New generation of mobile electrical power sources

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Abstract

Constant speed mobile electrical power sources (MEPS) with combustion engines driving brushless field excited synchronous generators will be soon replaced by optimally controlled variable speed diesel engine, driving robust permanent magnet generator (PMG) equiped with power electronics frequency and voltage control. The paper gives short revue of some problems in research and development of 3rd generation MEPS.

Keywords: power sources, mobile, variable speed.

1 INTRODUCTION

Mobile Electrical Power Sources (MEPS), initially developed and produced mainly for military purposes, gradually found their use as power supplies for various machines and appliances to increase their mobility, in mobile workshops, lighting systems, in communication and control systems. MEPS enable the independence on the common electrical power network and create an essential part of Uninterruptible Power Sources (UPS). They are used in building industry, in agriculture, in ground and air transport, in health service and in other branches of industry and economy. Quite indispensable are the MEPS in civil defence, crisis management forces, and naturaly in armed and security forces.

Sophisticated weapon systems, including aircraft and air defence, artillery systems, transport means, logistical structure and training systems based on computer simulation and virtual reality concepts require also modern and reliable MEPS, corresponding to new conditions and requirements.

Mobile electrical power sources (MEPS) of the 2nd generation, based on improved classical engine - generator sets, are gradually introduced in the course of last two decades. These MEPS are operating with constant speed corresponding to the required fixed frequency (50, 60 or 400 Hz). The investigations of MEPS operation in last years have shown, that the majority of sets operate under low load which does not exceed more than 20 % of rated permanent load. In these conditions both the engine and generator operate with low efficiency, affecting unfavourably the polution and fuel consumption.

Contemporary trends of future development in this field show, that the 3rd generation of MEPS will be based on some new technologies. [1], [3]. Constant speed sets with combustion engines driving brushless field excited synchronous generators will be soon replaced by optimally controlled variable speed diesel engine, driving robust permanent magnet generator (PMG) equipped with power electronics frequency and voltage control (so called variable speed technology - VST). For special purposes, as for example aircraft units and air defence systems, high speed gas turbine engines (50 000 RPM and more) with high speed PMG and corresponding power electronics are under the development.

The theoretical analysis, research, design and development of 3rd generation MEPS evokes many problems in the field of mechanical and electrical engineering, power electronics and mechatronics.

The main emphasis is given to the mutual cooperation of PMG with the power electronics frequency and voltage converter. Special design concepts of PMG are to be developed, including the dimensioning, calculation of main parameters and determination of characteristics suitable for power electronics converter control under the VST conditions.

2 CONCEPT OF VARIABLE SPEED MEPS

The analysis of MEPS operation regimes [3] has shown, that the average load, especially at the MEPS of higher output power used for general load, does not exceed 20 to 30 per cent of the rated permanent load, as shown in Fig. 1. The MEPS very often operate in idle run. In the course of operating time a number of MEPS operate in unoptimal run of both engine and generator, thus decreasing efficiency, increasing the fuel consumption and amount of harmful emissions. An optimal control of engine-generator set speed in the dependence on the instantaneous MEPS load can decrease the fuel consumption namely at low loads, as shown in Fig. 2. The engine speed of rotation is to be optimally controlled in such a way, as to adjust the operating regime for every load to the corresponding power output and torque.

Synchronous generators with permanent magnets are suitable for such an operating regime. They allow to reach a greater number of poles and thus also higher frequencies even at low speeds. They are sufficiently robust, compact and simple. Together with the driving engine the generator can create one compact unit with advantageous measures and mass relations. Low maintenance costs, higher reliability and longer service life can be also expected.

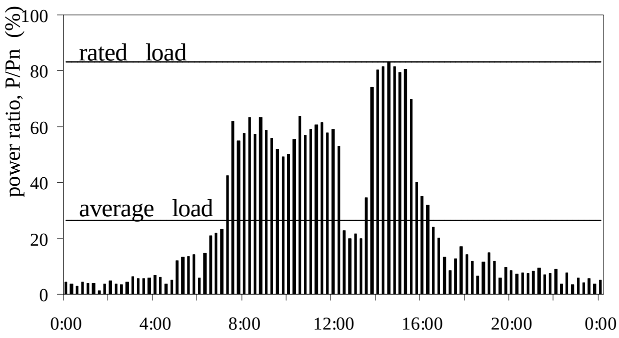

Fig. 1. The average load of MEPS

The generator output power with variable voltage and frequency proportional to the speed is then to be changed to the output power of the required controlled voltage and constant frequency. The structure of such an engine-generator-converter system is described in Fig.7.

