Analisys of Complex Hospital Electrical Systems

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***Abstract*—The construction of a large hospital complex requires a careful analysis of electrical loads so as to ensure reliability and availability of the service even under critical conditions. In addition, power systems, especially complex hospital electrical systems, have numerous nonlinear loads, which significantly inflict power quality (PQ) problems and the purity of the waveform of supplies is lost. Voltage sag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur a lot of expensive from the customer and cause equipment damage. So, in order to provide uninterrupted power to the hospital services and prevent equipment damage with varying voltage level and frequency, the correct distribution of active and reactive powers must be well-know. For this purpose, load flow analysis on medium and low voltage networks allows to determine the voltage profiles in all buses of the system and consequently the active and reactive power flows and the short-circuit currents in the various branches.**

This paper presents an approach method to the design of hospital electrical systems starting from the classification of electrical loads, from the topological network definition and load flow calculations in order to ensure the correct distribution of active and reactive powers and a real balance in terms of investment and operating costs. Significant variations in voltage beyond the limits are due to large reactive power flows and harmonics on the network, which can cause, in addition to considerable energy losses, the loss of voltage. Highly unbalanced electrical loads due to the use of recurrently intermittent electromedical equipment can cause unpredictable behaviors in the network, increasing the risk of damage to the most sensitive equipment and unplanned and unforeseen interruptions. This paper will be very useful for engineers, technicians and designers because it can be a tool for setting up a good electrical design project.

Keywords—load flow; active power; hospital electrical systems; electrical design; power quality.

I. INTRODUCTION

Determining the power system configuration that will service healthcare facility is most important. The electrical system serving a hospital complex must meet high criteria of reliability, efficiency and safety in order to ensure low pollution, proper implementation and maintenance costs and energy-efficient consumption [1]–[5]. Unfortunately, we must observe that the cost of building the structure or its renovating condition and sacrifice the reliability and the energy efficiency of the system is increasing frequently, with more difficult to maintain sustained time-consuming costs. In order to obtain high characteristics from the power system, it is sufficient to adopt some simple designs tips that require minimal engineering effort to get out of conventional schemes [6]–[10].

There are several different power system configurations that can be found in healthcare facilities. They do not represent all power system designs as they vary per engineering consultant, but are some of the most commonly seen in hospitals [11]. These designs generally meet the most stringent requirements for providing continuity of electrical service of essential electrical system, as hospitals. A single medium-voltage substation with one point of supply from the network operator and one or more distribution transformers for supply of the low-voltage loads is not sufficient in large infrastructure projects. Instead, an internal, separately operated medium-voltage system with several substations is required, because the high load concentrations in different areas or also the distribution of loads over large areas, such as hospitals [12].

In this paper, an approach method to the design of hospital electrical systems is presented. Starting from the classification of electrical loads, from the topological network definition and load flow calculations [6], [13]–[16], the correct distribution of active and reactive powers and a real balance in terms of investment and operating costs is ensured. For this purpose, load flow analysis on medium and low voltage networks allows to determine the voltage profiles in all buses of the system and consequently the active and reactive power flows and the short-circuit currents in the various branches. Significant variations in voltage beyond the limits are due to large reactive power flows and harmonics on the network, which can cause, in addition to considerable energy losses, the loss of voltage. Highly unbalanced electrical loads due to the use of recurrently intermittent electromedical equipment can cause unpredictable behaviors in the network, increasing the risk of damage to the most sensitive equipment and unplanned and unforeseen interruptions. This paper will be very useful for engineers, technicians and designers because it can be a tool for setting up a good electrical design project.

