Use of new technologies for air pollutionless public city transportation systems based on electrical drives

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Abstract – **In the paper is presented the research program that a network of 4 Italian Universities (Naples, Cassino, Milan and Padova) are doing within a project supported by the Italian Ministry of University and Research. The project is focused on innovative devices for electrical energy storage and generation, like fuel cells and supercapacitors: their high availability suggests to examine the possibility of their use for fixed trial means of transportation. This use seems to be, actually, suitable for city transportation, because of repeated tracks, of the existence of fleets, of the possibility to recover at the end of the task. Dealing with experimental application, this purpose can, moreover, bear the high initial costs, because they are paid by the collectivity that is not only the user of the service, but also the indirect beneficiary of the ecological and environmental advantages connected with the use of components that have no environmental impact.**

1. Introduction

The last decades scientific, technical and technological evolution in the field of electro-chemistry gave rise to new generations of static devices for generating and storing electrical energy. They enable us to obtain fully pollutionless means of transportation. Their use in practical applications is, however, limited by manufacturing costs, that are relatively expensive, so that we can not expect that single citizens support these costs, also due to the uncertainty of the life and of the maintenance of these devices. City public transportation systems can, on the contrary, benefit of the discoveries, because the costs are shared by ratepayers. Besides, they represent an ideal training ground, because they are fully air pollutionless, because they operate by means of fleets along repetitive journeys that facilitate the location of either recharging or supporting points, because they take shelders. We expect that costs will decrease with the widespread use of standardized devices fostered by knowledge improvement. Some prototypical applications of these new devices have been already made to individual and to public means of transportation. It is now possible that new technologies shall be applied to fixed trial systems of transportations to let them operate also autonomously for short lineless journey stretches.

Until now we have only overall information about the behaviour of systems including fuel cells and supercapacitors. Therefore, the knowledge does not allow to properly design these systems according to the performances required by loads. It seems that they both need always the use of auxiliary power electronic devices, because their output voltages change with the electrical power delivered. Also by using cunning devices the on board electrical network

supplies electrical drives with variable dc voltages when it operates lineless. The practical application of the above mentioned new technologies to city public transportation systems, hence, also require proper control techniques for traction and auxiliary electrical drives and services. Such systems can be schematically represented by the block diagram of the figure 1.

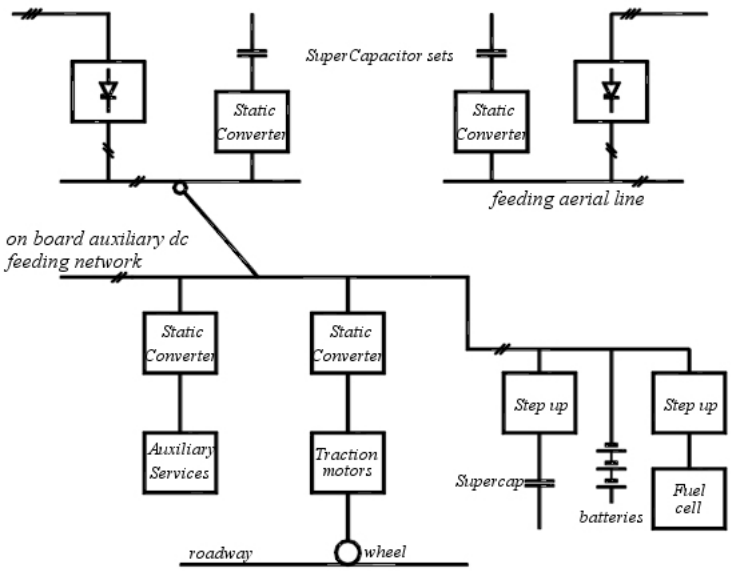

Fig. 1. City transport system scheme

The aerial line can also be not continuous to satisfy environmental conditions. The rectifying points can be located also very far one from another. The means of transportation are fed directly by the aerial line, but they must operate also lineless. For this reason they have an on board auxiliary dc network, fed by auxiliary electrical energy sources. The different energy sources, actually available, obtain different performances of the means of transportation. It is always possible to select the more profitable one according to the traction performances required. The goal of the researchers, in this case, is the evaluation of the designing guidelines that give rise to "optimised" solutions by means of specific analytical relationships among source weight and rating and load requirements and by means of proper control techniques.

