Quality control software development for testing the next generation of upgraded low voltage power supplies for the ATLAS Tile Calorimeter

E Nkadimeng[1], R Mckenzie[1], R van Rensburg[1], N Njara[1], T Lepota[1], O Moaune[1] and B Mellado[1,2]

[1] School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg, Wits 2050, South Africa

[2] iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, South Africa

E-mail: edward.khomotso.nkadimeng@cern.ch

Abstract. The High Luminosity Large Hadron Collider (LHC) will deliver five times the LHC nominal instantaneous luminosity, after a series of upgrades scheduled to take place in 2025 - 2027 during the long shutdown. The ATLAS TileCal will require the complete replacement of the readout electronics in order to accommodate its acquisition system to the increased radiation levels, trigger rates, and high pile-up conditions during the HL-LHC era. A major replacement of the on- and off detector electronics is required. The drawer electronics are powered by custom switching power supplies, called the Finger Low Voltage Power Supply. This contribution provides details on the ongoing development of quality assurance test benches that use custom built software packages to interface, monitor and verify parameters for check-out of the LVPS bricks. The strict procedure required for brick checkout during production constitutes of a series of highly automated tests that provides information about the general conditions of the brick and subsequently ensure the reliability and quality of the upgraded LVPS brick which will power the next generation of the upgraded readout system of ATLAS TileCal at CERN. The quality control procedure will be used as An initial virtual Instrument (VI) was written in LabVIEW to scan and read out voltages and current measurements and monitor the parameters in real-time. The tested LVPS bricks were monitored over a period of a day and were observed to fall within the required specification criteria of the TileCal Phase-II upgrade.

1. Introduction

At the European Laboratory, CERN, A Toroidal Large Hadron Collider ApparatuS (ATLAS) is one of 2 multi-purpose experiments at the Large Hadron Collider (LHC) [1]. The Tile calorimeter (TileCal) is the central region of the ATLAS detector and designed to absorb most of the particles coming from a collision, forcing them to deposit all of their energy and stop within the detector [2]. The calorimeter is composed of alternating layers of steel absorber and scintillating tiles as the active medium. Light produced in the scintillators is routed into the photo-multiplier tubes (PMTs) using wavelength-shifting (WLS) fibers. The TileCal is divided into four cylindrical readout sections along the beam axis: one central long barrel (LBA, LBC) and two extended barrels (EBA, EBC). Each barrel is segmented azimuthally into 64 wedge-shaped TileCal modules. Power is supplied to the front-end electronics of a single

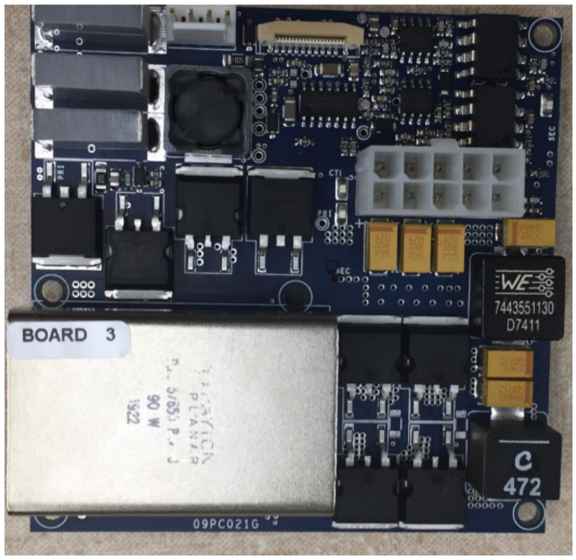

Figure 1: Custom built Wits University low voltage power supply brick.

.

super-drawer by means of a low-voltage power supply (LVPS) source, which is positioned in an external steel box mounted just outside the electronics drawer also referred to as a super-drawer. Each power supply provides power to one module, and resides on the outside of the drawer in a special metallic shielding called a "finger". Each supply is a package that consists of eight power supply "bricks," providing a range of currents and voltages as required by a module.