II. CLASSIFICATION OF HOSPITAL EQUIPMENTS

The first phase consists in defining and classifying hospital utilities into two large groups, each of which will contain homogeneous subgroups for the type of power demand. There are several different load configurations that can be found in healthcare facilities [11]. A first subdivision could be the following:

- MEDICAL UTILITIES
  - Operational blocks, intensive and sub-intensive therapies;
  - Cardiology, UTIC, Rehabilitation, Angiography;
  - Specialist departments (large burns, plastic surgery, neurology, gynecology, pediatrics, nephrology, stroke units, etc ...);
  - Hospital Departments, Day Hospital, Medical Outpatients;
  - Clinical analysis laboratories (withdrawals, dialysis, etc);

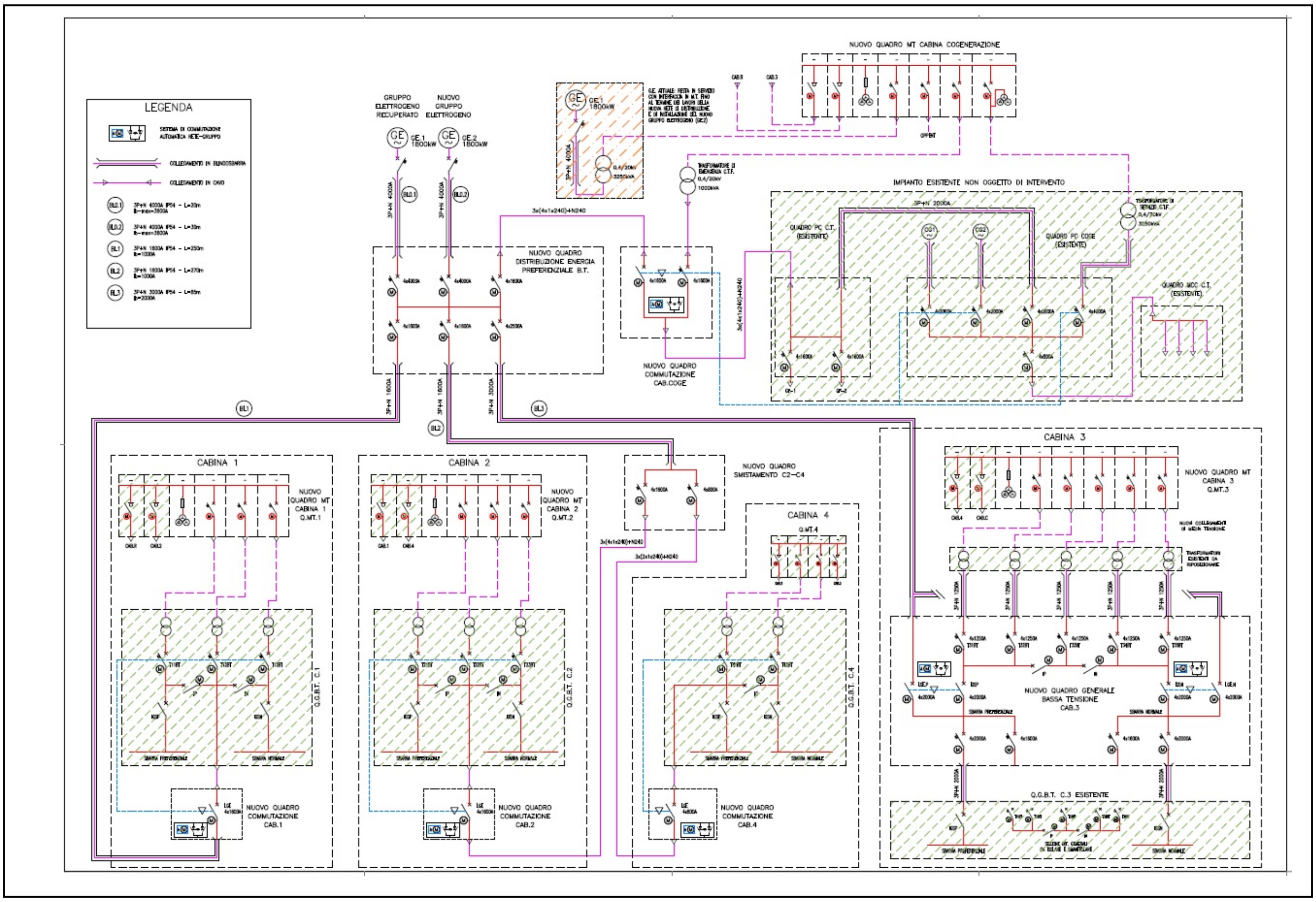

Fig. 1 - Single-line wiring diagrams

- Radiodiagnostics, radiotherapy, nuclear medicine, nuclear magnetic resonance imaging, computerized axial tomography, etc.
- Emergency and emergency relief.
- Lifts.

- SERVICE UTILITIES
  - medical gas center;
  - thermal conditioning and air treatment plants;
  - pneumatic and vacuum pumping stations;
  - warehouse and workshop;
  - biological and sewage services;
  - Chemist;
  - technical and administrative offices
  - specialized departments (large burns, plastic surgery, neurology, gynecology, pediatrics, nephrology, etc ...);
  - hospital wards, day hospital, medical clinics;
  - Clinical analysis laboratories (withdrawals, dialysis, etc ...);
  - Fire extinguishers and elevators.

Considering the parameters and magnitudes of the system, medical utilities and essential services differ from most of the general services in order to demand higher reliability and continuity of service, both in normal and emergency situations.

In this sense, the power system must be subdivided into two distinct subsystems, except for the possibility of local conjunctions to be implemented in special cases.

