

The CMS Detector Power System

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Abstract

The power system for the on-detector electronics of the CMS Experiment comprises approximately 12000 low voltage channels, with a total power requirement of 1.1 MVA.

The radiation environment inside the CMS experimental cavern combined with an ambient magnetic field (reaching up to 1.3 kGauss at the detector periphery) severely limit the available choices of low voltage supplies, effectively ruling out the use of commercial off-the-shelf DC power supplies.

Typical current requirements at the CMS detector front end range from 1A-30A per channel at voltages ranging between 1.25V and 8V. This requires in turn that the final stage of the low voltage power supply be located on the detector periphery.

Power to the CMS front-end electronics is stabilized by a 2 MVA uninterruptible power supply (UPS) located in a CMS surface building. This UPS isolates the CMS detector from disturbances on the local power grid and provides for 2 minutes of autonomy following a power failure, allowing for an orderly shutdown of detector electronics and controls.

This paper describes the design of the CMS Detector Power System, reviews the process of its installation and commissioning, and discusses issues of power distribution common to current-generation collider detectors.

I. OVERVIEW OF THE CMS DETECTOR

CMS is a general-purpose detector at the LHC accelerator at the CERN laboratory in Geneva, Switzerland. A description of this detector is beyond the scope of this paper, but may be found in reference [1].

A. Requirements of CMS Detector

The front-end electronics of the CMS detector has 12090 low-voltage channels, requiring 1182 KVA of power. The steel yoke structure of the CMS detector serves as a flux return for the 4-Tesla solenoid inside the detector structure. Since the magnetic field of the solenoid is large enough to drive sections of this steel yoke into saturation there is an ambient magnetic field that can reach up to 1.3 KG outside detector in the regions where low voltage power supplies are mounted. Typical commercial low-voltage power supplies are not designed for operation in a magnetic field and many have been noted to fail destructively at fields above 150 Gauss. In addition, the high radiation environment inside the CMS experimental cavern imposes constraints on the design of low voltage supplies from the standpoint of semiconductor displacement damage and single-event effects. Together, these constraints rule out the use of general-purpose commercial power supplies.

Typical front-end current requirements are 1 to 30A per channel, at voltages from 1.25 to 8.0V. Since cable power dissipation must be kept within reasonable limits, the placement of the final power supply stage is constrained to be within ~10m of the front-end electronics, that is, on the detector periphery.

B. CMS power distribution requirements

The power cable paths between CMS on-detector systems and the power distribution area in the adjacent equipment cavern are typically 100 to 140m in length. Power to the detector is supplied at 380 and 230 VAC (three-phase) and at 385 VDC. No neutral is distributed.

The CMS detector power system serves all of the low voltage power needs on the detector from a single distribution network. Although there are other power distribution networks at the CMS site, there are no persistent connections between the CMS detector and any of these other networks. This single-source powering scheme enables a unified earthing structure for the CMS detector and simplifies considerations of detector response to disturbances in power distribution.

C. CMS power distribution system architecture

The detector power system is powered by a 2 MVA uninterruptible power supply (UPS) installed on the surface. The UPS provides for at least 2 minutes autonomy in the event of a power failure. This length of time is sufficient to provide for an orderly shutdown of subdetector power systems.

The UPS powers a bank of 6 isolation transformers located underground in one of the CMS caverns. The transformers are apportioned by subdetector and geographical detector region. Each transformer feeds one or more power distribution cabinets containing circuit breakers, monitoring equipment and programmable logic controllers. Power from an individual circuit breaker channel can be turned on and off via a remote control system, but in the event of a fault condition the circuit breaker must be reset manually. This is a deliberate design choice to prevent casual responses to fault conditions.

The isolation transformers consist of four 230V and two 380V three-phase units, each containing an interwinding electrostatic screen. Static compensators are connected to selected distribution cabinets in order to provide power factor correction (PFC) for certain subdetectors (Fig 1.)

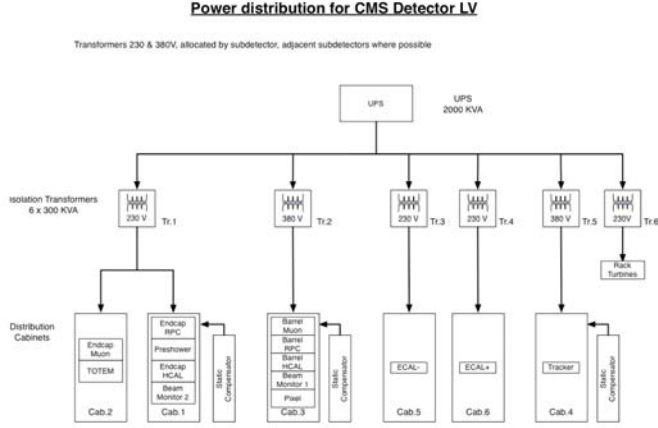


Figure 1: Overview of the first stage of the CMS Detector Power Distribution System

D. CMS power supply architectures

Power from the distribution cabinets is in turn fed to power supplies located in the two CMS underground areas. CMS uses power supplies from two manufacturers. One is the Wiener MARATON series from Plein & Baus GmbH [3]. The second is EASY (3000 & 4000) Series from CAEN S.p.A. [2] Each company has its own approach to meeting the radiation and magnetic-field tolerance requirements of CMS.

