</td>
</tr>
<tr>
<td>Plasma volume</td>
<td>17.8 m$^3$</td>
</tr>
<tr>
<td>Plasma surface area / cross section</td>
<td>56 m$^2$ / 1.6 m$^2$</td>
</tr>
<tr>
<td>Plasma shape</td>
<td>DN, SN</td>
</tr>
<tr>
<td>Plasma current, $I_p$</td>
<td>2.0 MA</td>
</tr>
<tr>
<td>Toroidal field, $B_0$</td>
<td>3.5 T</td>
</tr>
<tr>
<td>Pulse length</td>
<td>300 s</td>
</tr>
<tr>
<td>$\beta_n$</td>
<td>~5.0</td>
</tr>
<tr>
<td>Plasma fuel</td>
<td>H, D-D</td>
</tr>
<tr>
<td>Superconductor</td>
<td>$Nb_3Sn$, NbTi</td>
</tr>
<tr>
<td>Auxiliary heating /CD</td>
<td>~ 28 MW</td>
</tr>
<tr>
<td>Cryogenic</td>
<td>9 kW @4.5K</td>
</tr>
</tbody>
</table>
Tokamak and Ancillary Systems

- Cooling Water
- KSTAR Tokamak
- Motor Generator
- Heating Devices
- Cryogenic Refrigerator
- Magnet Power Supply
- Diagnostics
- Control Room
Operation and Experiments

- **About 6 months/campaign/year**
- **6 Long-term Operation Phases / Campaign**: Vacuum pumping – Cool down – Magnet test – Plasma Experiments – Warm up – Maintenance
- **Daily Operation**
  - Search – Readiness check – TF on
  - Every plasma shot is identified by shot number

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**Sequence**

- Prepare for next shot
- Create next shot #
- Configuring parameter
- Parameter set DONE?
- Lock
- Create MDStree

1. **Start of sequence** @T0 – 1 min.
2. **Start of shot** @T0 – 2 min.
3. **Timing generation**
   - MPS run
   - PCS standby
   - MPS ready
4. **PF On**
   - Fuel on by TSS
   - ECH RF on by TSS
   - Blip by TSS
5. **PFPS current=0?**
6. **PF Off**
7. **Shot Termination**
   - MPS Stop
8. **End of sequence**
   - End of sequence
9. **Post activities**
   - Create shot summary
   - Upload & visualize shot results
   - Send data, ...
10. **Processing & analysis**
11. **Data transferring**

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**Notes**

- About 6 months/campaign/year
- 6 Long-term Operation Phases / Campaign: Vacuum pumping – Cool down – Magnet test – Plasma Experiments – Warm up – Maintenance
- Daily Operation:
  - Search – Readiness check – TF on
  - Every plasma shot is identified by shot number

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2012 Fall EPICS Collaboration Meeting • Oct.22-26, 2012 • Mikyung Park (mkpark@nfri.re.kr)
Sequential Operation for Plasma Exp.

Operator’s Panel

Shot Sequences

Synchronized operation
KSTAR Control System

• Features and architecture
• Plant control and data acquisition system
• Time and Synchronization System
• Operator interfaces
• Management tools
KSTAR Integrated Control Systems

- Diagnostic DAQ Systems
- Heating Systems (ECH, ICRH, NBI-1)
- Tokamak Monitoring
- Fueling/Glow Discharge
- Quench Detection
- PFC Monitoring
- Vacuum Pumping
- He Distribution
- Cryogenic System
- Current Lead System
- Magnet Power Supply

Plant Control Systems

Operation/Experiments
Features

- Using every possible Open-source Tools for development
- Integration of Heterogeneous controllers
  - PLC, cFP, VME, VXI, cPCI, PCI, PXI, PMC, FMC, ATCA
  - But, Not 100%. A few systems have minimum interfaces.
  - ~ 140 IOCs
- Engineering data (managed by EPICS)
  - ~ 60,000PVs, low rate & continuous
- Experimental data (managed by MDSplus)
  - ~ 11,600 tags, high rate & pulse-based data
- Two Archiving systems: EPICS Channel Archiver, MDSplus
- Additional RDB: MSsql, Mysql
- Standardization: design guideline, standard S/W framework

