Dynamic Behavior of Mobile Generator Set with Variable Speed and Diesel Engine

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***Abstract*—The engine-generator dynamics at a sudden load change (from low load to high load) remains a challenge in case of variable speed diesel generator. The dynamic behavior analysis presented here proves that the introduction of an energy storage element into the EGS with variable-engine-speed concept eliminates this drawback. This paper addresses the identification of the dynamic behaviour of such variable-speed EGS systems and the problems encountered during a sudden increase of load (power and voltage drops).**

***Index Terms*—Electrical GEN-SET, Power Electronics, Efficiency, Dynamic Behavior, Diesel Engine**

I. INTRODUCTION

An electrical-generator set (EGS) is an electrical power source intended for any mobile electrical application. A simplified block diagram of an EGS with variable speed control can be seen in Figure 1. As a consequence of varying the engine speed when using the optimum variable speed control, both the output voltage and the output frequency of the generator vary and must be regulated to a constant value as required by the load. Therefore, a power electronic converter is required to regulate the output voltage and frequency. Such an EGS concept uses variable-speed, constant-frequency (VSCF) technology, which is already being used in aircraft generators and in some wind-power generators. The EGS system with VSCF technology is a sophisticated mechatronic system consisting of: a mechanical part (the engine), an electromechanical energy conversion part (generator), power electronics (including voltage and frequency regulation as well as optimum speed control, all implemented in a microprocessor program).

The real drawback of concept with optimum variable speed is the inferior engine-generator dynamics. In case of sudden power output increase, the engine can not deliver the requested torque and the result is further decrease of the speed and torque of the engine until the undesirable stop. The diesel engine has namely the time constant of few second, which is further limited by fuel injection limitation. This problem of the EGS with VSCF is investigated in the paper and a solution with the use of an energy buffer is suggested. To facilitate an investigation into the problems regarding an EGS with variable speed control an experimental set-up, consisting of a driving engine (diesel chosen here), a synchronous generator with permanent magnets, a power electronic converter, an output filter and a control unit, as shown in the block diagram (Figure 1), has been assembled.

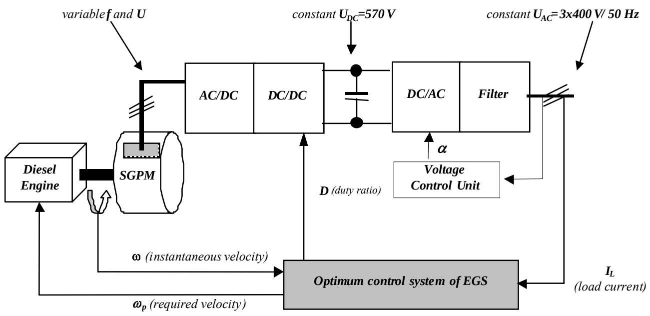

Figure 1. Block diagram of an EGS system with VSCF technology

II. THE EXPERIMENTAL MODEL OF EGS WITH VSCF

In military applications using a single type of fuel (diesel) eases the logistical challenges, therefore a modern diesel engine has been chosen to drive the EGS in this investigation. A diesel engine (HATZ 1D40) with an output power of 7.7 kW at 3600 rpm and 3.8 kW at 1500 rpm has been selected for a 6 kW EGS. The engine is slightly oversized (as regards power output) to facilitate dynamic changes of the load. The experimental EGS set-up can be seen in Figure 2.

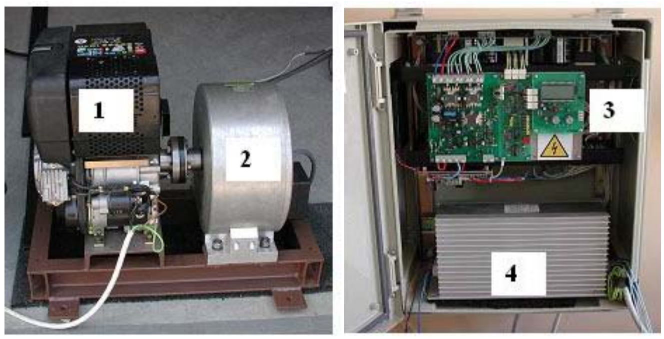

Figure 2. The EGS experimental model (1: diesel engine; 2: SGPM; 3: ac-dc-dc converter; 4:filter)

The output characteristic of the diesel engine is shown in Figure 3 as a function of engine speed, n (rpm).

