THE ELECTRICAL CIRCUIT DESCRIPTION FOR THE LHC

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Abstract

The LHC is a very complex machine, made of about 8000 superconducting magnets along a circumference of 26.7 km. The magnets are powered in about 1700 different electrical circuits with currents ranging from 60 A (for small corrector magnets) up to 13 kA for the main dipoles and quadrupoles.

The layout of the powering system reflects the complexity of the accelerator. About 80000 high current connections will have to be made. A minor fault in a circuit or one of the superconducting connections would have severe consequences for accelerator operation.

For the integration of the electrical equipment, for supporting the assembly and verifying the correctness of the electrical circuits, all relevant information should be included in one coherent database.

A simple method for the description of the electrical circuits is proposed, while an associated tool is translating this input into database information and back, checking the circuit description at the same time for inconsistencies. Out of the database information, electrical drawings and detailed views of the electrical connections at every LHC interconnection point can be recreated. This paper describes the approach and outlines several possible applications.

1. THE ELECTRICAL CIRCUITS AND THE LAYOUT OF THE LHC

More than 8000 superconducting and 100 warm magnets will be installed along the 26.7 km LHC accelerator. The layout comprises eight arcs, each with 23 F0D0 cells, and eight long straight sections with four experiments, betatron and momentum cleaning insertions, the RF and the beam dump system (see Fig.1). Most of the superconducting magnets are installed in the continuous arc cryostats. Several smaller cryostats are located in the long straight sections, essentially housing magnets for matching and separating / recombining the beams. At each side of an experiment several quadrupoles are grouped in a common cryostat and form a triplet to focus the beam into the interaction points.

The magnets are powered in 1712 electrical circuits with currents ranging from 60 A (for small orbit corrector magnets) up to 13 kA for the main bending dipoles and the main quadrupoles. The magnets in the arc cryostats are electrically fed from both extremities. The number of magnets in one electrical circuit varies from only one (for example all closed orbit correctors) up to 154 (main dipole magnets and sextupole correction magnets in the arcs).

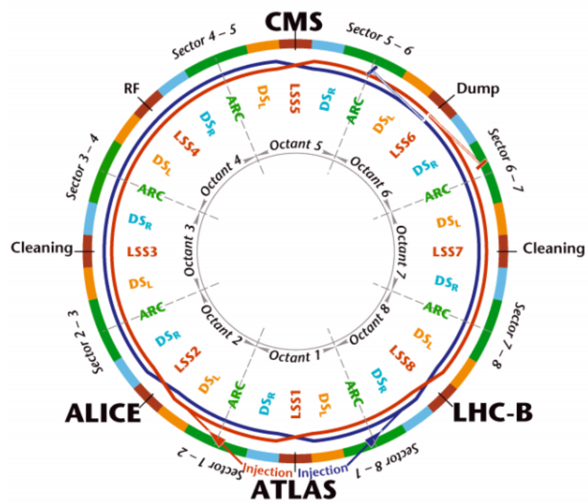

Figure 1: Layout of the LHC

The current is fed from room temperature to super fluid helium temperature at 1.9 K through current leads installed in electrical feed-boxes (DFB's). Inside a cryostat the magnets in one circuit are connected in series by superconducting connection cables, called bus bars. A typical electrical circuit in the LHC therefore includes several types of electrical circuit elements: power converters and magnets, warm cables, current leads, energy extraction facilities and bus bars (see Fig. 2).

Between two dipole magnets in the regular arc 20 bus bars rated for 600 A need to be connected as well as six bus bars for 13 kA. At each quadrupole, there are 42 additional connections for bus bars carrying 600 A (see Fig. 3). In total, about 80000 connections will be made, either by soldering or by ultrasonic welding [1].

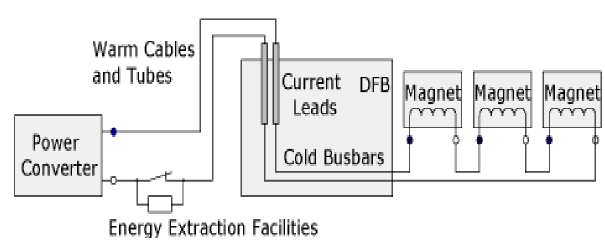

Figure 2: Typical electrical circuit in the LHC

Each 'electrical circuit element' in a circuit has a unique name within the whole machine. This allows a consistent storage of each element in the database with its name, type, subtype, location and index. Special configurations of electrical circuits that may appear in small numbers around the machine (e.g. embedded power converters in the inner triplet) need to be considered.