Each system spans two zones, referred to as the Safe and Hostile Areas. The magnetic field and radiation environment of the safe area is assumed to be compatible with conventional commercial electronics. The hostile area, on the other hand, is a special environment requiring electronics with enhanced radiation and magnetic-field tolerance.

The first stage of the Wiener power supply system consists of a bank of rectifier/power factor correction units located in the safe area which are powered via single-phase 230V inputs and which in turn supply 385VDC to MARATON supplies located in the hostile area, on the detector periphery. The input power is supplied by a phase-to-phase connection from one of three 230V three-phase isolation transformers shown in Figure 1. Since the rectifier units contain their own internal power factor correction circuitry, no additional static compensators are required at the level of the power distribution cabinets.

The MARATON supplies located in the hostile area contain up to 12 programmable output channels capable of supplying output voltages between 2 and 8V with a total unit power of 3.6 KW.

Control and monitoring of the MARATON supplies is accomplished via a CANBus readout chain that runs serially between some number of MARATONs on the detector. The CANBus readout chain is fed by a CANBus interface board mounted in a PC in the safe area. This PC is connected to the local network, through which the PC is connected to the CMS Detector Control System (DCS). The detector control system spans all subdetector systems on CMS. An overview of the Wiener power supply architecture is shown in Figure 2.

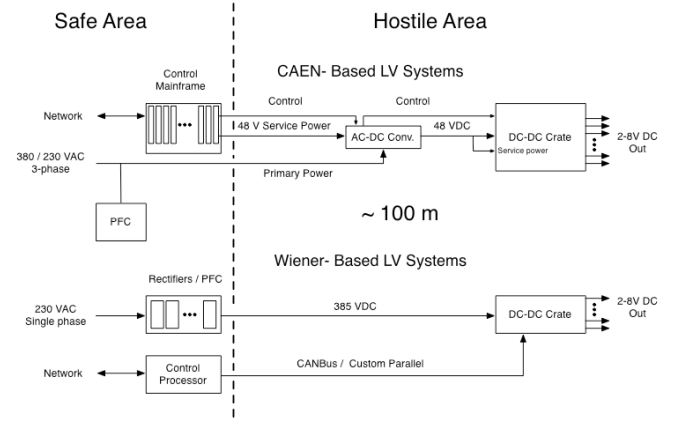


Figure 2: The architectures of the CMS low voltage power supplies

For the CAEN-based systems, on the other hand, three-phase power is fed directly to the hostile area, where it powers AC-DC converters which in turn supply 48VDC to modular crates containing DC-DC converter units that provide 1.25-8V to the CMS front-end electronics.

Control and monitoring of both the AC-DC converters and the DC-DC converter crates is accomplished via a serial readout chain using a proprietary protocol. Each chain controls up to 6 DC-DC crates and 6 AC-DC converters. The readout chains are driven from branch driver modules (CAEN A1676) located in readout crates (CAEN SY1527) located in the safe area. Each crate is connected to the local network, from which it is controlled by the CMS detector control system.

Each AC-DC converter and DC-DC converter module contains a communication board that interfaces with the control readout chain. This board requires 48VDC, which is supplied via a separate channel referred to as service power. Service power for the AC-DC converters is supplied via a dedicated channel in the branch controllers in the safe area, as illustrated in figure 2.

Only the AC-DC converters receive service power from the safe area, a consequence of limitations on the power available from the branch drivers. Service power to the DC-DC converters is derived from the outputs of the AC-DC converters once they are powered. This results in a two-step turn-on sequence. The power requirements of the DC-DC converter boards are significant (53KW vs. 9KW for the AC-DC converters alone,) making the supply of global service power from the safe area impractical as a result of cable voltage drop considerations.

II. OVERVIEW OF PHYSICAL INSTALLATION

The CMS detector is located in one of two adjacent underground caverns. The experimental cavern contains the detector itself, along with support infrastructure such as cooling equipment. Access to the experimental cavern is only possible when the LHC beam is not present. The detector is segmented longitudinally into 13 sections. The central section is fixed to the cavern floor. The other sections are movable in order to allow access to detector elements, and are capable of up to 10m of free travel in the direction of the beam axis.