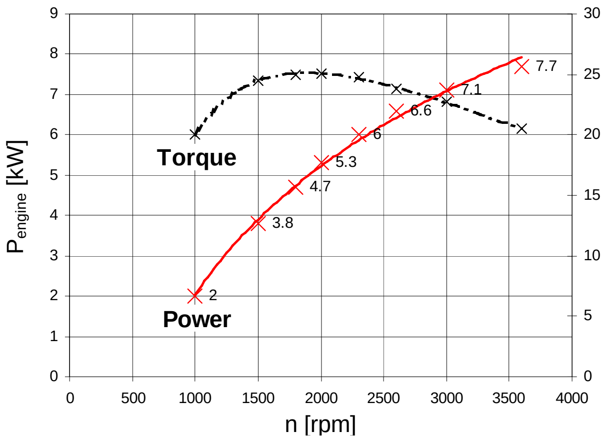

Figure 3. The output characteristic of the diesel engine (HATZ 1D40) (measured characteristics) [4]

Permanent-magnet synchronous generators (SGPM) are used in various applications implementing VSCF technology. In the experimental set-up the 12-pole, synchronous generator is connected to the diesel engine by means of a mechanical clutch. The output voltage of the generator has an unregulated frequency as it is generated by a varying engine speed (see Figure 3). The ac output voltage of the SGPM is in the range of 100V to 450V at a frequency ranging from 100 Hz to 300 Hz (Figure 4).

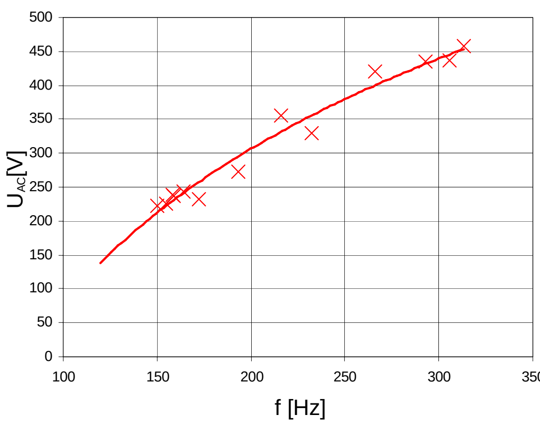

Figure 4. The output characteristic of a SGPM (measured with resistive load)

The unregulated voltage and frequency of the generator must be stabilized by using a power electronics converter to regulate at the constant voltage and frequency on the three-phase ac (400 V/ 50Hz) output. Figure 2 shows the block diagram of the power conversion steps including an ac-dc, dc-dc and dc-ac stage. The dc-dc converter with feedback control steps the voltage up from output variable voltage of uncontrolled rectifier to a constant value of 570 V. All the power generated by the EGS is processed by the power electronic converter in this way. Furthermore, the output voltage of the EGS must be independent of its load and engine speed. The system's operation can be concluded from the converter's schematic circuit (Figure 5) and from the output characteristics of the ac-dc, dc-dc and dc-ac converters respectively (Figure 6).

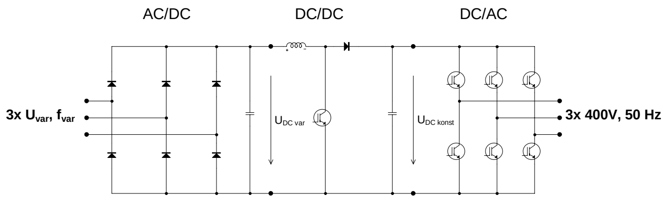

Figure 5. The power electronics of an experimental model of EGS with VSCF technology

A system comprising of a three-phase ac-dc rectifier and dc-dc converter is commonly used for VSCF applications due to its low cost and no need for high quality of its output voltage. The output voltage of the ac-dc converter (*U_{DC}_AC/DC)* is also shown in Figure 6. The shape of the *U_{DC}_AC/DC* characteristics corresponds to the output voltages of a synchronous generator with permanent magnets (see Figures 4 and 6).

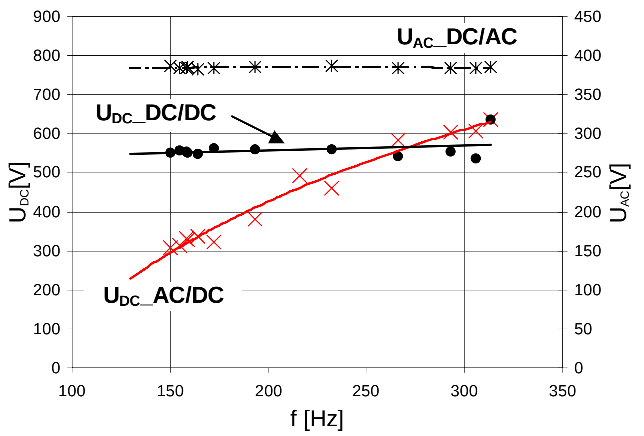

Figure 6. Characteristics of the respective ac-dc; dc-dc and dc-ac converters (test results)

The dc-dc converter is designed to function as a step-up chopper. If the rectified dc-voltage is less than 570V then the step-up chopper increases the voltage by adjusting the duty ratio of the switching element, *D* (Figure 5). The main goal of this dc-dc converter is to convert and stabilize the unregulated dc-output voltage of the rectifier. The output characteristic of the dc-dc converter (*U_{DC}_DC/DC)*, shown in Figure 6, shows that the output dc voltage is constant. The last measured point in the characteristic falls outside the operating area of the dc-dc converter. Here the duty cycle of the dc-dc converter has already reached one of its limits. The output voltage of the dc-dc converter simply follows the rectified voltage when it increases above 600V.

