

Analysis of the electrical disturbances in CERN power distribution network with pattern mining methods

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Abstract—The current research focuses on the perturbations within the electrical network of the LHC and its subsystems by analyzing measurements collected from oscilloscopes installed across different CERN sites, and alarms by electrical equipments. We analyze amplitude and duration of the glitches and, together with other relevant variables, correlate them with beam stopping events. The work also tries to identify assets affected by such perturbations using data mining and, in particular, frequent pattern mining methods. On the practical side we summarize results of our work by putting forward a prototype of a software tool enabling online monitoring of the alarms coming from the electrical network and facilitating glitch detection and analysis by a technical operator.

Keywords—LHC, electrical glitch, data mining, frequent pattern mining

I. INTRODUCTION

The Large Hadron Collider (LHC) and its injectors are sensitive to instabilities of the electrical network. When an electrical perturbation happens, it propagates through the technical infrastructure (TI) of the LHC affecting its subsystems in various ways and often resulting in a beam dump. Depending on the systems involved recovery of the normal operations takes few hours. As a result, frequent breakdowns of the accelerators not only decrease luminosity and increase operation costs but also affect schedule of the experiments and slowdowns exploration of new phenomena.

Electrical disturbances at CERN facilities are constantly monitored by CERN technical operators and engineers. An analysis of electrical glitches was delivered by K.Kahle in the research related to the quality of power converters [1]. In this study author describes types of electrical disturbance, conducts statistical analysis and defines immunity level of the equipment. Another study [3] has been performed by Math H.J. Bollen providing insights into the prediction of glitches.

From the technical point of view each glitch can be described by amplitude and duration. In majority of cases a typical glitch does not exceed 10 percent in amplitude with respect to normal voltage and 100 ms in duration. Interesting enough that identical, according to their parameters, glitches may behave in different ways by stopping the beam in one case and not stopping it in the other. This may be explained by differences in the working conditions of the LHC and of

the supporting technical infrastructure. In a certain state the whole systems is more resistant to glitches. In this context it is interesting to analyze and identify configurations that are less sensitive to perturbations and try to implement them.

According to this, a relevant goal is to develop a tool facilitating process of glitch detection and analysis. Currently, when beam suddenly stops this can be immediately detected by a technical operator in the CCC (CERN Control Center). However, the root-cause leading to this beam stop in many cases cannot be known right away and requires investigation with involvement of professionals from several departments. This investigation is carried out weekly during TIOC (Technical Infrastructure Operation Committee) meeting and results of the investigation are recorded into TI Logbook. The generalized workflow of described above TI monitoring is shown in the Figure 1.

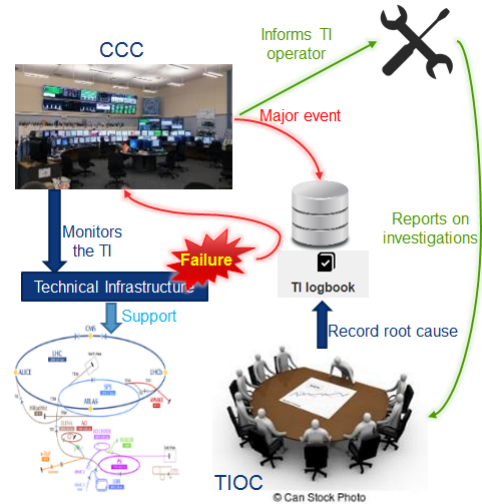


Fig. 1: Current glitch analysis workflow

Instead of following a currently existing workflow it is proposed to automate process of glitch analysis and detection by setting up a software tool which will be monitoring parameters of the CERN electrical network live and detecting patterns corresponding to electrical perturbations. Based on

this automatic analysis it will not only be possible to instantly classify beam dumps caused by the electrical glitches but also write major events and their analysis directly to the TI Logbook, facilitating work of TIOC and technical operators.

II. STATISTICAL ANALYSIS OF THE PERTURBATIONS

At CERN all critical equipment is constantly monitored by devices measuring specific parameters such as voltage, temperature, power, etc. The same applies to the electrical network, which is monitored by oscilloscopes spread over CERN's territory and installed in critical locations. When an anomaly is detected by an oscilloscope, it records a file in COMTRADE format [2] containing sampled signal of this perturbation as well as emits alarm which arrives to the CCC and can be seen by the technical operators. In the first part of our research it is essential to understand statistical properties of perturbations by means of duration and amplitude. Since there are thousands of COMTRADE files to be analyzed, it is necessary to implement algorithm enabling their automatic processing.