One of the parameter to be monitored is the electrical power (active power) demanded by the network operator, which obviously varies with the architectural dimensions of the hospital complex, with the number and extension of the halls that compose it and with the availability of services. A nearly constant value is the percentage ratio between the whole absorbed electric power (P_{abs}) and the whole installed electric power (P_{ins}). In peak hours, from 5am to 3pm on non-holidays, we have:

$$\eta_{peak}\% = \frac{P_{abs.}}{P_{inst.}} \cdot 100 = 20\% \quad (1)$$

In periods of lesser activity, we have:

$$\eta_{less}\% = \frac{P_{abs.}}{P_{inst.}} \cdot 100 = (5 \div 9)\%. \quad (2)$$

From an electrical point of view, energy consumption is higher in the summer due mainly to cold generation for the air conditioning system.

III. Hospital Electric Distribution Network

Electricity supply by the Network Operator usually occurs at medium voltage (MV). A complex hospital system is equipped with MV/lv transformation cabins connected to each other via an internal MV network. The MV link line can be arranged with a radial or open loop system. In each derived cabin, the medium voltage electrical panels are equally arranged in the in-out configuration. The busbars of these frames are connected to the transformer feeders with the general disconnector and the MV shutters of the individual transformers. Both essential users and normal users are powered by every cabin. The complexity of the hospital electrical system therefore suggests the application of rigorous methods of analysis typical of HV electrical networks

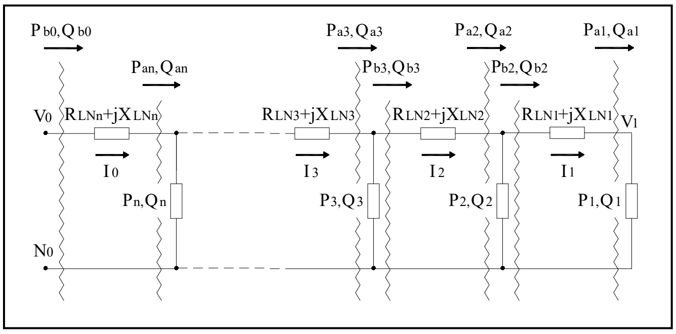

Fig. 2 – Layout of power of loads.

as may be the methods of AC load current. The results obtained can give us important information regarding the management and maintenance of the system.

A typical network architecture is shown in Fig. 1, to which the proposed analysis method [13] is based on the load flow analysis by applying the Boucherot theorem. The method assumes the knowledge of the electrical loads in terms of active and reactive power in the network load nodes referring to the rated voltage V_n.