All connections to the movable detector elements (such as cabling and cooling pipes) must be capable of accommodating this movement without the need for disconnection. All such connections are routed through flexible articulated cable chains laid in trenches under the detector.

A. Underground layout

The second cavern contains electronics racks for readout and triggering of the detector, the first layer of computing for the data acquisition system and infrastructure for providing services such as cooling and power. This cavern is referred to as the service cavern and is the “safe zone” mentioned earlier. Access to the service cavern is possible during the operation of the LHC. The two caverns are shown in figure 3.

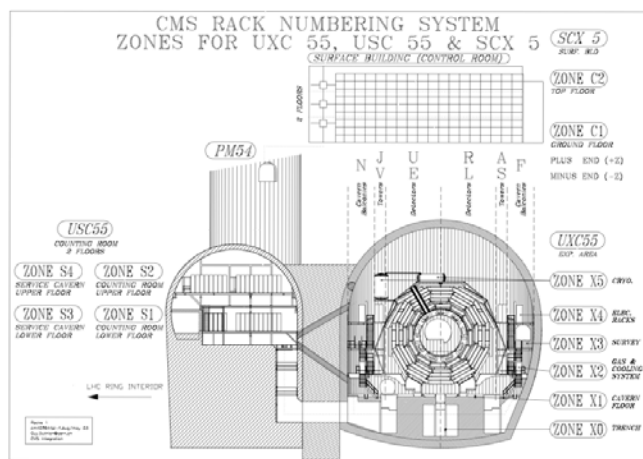


Figure 3: The CMS service cavern and experimental cavern

B. Power distribution area

The power distribution area in the service cavern contains 6 isolation transformers, 6 power distribution cabinets containing circuit breakers and programmable logic controllers, 10 electronics racks and a bank of static compensators. The racks contain banks of rectifier/power factor corrector units for the Wiener MARATON power supplies, control crates for the CAEN power supplies and additional power supplies for heating tape associated with the cooling system of the CMS tracker detector. The layout of the power distribution area is shown in figure 4.

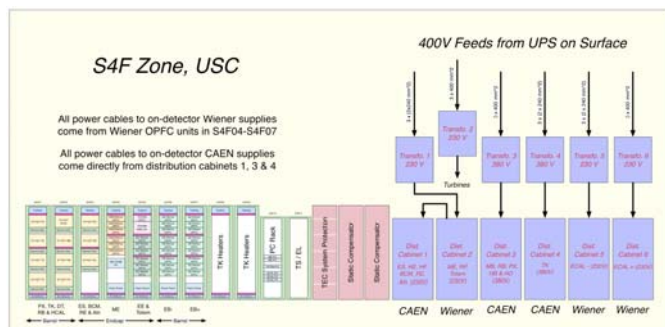


Figure 4: The power distribution zone in the CMS service cavern

One of the six isolation transformers is reserved for turbine fans for circulating cooling air in the on-detector racks.

C. Power cabling

Typical cable paths between the power distribution area and the CMS detector range between 100 and 140m. There are three types of cables: primary power, service power and control cables.

The primary and service power cables are screened 7x6mm² cables. These can be organized as two triplets for three-phase operation or as three pairs for 385VDC or service power. The 6mm cross-section was chosen to minimize the resistive voltage drop. The control cables are screened 25 twisted-pair cables for the CAEN power supplies or dual twisted pair for the CANBus cables used by the Weiner systems.

D. Patch panels

The CMS detector was assembled on the surface and lowered into the experimental cavern in sections. This strategy allowed for the assembly of the detector in parallel with excavation of the caverns and installation of service infrastructure. One consequence of such a design is the need for an interface connection for cabling and services in order to connect preinstalled infrastructure cabling to preinstalled on-detector cabling once the detector sections are lowered into the experimental cavern.

For the detector power system, this interface connection consists of a metallic enclosure mounted at the base of the equipment towers on each side of a detector section. These enclosures, or patch panels, are straight-through devices, but have provisions for splitting out service power and DCS connections. The patch panels also provide a low-inductance ground connection point for cable shields.

E. On-detector power distribution

The shields of the 7x6mm² cable segments are grounded at the end closest to detector, that is, for the segments between the patch panels and the power distribution area in the service cavern, the shields are grounded at the patch panel. The option for grounding the other end of shield at a later date may be exercised depending on operational experience with the CMS detector.