The three-phase EGS output is adjusted to the constant frequency (50Hz) by using a dc-ac inverter and a voltage control unit (Figure 2). The unit evaluates the three-phase information and makes the amplitude of the rotating output voltage vector suitable for feedback control. The output characteristic (U_{AC}_*DC/AC),* output voltage (rms) versus generator frequency, is shown in Figure 6. Figure 7 shows the measured quality of one of the EGS phase's output voltage and current. Figure 2 shows the EGS system complete with the main control structure necessary to implement optimum engine speed control to compensate for the EGS load. The required angular speed, ω_p, of the engine is calculated by using an EGS optimum control strategy. The PID controller receives its feed-back information in the form of the instantaneous angular speed, ω. Figure 8 presents a detail photo of the experimental EGS control system. The required speed of the engine is adjusted by the actuating lever and the instantaneous speed is calculated from the position sensor -- which measures the instantaneous position of the actuating lever. The servo unit is designed as a dc-servo machine and is controlled by means of variable PWM according to the required angular speed, ω_p, of the engine.

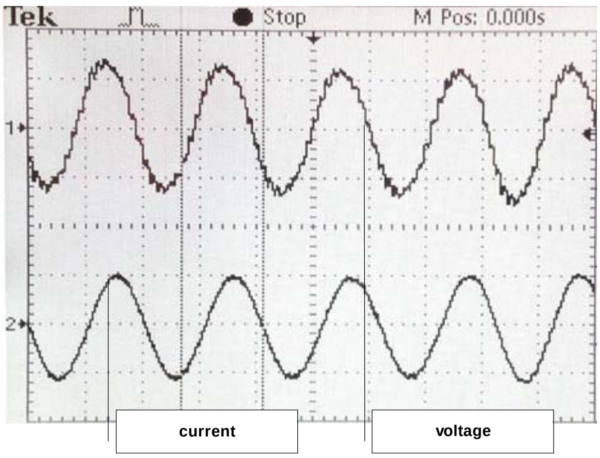

Figure 7. The output voltage and current quality of the EGS (experimental model)

III. EGS DYNAMIC BEHAVIOUR - EXPERIMENTAL RESULTS

The control of the EGS's speed can reduce the fuel consumption under low-load conditions, as shown in Fig. 1. The engine's rotational speed is to be optimally controlled by adapting the operating strategy for every load to the required power output and torque, while minimizing the fuel consumption. The engine-generator dynamics, during sudden transients from low-load to high-load conditions, still poses a challenge in this regard. The following experimental results (Fig. 8 and 9) show the oscilloscope reading of the EGS's dynamic behaviors. The measurements were performed in open-loop mode to show the dynamic behavior of only the generator set with its static speed error e_s (Δn) and also to determine the engine time constant, T_C.

In Figure 8 the measurements during a load change is shown. The yellow curve (CH 1) shows the output current of uncontrolled ac-dc rectifier (see fig. 5) and the red curve (CH 4) presents the engine speed. The output power is calculated from the output dc-voltage and dc-current. The result of this calculation is shown in Figure 8 as the violet curve (MATH). The exact point where the load is changed from low load to high load is indicated by point *A*. During time interval t_1 the system was loaded with 640 W at 1560 rpm. During time interval t_2 (580 ms) the load was changed to 2480 W and the transient occurs. Time interval t_3 shows the system operating in steady-state condition. In Figure 10 a drop in speed, Δn, of 160 rpm is shown. This drop in speed translates into the static error, e_s, of the diesel engine inter-regulator. The time constant of a diesel engine, T_C, is approximately 0.6s.

