An innovative monitoring and maintenance model for the INFN CNAF Tier-1 data center infrastructure

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Abstract. During the last years we have carried out a renewal of the Building Management System (BMS) software of our data center with the aim of improving the data collection capability. Considering the complex physical distribution of the technical plants and the limits of the actual building hosting our center, a system that simply monitors and collects all the necessary information and provides alarms only in case of major failures has proven to be unsatisfactory. In 2017 we suffered a major flood due to one main water pipeline failure in the public street. After this disastrous event, clearly far beyond our control, we were however forced to reconsider completely the physical site robustness of our building in addition to the current monitoring and alarm system capabilities. It was clear that in some specific cases, alerts should be triggered hours or days before the actual main problem arises in order to allow efficient human intervention and proper escalation process. This paradigm could be easily applied to almost all the infrastructure components in our site, mainly the electric power distribution and continuity systems as well as the whole cooling devices. For this reason, in parallel to a consistent increase in the sensor widespread distribution of our BMS data collector system, a study of a predictive maintenance approach applicability to our site has been started. Predictive maintenance techniques aims at prevent unexpected infrastructure components failures or major events with the study of the whole monitoring data collection and the creation of appropriate statistical models with the help of big data analysis and machine learning techniques. An improvement in the Power Distribution Units (PDUs) monitoring in our site and the introduction of a dedicated network of water leak sensors were the first steps for increasing the data collection information at our disposal. With sufficient monitoring statistical information stored in our BMS system a preliminary and exploratory predictive data analysis proof of concept could be constructed. This could lead to the model building phase and the creation of a prototype with the aim of forecasting future infrastructure main failure events and forthcoming error conditions. The general idea is, conceivably, an approach to the predictive maintenance model where it would be possible to introduce scheduled corrective actions for the purpose of preventing potential failures in the next future and increasing the site overall reliability.

1. The INFN CNAF Tier-1 infrastructure site

The INFN CNAF Tier-1 physical position is currently centrally located in the urban and university district of Bologna city. Our site has become the Italian national Tier-1 data center for the INFN computing activities since 2005,[1] at present the CNAF center offers resources, in terms of computing, storage and general IT services to all the four LHC experiments (ALICE, ATLAS, CMS and LHCb) and more than 30 others non-LHC collaborations, including Astroparticle Physics. The IT resource availability must be provided with a guarantee 24/7 level of service support (which means 24h non-stop every day) and this implies that the whole infrastructure have to grant the same level of reliability. The data center is hosted in a university complex building, as represented in Figure 1, and this choice has shown to be a quite inadequate location. During 2009, the upgrade activity of the Tier-1 required all the building available space and this corresponds to a total of 1950 m² space occupation distributed over different floor levels (including underground levels) for the two IT resources rooms (250 m² + 350 m²) and four additional locations for the remaining main infrastructure facilities. These four locations

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include the transformers room, the UPS room (rotary UPS + one standard generator used for backup), the chillers room (including water pumps and the related piping system) and the power room with all the power switches and electrical measurement instruments and connections. More deeply, the main UPS power supply for the IT resources is guaranteed by two redundant Eurodiesel diesel rotary uninterruptible power supplies (DRUPS) with a nominal power of 1700 kVA each (equivalent to 1340 kW real power) connected to three electric transformers. The cooling power is provided by six Emerson free cooling chillers with 300 kW cooling capacity in a N+2 redundancy configuration. All the power distribution is carried out using two separated physical lines (referred to as “red” and “green” lines), consequently it is technically possible to provide a full dual redundant power supply to all the IT hardware installed in our data center.

![Figure 1. The INFN CNAF Tier-1 data center and infrastructure rooms site.](image)

At the end of 2017 a main water pipeline located under the main front street of the building broke down [2] and we suffered a water flood of the lower underground levels of our Tier-1 including the whole power room and parts of the two IT resources rooms. This event has led to the unavailability of our Tier-1 for several months and furthermore, it has forced us to take note of the physical weaknesses of our building and the limits of the current monitoring and alarm system capabilities. During the months following this disastrous event we decided, in parallel to the restore of the full Tier-1 functionality, to refine and improve our Building Management System (BMS) layout in order to increase the monitoring information of the physical status of our center. The general idea was the increase of all the parameters at our disposal in order to take proper corrective actions within a response time as short as possible, with the aim of avoiding risks to the infrastructure facilities.