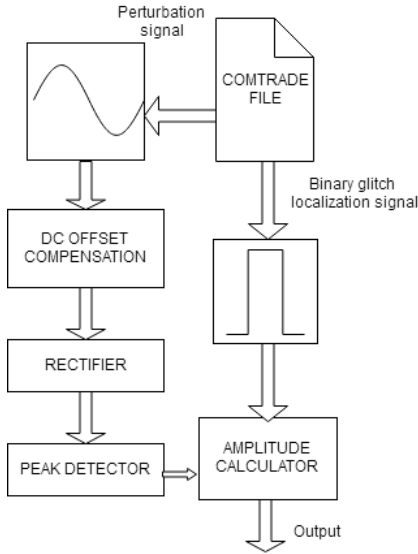


Fig. 2: Algorithm for extracting amplitude from Comtrade file

COMTRADE file, according to its specification, contains two types of signals - discretized analog signal of the perturbation and indicative binary signal which has a value "1" in the time window of the perturbation and "0" otherwise. Based on the information provided by binary signal, duration of the glitch can be calculated by analyzing length of the interval in which the signal equals to "1". On the other hand, for determining amplitude of the perturbation, the analog signal should undergo additional processing block diagram of which is shown in the Figure 2.

The key element in the amplitude extraction pipeline is a peak detector finding values of maximum amplitudes of the sinusoidal signal which then can be used for calculating relative amplitude of the glitch. With respect to the indicative

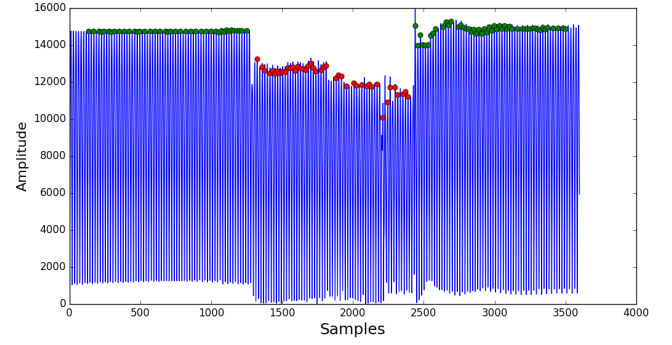


Fig. 3: Example of the glitch recorded in Comtrade file

binary signal we separate peaks into 2 sets - ones belonging to the interval of the glitch (shown as red dots in Figure 3), and the others - peaks outside of the glitch interval (shown as green dots). More formally, given that Y is a set of amplitudes of all peaks we define as Y_G set of amplitudes within the glitch interval and complement set $Y_{NG} = Y \setminus Y_G$. Following the notation above relative amplitude can be calculated according the following formula:

$$r = \frac{\overline{Y_G}}{\overline{Y_{NG}}} \quad (1)$$

Using this tool for automatic extraction of glitch amplitude and duration, we have processed COMTRADE files for the 2015-2016 years and obtained statistics on glitches which stopped and didn't stop the beam. With the information extracted from COMTRADE files is possible to generate a scatterplot (see Figure 4) of the data along with the amount of power consumed by the accelerators to see if there is any dependency.

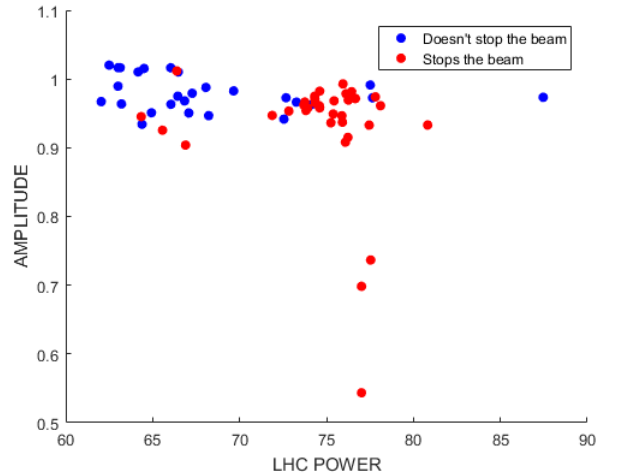


Fig. 4: Dependency Amplitude vs LHC Power during 2015-2016

By analyzing aforementioned scatterplots it is possible to infer that there can be a correlation between beam stops and total amount of power distributed to the LHC. One possible explanation of this phenomenon arises from the idea that when LHC and its infrastructure operate in the conditions close to their absolute maximum, the whole system is more sensitive to perturbations and even a small glitch can stop the beam.