2. Upgraded Tile Low Voltage Power Supply

The basic topology of the brick is a transformer-coupled buck converter. Each brick receives + 200 VDC at low current, and converts it using switching techniques to low voltage at the required currents. The heart of the design is the LT1681 controller chip [6]. It is a pulse width modulator (PWM) that operates at a fundamental frequency of 300 kHz. The LT1681 provides an output clock to the FET Drivers. These are transistor drivers that have sufficient current and voltage to drive the high-side and low-side power Field Effect Transistors (FETs) that perform the switching on the primary side. The upgraded design uses synchronous switching, for switching on the high-side and low-side transistors turn on and conduct for the duration that output clock signal oscillates between a high and a low state and both are in the off state when the clock is low. The transformer is a custom planar design with turn ratios suitable for the 10 V brick. The buck converter is implemented on the secondary side of the transformer. The output side also contains an additional LC stage for noise filtering. The design also incorporates a shunt resistor for measuring the output current, the voltage fed back using an opto-isolator. The brick has three types of protection circuitry built in as part of the design. There is a over-voltage protection (OVP) and over-current protection (OCP). Both of these circuits are on the primary side of the brick. These send facsimile analog voltages to the ELMB that represent the input and output voltage, the input and output current, and readings from two temperatures located on the brick. The upgraded version of the LVPS bricks are all identical with the same converted output of +10 VDC. This greatly reduces the complexity with regards to design, production and testing of the bricks. The LVPS brick (see figure 1) has a 4 pin connector, with two pins for +200 V and two pins for the signal return line. There is a 10 pin output connector to deliver the 10 V output of the brick to the Harting connector on the LVPS box. The is also a small 20 pin connector, which connects the brick to the Embedded Local Monitor Board (ELMB)

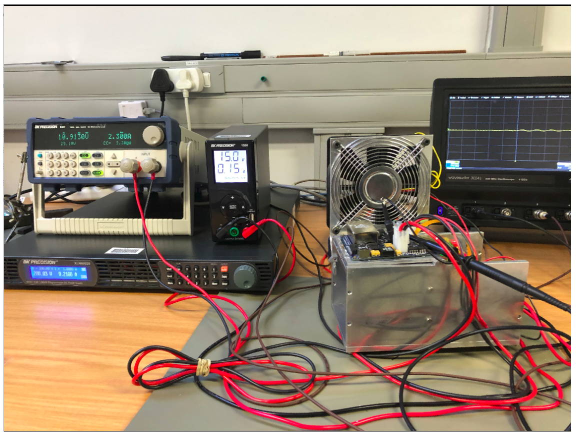

Figure 2: The initial test bench setup (left) consists of a test fixture providing support for both the LVPS brick and the interface card, a + 200 VDC power supply used for the input to the low voltage power supply, an electronics load meter to measure and display the output current and voltage, oscilloscope to measure the switching frequency of the converter and a PC computer. The Burn-In test bench (right) utilizes a programmable high voltage power supply for the input + 200 VDC, eight mounted DC/DC bricks with corresponding interface boards, two dummy-load boards, a mainboard for interface with all custom boards and water cooling station for cooling the LVPS bricks.

motherboard with a ribbon cable. This connector is used to receive the control signals from the Auxuilliary board used to generate all auxiliary signals and power voltages for the fLVPS via the ELMB motherboard, and send the monitoring signals in differential analog format to the ELMB motherboard.

3. Production checkout and test bench designs for quality control

The first checkout procedure is visual inspection consisting of: checking the soldering of each part and the cleanliness of the brick, as well as verifying the correct assembly of components. During the visual inspection the brick receives an identification serial number. At this point the brick is logged into the database.

3.1. Intial test bench

The next step is the initial tests, which consists of a series of highly automated tests (see figure 2). The tests provide information about the general conditions of the brick (voltages and currents output, clock efficiency, start-up and shut-down of the brick) and checks the correct functioning of the protection and monitoring circuits. The initial test bench is based on a computer, for the control and readout of several commercial equipment and custom built interface printed circuit boards (PCB) which perform the tests; a metal case that acts as brick and PCB support and provides the interface to the computer as well as the ground connections [5]. The data acquisition card can digitize eight channels simultaneously and has in/out registers for control purposes. If the brick fails one or more tests a technician and/or an engineer proceeds to identify the causes and to fix the problem. After that the brick will be fully retested, with the initial test results, repairs and final acceptance inserted into the database.