Four research groups (University of Naples, Cassino, Milan and Padova) are involved in a research project, supported by the Italian Ministry of University and Research, according to their own qualification and their previous experiences. The research project is focused on innovative new technologies for air pollutionless public city transportation systems based on electrical drives. In the following sections of the paper the research programme is outlined.

2. City transportation systems based on electrical drives: a research project on innovative technologies

Nowadays, it is to be expected that components of innovative technology, like fuel cells and supercapacitors, could be used as electrical energy auxiliary sources to ensure self-motion to guided running means of transportation which crosses limited "protected" areas, where it is not possible to feed them by aerial networks. Supercapacitors can be used also to supply, with adequate voltage levels, means moving far from transformation stations. In any case, traction electrical drives are supplied by weak electrical networks, that are not capable to ensure constant voltage.

From a scientific research point of view, the use of the above mentioned innovative components suggests, therefore, the immediate solution of the following problems:

i. individuation of typical tracks for self moving of autonomous means of urban transportation;
ii. analysis of working conditions and behaviours of innovative technology components and advantages of their use in parallel connection with traditional electrical energy storage systems;
iii. behaviour of traction drives supplied by not stiff electrical networks;
iv. determination of designing guidelines consisting in the choice of rating characteristics of the components, parallel connected, used for electrical energy storage and generation.

The above listed aspects are analysed by means of a research project entitled "*Use of new technologies for air pollutionless public city transportation systems based on electrical drives"* [1] which program can be considered as constituted by different phases each one having its own objective. The final objective of the research can be reached by completing the working phases through the intermediate objectives proper of the different phases.

After a preliminary analysis of the state of the art, should be considered, first of all, a reference "typical stretch" for self-moving action that could be assumed as the most significant for a general validation of the research results. Then will be defined circuital configurations, containing innovative devices, that could potentially better satisfy the requirements of a self-moving action in a "typical stretch". The evaluation of a reference typical stretch for self-moving action of an urban transportation mean and of the corresponding more proper electrical network structures must include new pollutionless devices.

In this phase the research activity will be devoted to the definition of designing guidelines of on board and of boostering feeding aerial lines auxiliary electrical systems for city transportation means, that benefit of new technical solutions for accomplishing their ways which include also short lineless stretches.

The block scheme in Fig. 2 represents the objects of the specific research activity, as proposed in the [1] that will be developed by the research groups of Cassino, Milan, Naples and Padova.