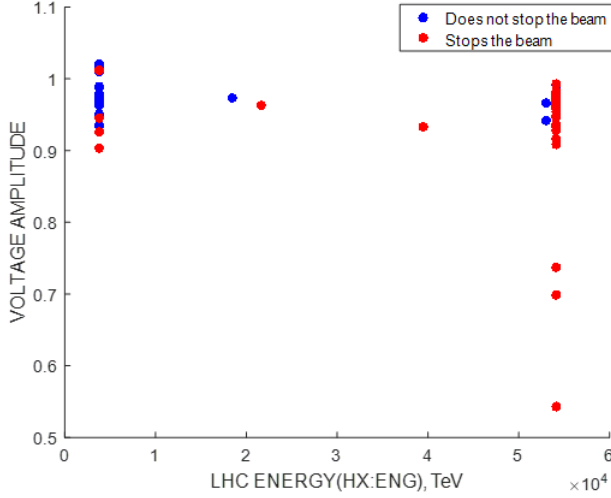


Fig. 5: Dependency Amplitude vs LHC Beam Energy during 2015-2016

Quite similar dependency can be seen if we correlate glitch amplitude and energy of the beam (see Figure 5).

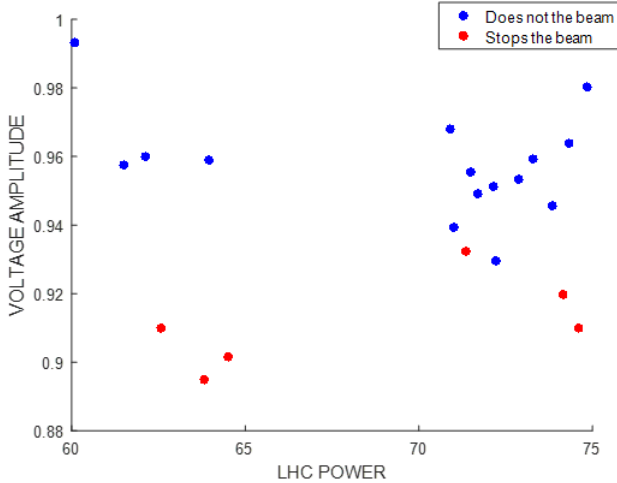


Fig. 6: Dependency Amplitude vs LHC Power during 2017

It is, however, interesting that for the first part of 2017 year scatterplot pattern (see Figure 6) differs from ones of 2015-2016, from which we can infer correlation of beam dumps with

the glitch amplitude only. This inconsistency can be explained by the upgrade of the equipment of power converters during the operational break to reduce their sensitivity to electrical glitches.

III. IDENTIFYING BEAM STOPS CAUSED BY COMMON PATTERNS

As it was mentioned earlier, one of main goals of this analysis is to facilitate identification of the beam stops caused by the electrical perturbations. Usually a glitch is accompanied by a set of alarms triggered by the electrical assets. The key problem is that usually these "electrical" alarms simply get lost among hundreds of alarms being raised by other different systems. Thus, it would be good to implement an alarm filter based on pattern recognition methodology which is able to learn and then detect frequent patterns associated with electrical glitches. During the pattern learning process it is necessary to search for ones which appear with high probability when beam is stopped and do not appear otherwise. More formally, discovered patterns should follow good sensitivity(recall, support) and specificity(precision) properties, which can be calculated according to the following formulas:

$$sensitivity = \frac{TP}{TP + FN} \quad (2)$$

$$specificity = \frac{TP}{TP + FP} \quad (3)$$

where TP, FP, FN are true positive, false positive and false negative rates respectively.

After running frequent pattern mining algorithms it was possible to find a list of pattern with aforementioned properties.

Frequent Pattern	Specificity	Sensitivity
EMD104/8E, EMD201/6E, EMD201/8E	0.89	0.65
EMD104/8E, EMD201/2E	0.88	0.63
EMD104/8E, EMD201/2E, EMD201/6E	0.88	0.63
EMD104/8E, EMD201/2E, EMD201/8E	0.88	0.6
EMD205/6E, EMD104/8E, EMD201/6E, EMD201/8E	0.87	0.6

High values of specificity make it possible not only to detect electrical glitch with a high probability but also to grab attention of a technical operator and help him to investigate a beam dump.

