

AUTOMATED VOLTAGE CONTROL IN LHCd

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Abstract

LHCb is one of the 4 LHC experiments. In order to ensure the safety of the detector and to maximize efficiency, LHCb needs to coordinate its own operations, in particular the voltage configuration of the different sub-detectors, according to the accelerator status.

A control software has been developed for this purpose, based on the Finite State Machine toolkit and the SCADA system used for control throughout LHCb (and the other LHC experiments). This software permits to efficiently drive both the Low Voltage (LV) and High Voltage (HV) systems of the 10 different sub-detectors that constitute LHCb, setting each sub-system to the required voltage (easily configurable at run-time) based on the accelerator state.

The control software is also responsible for monitoring the state of the Sub-detector voltages and adding it to the event data in the form of status-bits. Safe and yet flexible operation of the LHCb detector has been obtained and automatic actions, triggered by the state changes of the accelerator, have been implemented.

This paper will detail the implementation of the voltage control software, its flexible run-time configuration and its usage in the LHCb experiment.

INTRODUCTION

As an LHC experiment [1], LHCb relies on the LHC machine to provide the conditions for the production of events. In order to acquire the data from the events that happen in the experiment, LHCb has an infrastructure composed of several subsystems, namely several sub-detectors to record different parameters of the events. This infrastructure is sensitive to the type of configuration of the LHC accelerator and can be damaged if it's not configured properly according to the LHC status. As the experiment is built underground and is composed of many custom built detector components, it is not easily accessible nor can the parts be easily replaced in case of damage.

Furthermore, the efficiency of the detector must be optimized in order not to lose important beam time and record the most number of events with the best possible quality. In order to have the best efficiency, the LHCb detector must be configured as soon as possible into a state that matches the requirements for each particular LHC status.

As the LHCb detector is composed of several sub-detectors, for a given LHC status each of them must be configured in a particular state, which often differs between them. The configuration of all of them into the required settings one by one would prove inefficient as well as prone to errors.

A control software was developed that can, for each of the LHC states, drive each of the sub-detectors equipment into the appropriate voltage level and can easily be configured according to the sub-detector needs.

As this control software knows the current status of the voltages it is also able to calculate it in the form of status bits, which is then added to the event data and provides more information regarding the quality of the recorded events.

VOLTAGE CONTROL

The voltage control of the LHC experiments is based on the PVSS SCADA system [2], which interfaces the drivers of the equipment to the Finite State Machine toolkit [3].

The LHCb sub-detector voltage control is modelled into a FSM tree which has as the bottom nodes the modelled hardware devices (HV/LV) which are then grouped as sub-detector HV and LV systems, grouped then into logical units which contain all the sub-detectors HV/LV Voltage systems; these are all under the top node ECS (Experiment Control System) [4].

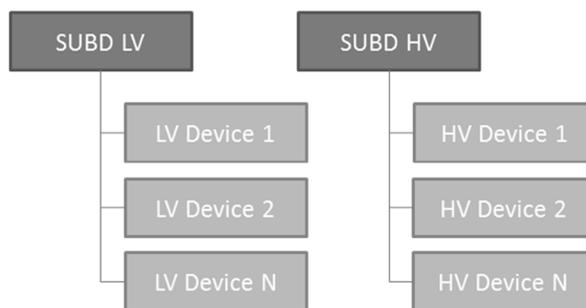


Figure 1: Typical sub-detectors voltage control FSM trees.

The commands flow down the tree, i.e. an action sent to the sub-detector top node flows down to the devices which perform it, while states flow up the tree, i.e. a state change at the device level is propagated up to the top nodes.

For the automated voltage control actions are sent to the top level nodes which group the HV and LV systems of each sub-detector.

Voltage FSM Control Units

The voltages in the LHCb experiment are controlled via the FSM control hierarchy and in order to set a particular voltage system into the desired state, commands are sent to the respective system top control node.