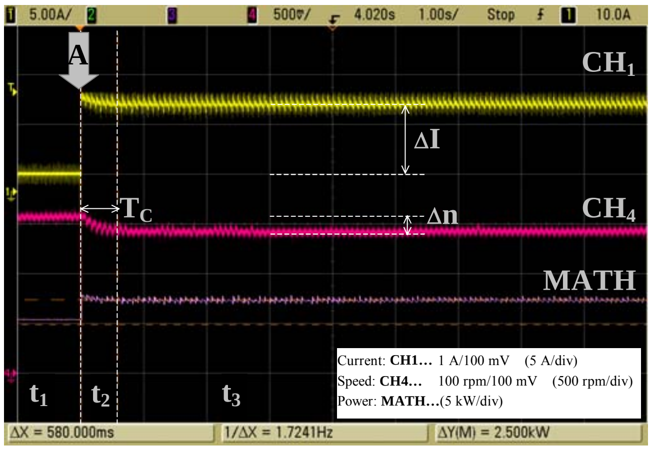

Figure 8. The oscilloscope record of the load change at engine speed of 1440 rpm

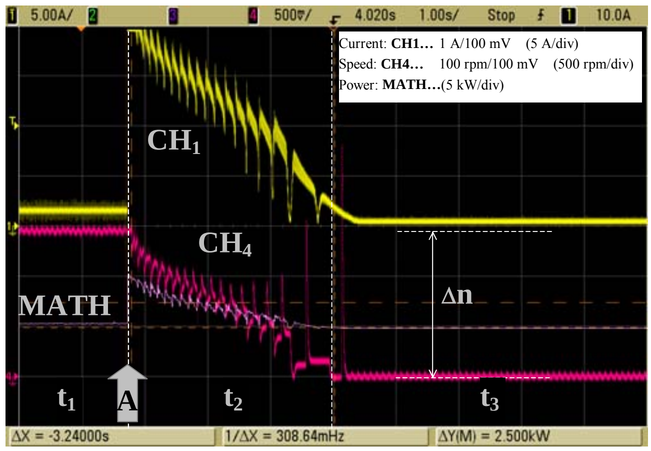

Figure 9. The load change of EGS from 0.6 kW to 6 kW at 1440 rpm

Figure 11 shows a load change, which can cause to stop of the diesel engine in during time interval t_2 in the Figure. The engine is unable to sustain the required torque under these conditions, and consequently the EGS is unable to deliver sufficient power to the load. The previous measurements indicate the serious nature of the dynamic behavior problem associated with the EGS with variable speed: its unsatisfactory reliability during sudden load changes as a result of the inferior dynamic behavior of the EGS. Therefore the dynamic behavior must be analyzed in detail, by using modeling methods for example, to understand these dynamics and to be able to improve it.

IV. MODEL OF THE EGS

The basic mathematical model of an EGS with variable speed includes the diesel engine (DE), the permanent magnet synchronous generator (SG), the power converter (PC) and two control units (RS-1 and RS-2). The model includes two main system variables: the first is the angular speed, ω, of the diesel engine that is fed into the synchronous generator and the second is the load torque, T_L, with which the generator loads the diesel engine. The resulting model, as implemented in Matlab-Simulink, is shown in Figure 10.

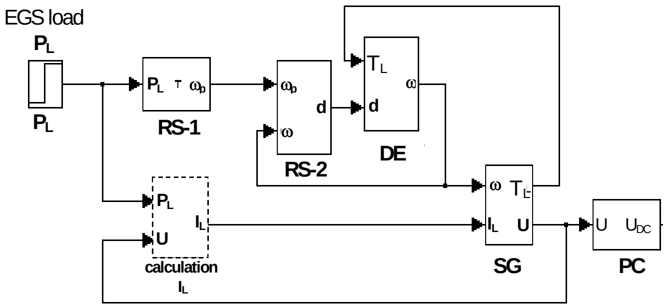

Figure 10. The mathematical model of the EGS in Matlab-Simulink graphics

The required angular speed, ω_p, according to the power load, P_L, is calculated by the control unit labeled *RS-1.* The diesel engine is controlled at the required angular speed, ω, by using a feedback regulator *(RS-2).* The control error between the required angular speed, ω_p, and the instantaneous speed, ω, is compensated by adjusting the fuel injection, *d [mg],* within the feedback regulator unit *(RS-2)*. The fuel injection, d, can be defined as a quantum of fuel in one injection [mg]. Behind the generator *(SG)* there is a model of the power converter (*PC)* that regulates the output dc-voltage. The dc-ac conversion is neglected because the dynamic response of the dc-ac converter is much faster than that of the dc-dc converter, generator and diesel engine. The details on the separate parts of the model are described in the transaction paper [21].

A Results of the dynamic behavior modeling

The main goal of the analyzing and modeling of the EGS is to determine both the dynamic behavior characteristics and steady-state characteristic of the EGS with variable engine angular speed. The dynamic behavior of the EGS system showed that the EGS system is stable and aperiodic and from this point of view the proportional regulator is sufficient. But the system is not astatic therefore its steady-state errors are not equal to zero. The steady-state error e_S is enforced by both required angular speed ω_P and load torque T_L and it is expressed by (1)

$$e_S = e_S(\omega_P, T_L) = \frac{\omega_P}{1+K_M K_R} + \frac{K_L(T_S+T_L)}{1+K_M K_R} = \\ = \frac{\omega_P + K_L(T_S+T_L)}{1+K_M K_R} = \frac{r_1\,\omega_P + (T_S+T_L)}{r_1 + m_1 K_R} \qquad (1)$$

Figure 11 presents the transient response of the feed-back controlled engine with proportional regulator (for K_R= 1). It shows the system response evoked by two step functions, First one, at $t_1 = 0,$ is the step change of the required engine angular speed from 200 to 300 rad·s^{-1} and the second one, at the time instant t_2 = 2, .is the step of the load change from 0 to 10 Nm. The steady state error is not negligible and it could be decreased by higher K_R. In general, we have more possibilities how to eliminate the steady-state error. For example the PI regulator could be employed. But because of the relation between the required angular speed and torque load is known the steady-state error is simply eliminated by correcting the course of required control law (1).

