AUTOMOTIVE ELECTRIC SYSTEM CHARACTERIZATION AND DEVELOPMENT OF A SOFT START CONVERTER FOR THE ELECTRIC FAN OF THE REFRIGERATION SYSTEM

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Abstract – **Over the past years, Power Electronics has spread substantially within different application fields. This paper presents the development of two applications of Power Electronics in the Automotive Electric Systems. These applications consist of: characterization, simulation, evaluation of a popular vehicle's electrical system and the development of a pulse-width modulated converter for the soft start of the electrical fan of the combustion engine's refrigeration system. Automation tools for electronic projects were used in the development of such applications - Electronic Design Automation – EDA, which made possible the optimization of the project development time. This set of applications confirms the current tendency of new technology incorporation in the automotive systems environment, such as: 42 V electrical systems, traction control, assisted guiding, navigation, etc.**

KEYWORDS

Automotive Electric System, Electric Fan Control.

I. INTRODUCTION

Due to the increasing load demands and growing use of electronic systems in automotive applications, a strategic review of the automotive electric system and power supplies was made necessary. Its goal is to promote high efficiency both for the optimization of battery power and reduction of the power dissipated.

To be able to quantitatively evaluate the static and dynamic performance of the many automotive sub-systems, a complete simulation of all system components is necessary. This often became an obstacle due to the lack of library resources of CAD softwares for electronics. One of the goals of this project is to develop such inexistent models, using the hardware description language for analog device (HDL-A) [1]. First of all an alternator model was developed so its behavior could be evaluated in face of increasing vehicle loads. Secondly, an engine cooling temperature model was also created for analysis of the Pulse Width Modulated - PWM converter behavior in electric-fan supply. This paper presents the simulated theoretical results, the validation of the models and the results of switched converter for the electric-fan supply.

II. CHARACTERIZATION, SIMULATION AND EVALUATION OF A POPULAR VEHICLE'S ELECTRICAL SYSTEM

A popular vehicle has the following basic characteristics: single source electrical system, which feeds all electrical loads in the vehicle and energy input through a generator axle started by the internal combustion engine. Its architecture consists of a generator, rectifier, voltage regulator, battery and electrical loads.

A variety of problems in the electrical system can normally be solved without the knowledge of the entire vehicle system, and generally that is justifiable. Vehicle project developers always face the challenge of dimensioning an adequate alternator – battery set to satisfy the vehicle's electrical power demand.

The classic method for solving these problems consists on the analysis of the electrical system itself, and its main steps are the following: independent analysis of the propulsion system, being alternator rotation per minute the only input for electrical system analysis; adequation of alternator and battery to the various load conditions and the adoption of a security margin on the specification. An advanced method consists of: electrical system's impact on total efficiency of fuel and emissions, demand increase of electrical power, dual voltage and demand supply analyzing the electrical and propulsion systems separately. A method for the analysis and evaluation of the automotive electrical system, which optimizes the dimensioning and minimizes the resources for field testing will be presented next. This method is based on a simulation tool which allows the evaluation of the electrical system for various course profile and demand conditions.

The initial phase for the characterization consisted on the dimensioning of the electrical system of a popular vehicle, using the classic method. The following steps were followed: theoretical study of the operation of the energy generation system, evolution analysis in terms of energy demand for automotive loads within the years and development of a program for the dimensioning of the alternator – battery set using the MatLab software, from Mathworks Inc. A description will be presented next.

The program has the objective of dimensioning the alternator from the necessary power demands, so the vehicle would function properly when all its loads are active. The vehicle loads can be divided in two categories: loads which are active continuously or for long periods of time and loads which are active for brief periods of time. The final results of the dimensioning program for the alternator are the maximum and minimum currents the alternator needs to supply the necessary power so the vehicle will function properly. The next phase of characterization consisted on the study of the electrical characteristics of the alternator, battery and loads of a popular vehicle with the following characteristics: FIAT PALIO 1.3 Fire ELX. The test bench is presented on Figure 1. The research adopted the following procedure: definition of alternator – battery – load set characteristic curve with voltage and current measurements generated by the alternator, voltage and current of battery and voltage and current of loads. During the measurements the most relevant loads were started in intervals of 30 seconds. The main results are presented next, on Figures 2 and 3. As it can be observed, the electric fan imposes a severe voltage drop to the electrical system, which compromises the functioning vehicle. It's important to point out that this problem aggravates when the vehicle is running on low gear, in a traffic jam, for example.

