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# *Topology of Continuous Availability for LED Lighting Systems*

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***Abstract. Lighting systems with a big number of luminaires in large halls are a case of distributed loads that need topologies with modularity, whenever possible to ensure a uniform distribution of the supplying circuits, an easier installation, management and maintenance. The LED luminaires give a great impact on the system operation due to their auxiliary series devices and to the high inrush currents of the ac/dc switching power supplies. This paper proposes a topology to design LED lighting systems, configured in a modular scheme of a main AC distribution and a branch DC distribution supplying luminaires clusters. Each cluster is provided as a "double-dual corded" equipment with double power supply and double control type, digital and analogic. The suggested topology aims to make available a system that allows overcoming fault situations by design and permits maintenance activities limiting and recovering degradation conditions. In this way, the lighting system of special locations, for which there is the willingness-to-accept greater financial costs against loss service risks, can satisfy the requirement of continuous availability system. To provide more details on the proposed design criteria this paper describes, as case study, the lighting system of a parliamentary hall with one thousands of luminaires.***

*Index terms: distributed loads, modular system, service continuity, In-Op approach, dual corded equipment.*

SYMBOLS

| | |
|---|---|
| A/D | switching power device AC/DC |
| CAS | system with continuous availability |
| DD | dimmer device |
| $i(pI_L)$ | inrush current in p.u. of A/Ds |
| $I_m$ | magnetic tripping current of PD |
| $I_n$ | current nominal value of PD |
| $k=I_m/I_n$ | magnetic tripping factor of PD |
| LL | LED luminaires |
| MC | manual control rate (%) |
| $n_{sd}$ | number of the A/Ds |
| PD | protective device |
| $pI_L$ | current of A/D |
| PSB | partition switchboard |
| S | sector lines serving related lighting sectors |
| SB | local switchboard in field |

## I. INTRODUCTION

Lighting systems in large halls are a case of distributed loads that need a modular configuration for a uniform distribution of the supplying circuits and to expedite the installation, maintenance and control procedures, besides exigencies of energy saving and visual comfort. A lighting system suitable for lower energy consumption, easy control and advanced technology is currently available with luminaires with LED lamps. The electronic LED luminaires require series devices such as switching power devices and dimmer devices, so systems with several hundred luminaires (the case study has one thousands of luminaires) are less reliable than the obsolete classic luminaires. Many control zones (CZ) compose the luminaires system that require independent regulations for various exigencies and scenic effects in a same scenario (Figure 1). For institutional environments, national and international assembly halls, congress centers, theaters, stadiums, sports centers and entertainment locations, a reduced availability of the lighting system is not admissible.

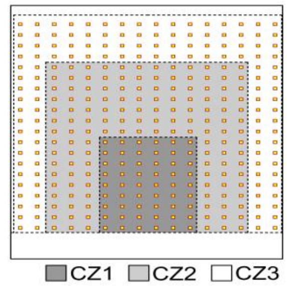


Figure 1. Lighting system with three control zones CZ1, CZ2 and CZ3.

Therefore, this paper suggests to adopt a topology for the lighting system usually adopted for systems that need continuous availability (CASs), adopting "double- dual corded" equipment supplied by two sources and dimmed by two control types. Availability differs from reliability, as it admits that the system components may suffer failure, but that the system is still available at the time or in the period in which its use is required. A CAS topology must allow operational performance by design for the service continuity such as fault selectivity, immunity from interference between different areas of the system, the easy maintenance of the system on its parts, the flexibility and the expandability (In-Op approach) [1].

The topology to be fault tolerant requires a backbone appropriate to the type of loads area with system sections that have active partitions supplied by different sources (Figure 2 UPS A-B). Each partition switchboard (PSB) has redundant distribution paths (S lines) simultaneously serving assigned load groups by modules of local switchboard (SB) in the S lighting sectors. Each distribution element (UPS, PSB, SB) with its serial components is operated independently, but via tie-switches, at each panel level, can restore local fault avoiding that a single faulted element affects downside the following subsystem (Figure 2, 3, 4, 5).