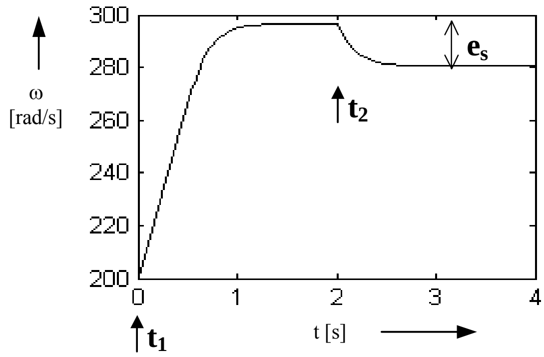

Figure 11. Transient response of feedback control [11]

The main results of dynamic behavior modeling are shown in Figures 12. Figure show the respective transient responses for various loads and for the controller gain K_R=1.

Figure 12 (a) shows the system response for power load change from 500 W to 1000 W. This load change brings about a change of the engine angular speed from 102 to 118 rad·s^{-1}. We can notice, that the difference between the required angular speed ω_p, and instantaneous speed, ω, i.e. steady state error is eliminated by way discussed above. The theoretical value of the time of regulation T_R is for known engine parameters and it is equal to 0,09 s. Real value of the T_R is affcted by *d* limitation and it is T_R, is 0,3 s.

Figure 12(b) shows a power load change from 500W to

2520W. At the initial angular speed the engine is not possible to surmount the instantaneous power load and the angular speed is decreasing. The EGS can not operate with such a load change. Figure 12(b) verifies the experimental results shown in Figure 9.

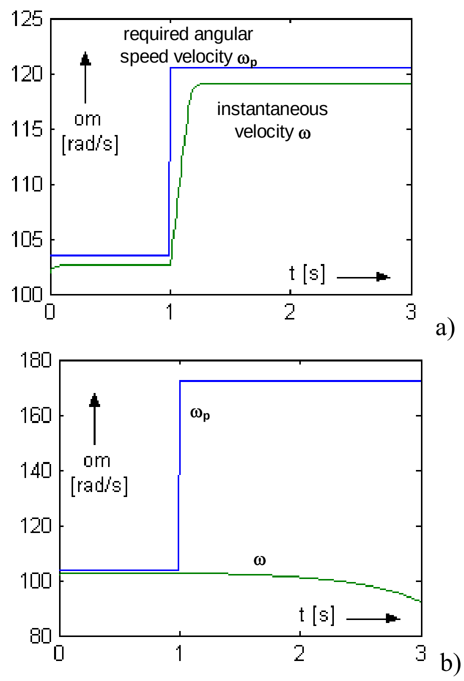

Figure 12. Transient responses for the load change from (a) 500 W to 1000 W, (b) from 500 W to 2520 W

A summary of the experimental results and observations is shown in Table I.

TABLE I
THE RESULTS OF THE EGS SIMULATION

	a)		b)		c)		d)	
	P_{L1}	P_{L2}	P_{L1}	P_{L2}	P_{L1}	P_{L2}	P_{L1}	P_{L2}
P_L [W]	500	1000	500	2000	500	2520	2000	3700
ω_P [rad/s]	102,5	118,5	102,5	150,5	102,5	172,2	154,5	212,3
ω [rad/s]	101,7	117,2	101,7	148,5	101,7	-	152,3	-
T_L [Nm]	5,1	8,9	5,1	15,7	5,1	-	15,7	-
I_L [A]	3,6	6,3	3,6	9,6	3,6	-	9,6	-
P_{Lmax} [W]	2500		2500		2500		3650	
ΔP [W]	500		1500		2020		1700	
T_R [s]	0.3		0,9		∞		∞	
Results	**OK**		**OK**		**NO**		**NO**	

This table shows the change of load power from P_{L1} to P_{L2}, the required angular speed ω_p and instantaneous speed ω, the load torque T_L and the load current I_L. In next columns are maximum values of power. This table shows a power P_{Lmax}, torque T_{Lmax} and the current I_{lmax} that could be provided by engine at level of ω_1. For carrying out the successful transition the P_{Lmax} must be higher then P_{L2} i.e. the condition $P_{L2} < P_{L\,max}$ must be fulfilled.

For any value of angular speed some value of P_{Lmax} exists. In Figure 13 the curve of P_{Lmax} is shown and it is margin of the EGS operating area in plane of (ω_P, P_L). The second curve designated as P_{opt} represents the power provided by engine working at the optimal angular speed. The third curve P_{rez} is the difference between P_{Lmax} and P_{opt} and it indicates the reserve of power of the system operating at optimal angular speed.