The control system is still growing!!
### Data generated from Experiments

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Storage</th>
<th>Campaign</th>
<th>P. Length</th>
<th>Data</th>
<th>Data/shot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Data</strong></td>
<td>Main (7.2TB)</td>
<td>2008</td>
<td></td>
<td>1.1TB</td>
<td></td>
</tr>
<tr>
<td>(EPICS data)</td>
<td></td>
<td>2009</td>
<td></td>
<td>420GB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2010</td>
<td></td>
<td>637GB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2011</td>
<td></td>
<td>675GB</td>
<td></td>
</tr>
<tr>
<td><strong>Experimental Data</strong></td>
<td>Main (7.2TB)</td>
<td>2008</td>
<td></td>
<td>204GB</td>
<td></td>
</tr>
<tr>
<td>(MDSplus data)</td>
<td></td>
<td>2009</td>
<td>3.5s</td>
<td>503GB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2010</td>
<td>5s</td>
<td>1.2TB</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2011</td>
<td>10s</td>
<td>1.7TB</td>
<td>1GB</td>
</tr>
<tr>
<td><strong>Image Data</strong></td>
<td>Image (50TB)</td>
<td>2008</td>
<td></td>
<td>20GB</td>
<td></td>
</tr>
<tr>
<td>- Visible TVs</td>
<td></td>
<td>2009</td>
<td>3.5s</td>
<td>42GB</td>
<td></td>
</tr>
<tr>
<td>- IRTVs</td>
<td></td>
<td>2010</td>
<td>5s</td>
<td>220GB</td>
<td></td>
</tr>
<tr>
<td>- BES, CES, MSE</td>
<td></td>
<td>2011</td>
<td>10s</td>
<td>3.7TB</td>
<td>2GB</td>
</tr>
<tr>
<td><strong>High Volume Data</strong></td>
<td>Distributed (50TB)</td>
<td>2011</td>
<td>10s</td>
<td>3.7TB</td>
<td>3.6GB</td>
</tr>
<tr>
<td>• ECEI</td>
<td></td>
<td>2012</td>
<td>&gt; 10s</td>
<td>&gt; 9TB</td>
<td>8.5GB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Data generated from Experiments
Time and Synchronization System

**Missions of Timing system**

1. Synchronized operation and experiments according to the sequences
   - **Hardware triggering (including clocks) along with GPS time using timing board**
2. Provision of reference time data to all computers at KSTAR
   - **NTP (Network Timing Protocol)**
3. Additionally, it must provide **multiple triggering** during a shot,
   • to support **long pulse operation**
   • to efficiently manage data generated during plasma shot

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**GPS Antenna**

- **L1, 1.575GHz**

**Central Timing System**

- **GPS Receiver**
- **IRIG-B DCLS**
- **Rubi Source**
- **10MHz (1x10^-11/month)**

**Optical SW**

- **2Gbps**
- **F/O: 850nm, Multi-mode**

**Synchronization Calibration**

**Central Timing Unit (CTU)**

- **NTP**

**Local Timing Unit (LTU)**

- ~40 being used

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*Mikyung Park et. al, “The upgrade of KSTAR timing system to support long pulse operation and high-speed data acquisition”, Fusion Engineering and Design Vol.87 (2012)*

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**2012 Fall EPICS Collaboration Meeting • Oct.22-26, 2012 • Mikyung Park (mkpark@nfri.re.kr)**
Time and Synchronization System

**CLTU Timing Board**
- **Extension Module**

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### Specifications

- **O/S**
  - VxWorks 5.5.1
- **EPICS**
  - Release 3.14.12.2
- **EPICS device driver in**
  - Vxworks, Linux 2.4x/2.6x
- **PMC Form-factor**
  - 32/64-bit, 33/66MHz
- **FPGA**
  - Spartan-6 (150K logic cells)
- **IRIG-B GPS time decoding**
- **Timing accuracy**
  - max. 5ns (1 tick)
- **Timing Jitter**
  - <100ps, max
- **Output clock**
  - 1Hz ~ 100MHz
- **Master clock**
  - 200MHz
- **Trigger/Clock output**
  - 8, configurable
- **Multi triggering sections**
  - 8, configurable
- **Optical communication**
  - 2 Gbps

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**Device support routine**

**VxWorks**

**Hardware (CTU, Central Timing Unit)**

**LTU EPICS IOC**
- System monitoring library
- Device support library
- Linux base kernel
- Linux device driver module

**KSTAR machine network**

**KSTAR timing network**

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Max. 8 configurable sections /shot