Figure 1: automotive test bench.

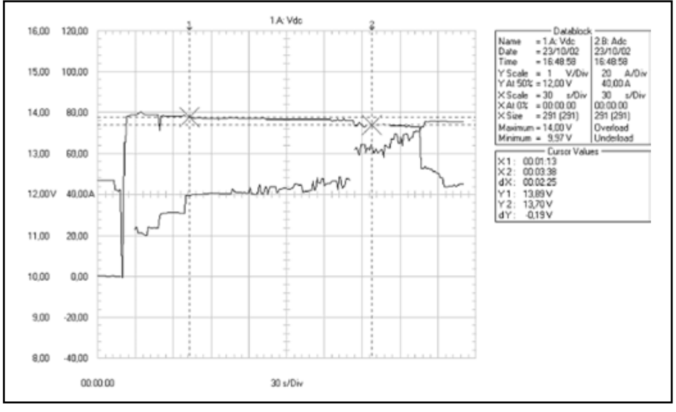

Figure 2: voltage and current in the output of the alternator.

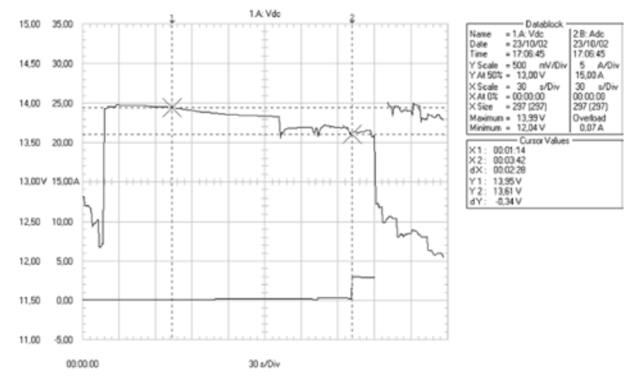

Figure 3: voltage and current on the electric fan.

After characterization, came the development of component models for the electrical system using Hardware Description Language – Analog, HDL-A, with the objective of optimizing the dimensioning of the automotive electrical system. For simulation, the flowchart and diagram presented on Figure 4 and 5 were developed. The simulation results are presented on Figure 6. On the alternator and regulator system results, the following wave forms are presented: output voltage signal of complete wave rectifier, current signal on alternator rotor, output voltage signal of half wave rectifier, rotation velocity of alternator axle (rad/s), output voltage signals of alternator (3 signals with phase difference of 120º).