The natural deterioration of the components need monitoring the residual time of their good operation. Considering that the system is constituted by a large number of electronic components subject to childhood failures and successively for the ordinary operation, the design of a CAS requires adopting

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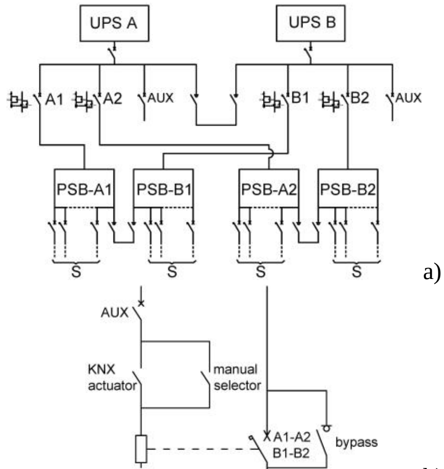


Figure 2. a) The two UPSs, A and B supply 4 partitions, PSB A1&B1, A2&B2, for a MC rate of 25%. b) shows the scheme of the contactor relay, able to be delayed in its closing, installed on the main switch A1,2; B1,2 of each PSB.

an adequate redundancy of components and circuits, to ensure the availability of their function by design. The designer should adopt precise selection criteria for the components: uniform partitions of the distribution system, different supplying sources and technology systems.

Uniform partitions of the distribution system allow ensuring the service continuity even during the maintenance time of every part of the system. Uniform partitions in m-parts consent a delayed insertion of the LED luminaires and guarantee the direct switching procedures on the distribution circuits in case of failure of automation with a manual control rate of the m %.

The service continuity requires different supplying sources as power supplies from UPS, Engine Generators Sets or, at least, a pair of utilities sources (A, B). Let us consider that two contemporary utilities A, B allow a service continuity of the 50% thanks to the partitions (Figure 3). Analogously the adoption of different technology systems contributes to the service continuity as diverse types of controls such as manual (structural by partitions), digital (DALI), analogic (0-10V).

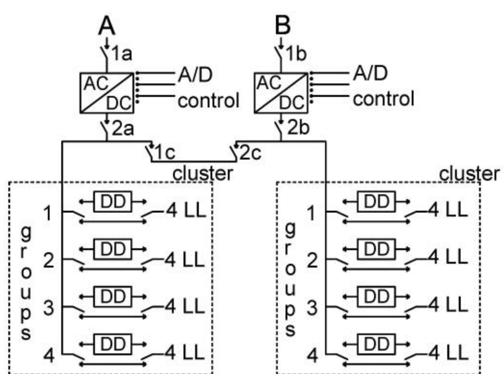


Figure 3. Pair of SB modules, each one with an A/D supplying a cluster of 4 groups of 4 LED luminaires. Each group is controlled by a DD that the shunt switches allow inhibiting.

## II. THE IMPACT OF LED LUMINAIRES AND THE MODULAR DISTRIBUTION AC/DC

The LED luminaires (LL) require ac/dc switching power supplies (A/D) and dimmer devices (DD). The DD can be for controlling a single luminaire or more luminaires. Analogously, the A/D can be for supplying a single luminaire or a cluster of luminaires.

A problem of considerable impact on the configuration of the electrical power system of LED lighting systems with numerous luminaires is the difficulty of simultaneously activating the system due to the high inrush currents of the ac/dc switching power supplies (Table I) [2,3,4,5,6,7,8]. This phenomenon occurs because a switching power device at insertion absorbs a very high current peak, for the charge of the electrolytic capacitors of the AC section that are quite high and so causing a strong current peak. These currents $pI_L$ of the cause the tripping of the protection device PD not appropriately calibrated and could become inadmissible overcurrents for UPS power supply. As a basic solution to the problem, a partition of the supply distribution is advisable to facilitate the coordination of the circuit breaker of the individual circuits and to program their insertion to be not simultaneous.

To avoid the tripping, it is necessary to verify that the instantaneous tripping current $I_m$ of the PD must be no lower than the inrush current $i(pI_L)\, n_{sd}\, pI_L$ of the number $n_{sd}$ of the A/Ds.

$$I_m = k\, I_n \geq i(pI_L)\, n_{sd}\, pI_L \qquad (1)$$

being $pI_L$ the current of the switching device A/D, $n_{sd}$ the number of the A/Ds, $i(pI_L)$ the inrush current in p.u. of the A/Ds, k a factor equal to the ratio between the instantaneous tripping current $I_m$ and the nominal value $I_n$ of the PD.

The IEC/EN 60898-1 standard [9] shows three tripping curves for overcurrent protection of miniature circuit-breakers with the nominal current $I_n$: the B curve with the k factor equal to 5, the C curve with k =10, the D curve with k=12-20. Therefore, the PD rating $I_n$ has to satisfy the condition (2)

$$I_n \geq (i(pI_L) / k)\, n_{sd}\, pI_L \qquad (2)$$

where $i(pI_L)/k \geq 1$ that is, if the ratio $i(pI_L)/k$ is no higher than 1, it has to be assumed equal to 1.