The nodes that group all the voltages for each of the systems (HV/LV) and each sub-detector are FSM Control Units and they can be in the following discrete states:

For the Low Voltage:

- NOT_READY – when not all of the low voltage devices are ON
- READY – when all the low voltage devices are ON
- OFF – when all the low voltage devices are OFF
- ERROR – when any of the low voltage devices is in ERROR
- EMERGENCY_OFF – when any of the low voltage devices has switched OFF due to an emergency action or trigger

For the High Voltage, as the time it takes to reach the appropriate voltage level is not negligible, the states can be of 2 types: stable states and transition states.

For the stable states, the voltage systems can be in the following states:

- NOT_READY – when not all of the high voltage devices are in a stable state
- OFF – when all the high voltage devices are OFF
- STANDBY1 – when all the high voltage devices are STANDBY1
- STANDBY2 – when all the high voltage devices are STANDBY2
- READY – when all the high voltage devices are READY
- ERROR – when any of the high voltage devices is in ERROR
- EMERGENCY_OFF – when any of the high voltage devices has switched OFF due to an emergency action or trigger

The transition states are called RAMPING_<Stable_State> and are set whenever the voltages are moving to that particular stable state.

The actions available to these Control Units are of the type GOTO_<Stable_State> and can take a parameter RUN_TYPE which allows for the selection of the proper recipe for the configuration settings of the devices.

These FSM objects serve as templates for the sub-detectors to model their voltage systems and allow for a transparent integration of its systems into the global LHCb Control System.

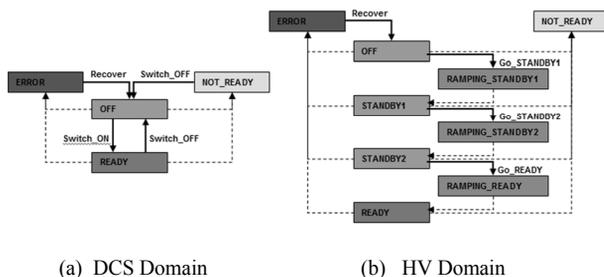


Figure 2: Simplified Voltage Control FSM Domains.

LHC State

The LHC machine publishes the status of the accelerator to all the experiments at CERN via DIP (Data Interchange Protocol).

LHCb subscribes to the LHC data and computes the state of the LHC accelerator, using this data; a FSM Device Unit models this data into 12 discrete states, 10 for different LHC configurations and 2 for error reporting (“ERROR”, “UNKNOWN”). This Device Unit can then be included in the FSM control hierarchy and be used as a trigger for automated actions as well as information for other FSM Units in the hierarchy.

Some of the computed LHC states are:

- PHYSICS – stable beams are declared and LHC is running with its nominal parameters
- PHYS_ADJUST –
- INJECTION – the beams are being injected into the LHC accelerator, the detectors voltages need to be in a safe state.
- MD – Machine Development; the LHC is adjusting operation parameters in order to optimize operation (e.g. cleaning, injecting probes). The detectors voltages need to be in the safest state possible
- DUMP – the beams have been dumped from the LHC accelerator

The actions available on the automated voltage control system can then be configured according to each of these individual computed LHC states instead of particular voltage states.

For the most dangerous states of the LHC, in respect to possible damages to the front end systems, LHC has implemented a handshake system to insure that the operation in these states is acknowledged by the experiments and they have set their systems to safe parameters of operation.

AUTOMATED VOLTAGE CONTROL

The automated voltage control system developed takes advantage of the FSM control hierarchy and is based on the FSM toolkit.

By using the voltage control FSM objects templates implemented by the sub-detectors, which are integrated into a global control FSM, and knowing the possible LHC states, it is possible to develop a control software which can configure the voltage systems in coordination with the specific needs for each LHC state.

For each sub-detector voltage system, you can define, for each of the available LHC states, in which voltage setting the respective voltage system should be set. The voltage settings can be any of the available states for that voltage system as well as a state called “_ANY_”. In this case the sub-detector voltage system is allowed to be in any of its available voltage settings (safe for ERROR) and the state of this system in respect to the LHC state will always be OK. This is to allow for independent control from the part of the sub-detectors, when the LHC is in a state that allows for periods of development (e.g.

“NO_BEAM”) without interfering with the global state of the experiment voltage systems control.

The configuration of the voltage states required for each sub-detector and each LHC state is easily done via a configuration table, which is also useful as an overview of the settings.