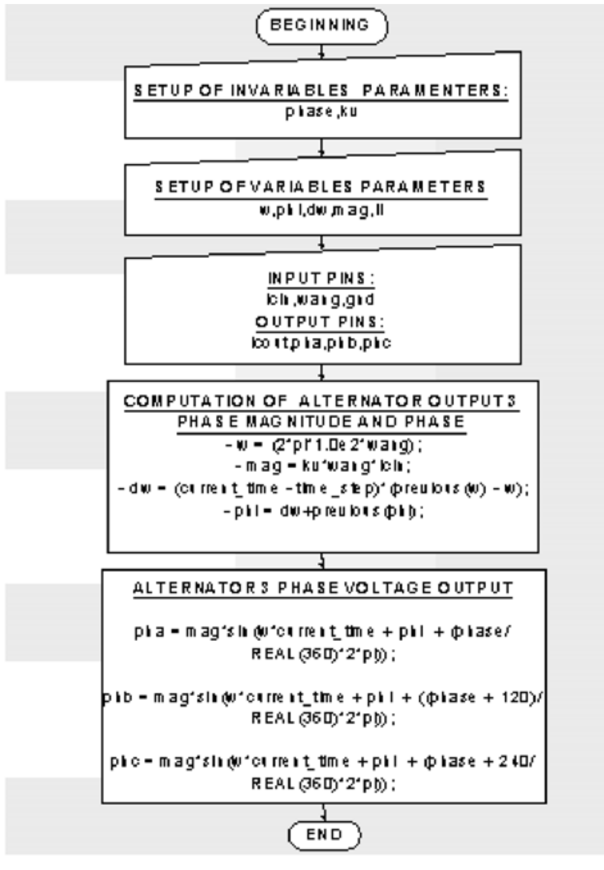

Figure 4: flowchart of alternator voltage output.

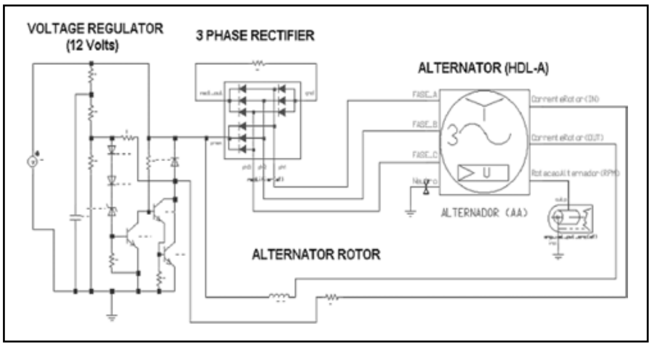

Figure 5: simulation diagram for the electrical system.

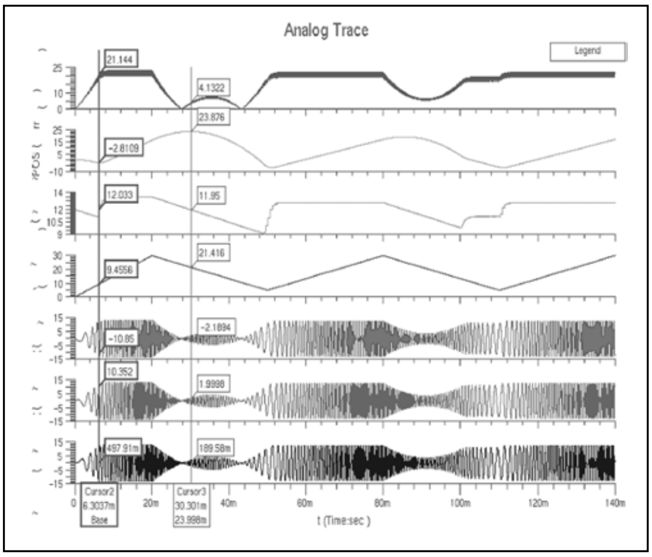

Figure 6: results of automotive electrical system simulation.

III. DEVELOPMENT OF A PWM CONVERTER FOR SOFT START OF THE ELECTRICAL FAN OF REFRIGERATION SYSTEM

Nowadays, the rotation speed control of the electrical fan is made through a thermostatic switch, which closes the circuit between the battery and the engine when the temperature reaches a certain value. Still, the electrical fan is a high power load and its start by a thermostatic switch provokes a sudden current elevation–high (di/dt)–affecting the energy distribution between loads that are being fed by the alternator – battery set. The model development, simulation and project of a switching converter for the soft start of the electrical fan of the refrigeration system will be presented next. The flowcharts of engine coolant model and of the control of the electric fan are presented in Figures 7 and 9. The representative circuit for the new feeding proposal for the electrical fan using a pulse width modulated converter is presented on Figure 8. The refrigeration system model generates the refrigerating liquid temperature, transforming this signal in electrical voltage through a thermocouple and subtracting the desired value (set-point). The resulting signal is a reference voltage that inputs the PWM, which sends pulses to the engine starting circuit, which is directly connected to the fan.