TABLE I CHARACTERISTICS OF LED SWITCHING POWER SUPPLIES

| | Nominal Power [W] | $pI_L$* [A] | $i(pI_L)$** [p.u.] | |
|---|---|---|---|---|
| | | | min | max |
| Single-Phase | 15 | 0.08 | 61 | 613 |
| | 30 | 0.16 | 80 | 276 |
| | 70 | 0.38 | 39 | 92 |
| | 120 | 0.65 | 31 | 54 |
| | 240 | 1.30 | 27 | 42 |
| | 480 | 2.61 | 10 | 31 |
| Three-Phase | 240 | 0.43 | 46 | 115 |
| | 480 | 0.87 | 46 | 92 |
| | 960 | 1.73 | 12 | 29 |
| | 2400 | 4.33 | 2 | 10 |

* cosφ=0.8; ** values found in technical literature

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The IEC standard 60364 at the art. 433.3.1 b) (Omission of devices for protection against overload) [10] states that devices for protection against overload need not be provided for a conductor that is not likely to carry overload current. It applies to the luminaires that do not have overload.

In order to limit the number of circuits, it is suitable the partition of the main distribution AC into sections and at the branch level to gather the luminaires into clusters at the aim of using ac/dc switching power supplies (A/Ds) of high power [7,8], which guarantee a limited inrush current allowing you to have a ratio $i_{(pI_L)}/k$ no higher than one.

An A/D presents generally a lower inrush current at the increasing its power and higher functional performances (such as protections against overcurrents and overvoltages) [7,8]. It also has auxiliary outputs that allow, through appropriate actuators and input modules, to monitor the status of the power supply and to command shutdown of the power supply on the DC side, without the need to switch off the AC side power supply. The A/Ds remain powered to avoid the perturbation at successive switching on of the lamps. It is therefore preferable to collect many lamps under a single A/D and to supply them in DC through a branch distribution as short as required by the dimmer devices (DD) and so with limited energy losses. Therefore, the number of A/Ds installed is reduced and thus the global inrush current. In this way, the supplying distribution of the luminaires remains configured in a modular scheme. The area to be provided with a lighting system can be properly subdivided in many sectors S (8 in the case study).

In each sector of the lighting system area, the luminaires can be set in groups, each one of a number adequate to be controlled by a same dimmer device (DD) and the same groups can be set in clusters, each one in number adequate to be supplied by a same A/D (Figure 3).

Thus, a primary electric distribution in alternating current feeds the A/D power supplies spread in adequate number in the lighting sectors; downstream the A/Ds branch circuits supply in direct current trough the DDs the g-groups of y-luminaires (4-groups of 4-luminaires in the case study).

The provision of three-phase ac/dc power supplies allows guaranteeing the balancing of the load made up of numerous devices, reduced energy losses and the blocking of all the third harmonics, for a better quality of the distribution network .

In conclusion, the supplying distribution of numerous LED luminaires remains configured with a main AC distribution and a branch DC distribution.

## III. LIGHTING SYSTEMS FAULT TOLERANT

In order to guarantee the expected level of performances and service quality of continuous availability, the design strategy of the lighting system has to be based essentially on the adoption of multiple sources and technologies for the same function. The provision of intelligent components allows the system to be active to ensure easy management ( DALI system allws controlling each identified luminaire). On the other hand, it is essential to ensure the possibility to passivate the system for a manual management, as far as possible direct by the operators, disabling any intelligent component of the system in failure cases. At this aim, the control system can operate not only by automation, but also by direct switching procedures on the distribution circuits.

The configuration of the primary and branch distributions connects clusters of luminaires as “double-dual” corded equipment in the lighting system, both for power and control. This configuration provides double supply and double control type, digital and analogic [11], to the luminaires assembled in clusters. In fact, for the service continuity, at least two continuity/preferential sources (A and B) have to supply simultaneity the lighting system in order to guarantee a 50% of loss of service for a black out of one source.

Therefore, the main AC switchboard has to be constituted at least by two sections, each one with a switchboard, PSB-A, PSB-B, independently supplied, that guarantees a basic manual control of the rate MC= 100/2%=50% of the system.