At the on-detector racks, the power cables must be broken out to the power supplies, in a way that is uniform for all the subdetectors. This is done using metallic rack-mounted distribution boxes, 2U high, which can accept up to two power cables, each of which can be broken out up to three ways. These distribution boxes can be mounted at the front or rear of the rack and may be located inside or outside the rack volume. The output connectors are keyed according to output power type to prevent application of the wrong voltage. The distribution chassis also serves as a low-inductance tie point for the cable shields. At this point, connections are made to the CAEN AC-DC converters and to the MARATON supplies.

III. POWER UTILIZATION IN CMS

The CMS power utilization has been calculated taking into account known efficiencies and cabling power losses.

A. Power utilization by subdetector

Broken down by subdetector, as shown in figure 5, the CMS electromagnetic calorimeter (ECAL) has the largest power requirements (38%) followed by the tracker detector (21%). It is interesting to note that the on-detector turbines are a significant part of CMS power requirements (11%). The power figures shown here represent the total power drawn at the level of the UPS by a given subdetector, and so include all power supply inefficiencies and cabling losses, as well as the front-end power required by the subdetector.

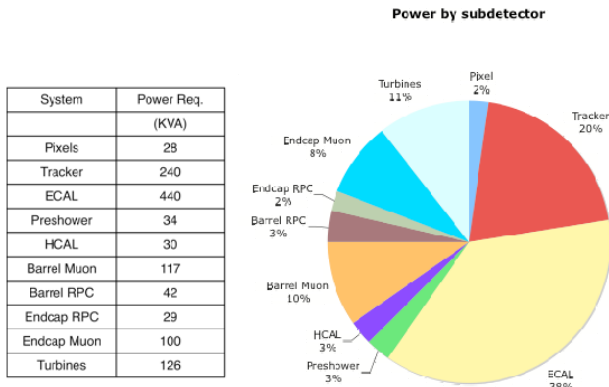


Figure 5: Power by CMS subdetector

B. Power utilization by distribution stage

An examination of the losses incurred at different stages of the power distribution system is shown in figure 6. It is immediately obvious that the global efficiency of the distribution system is very low. The power used by the front-end electronics is only 34% of the total power. The rest is lost to heat, either as power supply inefficiency or dissipation in the cables. These losses represent a significant load on the detector cooling system.

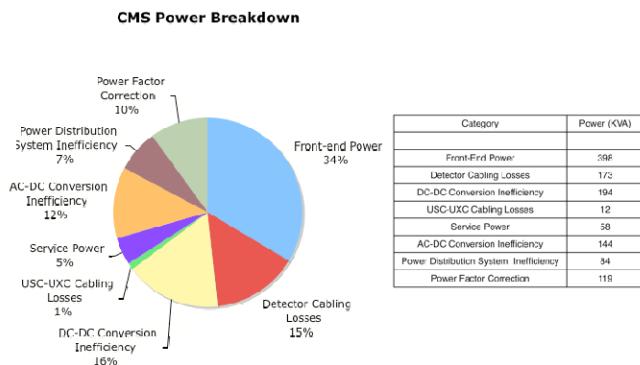


Figure 6: The power dissipated at each stage of the CMS power distribution system. All values are in KVA.

The losses are split roughly evenly between power supply inefficiencies and cabling losses. The bulk of the cabling losses (15% of total dissipation) occur in the last 10m to the front-end electronics.

The low efficiency for power distribution is common to all detectors of this type and is caused by the combination of large detector size, low front-end voltages and hostile operating environment.

IV. SUMMARY

The particularities of current collider detectors place special demands on their low voltage power distribution systems. Front-end voltage requirements are low (1-5V), requiring the final stage power supplies to be located close to (~10m) the front-end electronics. As a result, these power supplies must operate in a hostile area.

The commercial market for suitable power supplies is sparse. Even commercial power supplies developed for HEP sometimes need to be adapted to a particular experiment, resulting in a dependence on a single source.

EMI/EMC issues need to be addressed in the design of the distribution system. In many ways this is a question of mechanical engineering as much as electrical design. Long cable runs require attention to shielding and the means of grounding the shields. The meaning of detector "ground" for a metallic object 15m in diameter and 30m in length is not obvious.

The efficiency of current detector power distribution systems is low. Power losses are dominated by cable dissipation and power supply inefficiencies. These issues will need to be addressed in the designs for the next generation of detectors.

V. REFERENCES

- [1] CMS Collaboration, Physics Technical Design Report Vol. I, Detector Performance and Software, CERN/LHCC 2006-001 (2006).
- [2] CAEN (Costruzione Apparecchiature Elettroniche Nucleari), 11 Via Vetraria, 55049, Viareggio, Italy
- [3] WIENER, Plein & Baus GmbH, Mullersbaum 20, D-51399 Burscheid, Germany