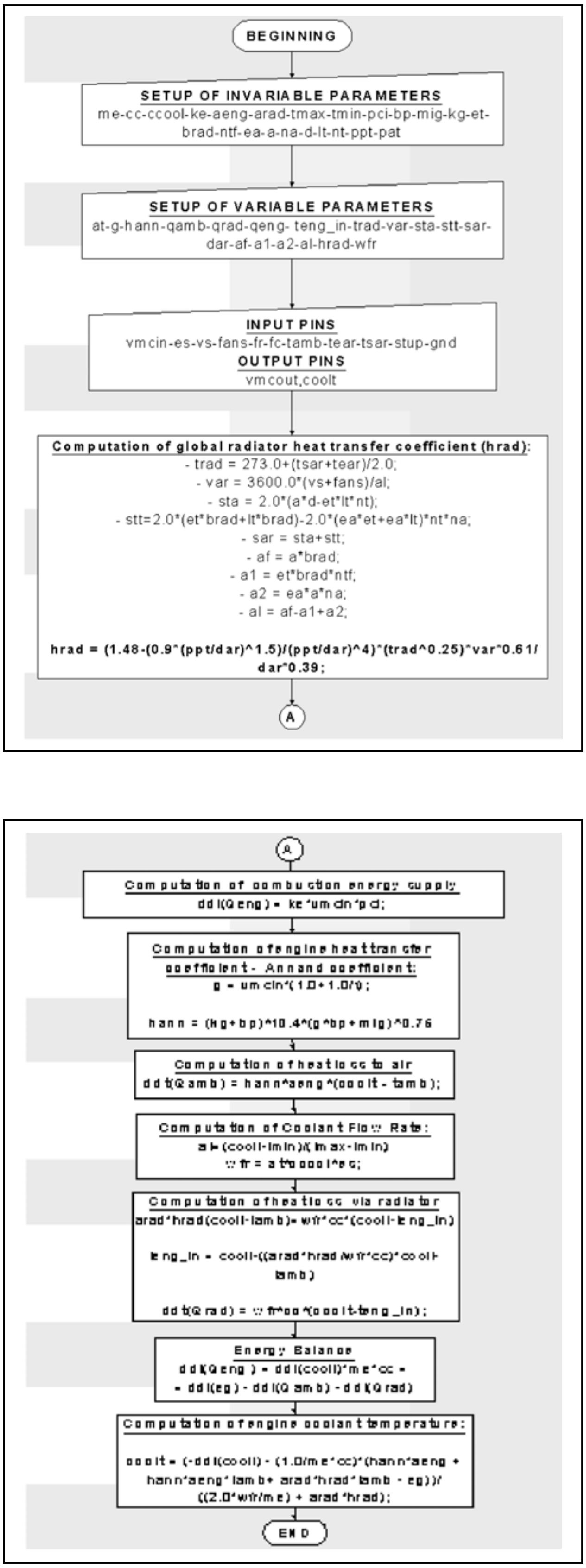

Figure 7: flowchart of engine coolant model.