The next step in this process is a development of a tool incorporating described above glitch detection functionality as

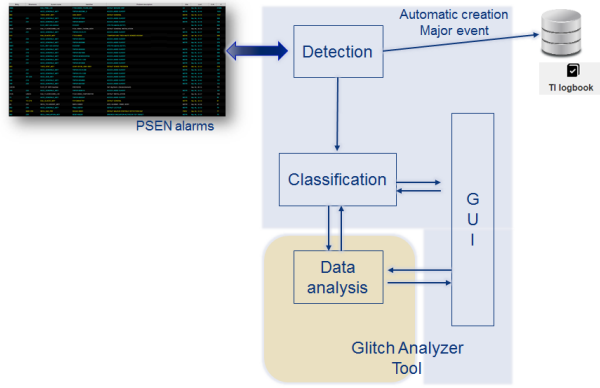


Fig. 7: Architecture of the glitch analysis tool

well as analysis part helping to monitor glitch statistics over the time.

According to the architecture presented in the Figure 7 glitch analysis tool should consists of detection module in charge of splitting stream of alarms into events and monitoring beam presence, classification module responsible for maintaining database of frequent pattern and detecting them from the incoming stream, analysis part providing opportunity for statistical analysis of the glitches in the selected time window and writing functionality, utilizing power of REST API for automatically recording detected electrical glitches into TI Logbook.

IV. IMPLEMENTATION

For implementation of the prototype it was decided to use Python scripting language in combination with Qt library [4] for GUI (Graphical User Interface) development. Such a choice is primarily forced by availability of great variety of relevant libraries and simplicity of the implementation on Python's side as well as by cross-platform nature of Qt which in case of need will easily enable conversion of the GUI to another language. Example of analysis window is presented in Figure 8. The application is divided into 2 independent parts - GUI, responsible for interaction with user, and Core, implementing algorithms and approaches described in this paper (Figure 9). It should be also noted that application consists of multiples threads, ensuring that all "heavy" job is executed on the background without any interference with user's actions.

V. CONCLUSION AND FUTURE WORK

This research has made an attempt to analyze electrical glitches which contribute greatly to LHC downtime and reduce the beam availability for physicists. Tolerance of the system to glitches in many situations depends upon operation conditions of the LHC. One prominent example of this dependency is the correlation between tolerance to the glitch and amount of power distributed to the accelerators. It is interesting to note that when LHC is running on its full power, it seems to be

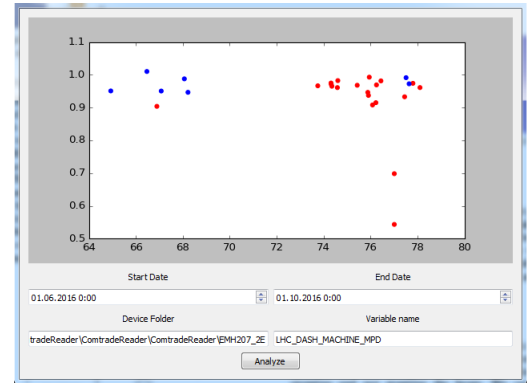


Fig. 8: Analysis window of the glitch tool

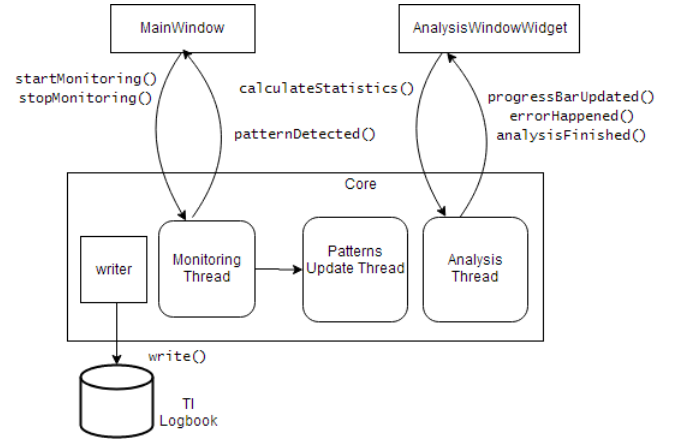


Fig. 9: Functional diagram of the multithreaded structure of the application

less resistant to perturbations and even small glitch can stop the beam. On the other hand, when operation conditions are not that severe, level of tolerance can be higher. This dependency should be further investigated on the data of 2017 year and also with respect to other variables and assets which can also correlate with beam stopping events. Additionally, it can also be useful to identify list of the most critical subsystems (such as cooling or power converters) sensitive to perturbations and find the root-cause of each glitch. In addition to the general analysis of the glitches we propose a prototype of the software tool facilitating glitch detection and recognition. From practical point of view, the proposed tool should serve as an alarm filter combined with embedded statistical analysis functionality enabling faster identification of a glitch in case of beam dump. Further development of this tool would be adding functionality to automatically log glitches into TI logbook bypassing technical operator and TI OC.

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