In practice, each power busbar, both for horizontal tunnels in the technical tunnel and for vertical pathways in the pipeline, can be seen as a power line powered by an end with loads that can be applied to all known methods for network analysis in addition to the load flow method with the use of the Boucherot theorem.

IV. LOAD FLOW METHOD APPLICATION

Starting from the classification of electrical loads it's possible to derive an approach method to the design of hospital electrical systems. In order to ensure the correct distribution of active and reactive powers and a real balance in terms of investment and operating costs the topological network definition and load flow calculations are considered.

For the calculation, we make the following assumptions:

- fix the voltage at the node of the power supply bar: $V_{0,Fix}$;
- V_n is the nominal voltage of the loads and of the grid;
- the voltage amplitude on the last load is $V_1 = V_n$ and the phase angle $\varphi_{a1} = 0$, then $V_1 = 1$ p.u.;
- the line parameters R_{LNi} and X_{LNi} are constant;
- the relationship that links the power of the loads to the supply voltage is known and is equal to:

$$P_i = f_P(V); \qquad Q_i = f_Q(V). \tag{3}$$

Referring to Fig. 2 and starting from the powers P_{a1} and Q_{a1} upstream of the last load, equal to its rated powers P_{1n} and Q_{1n}, it's possible to calculate the downstream powers of the load n. 2, which is immediately previous:

$$P_{b2} = P_{a1} + R_{LN1} I_{b1}^2; \qquad Q_{b2} = Q_{a1} + X_{LN1} I_{b1}^2; \tag{4}$$

where $I_{a1} = I_{b2} = I_1$. Then it's possible to determine the voltage of the user n. 2:

$$V_2 = \frac{P_{b2}}{I_{b2}} \cos\left(\arctan\left(\frac{Q_{b2}}{P_{b2}} \right) \right) \tag{5}$$

Now, it is possible to calculate the powers actually taken by the load n. 2, depending on voltage V2:

$$P_2' = f_P(V_2); \qquad Q_2' = f_Q(V_2) \tag{6}$$

and, if load n. 2 is linear, we obtain:

$$P_2' = P_2 \left(\frac{V_2}{V_n} \right)^2; \quad Q_2' = Q_2 \left(\frac{V_2}{V_n} \right)^2 \tag{7}$$

Finally, we calculate the powers upstream of load n. 2:

$$P_{a2} = P_{b2} + P_2'; \qquad Q_{a2} = Q_{b2} + Q_2'; \tag{8}$$

Now it is possible to calculate the currents and, subsequently, the voltages on the loads. The procedure is repeated for all users upstream of n. 2, to determine the voltage profile of the entire network and finally the voltage $V_{0,Calc}$ of the supply busbar, which in general is different from the assigned value $V_{0,Fix}$. The solution in function of $V_{0,Fix}$ or any other desired value, it's calculated by an iterative procedure by imposing this constraint between the terminal load voltage and the supply busbar:

$$V_1^{(j)} = V_{0,Fix} - \left(V_{0,Calc} - V_1^{(j-1)} \right) \tag{9}$$

In addition to the voltage profile at the nodes of the network, this process also provides the load flow and network losses.

If the network is completely linear, the voltage profile can also be calculated by multiplying the values obtained from the first calculation for the $V_{0,Fix} / V_{0,Calc}$.

Actual desing softwares are sufficient to perform the calculations described. The presented method is easily extensible to three-phase, neutral and neutral loads with balanced and unbalanced loads.

V. APPLICATION EXAMPLE

The radial architecture of a complex hospital electrical power system is generally carried out with main upright electrical lines made of cable or electrified busbars from which the electrical loads of floor or department are distributed. Each of this mail lines can be seen as a constant section electric power line that is powered by one side and with electrical loads that in terms of active and reactive power absorption. This configuration is valid both for power users under normal power section and for power users under a essential power section with generator power supply or absolute continuity through static or rotary systems. For systems of this type, the method outlined in [13] provides significant results for the proper dimensioning of lines and for Power Quality.