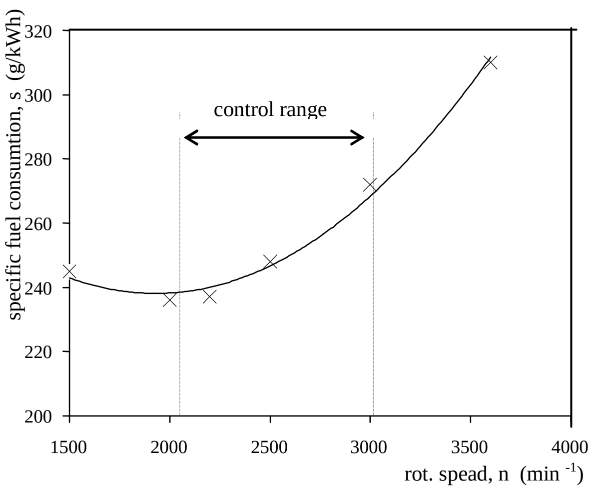

Fig. 2. The fuel consumption saving

Fig. 3. compares the classical MEPS concept (2. generation) with the variable speed PMG concept (3. generation) from the point of view of arrangement, size and corresponding weight.

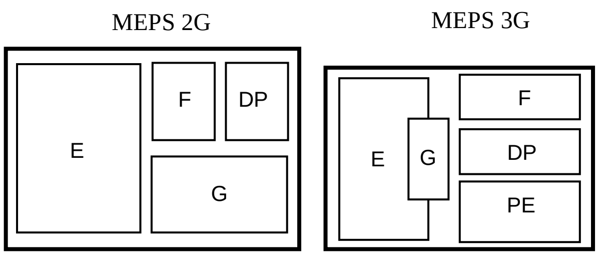

Fig. 3. The comparison of MEPS 2G and MEPS 3G
E - engine, F - fuel tank, G - generator, DP - distribution panel, PE - power electronics control

Smaller dimensions, lower weight, more compact design with suitable arrangement could be expected. On the other side the costs can slightly increase due to more expensive electronics.

3 THE DRIVING ENGINE

The up-to-date diesel engines are supposed to be used in the whole scale of power outputs according to the MEPS development trends. In the military use it means the unification of fuel, which is very important with respect to logistics.

Modern diesel engines are compact, fully capsuled driving units of high efficiency and reliability, low fuel consumption, decreased acoustic and infrared radiation and simple maintenance. They are able to fulfill highest requirements on the speed, torque and power control. The mechanical and electronic speed control in wide range matches the VST concept.

One of the serious problems is the dynamical behaviour of the driving engine – PMG unit in the case of sudden power output increase. For the low power output the engine decreases its speed automatically to the optimal low value (about 2000 r.p.m), corresponding to the optimal fuel consumption. When covering the required rated power output at low speed, the engine will have sufficient power reserve to overcome the sudden load increase, as can be seen in Fig. 4.

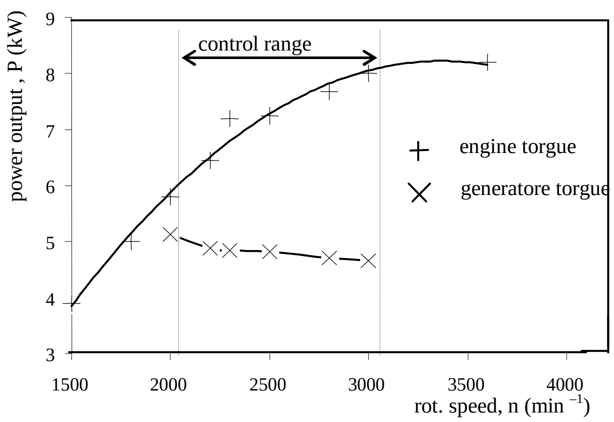

Fig. 4. The power reserve of the MEPS driving engine

The high speed gas turbine MEPS drives have the benefit of a considerable size and weight reduction. When compared with common diesel engine driven MEPS, the typical high speed 40 kW MEPS driven by gas turbine has the specific power output about 200 W/kg, while the classical 40 kW one, driven by diesel engine, yields only 20 W/kg.

4 THE GENERATOR

Synchronous generators with permanent magnets (PMG) operate without electromagnetic exciting system. They are of robust design, comparatively simple technology, can have a greater number of poles and high specific power output can be achieved. Due to the compact construction, high speeds can be reached.

The design of PMG substantially differs from that of the classical synchronous generator. The simplicity of the PMG enables the arrangement with an inner stator and an outer rotor replacing simultaneously the engine flywheel [2]. This topology enables the generator to be mechanically integrated into the engine to produce a compact and lightweight power unit.

The comparison of the engine-generator unit with common field excited brushless synchronous generator and with integrated PMG can be seen in Fig. 5a and Fig 5b.. The size and arrangement advantage of the PMG is clearly evident.