3.2. Burn-In test bench

The power supply is then subjected to a the burn-in procedure. This comprises of a 7 hours test during which the brick runs at an upper limit current to stress components and solder

Parameter	Value
Threshold for Stable Load	2.3 A
Over Voltage Protection	12.5 V
Over current Protection	7 A
Duty Cycle at Nominal Load	> 45 %
Frequency at Nominal Load	300 kHz
Efficiency at Nominal Load	75 %
Input Current at Nominal Load	0.2 A
Over Temperature Protection	72 °C

Table 1: Specification parameters used to ensure uniformity of individual bricks in the test station software.

joints that are on the edge of failure. The burn-In test bench consisting of an aluminum chassis and custom built printed circuit boards to interface and read out several parameters using a desktop computer. Interfaced with a LabVIEW 2020 framework, external 200 V DC power supply, and a water cooling circuit utilized to cool the bricks and internal electronics. The circulating water temperature in the test-benches is stabilized between 17 - 19 °C. During the burn-in, bricks are thermally coupled to a water-cooled plate to mimic during standard working conditions and thermal grease applied under the posts to help the coupling. Temperatures from the burn-in are registered along with several parameters of the brick (voltages, currents and temperatures) [5]. The brick efficiency rating is also verified which is the power output to those components divided by the wattage drawn by the front-end electronics. Any wrong functioning of the monitoring circuits on the LVPS bricks in response to the front-end electronics may prevent the detection of critical malfunctioning therefore preventing any possible response in the detector. It is also important to note that a malfunctioning in the electronic components of a module, would undoubtedly involve a severe data loss from the module.

4. Software architecture for monitoring and control

The LVPS system and all subsequent components are integrated with various software packages to allow for advanced monitoring and control in a graphical manner from a LabVIEW framework. The Framework allows for live monitoring of sensors, (hardware control), automated recovery and more. The use of custom built interface boards do all the data acquisition and further multiplex and parse the data to the desktop personal computer (PC). The central software is used on the desktop PC, which communicates all the interface boards and graphically displays and logs data points. Parts of the legacy software, an old and outdated program that is still used to perform a task for a user at CERN was recycled for the front-panel graphics as seen in figure 3. Several custom LabVIEW drivers were also created to communicate with the high voltage source via the virtual instrument software architecture (VISA) communications layer over ethernet and to test and measure the standard communication API (Application Programming Interface) for use with any testing and measurement devices. The VISA libraries enables communication for many interfaces such as General Purpose Interface Bus (GPIB), Universal serial bus (USB), and Ethernet. [4] In the control software the main functions and parameters of the bricks are verified to be correct. The required accuracy of all parameters need to be within the 3σ limit from the nominal specification values for all tests, where the measured data is within three standard deviations from the mean.