To increase the grade of manual management, m-pairs of PSB-A, PSB-B allow controlling the lighting system in rates of

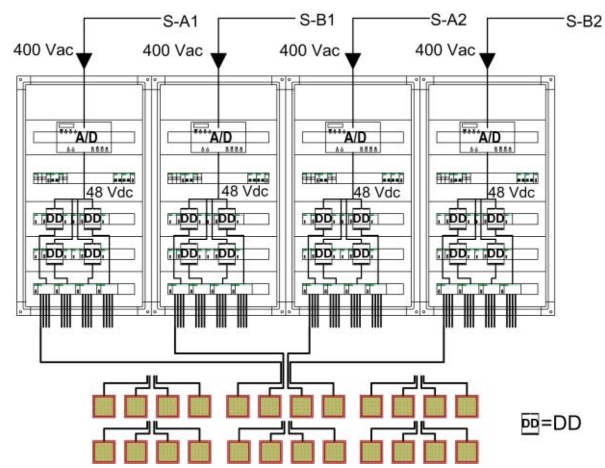


Figure 4. The four modules (A1, B1, A2, B2) of each local switchboard SB4 distributing the supply to beams of four adjacent luminaires.

MC=50/m %. Assuming as reference the case study of m=2, the main AC switchboard has to be constituted by four partitions, PSB-A1, PSB-A2, PSB-B1 and PSB-B2 (Figure 2). Therefore, the rate of manual control is MC=25%.

Each partition unit PSB of the main switchboard is energized through a contactor relay with time delayed (ANSI 2) in its closing (Figure 2). The delay prevents the simultaneity of the inrush currents at every switch- on. Since inrush current is a very fast phenomenon, it’s enough delay the switch on of each PSB by about 1 second (PSB: A1=0s, B1=1s, A2=2s, B2=3s).

Distributed in the sectors of the lighting system, many local switchboards provide the conversion AC/DC to feed the DC branch circuits via DDs groups of luminaires.

The four modules (A1, B1, A2, B2) of each SB4 local switchboard guarantee the rate of manual control MC=25%, each one of which is powered by a section PSB-A1, PSB-A2, PSB-B1 and PSB-B2 of the main AC switchboard. In other words, each 25% partition of the main switchboard PSB feeds

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the correspondent module of the local SB4 concerning to a 25% of the lighting system (Figure 4). In order to guarantee in an easy manner a uniformity of the supply with the rate MC=25 %, the following executive procedure has to be provided in the installation. Each group of 4-adjacent luminaires has to be selected to form a beam (Figure 4). The power cables connecting the luminaires of each beam will be gathered and in the supplying side distributed on the 4 modules A1, B1, A2, B2 of the SB4. In this manner the switch ON/OFF of each module of a SB4 ensures the uniform distribution of ON/OFF on actual 25 % of the supplied luminaires, one luminaire in each group of adjacent four. Such a configuration involves: - a 50% service guarantee if one of the two power supply systems (A, B) goes down, - the direct manual control of the partitioning of the system divided into 2m-parts (4 parts in case study), thus limiting the loss of service to not more than a rate of 50/m % of the total (25% in the case study), in case of maintenance of components or for failure during service on the distribution switchboards.

The DC supply of the branch distribution to the luminaires, with short lines in each lighting subsectors allows an intrinsic safety adopting value of 48 V. It is certainly optimal, because it allows the parallel connection on DC-side of the switching devices A/D. On the DC side there is not necessity of synchronization and of sequence compliance as should be necessary on the primary power supplies from independent sources. The pair of A/Ds, if each one is charged to less than 50%, can feed the clusters of luminaires as dual corded equipment, guaranteeing the 100% service, also if one of the two A/Ds goes into failure. In particular, a pair of DC- side tie-switches can allow the parallel or emergency operation to be carried out between two adjacent power supplies (Figure 5). The A/Ds normally do not run in parallel to allow the rate of manual control MC=25%, so the tie-switches are open. In case of failure of an A/D, by opening the switches 1 and 2 installed up and down of the A/D and by closing the tie-switch (c1 and c2 in Figure 3), it's possible to operate in safety on the failed A/D without maintaining switch off its LED luminaires: this is prospected as a rare manual operation.