2. The Tier-1 infrastructure facility BMS monitoring improvement

The current Tier-1 BMS implementation was designed and realized as part of the new supervision system project during 2016 [3]. The system is based on two principal and distinct software packages:

- The Schneider StruxureWare™ Building Operation software (SBO) architecture: this is the principal BMS and alarm system with long-term trends archiving capability.
- The Schneider APC StruxureWare™ Data Center Expert (DCE): for fine monitoring, tuning and notification over APC InRow RPs, environmental sensors and metered Power Distribution Units (PDUs) as described later.

Both tools are essential to the monitoring activity of the infrastructure equipment and they share their information using the ModBUS TCP [4] communication protocol. They also can be accessed easily.

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using customizable web interface from standard browsers. One of the most important part of our infrastructure is the Schneider APC “hot-aisle” model block. In Figure 2 a sketch of our “hot-aisle” model is represented with the evidenced hot corridor containment. In our Tier-1 IT rooms we have a total of 44 APC InRow RP (IRP) Precision Cooling with 2-ways valves, 3 fans and humidity control with 50 kW of nominal cooling capacity each. This provides a total of 1600 kW nominal maximum cooling power for the IT equipment with N+2 redundancy in a total of 6 "hot-aisles" over 2 IT rooms. With the current setpoints in out chillers hot/cold water circuit (15°C/20°C) the real APC IRP cooling capacity is ~42 kW each with an air temperature and humidity setpoints (as IRPs group control parameters) of 24 °C and 45%/60%. This translates in a real measured cold/hot detected air temperature of 24 °C and 31 °C for the cold and hot corridors. In order to improve the detection and control of these and others physical parameters of our data center we decided to refine and improve the data collected using the two elements also depicted in Figure 2: the Schneider Sensors Collector Units for the temperature, humidity flood and fire alerts and the Schneider metered Power Distribution Units (PDUs) for the power supply measurement.

A new high definition closed-circuit television (CCTV) system with recording capability was also introduced to improve the data center remote surveillance and retrospective problem analysis. Combing the results of the previous instruments and the new networks of sensors (in particular the new water leak detectors over all the datacenter area and perimeter) it is now possible to have available a greater amount of information that can be monitored and analyzed. In Figure 3 a screenshot example of the BMS monitoring over the PDUs distribution of one of the IT rooms is reported. On the left part of the figure it is possible to identify the physical PDUs allocation in a section of the “hot-aisles” rack area and in addition, convenient “virtual” instrument has been created for aggregating the power consumption to the level of single rack or, potentially, aisle. In the right side of the figure the corresponding historical trend of one PDU electric power value is reported as an example. The introduction of the fine monitoring of power usage values can allow the detection of anomalies in the power distribution network, the exact calculation of the electrical load consumption and finally an historical statistical data collection of eventual PDUs or power supplies failures.

Figure 2. Schematization of the Schneider “hot-aisle” model used in our INFN CNAF Tier-1.
In a similar way as we reported for the power distribution, all other environmental parameters sensors and the related detection and collection systems has been substantially improved and optimized. The GSM alarm system connected to the fire, flood and anti-intrusion probes was revised with the aim of providing automatic call to the committed Tier-1 staff members and one dedicated external supervision firm. As already mentioned, the water leak sensors network has been drastically increased and it now includes all the rooms within the building main risk areas from water flooding. This new monitoring system, in addition to some structural improvement works in the whole building that are under way, should guarantee greater robustness and reliability to our site.

3. Proposal for a predictive maintenance system
The availability of such a large amount of monitoring information in our BMS system has suggested us that a new approach to the maintenance model for our Tier-1 infrastructure devices could be technically possible. In particular our BMS software (DCE and SBO tools) natively provides long term archive on standard Microsoft SQL Server database over a dedicated Report Server machine that is used for archiving the long term trends data and for advanced statistical reporting capabilities. All the monitoring data are stored in SQL tables as “human readable form” entries and there is the possibility of database indexing strategy and the utilization of standard SQL queries for data mining. Furthermore we have implemented a system where all the infrastructure sensor data that are present in our site BMS software can also be directly accessed in “real time” using the open standard Web Services “serve” commands (as software SOAP calls to our BMS). All this translates into the consideration that our system is already suitable for any type of data analysis.