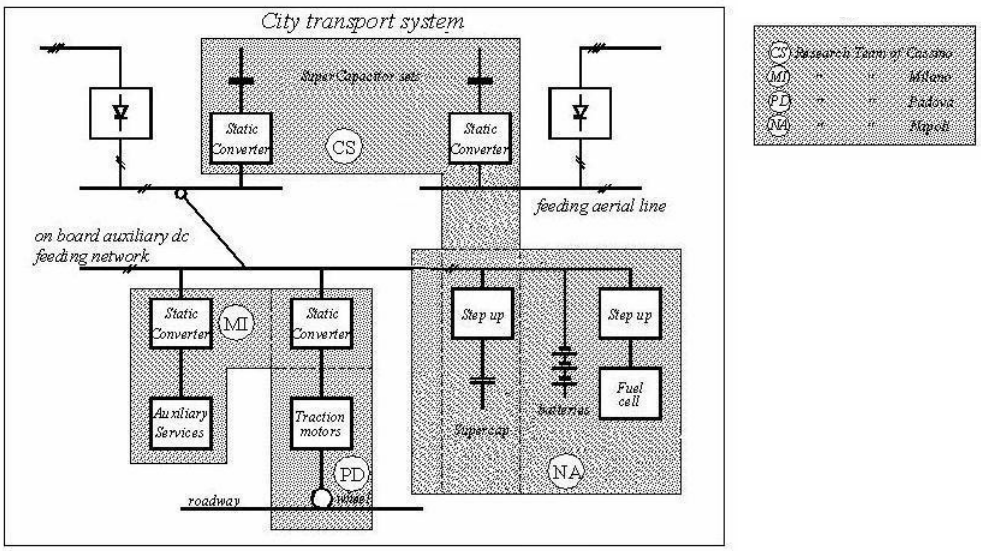

Fig. 2. The analysed transport system: research teams' activity and objectives

Boostering feeding aerial lines auxiliary electrical systems are represented by energy boost stations which are placed in critical points of the network, such as end or peripheral stations. These energy boost stations are normally made by accumulators. In the research project, it is proposed to substitute the standard electric accumulators with supercapacitors. The power circuit will be then simulated, designed, implemented and tested. Besides, the overall system efficiency will be improved by optimising the modulation strategy for the power modules commutations and by modifying the circuit in order to adopt a resonant topology. Tests in anechoic chamber will be also performed to set-up a proper power circuit layout in terms of EMC compliances.

The problem of designing the super capacitor banks and to test the suitable power electronic equipment for a particular application will be considered. In fact, the whole electric vehicle feeding system strongly depends on the particular operating condition in which the vehicle works and, also, on the particular run of the electric vehicle. In the designing stage, it would be really useful to have a suitable tool, which allows performing a preliminary test analysis to achieve:

- -correct dimension of the super capacitor bank related to the actual vehicle runs;
- -drive motors and power modules size;
- -control or communication errors-free set-up of the drive;
- -safety checks.

This mentioned test tool will be realized by means of an “hardware in the loop simulator”, which is a real time equipment able to create a “virtual” copy of part of the process in a software environment, by taking into account the actual dynamics of all the parts which compose the controlled process. In this way, the results of the tests achieved in all the possible operating and fault conditions make possible also a realistic analysis for the safety and reliability assessment of the design process.

Regarding the propulsion system, the research activity will mainly concentrate on the identification and analysis of electric motors and drives to be used as means of propulsion in rubber-tyred systems with guided running mode, taking into account not only the present supplies, but also the new on board energy sources expectably available in short/medium times (for example, the fuel cells). While selecting the motor for traction applications, some items need to be considered as high efficiency, flexibility of use in different load conditions, high starting torque, low cost per unit power, regenerative braking, field weakening, ruggedness, manufacturability and little maintenance, ease of control.

The types of motors usually taken in consideration for the described applications are the three-phase induction motor and the PM synchronous motor. In addition, the proposed research intends to analyse and evaluate also other configurations that could have some favourable characteristics: the switched reluctance motor, the DC brushless motor and the in-wheel axial-flux motors. A specific objective is therefore to define configurations of the propulsion apparatus in function of the type of supply in order to get the best performance of the entire system.

For each motor configuration under investigation, a detailed electromagnetic analysis will be performed; the aim is to define a mathematical model that makes possible the detailed evaluation of the interactions of the motor with the supply system and the converter. The analysis will take into account several aspects, in particular the required number of electrical motors to assure the propulsion and their location on the vehicle, the utilization of electrical motors bearing in mind also the possibility of hybrid systems, the definition and choice of the drive, the choice of the control strategy more suitable in order to optimise the efficiency of the propulsion system in connection with the energy sources.

The research will be devoted also to proper static converter systems for traction drives. To set up the static conversion system is necessary to analyse the subsystems that constitute the typical configurations adopted in case that fuel cells or electrochemical batteries are utilised. Such subsystems generally are the DC/DC converter, the motor supply power converter (three-phase inverter for AC motors, bridge converters or converters with other topologies for brushless DC motors for switched–reluctance motors), other possible converters for auxiliaries supply.

The converter preliminary design and the implementation of a mathematical model for the simulation of its behaviour will be completed through the following steps:

- preliminary design of the converter including the identification of the power devices, of the control strategy and of the switching technique;
- implementation of a mathematical model of the converter to simulate its dynamic behaviour under different operative and fault conditions both on the supply side and on the load side.