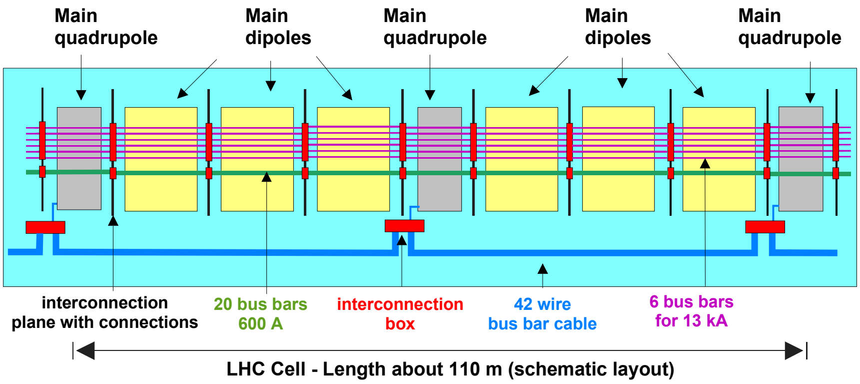

Figure 3: Layout of a LHC Cell including bus bars

The development of the electrical systems of the LHC required drawings for all electrical circuits. The complete information about the connection sequence is stored in such drawings (see Fig. 4). However, verification of the correctness of such drawings is laborious and error-prone. It is difficult to perform modifications. It is not straightforward to extract data, for example, describing the interconnections between two adjacent magnets. Therefore it was decided to introduce this sequence information via a circuit description language into a coherent database.

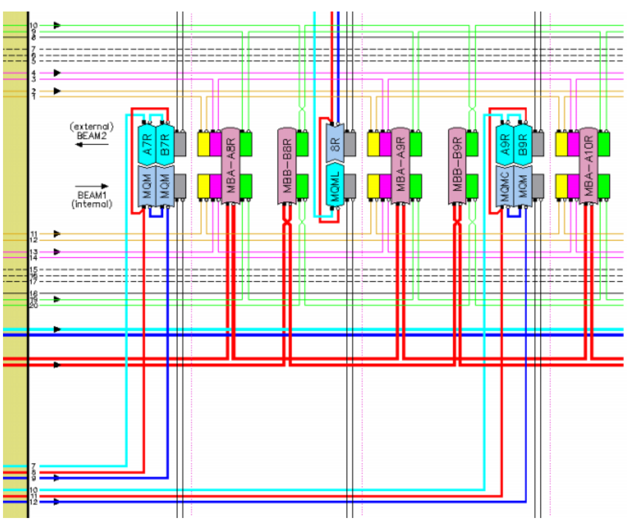

Figure 4: Example for a circuit diagram for the LHC (representing less than 0.5% of all circuit diagrams)

2. CIRCUIT DESCRIPTION

Each electrical circuit for powering magnets is described in a simple text format (CDL=circuit description language). In general, the description of a circuit starts at the positive terminal of a power converter and specifies the sequence of connected elements in the circuit as well as the connection side or the pole of the connected element (e.g. pole A or B for a magnet). If the circuit contains any bifurcation, a generic element of a T-junction is introduced. The description continues with the first branch, while the remaining part of the circuit is described as a 'segment' at the end of the 'main' circuit description. Embedding such T-Junctions into each other for the description of more complex circuits is possible.

An example of the CDL for a circuit connecting four MQS magnets inside the cold mass to a power converter and its energy extraction facilities is given in Table 1. As several circuits are described in one file, keywords such as CIRCUIT, SEGMENT and AUXILIARY are used for distinction.

Table 1: CDL for a typical circuit in the LHC

CIRCUIT	Main branch
RQS.A78B2.RR77	Circuit name
RPMB.#RQS.A78B2.RR77.A	Power converter, positive side
DWACF.1.#RQS.A78B2.RR77	Water cooled cable
DFLB.7R7.33	Current lead
DCAD.7R7.24	Busbar number 24 in DFBA
DCA.24	Cold busbar number 24
MQS.23L8.B2.B	Skew quadrupole in HC23L8
DCA.23	Cold busbar number 23
MQS.27L8.B2.B	Skew quadrupole in HC 27L8
DCA.23	Cold busbar number 23
MQS.27R7.B2.B	Skew quadrupole in HC 27R7
DCA.23	Cold busbar number 23
MQS.23R7.B2.B	Skew quadrupole in HC 23R7
DCA.23	Cold busbar number 23
DCAD.7R7.23	Busbar number 23 in DFBA
DFLB.7R7.34	Current lead
DWACF.2.#RQS.A78B2.RR77	Water cooled cable
T.DWACF.2.#RQS.A78B2.RR77	T-junction - beginning
DQS.#RQS.A78B2.RR77.A	Energy extraction switch
T.DQS.#RQS.A78B2.RR77.A	T-junction - end
RPMB.#RQS.A78B2.RR77.B	Power converter, negative side
SEGMENT	Segment
T.DWACF.2.#RQS.A78B2.RR77	T-junction - beginning
DQR.#RQS.A78B2.RR77.A	Energy extraction resistor
T.DQS.#RQS.A78B2.RR77.A	T-junction - end