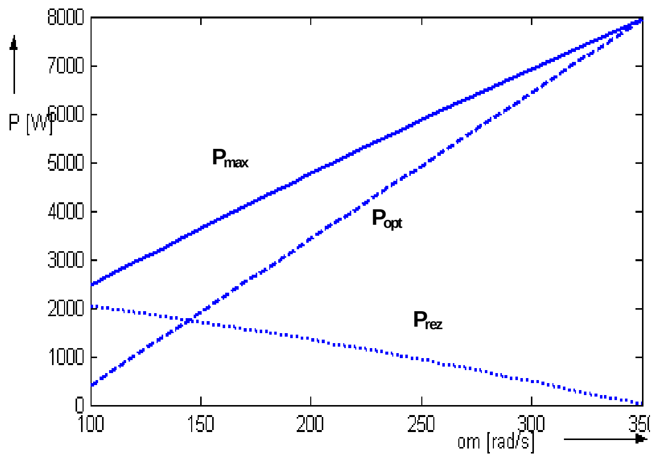

Figure 13. Identification of the power margin (simulation that was verified by measurement)

For example: if the engine operates with an angular speed of 150 rad·s^{-1} than the output power of engine is 1900W and the power margin of engine is as high as 1700 W. If the power drop is higher, than diesel engine cannot make enough power that is required by the load.

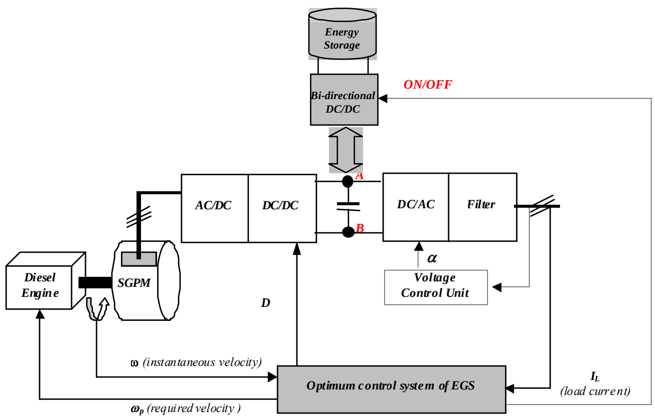

Figure 14. The EGS system with peak power delivered to the dc-link of the ac-dc-ac converter from a storage element

V. VERIFICATION OF EGS CONCEPT WITH ENERGY BUFFER

The energy buffer selection is in details described in paper [21]. The mathematical model of the EGS including the energy storage element, for delivery of the peak energy, is shown in Figure 15. The model includes the modules EB and RS-3. EB is the energy buffer (EB) including a dc-dc bi-directional converter and RS-3 is a power management controller regarding the energy storage element, which is indispensable for regulation of the buffer voltage level. The module RS-3 controls the flow of energy based on the output voltage, U_{DC}, and the load current.

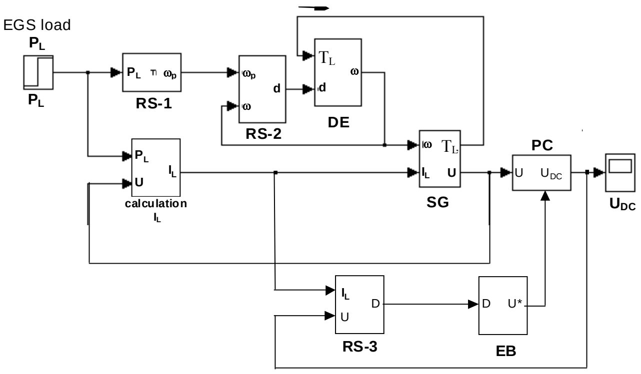

Figure 15. The model of EGS with energy buffer for delivery of peak power

The energy storage system is controlled in such a manner that current flows out of the EB when it is discharging or flows into the EB when it is charging. The dc-dc converter operates in BOOST mode when power is delivered from the EB to the dc-line. Alternatively, the dc-dc converter operates in BUCK mode when regenerative energy is absorbed into the EB. Figure 16 shows the results of a feasibility test performed on the energy buffer concept (to deliver the required peak energy) in the EGS. The verification of the EGS concept with energy buffer is summarized in Table II.

TABLE II.
THE VERIFICATION OF EGS WITH ENERGY BUFFER

	c)		d)		e)	
	P_{L1}	P_{L2}	P_{L1}	P_{L2}	P_{L1}	P_{L2}
P_L [W]	500	2520	2000	3700	500	7000
ω_P [rad/s]	103,5	172,2	154,5	212,3	154,5	324,5
ω [rad/s]	102,5	169,5	152,3	209,1	102,5	-320,4
T_L [Nm]	5,2	18,1	15,7	22,3	5,2	28,8
I_L [A]	3,6	10,9	9,6	12,9	3,6	16,0
P_{Lmax} [W]	2500		3650		3650	
ΔP [W]	2020		1700		6500	
T_R [s]	0,49		0,42		1,6	
Results	**OK**		**OK**		**OK**	