Implementation of basic knowledge on:

- proper hardware/software structures for short stretches lineless transportation means and for boostering stations;
- electrical power converters needed by new devices (step-up, step-down dc/ac);
- proper power train structures (traction motor and drives, supplying static converters);
- proper software for hierarchized and harmonized control of integrated system including fuel cells, supercapacitors and different types of traditional electrochemical batteries;
- evaluation of designing guidelines consisting in simple relationships among electrical circuit configurations, powers, weights and dimensions of electrical electrochemical and electronic power devices, self-moving stretch length;
- development and construction of scale models;
- comparison among different technical solutions individuated and validation by means of experimental tests.

The aim of the research is the evaluation of the performances of interconnected systems of new supply and storage devices in the field of city transportations means.

It is known that different environmental considerations lead to avoid the use of aerial supplying networks along short running stretches. In these regions it is required that transportation means could be capable of self-moving. Electrochemical batteries have been until now used to satisfy this requirement. The increase of auxiliary service power, needed today to improve passengers' comfort, implies that weights and dimensions of traditional electrical energy storage systems become too large, so that alternative solutions must be dealt with, also to avoid the use of pollutioning products. Fuel cells and supercapacitors appear to offer a very satisfactory solution to incoming practical problems, because they have higher electrical power density than electrochemical batteries. Besides, they do not give rise at all to pollution. Their use has been not yet fully experimented and tested, particularly with reference to their behavior when they operate together connected in parallel. The auxiliary electrical networks obtained by means of these new devices are weak. Traction drives must, hence, operate with no-constant voltage.

3. Performance analysis and designing guidelines for matched storage and generator systems of electrical energy

Air pollutionless city public transportation systems can benefit, nowadays, of two possible new solutions: the former one implies on board electrical energy sources, the latter one

implies on board storage systems. Both feeding systems can be used either alone or all together. Both solutions offer new chances to fixed trial systems and let them to cover short journey stretches "autonomously", i.e. aside from their customary supplying aerial line. Electrical energy required during short lineless stretches is needed to drive the transport means and to cover on board auxiliary services. This energy has been given until now only by traditional electrochemical batteries. Fuel cells and ultracapacitors offer the same amount of energy with reduced weights of on board devices. Therefore, they represent an attractive alternative to traditional batteries. The state of the art in the knowledge of the behaviour of these new feeding systems is very poor at the present. Some experiments have been made and some theoretical considerations have been carried out. Poor is the actual experience in relationship with the behaviour of electric circuits including "alternative" energy sources, i.e. fuel cells and ultracapacitors. It is, however, already known that it is difficult to achieve industrially useful voltage values by means of fuel cells, because their elements develop very low electric powers. Therefore, sets of cells are required with series or parallel connection. Moreover, it seems that battery or ultracapacitor packs should be connected in parallel to fuel cell systems either to cover energy request during fuel cells starting time or to work like a voltage stabilizer for the load. The research team of University of Naples has just experimentally verified that a parallel connection of electrochemical batteries and ultracapacitors does not obtain satisfactory operation of the last one [2]. A theoretical contribution to new devices selection criteria has been also given by paper [3], where some reference quantities are defined for on board storage systems of electrical or mechanical energy. As a conclusion it seems that either fuel cell system or ultracapacitors have to be equipped with auxiliary power electronic devices, because they are very variable voltage energy sources.

It is then clear that one of the main aspects of the research regards the storage and generation of electrical energy. In this sense the aim of the research is the analysis of different circuital solutions capable, by adopting proper innovative storage and generation systems, to let that city transportation systems cover lineless short journey stretches. Reference is made to the use of fuel cells, ultracapacitors and traditional electrochemical batteries. By means of these devices different circuital configuration are, indeed, actually, possible according to the main block diagram of fig. 3.