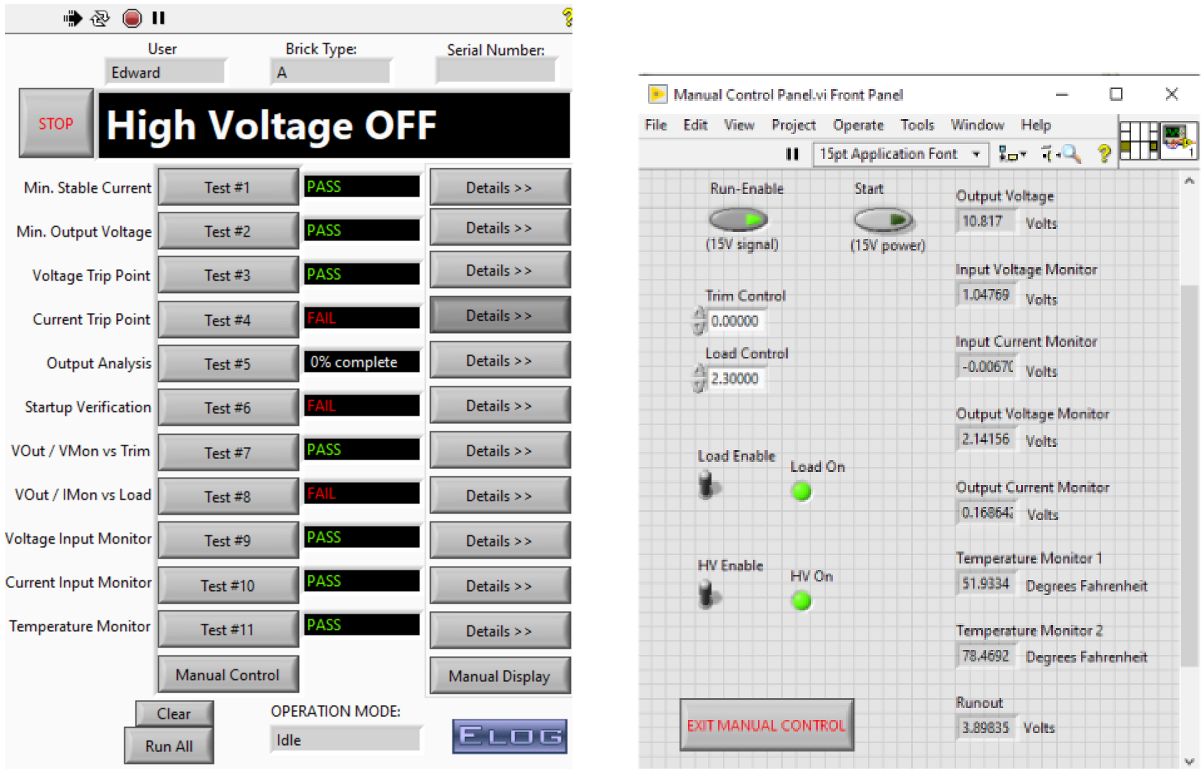

Figure 3: Programme test panel used to perform various tests to guard against over temperature, over current and over voltage. These also include tests such as startup verification to start the brick and minimum stable current when the brick is on (left). The manual control panel displays parameters such as output voltage in real-time on a graphical user interface (GUI) (right).

5. Performance testing of latest version of power supply

The initiation of a test is straight forward with the user executing the desired test, where the software automatically configures all relevant parameters and follows the specific algorithm associated with the test. Following the test, the software renders a binary pass or fail and displays the outcome alongside the respective test as shown in figure 3. The software is also able to export the resulting data as a text file and/or display plots and other graphical representations of the test data, depending on the test run involved. For the completion of a test sequence, by an operator, all tests need to be successfully completed without any error messages. The test measures the stability of the voltage over a long period as seen in figure. For a brick to receive an overall pass status all eleven tests on the test panel as seen in figure 3 must have yielded results within the allowed parameter distribution.

The most notable metrics measured is the feedback signal where the test checks the correct functioning of the monitor circuit of output voltage and input current (see results in figure 4 and 5) to be distributed to the front-end electronics of the TileCal. The brick is started at a nominal load of 2.3 A. The manual control feature is a new addition, which allows the brick to be monitored at any period interval through the data acquisition card. To determine this value, the brick is connected to the nominal load and the clock output from the LT1681 controller chip [6] read with an oscilloscope. The load is then decreased until missing clock cycles are registered, and the load value recorded. Permitted values for all the bricks should be within the 3σ range as summarized in table 1. Any values outside the 3σ of the specified values are considered as a failure of a brick. The expected voltage of the power supply should not exceed 12.5 V which can