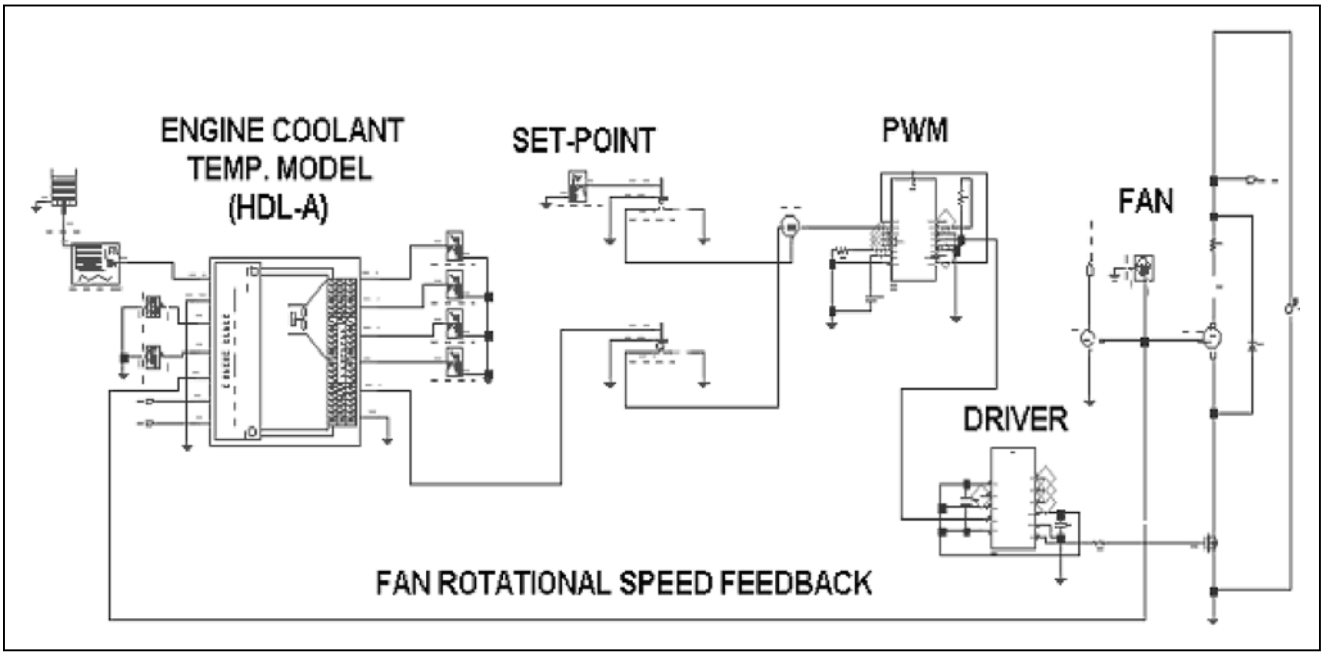

Figure 8: circuit for the new feeding proposal of the electrical fan using a PWM converter.

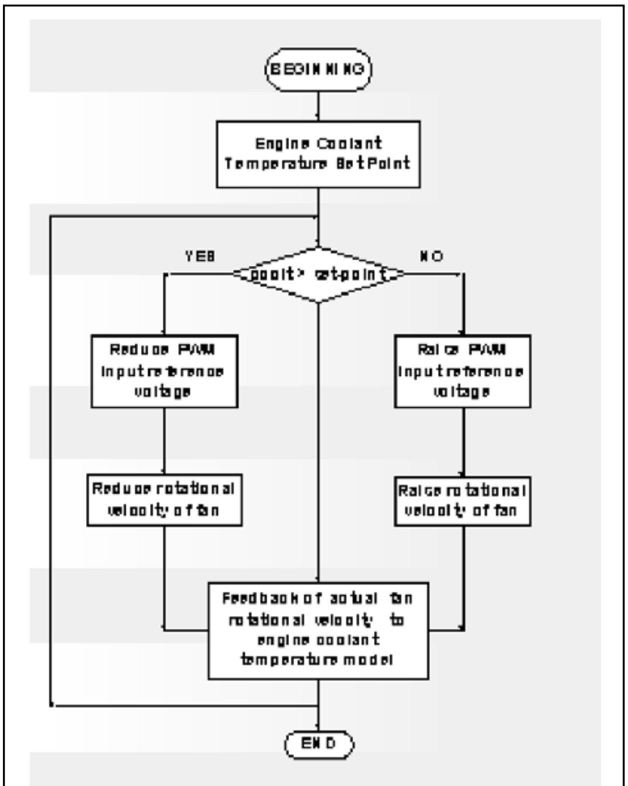

Figure 9: flowchart for control of electric-fan.

The fan's rotation speed is fed into the refrigeration system, which calculates the new temperature for the refrigerating liquid. The simulation results for the engine's refrigerating system are presented on Figure 10. It's important to point out that due to the unavailability of engine data, some constants used in the simulation were established using standard values of similar engines.