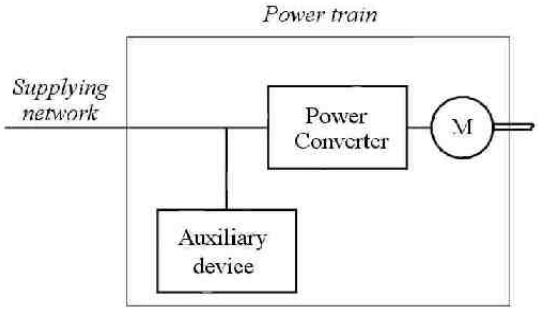

Fig. 3 Main Block diagram of air pollutionless power traction system for urban means of transportation

According to theoretical and experimental results of previous researches made by other authors and by ourselves, the following listed arrangements of auxiliary supplying devices are worthy to be taken into account today:

- traditional electrochemical batteries, alone;
- fuel cells with auxiliary traditional electrochemical batteries;

- fuel cells with ultracapacitors and with or without auxiliary traditional electrochemical batteries;
- ultracapacitors with or without auxiliary traditional electrochemical batteries;

The goal of the research is to carry out designing guidelines for the above mentioned structures of auxiliary devices. Designing guidelines consist on analytical relationships among journey stretch length, means of transportation performances and weights and rating of auxiliary supplying devices. Theoretical analysis will benefit of our previous results on the subject-matter [2, 3, 4, 5, 6] and it will be also based on a set of experimental results obtained by a scale model. Its configuration is shown in fig. 4. The scale model will be designed to give chance to analyse the behaviour of the on board traction system with different contribution of different auxiliary sources of electrical energy. It will offer also the chance to experimentally verify some different control techniques, their harmonic cooperation and the hierarchised operating conditions of the devices at each time involved.

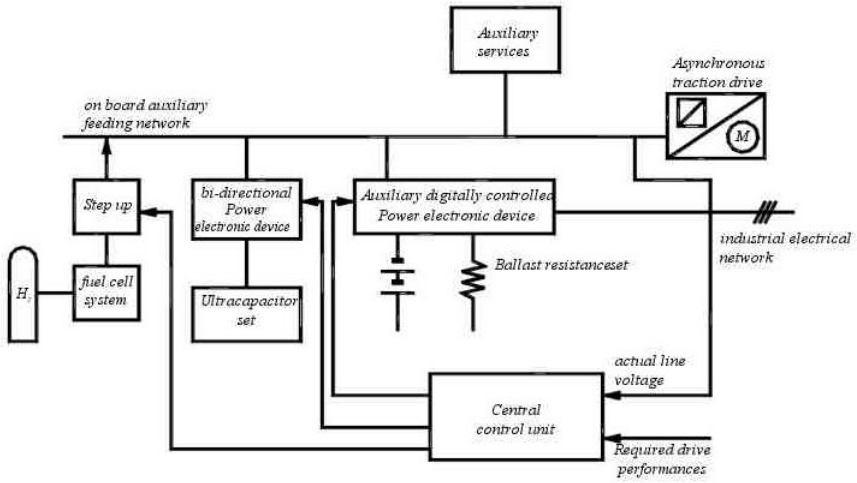

Fig. 4 Block diagram of the scale model for experimental analysis of different structures of auxiliary devices

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4. Conclusions

The research programme of the Project “Use of new technologies for air pollutionless public city transportation systems based on electrical drives” has been outlined in the paper. The project is supported by the Italian Ministry of The University and Research and is done by a network of 4 Universities research teams (Nalpes, Cassino, Milan and Padova).

The project concerns the whole transport system, including the feeding line and traction and auxiliary drives (motor and static converter), but is particularly focused on innovative devices for electrical energy storage and generation, like fuel cells and supercapacitors, their use for fixed trial means of transportation has been examined. This use seems to be, actually, suitable for city transportation, because of repeated tracks, of the existence of fleets, of the possibility to recover at the end of the task. Different circuital solutions and possible experimental application are proposed, which can bear the high initial costs, because they are paid by the collectivity that is not only the user of the service, but also the indirect beneficiary of the

ecological and environmental advantages connected with the use of components that have no environmental impact.

5. Acknowledgment

The research project presented in the paper received the granting support by the Italian Ministry MIUR (Ministero dell'Istruzione dell'Università e della Ricerca) within the PRIN (Progetti di Ricerca di Interesse Nazionale) framework.

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