The screenshot shows a window titled "LHCb LHC_VH_Info: TOP (on ui01)" with a "Device" dropdown set to "LHCb_LHC_VH_Info" and a "State" dropdown set to "OK". The window contains two main configuration tables: "HV Configuration" and "LV Configuration".

HV Configuration Table:

Subdetector	Injection	S	Ramp	S	PhysAdjust	S	Physics	S	Adjust	S	Dump	S	Notbeam	S	MD	S	EOF	S
ECAL	STANDBY1	✓	READY	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
HCAL	STANDBY1	✓	READY	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
IT	STANDBY1	✓	STANDBY1	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
MUON	STANDBY1	✓	STANDBY2	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
OT	OFF	✓	STANDBY1	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
RES	OFF	✓	READY	✓	READY	✓	READY	✓	READY	✓	OFF	✓	ANY	✓	OFF	✓	OFF	✓
RCAL1	OFF	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	ANY	✓	OFF	✓	READY	✓
RCAL2	OFF	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	ANY	✓	OFF	✓	READY	✓
TT	STANDBY1	✓	STANDBY1	✓	READY	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	STANDBY1	✓
VELO	OFF	✓	STANDBY1	✓	STANDBY2	✓	READY	✓	READY	✓	STANDBY1	✓	ANY	✓	OFF	✓	OFF	✓

LV Configuration Table:

Subdetector	Injection	S	Ramp	S	PhysAdjust	S	Physics	S	Adjust	S	Dump	S	Notbeam	S	MD	S	EOF	S
IT	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	OFF	✓	READY	✓
RCAL1	OFF	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	ANY	✓	OFF	✓	READY	✓
RCAL2	OFF	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	ANY	✓	OFF	✓	READY	✓
TT	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	OFF	✓	READY	✓
VELO	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	READY	✓	ANY	✓	OFF	✓	READY	✓

At the bottom of the window, there are buttons for "Revert Changes" and "Apply Changes", and a "Messages" section.

Figure 3: Configuration table (LHC state – LHCb voltage settings).

The Automated Voltage Control software is based on a set of FSM objects which will now drive the voltage systems, acting as a proxy between requests for configuration for a particular LHC state and the required HV configuration and a new FSM tree built upon these units and with references to the particular voltage systems to control.

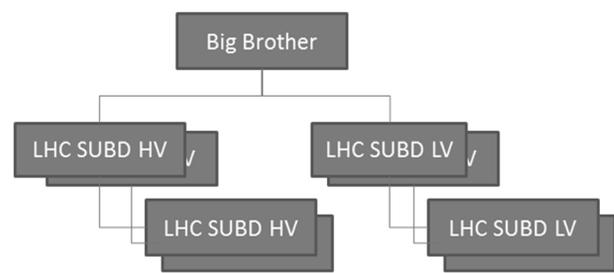


Figure 4: LHCb – LHC voltage control FSM Tree.

This new FSM tree will be the main control system for the LHCb sub-detectors voltage systems. It should have a top node with the CUs (Control Units) for the Voltage Systems to control as children. Typically each of these CUs is a sub-detector voltage system and references, as its children, the sub-detectors FSM voltage objects. These references serve as configuration for the new FSM object which will now drive the voltages.

The new discrete states of all these FSM objects are now a reflection of the state of the sub-detectors voltage systems in respect to the possible LHC states defined for

the LHC state device unit. The actions are now, as well, commands to configure the voltage systems according to the configuration needed for each particular LHC state. This means that the actions are no longer e.g. “GOTO_STANDBY” but e.g. “GOTO_INJECTION”, and the voltages of each sub-detector will be configured according to the setting which corresponds to the “INJECTION” LHC state. Also the transitional states represent the movement of the voltage devices into the final requested LHC state configuration settings (e.g. “RAMPING_INJECTION”).

Device Units

There are 2 Device Unit types needed to properly run the voltage systems.

One retrieves the parameter RUN_TYPE from a PVSS datapoint, in order for it to be correctly defined when the action for the voltage systems to go to a particular LHC state is requested.