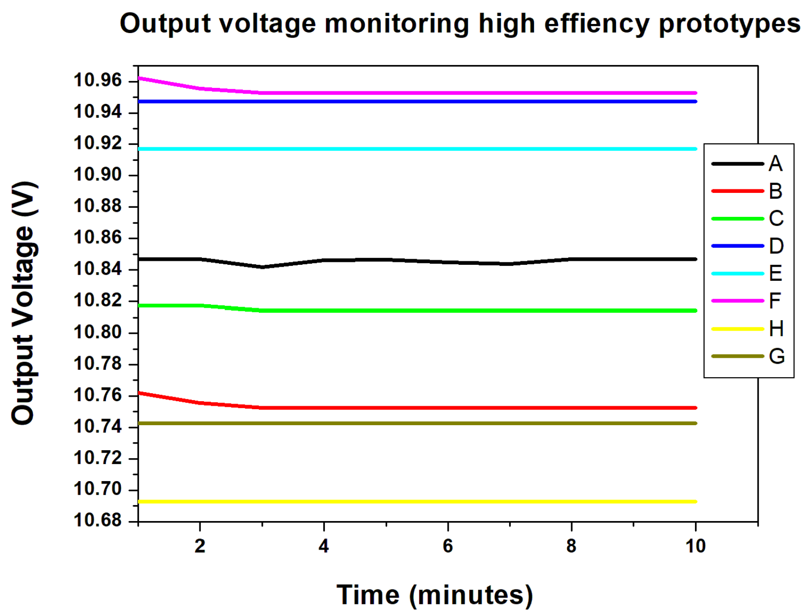

Figure 4: The output voltage monitored over elapsed time during initial testing of LVPS brick. All eight bricks tested fall within the acceptable tolerance range between 9 V to 12.5 V. The difference in monitoring data is due to electronic components of a given type not being identical. Even for components made from the same materials and by the same processes, differences still exist due to noise factors such as microscopic material defects or variations within a single manufacturing process. Therefore, the strength of a component is considered to be a random variable. Thus, statistical distributions are usually used to describe any anomalies in data.

be observed from figure 4 where both the upper and lower bounds of the tested brick are with the required specifications. The same can be observed for the input current of the brick which should not exceed a value of 0.220 A as seen in figure 5.

6. Conclusion

The ATLAS collaboration has planned a huge upgrade for the next phase that will allow the collaboration to fully exploit the LHC physics opportunities. The quality assurance testing station has been commissioned at the University of the Witwatersrand's electronics laboratory. These test benches will ensure high quality and reliability of the hardware that will be delivered to CERN. Each LVPS brick will undergo a long list of tests and compliance with set parameters are to ensure correct functioning of bricks and of components powered. Any departure will cause severe consequences for the Calorimeter module electronics such as the front end electronics powered by the LVPS bricks. If the output (voltage or current) or the temperature of the brick exceeds the allowed range during operation, measures will be put in place to protect the front-end electronics. However a failure in a brick may result in the loss of data in a mini-drawer.

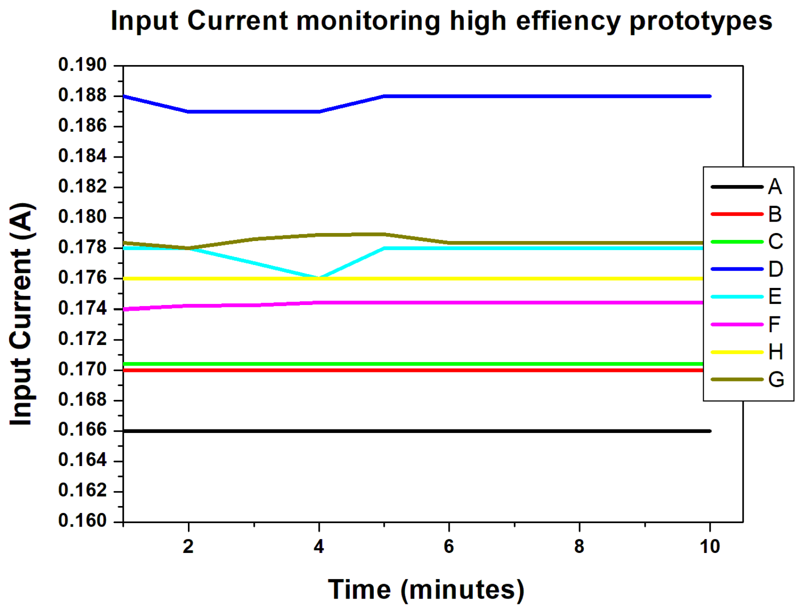

Figure 5: The Input current monitored over time of the LVPS brick. All eight bricks tested, fall within the acceptable tolerance range between 0.15 A to 0.22 A.

.

References

[1] ATLAS Collaboration. (2008) The ATLAS Experiment at the CERN Large Hadron Collider. JINST. vol **3** p 150.

[2] Ryan Mckenzie. (2021) The ATLAS Tile Calorimeter performance and its upgrade towards the High Luminosity Large Hadron Collider. Technical report. p 1-4.

[3] Nkadimeng E. (2019) *Proc. SAIP Conf. (Venda)* p 257 - 262

[4] Lepota T. (2019) *Proc. SAIP Conf. (Venda)* p 251 - 256

[5] Nkadimeng E and Mellado B. (2020) *Proc. Int. Conf. on Particle Physics and Astrophysics (Moscow)* JPCS Ser. **201** p 589

[6] LT1681 datasheet, *Technical datasheet* p 1 - 16