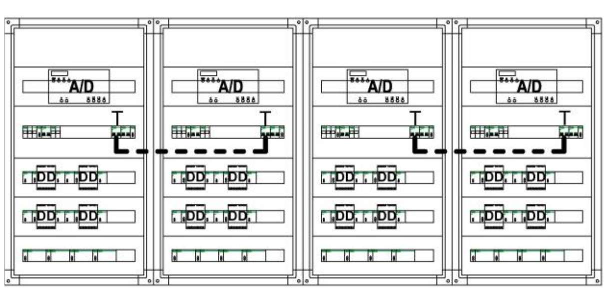


Figure 5. A pair of DC- side tie-switches allow the parallel or rescue between two adjacent A/Ds (A1-B1; A2-B2)

For the purpose of the service continuity of the active lighting control, the dimmer devices DDs can be selected to allow receiving a pair of control systems [11] that for example they can be of digital type (DALI) and of analogical type (0-10V) (Figure 6). Each DD is provided of an automatic switching that

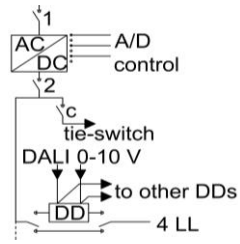


Figure 6. The dimmer device receiving the pair of control systems of digital type (DALI) and of analogical type. (0-10V) [9]

makes the transfer between the two control systems in case of failure of the preferred one (DALI). To allow the exclusion/inhibition of the automatic lighting control, shunt switches are installed to operate the deactivation of each DDs.

## IV. CASE STUDY OF LIGHTING SYSTEM

In order to illustrate in more details, the proposed design criteria, this paper deals with the case of a parliamentary hall with a glazed ceiling illuminated with a lighting system of about one thousands of LED luminaires of 70 W installed in an accessible room, called Velario, in the interspace between its roof and the underlying glazed ceiling (Figure 7).

### *A) Configuration of the power supply and control system*

In order to optimize the lighting system, the electrical distribution has been arranged on the Velario floor constituted by a supporting structure. The lighting area has been subdivided in eight sectors, characterized by three control zones CZ1, CZ2 and CZ3, each one with a proper density of luminaires distribution. The general switchboard powered by two UPSs consists of four partition switchboards, each on 25% of the total luminaires load, named PSB-A1, PSB-B1 PSB-A2 and PSB-B2 (Figure 8).

These partition switchboards feed the local SB4 switchboards consisting of four modules, each of which is powered by a partition section A1-B1-A2-B2. The three-phase supply circuits (S-lines of Figure 2) are placed along the distribution ducts serving the eight S-sectors. Each S-duct distributes four circuits, (3 phase – 4 wire), one for each module A1-B1-A2-B2 of the SB4 to spead the load on four quarters (Figure 4).

Figure 7. A sample of a glazed ceiling: the Velario in the Hall of Italian Parliament

### *B) Command, regulation, supervision and monitoring systems*

The lighting system is equipped with an integrated control, regulation, supervision and monitoring system that is with 4 subsystems:- ON/OFF control system; -Regulation system; -

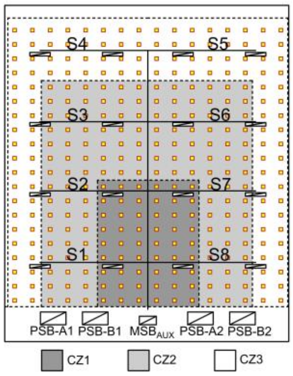


Figure 8. Lighting areas of the local switchboards SB4 in 8 sectors. Each sector S has two SB4 the four modules supplied by 4 three-phase circuits (A1, B1, A2, B2)

Supervision system; - Monitoring system. The following communication standards are used (Figure 9): -Konnex as the main BUS; -DALI for controlling the LEDs adjustable via the LED dimmer device; - 0-10V as a redundant analogue system for controlling the LEDs adjustable via LED dimmer device; -Modbus for the supervision part of the electrical switchboards; -TCP / IP for high level integration [12,13].

### *C) Partition switchboards and auxiliary switchboard*

The general switchboard consists of four partition switchboards, called PSB-A1, PSB-B1, PSB-A2 and PSB-B2 (Figure 2). Downstream of the general switch of each switchboard there is a three-pole contactor relay for the general ON/OFF with time delayed (ANSI 2), as already cited. The contactors allow remote control of the switchboards by means of buttons from the control system and manual selectors (Figure 2b). The regulation and ON/OFF panels are provided in proximity to the main partition switchboards and in the dedicated room where the lighting is controlled. The monitoring of the currents of all three-phase circuits starting from the PSBs is foreseen through measurement sensors. Sensors and auxiliary contacts are connected to switchboard concentrators with modbus communication standards and then through gateways to the general supervision system. From a partition switchboard, derived upstream of the general disconnector, is supplied the main auxiliary switchboard $MSB_{AUX}$.