As an application example, Fig. 3 shows a simplification of a upright main power line representing several floor units present on 8 levels and Table I shows the active and reactive power values and the voltage module in p.u. referring to the respective base power values of apparent power $A_b = 100$ kVA and voltage $V_b = V_N = 400$ V.

On the sixth floor (terrace) there are conditioning groups, while the lower floors from 5th to 1st are departments and hospital stays and from floor 0 to floor -1 are clinics and laboratories. The simplified example clearly does not identify the whole floor.

TABLE I. ACTIVE POWER, REACTIVE POWER AND VOLTAGES IN P.U.

n.	Busbar "Sezione Normale" 1250 A $S_F = S_N$					
	Floor	***L to Node N.(n-1)***	***Rated P (p.u.)***	***Rated Q (p.u.)***	***Voltage (p.u.)***	***Actual P (p.u.)***
1	6°	45	2,200	0,780	1,007	2,212
2	5°	40	0,700	0,240	1,0	0,708
3	4°	35	0,800	0,320	1,009	0,812
4	3°	30	0,800	0,280	1,015	0,823
5	2°	25	0,700	0,240	1,012	0,740
6	1°	20	0,600	0,170	1,012	0,618
7	0	15	0,800	0,180	1,015	0,825
8	-1	10	0,500	0,210	1,018	0,533
Total Values			7,100	2,180		7,271
Total Loss Active Power = +0,198 p.u. (P_{losses} =1,41 % $P_{tot.}$)				**Load Power excess +0,171p.u. (Plosses =0,98 % Ptot.)**		

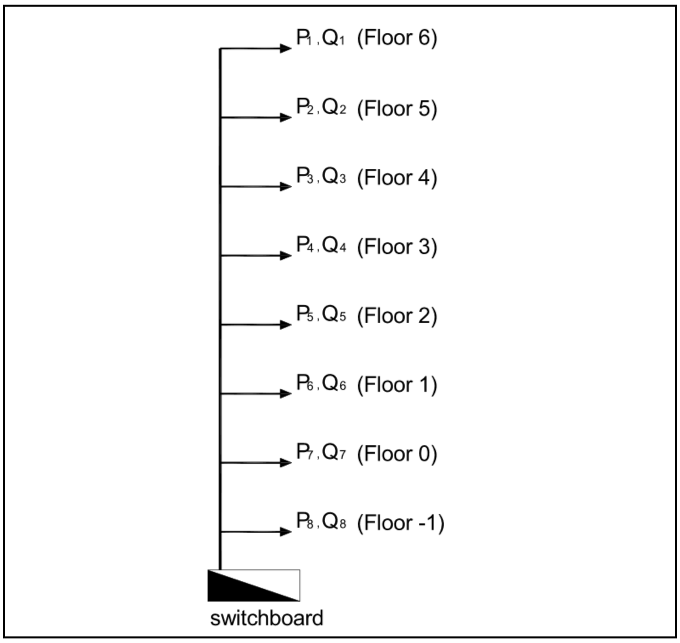

Fig. 3 -Main distribution in hospital departments

VI. CONCLUSION

The calculation method proposed in this paper provides the values of many important power network parameters, in addition to the voltages profile comparable to the results obtained with other known and widely tested methods. It is therefore possible to evaluate different project design solutions in different features, or possible improvements to existing electric networks. The simpleness of the calculations required in the application of the proposed method allows for a flexible tool to evaluate the effects of energy saving strategies based on the choice of conductor choices that are used to ensure greater regularity of the load voltage profile, or on reactive power compensation. Finally, it is possible to easily extend the proposed method to the case of nonlinear loads by defining experimentally the functions $P(V)$ and $Q(V)$, which serve to describe sufficiently approximate the load behavior at the variation of the voltage.

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