During the last years the concept of “predictive maintenance” over standard reactive hardware support intervention has arisen, with the target of predicting when critical equipment might fail. The general idea of predictive maintenance is to process huge volumes of sensors data from hardware equipment in order to obtain meaningful information. Suitable analyses should be performed in order to build an appropriate model and implement it in a specific use case. The model could suggest, for example, the replacement in advance of one infrastructure hardware part or one specific full device before a critical fault happens. This could avoid unplanned service interruption in our Tier-1 data center due to major infrastructure breakdown. Alternatively, the model could also demonstrate that the early technology refresh of specific strategic part of the infrastructure equipment could avoid unaffordable increase of maintenance cost in the future. The predictive maintenance approach starts with the data collected from a great number of sensors and usually stored in long term archiving storage. With the potential use of machine learning techniques, it should be eventually possible to define suitable
algorithms for the learning phase and, therefore, create a model prototype that can be tested over a specific use case before actual production.

In our specific case the three “first steps” that we are going to take into this predictive maintenance proof of concept are outlined in the Figure 4 schema.

**Figure 4.** The INFN CNAF Tier-1 infrastructure predictive maintenance early development.

As clearly described in the figure, the first step is about the sensors. In addition to the increase of the standard sensors number we could investigate the possibility to integrate the actual network of probes with low-cost environment equipment based on Arduino or similar hardware platforms. This gives us the undeniable advantage of increasing enormously the number of information at our disposal with almost negligible costs. Another idea is the acquisition of only and exclusively “condition monitoring compliant” hardware for the future upgrade of the Tier-1 infrastructure equipment. Condition monitoring could be defined as the process of monitoring a parameter of condition (vibration, noise, temperature etc.) in hardware equipment with the aim of detecting any significant change that could be indicative of a developing fault. In other words this “smart” equipment will include a greater number of sensors compared to traditional devices and that can help us greatly in the development of predictive models. The second point is about our Tier-1 BMS. We are currently working on the upgrade of our Microsoft SQL server license for increasing the data storage capability of our database and the available tools for direct analysis within the BMS monitoring system itself. Also the Web Services implementation will be increased in order to make available a greater number of strategic variables from our BMS to external software analysis tools (e.g. neural network learning software). This leads to the last step in our schema that is the definition of the predictive model method. According to our preliminary analysis there are different approach that are theoretically promising depending on the purpose of the analysis model and its final objective.

- **Error detection prediction.** If the target of the analysis is the early detection of anomalies we would have at our disposal data that primarily comprises non-failure situation since failure events are usually very rare. Consequently, anomaly detection of such data generally takes the form of looking for the unusual [5]. One interesting method could be the Principal component analysis (PCA), a statistical procedure that uses an orthogonal transformation over set of observed variable in order to build a model for detecting unusual situations. Currently our monitoring system is just collecting time series of events that are related to normal behavior or otherwise, to errors and anomalies. The idea is running algorithms that can identifies behavior that are not showing a normal distribution over the whole SQL Server database than contains the total amount of infrastructure monitored data. This could be
followed to an analysis of the non-normal situation in order to identify the sporadic anomalies from the actual hardware failure condition that are real critical error conditions.

- **Estimation of the equipment lifetime.** The target of the analysis could also focus over the estimation of hardware lifetime, a value that could prove very useful in case of battery-based UPS system for data center or very expansive chiller equipment investment. In this case two statistic methods seem interesting for our purpose: the Weibull distribution method and the Kaplan-Meier estimator, a survival function from lifetime data that is very popular in medical research [6]. As outlined before, recent “condition monitoring” hardware will include a greater series of sensors that will help the real and accurate estimation of the hardware lifetime, in comparison with the one that is recommended by the manufacturer using the standard estimate obtained from the factory statistic that is usually conservative. This could prove significantly advantageous in case of very expansive hardware investment (i.e. our next generation rotary or battery UPS), since the maintenance plan, and the related costs, could be dynamically adapted to the real use-case situation and this could substantially increase the useful life of specific equipment.

At present we are working in deep for the first two steps of the schema described in Figure 4 with the purpose of collecting enough significant data for applying in the short future the chosen predictive learning algorithm. It will probably take quite a lot of time in order to have available a working predictive maintenance prototype model that can be successfully used in production. Nevertheless, we are confident that the chosen path of working on predictive techniques is the right one for improving our Tier-1 toward a more modern vision of data center management.

4. Conclusion

This paper briefly describes the INFN CNAF Tier-1 infrastructure equipment current layout and the latest developments in our Building Management System (BMS) monitoring system. During the last years some unfortunate events have alerted and, at the same time, suggested us that a traditional “reactive” technical intervention in case of failure may probably not be enough for preventing damage or unexpected shutdown. For this reason an innovative “proactive” predictive maintenance proof of concept is currently under investigation. We are confident that despite the probable long time needed for the data collection, development and fine-tuning of the system, a future working model can be used in production in our Tier-1 data center and this will greatly increase the reliability and efficiency of our service provision.

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