The other Device Unit is the object that now drives the voltage systems. This Device Unit holds the proper configuration of all the required voltage settings for each LHC state per sub-detector and voltage system (e.g. “LHC_MUON_HV”, “LHC_OT_LV”).

There are also some other possibilities for configuration settings for each of the actions to be sent in respect to each particular LHC state request:

- Send action – The action can be set not to be sent until a user manually does this. The user does not need to know the correct voltage state needed but it does need to intervene in order for the voltage systems getting configured to the proper state.
- Ignore State – The action can be configured to automatically exclude the voltage system.

This Device Unit, on startup, connects to the states of the voltage system references of the particular sub-detector it controls and its state is computed from the accordance of the state of the voltage systems with respect to the last requested LHC state configuration. Its states are defined as follows:

- UNKNOWN
- ERROR
- RAMPING_<LHC_STATE>
- WAIT_MAN_CONFIG – Manual Configuration for this sub-detector for this LHC state is required
- OK – State of the Voltage systems IS in accordance with the needed state for this LHC state
- NOT_OK – State of the Voltage systems IS NOT in accordance with the needed state for this LHC state

High Voltage Status Bits

This Device Unit also computes a set of status bits for each High Voltage system, which is then saved with the events data in order to provide more information of the quality of the events.

For each sub-detector a majority limit threshold for the number of not working HV channels is defined and the status bits computed are based on the information of the individual channel states of each sub-detector and whether the number of incorrectly configured channels is greater than the majority threshold defined.

The status bits are as follows:

- 00 – All HV channels are correctly configured and running;
- 01 – There are some HV channels in an incorrect state in regards to the LHC state, but their number is below the majority threshold set.
- 10 – The number of channels in an incorrect state in regards to the correct state is above the defined majority threshold

The computation of the status bits is done by a thread which is launched for each controlled voltage system. This thread monitors periodically the state of each sub-detector High Voltage channel states and sets the status bits.

LHCd OPERATION

The Automated Voltage Control System implemented in LHCb is connected to a handshake system with the LHC. The LHC state based voltage operation allows this integration to be simplified as, whenever the LHC state changes and requests a handshake to move to a particular state, a simple action is the only required input from the part of the operator. A PVSS panel displays the readiness of all the sub-detectors Voltage Systems for the current LHC state. In this panel it is also visible the percentage of the each sub-detector which is in the correct voltage state (in terms of number of channels).

Further automation has also been implemented, and several actions can now be auto-piloted, providing a greater level of efficiency.

CONCLUSION

The control software developed to drive the voltage systems in LHCb in accordance to the required settings for each of the LHC states proved to be a very efficient way of running the voltage systems of the experiment. The Automated Voltage Control is able to remove complexity from the system and improve the operation of the Experiment Control System as there is no need to track the different voltage settings for each of the sub-detectors at the different LHC states.

The safety of the detector is also assured as incorrect and unsafe voltage configurations can now easily be viewed in the main panel of the LHCb voltage control system and adjusted according to the current LHC state requirements.

The development approach based on the already implemented control system via the FSM toolkit also proved to be very reliable and configurable as well as scalable. Other voltage systems that use the LHCb FSM voltage control objects can easily be added.

This system also provides a base for further automation as LHC state changes can automatically trigger the correct voltage settings in a way very easily integrated in the current control system.

REFERENCES

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- [2] “PVSS II”, <http://www.pvss.com/>.
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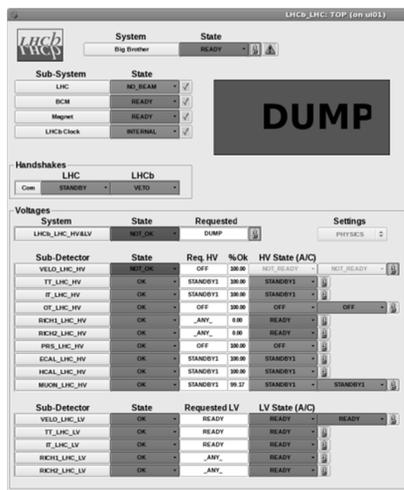


Figure 5: LHCb – LHC voltage control PVSS Panel.