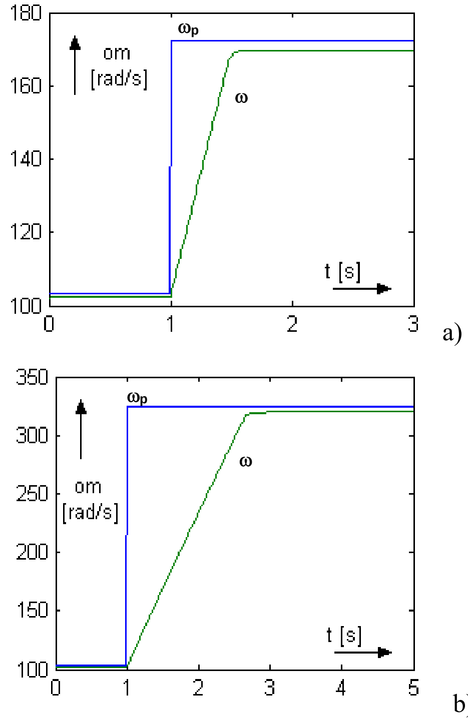

Figure 16. Transient response of EGS with energy buffer for load change (a) 500 W to 2520 W (b) 500 W to 7000 W

Figure 16 (a) illustrates a load change from 500W to 2520W. This situation caused the diesel engine to stop running in previous experiments (Figure 12 (c)) of the EGS without any energy buffer. It is shown that the EGS system can now tolerate this load change, as the required peak energy is delivered from the energy buffer to the load during T_R=0,5 s . The energy buffer supports the motor transition from one speed to the new optimal speed value and torque T_L as well as current I_L. Figure 16 (b) illustrates the maximal step change from 500 W to 7 kW. Both cases shown in Figure 16 exceed the maximal allowed value of P_{max}, as shown in Figure 12. In both cases the regulation time T_R is shorter than 2s (according to the calculation of the energy buffer).

In Figure 17 it is possible to see the experimental verification of the EGS concept with energy buffer as well as feed-back control of the speed. Channel 1 curve (CH 1) is the same as in Figures 10 & 11 and shows the current of the rectifier. The red curve (CH 4) shows the engine speed. The output dc voltage is shown by the green curve (CH 2), while the output power is shown as the violet curve (MATH), which is calculated from the output dc voltage and dc current. In time interval T_1 the system was loaded with 1kW at 1500 rpm. In time interval T_2 the power load was changed from 1 kW to 5.06 kW. During this time (2,28 s) the transition takes place and power is extracted from the energy storage element. Time interval T_3 shows the steady-state condition of the system. It is possible to see that the system is now capable of handling the power load change combined with the feed-back control of the engine speed (set at an optimal speed of the diesel engine). This proves the feasibility of the EGS with variable speed of engine concept.

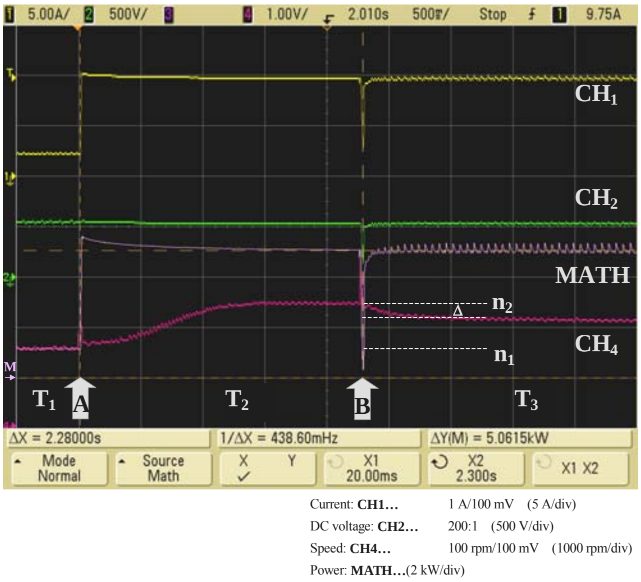

Figure 17. The verification of EGS concept with energy buffer

VI. CONCLUSION

Mathematical analysis and simulation of the static characteristics as well as dynamic behavior of mobile electrical power sources with VSCF technology has shown that the bad dynamical properties of the system (at substantial, sudden increases of load (from low loads at low speed to high loads) can be considerably improved by implementing power electronic converters with an energy buffer. This publication includes detailed analysis of an EGS mathematical model as well as identification of its dynamic behavior. Figure 14 shows the proposed concept of the EGS with optimum variable speed used in combination with an energy storage element to improve the dynamic behavior of the EGS. The drawback of the proposed EGS with variable speed and energy buffer concept translates into a higher initial cost when compared to the EGS with constant speed control.

ACKNOWLEDGMENT

The above research work is supported by the Grant Agency of the Czech Republic (project no. 105/05/P001).

REFERENCES

[1] H. Knitterscheidt, "Neue Generation SEA füer militärische Nutzung," *Symposium moderne elektrische Energietechnik*, Germany, 1998, pp. 14.1 - 14.22.

[2] L. M. Tolbert, W. A. Peterson, C. P. White, T. J. Theiss, M. B. Scudiere, "A bi-directional dc-dc converter with minimum energy storage elements," *in Conf. Rec. IEEE IAS Annu.*, Meeting, 2002, pp. 1572-1577.