The project consisted of the following steps: switching converter project with voltage lowering configuration – Buck, project of power switch (Insulated Gate Bipolar Transistor – IGBT), project of micro-controlled system using a PICmicro from Microchip Technology Inc and development of command and control software. The system has a serial communication port RS 232, an output connector for 14-input/output pin expansion and 5 analog/digital converters. Figure 11 presents a picture of the projected system and Figure 12 presents the obtained results. The acceleration ramp implemented in the software lasts for 90 seconds. In the oscillograms on Figure 12 the integrated voltage and current, voltage and current in time and FFT of voltage of the electrical fan are presented. As it can be observed there is a soft current increase, which minimizes the voltage drop on the electrical system.

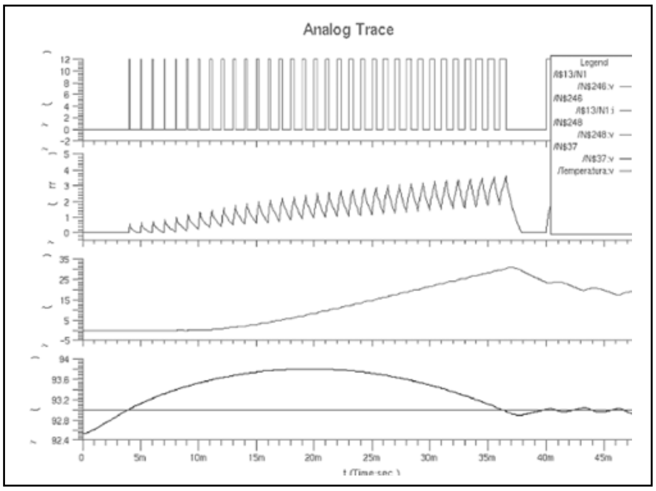

Figure 10: simulation results for the engine's refrigeration system – PWM output signal, motor current, fan's rotation speed (rad/s) output temperature signal of the refrigerating liquid (ºC) compared to the set-point = 93°C.

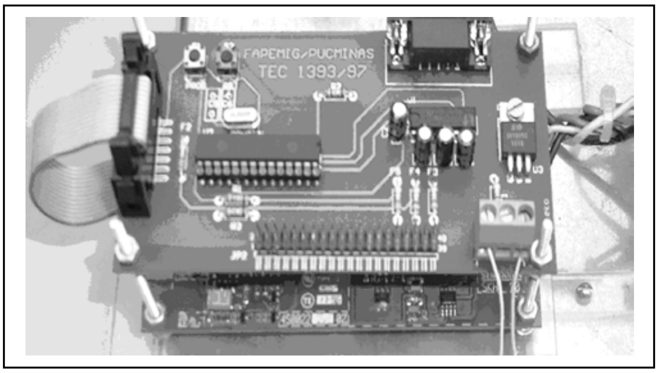

Figure 11: picture of the developed system.

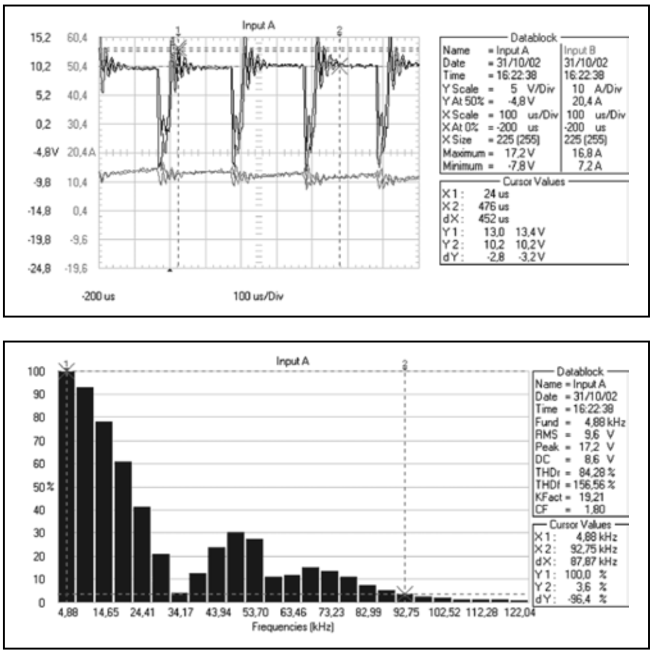

Figure 12: prototype results.