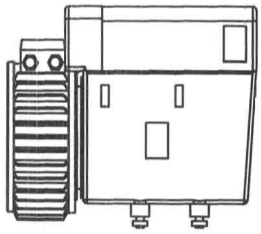

Fig. 5a. The engine – generator set with PMG

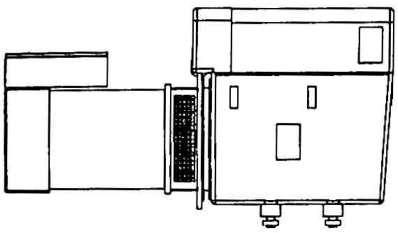

Fig. 5b. The engine-generator set with field excited SG

The construction and arrangement of a high speed (up to 100 000 r.p.m.) SGPM is quite different. To decrease the centrifugal forces and the moment of inertia, the generator is usually composed of several permanent magnets discs, moving in gaps of the stator armature winding. The depicted high speed PMG consists of 5 discs, each with 8 permanent magnets poles. On both sides of discs stator armature windings are placed. At 60 000 r.p.m, the output voltage frequency kHz is converted by means of frequency convrter to 50, 60, 400 or other required value. At the power output 50 kVA and mass 9 kg the specific power output of this PMG equals to 5,5 kVA/kg. Simplified diagram of a high speed generator driven by the gas turbine can be seen in Fig.6 [4].

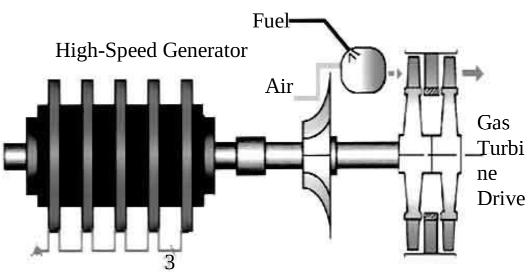

Fig. 6. The MEPS with high speed gas turbine driven PMG

5 POWER ELECTRONIC CONTROL

With respect to the variable speed of the driving engine dependent on the MEPS immediate load and taking into account that the voltage control of PMG by means of field (exciting) current is not possible, the voltage and frequency converter is to be used to get constant frequency and voltage at the MEPS output. The recent advent of inverters using the insulated gate bipolar transistors (IGBT) looks as a promising solution to the above mentioned problem. Frequency inverters based on IGBT, using pulse width modulation (PWM) techniques, eliminate the low frequency harmonics and the first harmonics appear around the switching frequency of the inverter.

Different types of inverters are used according to the MEPS system configuration and with respect to the MEPS use. Majority of MEPS will operate independently on the local network or to the weak autonomous power system without the requirement to the energy recuperation. For this case the power electronic system consisting of AC/DC converter interfaced to the frequency converter and corresponding filter with a suitable feedback to driving engine speed and power control can be successfully used.

Schematic diagram of the possible variant, suitable for variable speed MEPS with PMG, is schematically shown in Fig. 7.

The AC/DC converter, supplied from the PMG, controls the voltage to the required DC interface of the frequency converter. In the case of economic run of the MEPS, the decreased generator voltage will be adapted to the proper level to ensure the frequency converter operation. The change from the nominal to the economical run can be executed in one or more steps or continuously.

The function of AC/DC converter is apparent from Fig. 8. The converter starts its controlled operation at the input voltage corresponding to the generator output U_{Acmin} when increasing the output DC voltage to the required level $U_{DC.}$ The U_{DC} level can be adjusted according to the generator operating conditions in the control region from U_{Acmin} to U_{Acmax}.

The frequency converter can be adjusted to the required constant output frequencies (50, 60, 400 Hz) at the corresponding output voltage. The output voltage amplitude and course will be controlled by means of the output voltage evaluation unit. The unit will evaluate the three-phase information as to transform the amplitude of rotating vector of the output voltage.

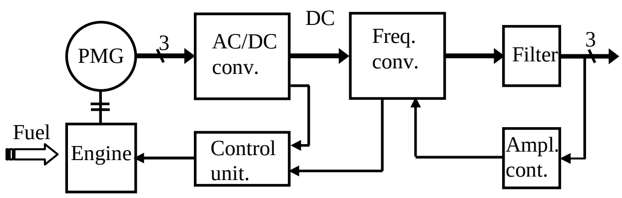

Fig. 7. Schematic diagram of the MEPS 3G

The speed of this evaluation must correspond to the possible changes and distortions of output voltage curve, caused by nonlinear, unbalanced and single phase loads, by supplied electrical machines and appliances.

The output passive filter will be designed for full load conditions. It might be useful to divide output power to filtered and unfiltered part with respect to the load character. This solution complicates the system structure of the power electronics part.

The control of the driving engine speed and power will be provided by means of the control unit evaluating information from both converters and MEPS output. This unit will control the servo-drive of the engine fuel input valve.

6 CONCLUSIONS

The MEPS variable speed technology in connection with the use of PMG, high speed turbine driven PMG and sofisticated power electronic voltage, frequency and power control opens a new age of mobile electrical power generating sets.

Not all above concepts will bring successful results and meet expectations of the output electrical power quality, manufacturing and performance economy, corresponding electromagnetic, acoustic, infrared radiation reduction and further increase of specific power/weight ratio, reliability and operability.

The authors of the paper are members of the research team, prepared to solve main problems of new technologies in MEPS 3G, to build the models of respective variants and to introduce positive results in practice.

Acknowledgement
The above research work is supported by the Grant Agency of Czech Republic (project No. 102/00/0917).

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