- **2V/div**
- **100ms/div**
- **R_{IN}=1MW**

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**Trigger**

**Clock**
### KSTAR Widget Toolkit (KWT)

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Description</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qt designer plug-in interface</td>
<td>KSTAR Widgets group</td>
<td>•CustomWidgetItem to make widget group in Qt designer</td>
<td>No</td>
</tr>
<tr>
<td>Common library</td>
<td>AttachChannelAccess</td>
<td>•Qt-CA interface (attach library)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>ChannelAccessThr</td>
<td>•Qt-CA interface (thread library)</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Password</td>
<td>•Password class for some control widgets</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>SinglePlot</td>
<td>•Single channel plotting library</td>
<td>Run-time</td>
</tr>
<tr>
<td></td>
<td>CachedChannelAccess</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Update rate definition widget</td>
<td>CAUITime</td>
<td>•Update rate definition widget (Periodic or Event-driven)</td>
<td>Empty</td>
</tr>
<tr>
<td></td>
<td></td>
<td>•Master PV defined in the ‘pvname’ property disables all control</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>widgets.</td>
<td></td>
</tr>
<tr>
<td>Plot widgets</td>
<td>CAMultiplot</td>
<td>•Multi-channel plotting widget</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>CAMultiwaveplot</td>
<td>•Multi-channel plotting widget for Waveform record</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>MDSplusplot</td>
<td>•Node data of MDSplus tree plotting widget</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>CAColorCheckBox</td>
<td>•A part of CAMultiplot or CAMultiwaveplot widget which displays color information and value</td>
<td></td>
</tr>
<tr>
<td>Simple graphic widget</td>
<td>StaticGraphic</td>
<td>•Symbol library including vacuum devices, arrows, ellipse, rectangle, etc.</td>
<td></td>
</tr>
<tr>
<td>Status monitoring widgets</td>
<td>CALabel</td>
<td>•Text indicator widget</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAGraphic</td>
<td>•Symbol library which changes its color by alarm status.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>•It inherits StaticGraphic.</td>
<td>StaticGraphic</td>
</tr>
<tr>
<td></td>
<td>CAImageMbibi</td>
<td>•Collection of multiple QLables for mbbi record</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAWclock</td>
<td>•Text indicator widget for the timestamp record</td>
<td>2011/06/16 19:00:51</td>
</tr>
<tr>
<td></td>
<td>BlinkLine</td>
<td>•Display alarm for the network status of IOC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CABlinkLabel</td>
<td>•Display alarm for the health status of IOC resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CADisplayer</td>
<td>•Text indicator widget which displays numeric data with the corresponding alarm color</td>
<td>2.25e-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>•It pops SinglePlot up with right click</td>
<td></td>
</tr>
</tbody>
</table>
## Operator Interfaces

### KSTAR Widget Toolkit (KWT)

<table>
<thead>
<tr>
<th>Control widgets</th>
<th>CAPushButton</th>
<th>A QPushButton which sends operator’s command to the PV</th>
<th>SHOT START</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CABoButton</td>
<td>A pair of QPushButton</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>CACheckBox</td>
<td>A QCheckBox which sends operator’s command to the PV</td>
<td>VMS VALVE ON</td>
</tr>
<tr>
<td></td>
<td>CAComboBox</td>
<td>A QComboBox which sends operator’s command to the multi-bit PV</td>
<td>CLB TE_RGA M2</td>
</tr>
<tr>
<td></td>
<td>CAMButton</td>
<td>A collection of multiple CAPushButton for EPICS mbbo record</td>
<td>Ready/Lock</td>
</tr>
<tr>
<td></td>
<td>CALineEdit</td>
<td>A QLineEdit which sends numeric data to the PV</td>
<td>NEXT SHORT AT</td>
</tr>
</tbody>
</table>

| Other widgets   | CAScreenShot | Screen shot according to PV’s value                   | Empty |
|                 | CAQtSignal   | Conversion PV’s value to Qt-valued signal             | Empty |
|                 | CAFanOut     | PV’s value synchronization for the user-defined PV list | Empty |
|                 | CAScheduler  | Control PV’s value according to the user-defined policy | |

• Sulhee Baek, et.al “Development status of KSTAR Widget Toolkit (KWT)”, 2010 Spring EPICS Collaboration Meeting, France
• Sangil Lee, et. al, “Operator Interface Programs for KSTAR Operation”, 2011 IAEA TM, San Francisco, USA
## Management Tools and Utilities