IV. CONCLUSION

This project has demonstrated the potential of the power electronics in optimization of automotive energetic management, being one of the most discussed subjects among the automotive industries. The simulation and characterization of electrical systems show the most recent evolution on implementation of control systems applied to vehicles. The implementation of PWM control prototype permits, besides power reduction, the possible improvement in the thermal efficiency of the combustion motor, which will directly affect the fuel consumption, the extended life of the motor, and emission of harmful gases to the environment. A new automotive electrical system simulation tool was developed, based on electrical system characterization and model development, which permits project developers to incorporate new loads and analyze the efficiency of the electrical system under various course and load profiles.

The refrigeration system and electrical fan simulations show the recent evolution on the implementation of control systems applied to automotive vehicles. The obtained results with the soft start of the electrical fan through a switching converter demonstrate the great applicability of these converters in automotive electrical systems.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Engine Cooling Temperature Model
me: Effective Engine Mass [Kg];
cc: Specifc Heat for Coolant [KJ/Kg°K];
ccool: Compesation Gain for Coolant Flow Rate;
aeng: Surface Area of an Engine [m^2];
arad: Surface Area of an Radiator [m^2];
tmax: Maximum Temperature of Thermostat to Max Lift [°K];
tmin: Minimum Temperature for Thermostat Open [°K];
bp: Pistom Diameter (m);
pci:Lower Calorific Power [nJ/Kg];
mig: Medium Gas Viscousity [Kg/sec.m];
kg: Médium Gás Thermal Conductive [W/m.K];
et: Radiator Tube Thickness [m];
brad: Radiator Height [m];
ntf: Number of Tubes Per Row on Radiador;
ea: Radiator Palette Thickness [m];
a: Radiator Widht [m];

na: Number of Palette of Radiator;
d: Radiator Depth [m];
lt: Radiator Tubes Widht [m];
nt: Number of Tubes of Radiator;
ppt: Transversal Step of Radiator Tube [m];
at: Thermostat Opening Area Coefficient;
hann: Annand Heat Transfer Coefficient [W/m^2.K];
Qamb:Heat Energy Loss to the Ambient [KJ/sec];
Qrad: Radiator Heat Trasnfer Rate [KJ/sec];
Qeng: Engine Heat Rejection Energy Flow Rate [KJ/sec];
ke: Adaptation Coefficient;
teng_in: Coolant Temperature at Radiator to Engine [°K];
trad: Medium Air Absolute Temperature [°K];
var: Air Speed Across Radiator [m/h];
sta: Total Area of Palette Surface [m^2];
stt: Total Area of Tube Lateral Surface [m^2]
sar: Total Area of Heat Transfer Beside Air [m^2];
dar: Air Hydraulic Diameter Across the Radiator [m];
a1: Front Surface Area of the First Tube Row [m^2];
a2: Front Surface Area of all Tube Row [m^2];
al: Total Area of Free Air Passage [m^2];
hrad: Radiator Heat Transfer Rate [KJ/sec].

INPUT PINS
vmcin: Input Mass Flow Rate of Fuel [Kg/sec];
es: Engine Speed [rad/sec];
vs: Vehicle Speed [rad/sec];
fans: Fans Speed [rad/sec];
tamb: Ambient Temperature [°K];
tear: Radiator Inlet Air Temperature [°K];
tsar: Radiator Outlet Air Temperature [°K];
gnd: Ground (reference pin).

OUTPUT PIN
vmcout: Output Mas Flow Rate of Fuel [Kg/sec];
coolt: Engine Coolant Temperature [°C].