Dynamic System Modelling and Performance Optimization of a Distributed Generation Power Pack

Dr. Pericle Zanchetta, Dr. Mark Sumner, Dr. Nazar Al-Khayat & Christopher Hill, University of Nottingham; Cummins generators

The use of power electronics converters has led, in recent years, to a rapid improvement of the technology associated with AC power supply applications such as for uninterruptible power supplies (UPS), automatic voltage regulators (AVR), programmable AC sources (PACS), ground power units (GPU) for airplanes [1]. Among them Fixed and mobile distributed AC generators with a combustion engine prime mover are becoming more and more popular above all for applications in rural networks, micro grids, emergency power supplies and for example for use in conjunction with renewable energy sources to guarantee constant power [2].

When considering the design of these systems, the maximization of energy transfer ratio, reduction of power electronics conversion losses and size, minimization of fuel consumption and decrease of emissions are the main targets. Traditionally generator sets (gensets) include a prime mover fueled by diesel, natural gas or propane and a synchronous generator driven with constant speed that provides power at 50 Hz or 60Hz, depending on the application. With this configuration the prime mover will be run at a fixed specific regime no matter what the requirements of the load are. Operation at an average load lower than 30% of genset capacity would lead unnecessarily to high fuel consumption in relation to power output, engine oil dilution, carbon build-up or wet-stacking, cylinder glazing, reduced engine life and increased polluting emissions: not a good achievement in a world in which fuel cost and greenhouse effect represent some of the human community biggest problems. A load-adaptive variable speed technology has been recently made possible thanks to the advances in power electronics whereby a suitably designed AC to AC power electronic conversion stage converts the input variable amplitude and variable frequency voltage into a regulated fixed amplitude/frequency supply. This solution enables the correct sizing of the genset for the specific application, makes the system adaptable to any load and run its engine at the most economical speed for the instantaneous load. The power electronic conversion part therefore represents the key element for the optimization of the genset system, and its operation for a variety of applications, in term of efficiency, size and performance. To even further improve the performance of variable speed systems, together with the power electronics stage, an optimization of the control design and the engine/generator performance is instrumental.

To maximize the system energy transfer ratio, great attention needs to be given also to the efficiency of the power electronics conditioning stage to reduce losses in switching and passive filtering devices, to optimise the conversion structure in terms of size, cost and number of power devices, but still exploiting the conversion performance. As a further consideration, the output quality of the voltage and power may be of paramount importance to sensitive applications, for example computer based devices, test and measuring instruments, communication and security systems. The reduction of output voltage distortion, when feeding linear or distorting loads, and the transient behavior associated with a load "connection – disconnection" are challenging issues which need the development of advanced, optimized system and power electronic control schemes. Therefore the investigation of accurate modeling and optimization of all the abovementioned aspects of such systems is of fundamental importance for an effective and efficient design prior to implementation.

Different levels of detail in the genset model development have been considered according to the specific target of the optimization, in function of the dynamics of the single parts.

Modeling of the power electronic system at a physical power device level for conversion structure, switching losses, PWM modulation, power quality and filter design optimization. Three possible circuital solutions have been taken into account for final evaluation;

Permanent Magnet generator accurate modeling for design and efficiency optimization;

Average modeling of the power generation and conditioning system for steady state and dynamic control performance optimization;

Model of the diesel generator;

Power flow modeling of the entire genset for overall fuel consumption control optimization on the basis of specific test load profiles.

An original dedicated optimization routine has been developed using a heuristic approach based on genetic algorithms technique and it has been successfully used for optimization of simulation models in cases 1,2 and 3. Experimental validation of optimized design for the best performing conversion structures, as in case 1, is on-going in the University of Nottingham laboratories. After completion of simulation model optimization of case 5, experimental validation of design of the single parts and of the overall system will be carried out in relevant environment for final prototyping.

Current state-of-the-art applications of variable speed genset systems have demonstrated a fuel saving of more than 25%. It is anticipated that knowledge gained from this work could potentially improve fuel saving by a further 4 – 5%.