### Monitoring of control system and supporting experiments

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSM</td>
<td>Tool for monitoring all control systems and computing infra</td>
</tr>
<tr>
<td>PVListViewer</td>
<td>DB and UI to have IO information of all IOCs</td>
</tr>
<tr>
<td>FaultListSummary</td>
<td>Tool for logging faults, Redmine used</td>
</tr>
<tr>
<td>OpiUpdate</td>
<td>Too to deploy all developed OPI images of developed OPI</td>
</tr>
<tr>
<td>Version control</td>
<td>Subversion</td>
</tr>
<tr>
<td>KSTARMon</td>
<td>Tool for providing UI pages including live PV data to users outside exp. LAN</td>
</tr>
<tr>
<td></td>
<td>- using access control of CA gateway, read-only</td>
</tr>
<tr>
<td>SessionSummary</td>
<td>Automatically calculate exp results and load them to DB after each shot</td>
</tr>
<tr>
<td>AutoShotDisplay</td>
<td>Automatically visualize summarized exp data and send captured image for web service after each shot</td>
</tr>
<tr>
<td>rtEfitMovier</td>
<td>Tool to automatically generate movies to have results of rtEFIT data and images of plasma and to provide them web interface</td>
</tr>
<tr>
<td>RTMON</td>
<td>System to monitor real-time data thru RFM Network</td>
</tr>
</tbody>
</table>

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*Woongryol Lee “Application of rt-patched EPICS for real-time monitoring”, 2012 Fall EPICS meeting, Oct.23(Tue), 2012, 13:30-13:40*
**Management Tools and Utilities**

- **Control System Monitoring**
  - Developed Several Modules:
    - Network Status: Using Internet Control Message Protocol
    - Storage/Switch: Using Simple Network Management Protocol
    - Two Widgets: BlinkLine, CABLinkLabel for User Interface
    - Environment Monitoring: Using NI’s Compact Field Point
    - sysMonLib with EPICS Lib in All IOC Servers
      - Itself Monitoring Resources in Each Server
        (CPU, Memory, Used Network Packet)

- **Virtualization for KSTAR IT Infrastructure**
  - Using VMWare (ESX / ESXi)
  - Can use ESXi Hypervisor for free (Not support vMotion and Fault Tolerant)
  - Commercially ESX Hypervisor

Data Sharing and User Services

- Services for on- and off-site users
- Data sharing with collaborators
Transferring Data file

- **~2011**: send experimental data to collaborator in U.S at every shot
  - ~140MB, compressed data using FTP (GridFTP) thru non-Gloriad net
  - Drawback: ~8min, sometimes 10min ~ 20min

- **As an alternative**:
  - Using GLORIAD and a commercial fast file transferring solution (**ASPERA**)
  - Test results: decreased to **7sec** at a maximum BW

- **Future plan**: Establish the KSTAR data center at NFRI

Access to KSTAR Data for general users

- A gateway server and a virtual desktop tool (**NoMachine**)
Services of Experimental Info

Shot Info

KSTAR Experiments Summary Information: 20121008

- Electronic Logbook Entries Found: 53
- Click here for executive view

No plasma shots in summary table.

SESSION_LEADER SUMMARY (click here for a printable version) - jayhyunkim

KSTAR Experimental Science Web Portal

KSTAR - Korea

Current Exp Summary

KSTAR Electronic Logbook

KSTAR EXPERIMENTAL WEB

Shot Info
Summaries and Conclusions

- Encountered Problems and Issues
- Summaries and Conclusions
Encountered Problems and Issues

- Sometimes unstable CA connection and operation of Cagateway due to heavy UIs

- ArchiveViewer
  - Drawbacks to display data for long time history due to lack of cache
  - It takes long time to move to CSS

- Implantation of unified environment for managing whole control system
  - Many home-made and other tools
  - Poor interconnection between them

- Decision of new standard data format for bid experimental data
  - Not related to EPICS, but big issue for coming experiments
Encountered Problems and Issues

● Solution for Heavy Traffics of UIs

Cached Channel Access Algorithm in KWT

● Possible Problems for a lot of CA Connections
  ✓ Network Bandwidth due to Network Packet Increasing
    - Use a lot of same OPI programs by multiple users on a single host
    - Use a lot of OPI programs by one user
  ✓ Limited Socket Descriptor Count of Gateway Server
    : “select” used in gateway has the limited file descriptor count, 1024

● To Solve the Problems => “Cached Channel Access”
  ✓ Shared Memory Based Hash Table
  ✓ Decreasing Network Packet Volume
  ✓ Decreasing Socket Descriptor Count Between OPIs and Gateway server
Conclusions

◆ The EPICS-based KSTAR control system has proved its performance and reliability for last 4 campaigns.

◆ Now, we encounter the lack of performance of infrastructure like resources of servers, storage capacity and network bandwidth too.

◆ We will apply the standard rules more strictly for increasing the availability of control systems.

◆ We will also focus on the upgrade of control system to support long pulse experiments.