3. THE CDL INTERPRETER

Transforming the CDL into an appropriate format for being stored in a database is one of the tasks of the CDL Interpreter. While the CDL input file only specifies the type and index of the busbar that is used to connect e.g. a single magnet in the centre of an arc, the interpreter ‘expands’ the input and lists each single piece of connectable busbar that is used throughout the arc, based on the elements that are physically present. Within this step, feasibility tests of the CDL input are performed. Based on the geographical layout of the machine and the connection information described in the CDL, the CDL Interpreter produces a file in XML-format (see Table 2 for the example of CDL in Table 1), describing the sequence of connected elements within a circuit. This includes verification of the existence and correct naming of specified equipment and their unique usage in one of the electrical circuits.

After inserting the circuit description into the database, it will be possible to delete and reinsert the information for single circuits as well as for an entire powering sub-sector (which is one of about 30 independent areas of the LHC machine in terms of powering).

Versioning of the introduced information is a further issue for guaranteeing the consistency of the data.

Table 2: XML-file of the Example in Table 1

```
<CIRCUIT name=” RQS.A78B2.RR77”>
&lt;SEGMENT&gt;
<LINE code=” RPMB.#RQS.A78B2.RR77” pole=”A”/>
<LINE code=” DWACF.1.#RQS.A78B2.RR77” pole=””/>
<LINE code=” DFLB.7R7.33” pole=”A”/>
<LINE code=” DCAD.7R7.24” pole=””/>
<LINE code=” DCAF.8R7.24” pole=””/>
<LINE code=” DCAG.9R7.24” pole=””/>
<LINE code=” DCAH.10R7.24” pole=””/>
…
<LINE code=” DCAE.24L8.24” pole=””/>
<LINE code=” MQS.23L8.B2” pole=”B”/>
<LINE code=” DCAE.24L8.23” pole=””/>
…
<LINE code=” DQS.#RQS.A78B2.RR77” pole=”A”/>
<LINE code=” RPMB.#RQS.A78B2.RR77” pole=”B”/>

&lt;/SEGMENT&gt;
<LINE code=” DWACF.2.#RQS.A78B2.RR77” pole=””/>
<LINE code=” DQR.#RQS.A78B2.RR77” pole=”A”/>
<LINE code=” RPMB.#RQS.A78B2.RR77” pole=”B”/>
</CIRCUIT>
```

4. VERIFICATION

Verification of the correctness of the data is essential. Wrong connections of magnets in most of the circuits would obstruct beam operation and could require the opening of the cryostat for repair, an operation that takes several weeks. Due to the complexity of the LHC and the large number of electrical circuit elements, a manual inspection of the data cannot be envisaged. Therefore it is planned to derive from the database an input file suitable for an optics program such as MAD [2] that includes all elements in the LHC (magnets, beam position monitors, RF cavities, etc.) and the electrical circuits for powering each magnet. With MAD, it can be checked that each of the 8000 magnets is providing the expected orientation and strength of magnetic field by using the powering layout from the database.

5. FUTURE DEVELOPMENTS

For each type of electrical circuit element, parameters such as electrical resistance will be introduced. This allows accurate calculation of the circuit resistance, and comparison with measurements. Another objective is to re-create electrical drawings for visualisation. When the information associated to the power converters will be introduced into the database (max. current, voltage…), data for operating the accelerator can be derived.

6. CLIENTS OF THE DATABASE

The installation of the magnets, starting in 2004, will be supported by the data [3, 4]. For all interconnection planes, the information describing the necessary connections between the bus bars will be provided in an appropriate format.

The information for each electrical circuit allows deriving the data for the powering interlock system for each powering subsector.

7. CONCLUSIONS

The description of electrical circuits with about 100000 elements within the LHC database is in progress. So far, about half of the electrical circuits have been described.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] J.-C. Brunet, “An Automatic Ultrasonic Welding Process for Interconnecting Superconducting Wires of the CERN Large Hadron Collider (LHC)”, CERN-LHC-Project-Report-384, 2000, Geneva

[2] http://mad.home.cern.ch/mad/, “MAD homepage”

[3] http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/ , “The new LHC homepage”

[4] T. Pettersson, “The CEDAR Project”, CERN-EST/98-04 (ISS), Dec. 1998, Geneva (Paper presented at EPAC’98, Stockholm)