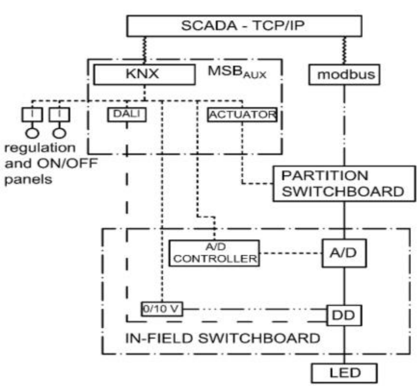


Figure 9. The integrated control, regulation, supervision and monitoring system

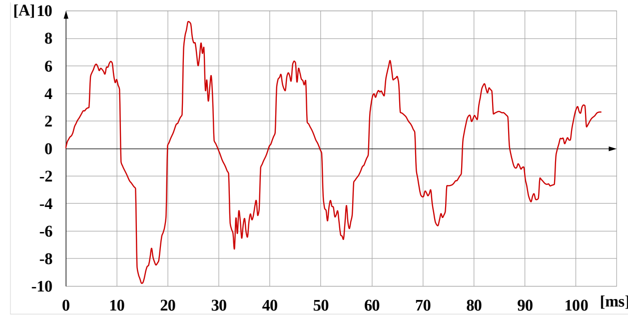


Figure 10. Current line waveform of a 3 phase A/D [7], 50% loaded, registered during the turn on transient.

### *D) Local switchboards SB4s and DC distribution*

The local SB4s are made up of 4 modules. Each SB4 switchboard supplies in DC in a uniformly distributed way up to 64 luminaires (Figure 8). Each module is equipped with a three-phase A/D (each one of 2400 W) used for a maximum of 16 luminaires and for a power less than 50% of the rated power (Figure 10). Using the A/Ds with a load lower than their nominal load increase their life, in fact, in this way, their work temperature is lower than the nominal one. This is an important aspect also in applications where is required a controlled operating temperature. As already mentioned, due to the limited power use of A/Ds, a tie-switch allows to the pair of adjacent SB-A and SB-B running in parallel or providing restore service of the supplied luminaires in emergency operation (Figure 5). The A/D is also equipped with a serial interface that allows remotely piloting and monitoring the power supply via a communication device. In this way, in the ordinary operation, it is also possible to keep energized the A/D and switch off the luminaires only, avoiding any inrush current. Only the A2-B2 SB4 modules of figure 5 are equipped with 4 dimmer devices DDs that manage the two digital and analogic control systems. In this way, the lighting regulation is operated with two fixed steps (A1-B1) of 25% and two variable steps (A2-B2), each one from 0 to 25%.

Another important aspect is the considerations about the efficiency of the A/Ds selected for a cluster of luminaires and not singularly for each luminaire: in fact, increasing the A/Ds power from 70 W to 2400 W, the efficiency increases from 90% to 93%. The complete lighting system of the case study had a cost of about 1000 $ per luminaire: the A/D redundancy required an increase of 8%, while, the integrated regulation system and the DDs installed only on the A2-B2 SB4s required an increase of 12%. In the case study, the willingness-to-accept the financial amount of the 20% plus has prevailed in prevention against a risk of availability loss, as it can be feared in similar primary sites.

## V. CONCLUSIONS

The lighting system of continuous availability such as for institutional halls, congress centers, stadiums, theaters and entertainment locations must provide a service continuity remaining available at the time or in the period in which its use is required. The suggested design criteria for a system numerous LED luminaires aim to a correct installation and an optimal operation (In-Op approach) selecting reliable components, easily available in the medium and long term, with self-diagnosis of faults and /or fault identification procedures [14]. The proposed topology presents a structure with a uniform partitioned distribution, flexible and redundant for the scope of service continuity and aims also to solve the problem of the high inrush currents of the ac/dc switching power supplies of LED luminaires. It requires to provide multiple supplying sources and to adopt different technological systems [12,13], in particular, allowing a digital, an analogic and a manual ON/OFF control. Therefore, the modular distribution is configured with a main AC distribution and a branch DC distribution that connects clusters of luminaires as double-dual corded equipment, with double power supply and double control type, digital and analogic. In this way, the lighting system of special sites, where the loss service risk is feared, can satisfy the requirement of continuous availability system.

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## BIOGRAPHIES

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