[3] L. M. Tolbert, W. A. Peterson, T. J. Theiss, M. B. Scudiere, "GEN-SETS," *in Industry Applications Magazine*, vol. 9, 2003, pp. 48 - 54.

[4] J. Leuchter, "Power Electronics in New Generation in New Generation of Mobile Electrical Power Sources with Variable Speed," *Doctoral Thesis*, Military Academy in Brno, 2003. [in Czech]

[5] J. Leuchter, O. Kurka, P. Bauer, "Mobile Electrical-generator Sets," *Power Systems Design EUROPE Transl.*, Germany, vol. 3, ISSN: 1613-6365, 2006, pp. 40-44.

[6] M. E. Elbuluk, M. D. Kankam, "Potential starter/generator technology for future aerospace application," *Aerospace and Electronic Systems Magazine*, vol. 11, 1996 pp.17 – 24.

[7] R. K. Járdan, I. Nagy, A. Olasz, "Time Domain Control of a Power Quality Conditioning System, " *Proceedings of the international conference EDPE 2005*; Croatia, 2005.

[8] J. Jeong, H. Lee, CH. Kim, H. Choi, B. Cho, "A Development of an Energy Storage System for Hybrid Electric Vehicles Using Supercapacitor," *Web of IEEE association*, 2002, pp. 1379-1389.

[9] O. Kurka, O. J. Leuchter, "Variable speed integrated generating set an emerging technology for distributed power generation," *Proceedings of the international conference ICEM 2000*, Finland, 2000, pp. 1366-1369.

[10] W. Koczara, N. Al-Khayat, R. Seliga, J. Al-Tayie, "Variable speed integrated generating set an emerging technology for distributed power generation," *Power Tech Conference Proceedings*, vol. 3, 2003.

[11] V. Řeřucha, Z. Krupka, O. Kurka, J. Leuchter, "The EGS 3G – Control Synthesis under Condition of Huge Changes of Power Load," *Research Report of GAČR 102/03/0795*, University of Defence, 2005. [in Czech]

[12] V. Řeřucha, Z. Krupka, O. Kurka, J. Leuchter, "The Analyses of dynamic Behavior of EGS," *Research Study of the project GAČR 102/03/0795*, University of Defence, 2003. [in Czech]

[13] L. Grzesiak, W. Koczara, M. da Ponte, "Application of a permanent magnet machine in the novel Hydrogen adjustable-speed load-adaptive electricity generating system," *Electric Machines and Drives, International Conference IEMD*, 1999, pp. 398-400.

[14] R. Cardenas, R. Pena, M. Perez, J. Clare, G. Asher, F. Vargas, "Vector Control of Front-End Converters for Variable-Speed Wind–Diesel Systems,", *IEEE Transactions on Industrial Electronics,* vol. 53, Issue 4, 2006, pp. 1127 – 1136.

[15] S. Lemofouet, A. Rufer, "A Hybrid Energy Storage System Based on Compressed Air and Supercapacitors With Maximum Efficiency Point Tracking (MEPT)," *IEEE Transactions on Industrial Electronics*, vol. 53, Issue 4, 2006, pp. 1105 – 1115.

[16] G. O. Cimuca,; C. Saudemont, B. Robyns, M. M. Radulescu, "Control and Performance Evaluation of a Flywheel Energy-Storage System Associated to a Variable-Speed Wind Generator, "IEEE Transactions on Industrial Electronics, vol. 53, Issue 4, 2006, pp. 1074 – 1085.

[17] J. Wang; W. Wang; G. W. Jewell, D. Howe, "Design of a miniature permanent-magnet generator and energy storage system, "*IEEE Transactions on Industrial Electronics*, vol. 52, Issue 5, 2005, pp. 1383 – 1390.

[18] M. T. Tsai; Ch. E. Lin; W. I. Tsai, Ch. L. Huang, "Design and implementation of a demand-side multifunction battery energy storage system, "*IEEE Transactions on Industrial Electronics*, vol. 42, Issue 6, 1995, pp. 642 – 652.

[19] J. Moreno, M. E. Ortuzar, J. W. Dixon, "Energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks, " *IEEE Transactions on Industrial Electronics,* vol. 53, Issue 2, 2006, pp. 614 – 623.

[20] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. PortilloGuisado, M. A. M. Prats, J. I. Leon, N. Moreno-Alfonso, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources," *IEEE Transactions on Industrial Electronics*, vol. 53, Issue 4, 2006, pp. 1002 – 1016.

[21] J. Leuchter, P. Bauer, V. Rerucha, V. Hajek, "Dynamic Behaviour Modeling and Verification of Advanced Electrical-Generator Set Concept," *IEEE Transactions on Industrial Electronics, 2007* accepted paper

[22] J. Lettl, "Matrix Converter Induction Motor Drive, " *12th International Power Electronics and Motion Control Conference,* 2006, pp. 787 – 792.