Use of the EMTP-ATP Software to Develop a Dynamic Model of the Technological Centre

Tomas MOZDREN, Stanislav RUSEK, Radomir GONO, Veleslav MACH

Department of Electrical Power Engineering, Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava, 17. listopadu 15/2172, 708 33 Ostrava, Czech Republic

tomas.mozdren.st1@vsb.cz, stanislav.rusek@vsb.cz, radomir.gono@vsb.cz, veleslav.mach@vsb.cz

Abstract. *This paper deals with analysis of power generating units installed within the technological centre. To be able to analyse behaviour of such a complex system with accumulation, the dynamic model of the technology was created using the EMTP-ATP software. The current configuration of the dynamic model is based on the block diagram containing all the unconventional sources of electric power. The values produced by ATPDraw are shown in graphs for reference. The dynamic model will serve the purpose of research and observation of the entire technological centre with respect to transients at individual sources of power.*

Keywords

AC/DC inverter, battery bank, co-generation, diesel generator, dynamic model, power convertor.

1. Introduction

The current demand for sources of electric power keeps rising and the existing deposits of fossil fuels are unfortunately exhaustible. This is the reason for accelerated efforts towards search and application of new renewable energy sources for mankind. The reasons mentioned above then resulted in support development of the ENET project dealing with research on utilisation and application options covering non-traditional sources of energy in the laboratory of the technological centre in Ostrava-Vitkovice ("TCO") since the year 2010.

2. Connections and Technologies

For a simplified circuit diagram of TCO, refer to the Fig. 1. Individual energy sources have been divided and drawn into technological blocks for legibility purposes; these blocks are formed per basic functioning principles of the sources or with respect to the assumed relevance to other technologies within the TCO. The primary supply of power to TCO and the power outlet from the centre are ensured in terms of connection to the local distribution system. The backbone source of electric output from TCO is the co-generation unit with a synchronous generator with the power output of 100 kW cooperating with a gas piston combustion engine. This unit is supplied with gas fuel in volumes of 250–450 kg per hour (depends on the fuel composition). The topology of electric power distribution system of TCO comprises the main AC bus with the option to connect onto the backup AC bus. The whole distribution system at the centre has been designed and built as fully subsistent with potential opportunity to switch into island operation mode with $3\times230/400$ V and with the optional power supply to the adjacent industrial buildings.

Installation of various accumulation systems forms a vital part of the whole TCO. This accumulation is ensured with various types of batteries that are always linked to the main direct-current bus DC 400 V. The bus enables distribution of electric power into the individual parts and components of the system using reversible inverters. The links between direct-current buses and the standard network buses are made of power semi-conductor inverters combined with transformers and chokers TR1+TL1 and TR2+TL2 to enable two-way transfer of power between AC and DC buses. If the centre is disconnected from the grid supply and its internal accumulation capacity has been
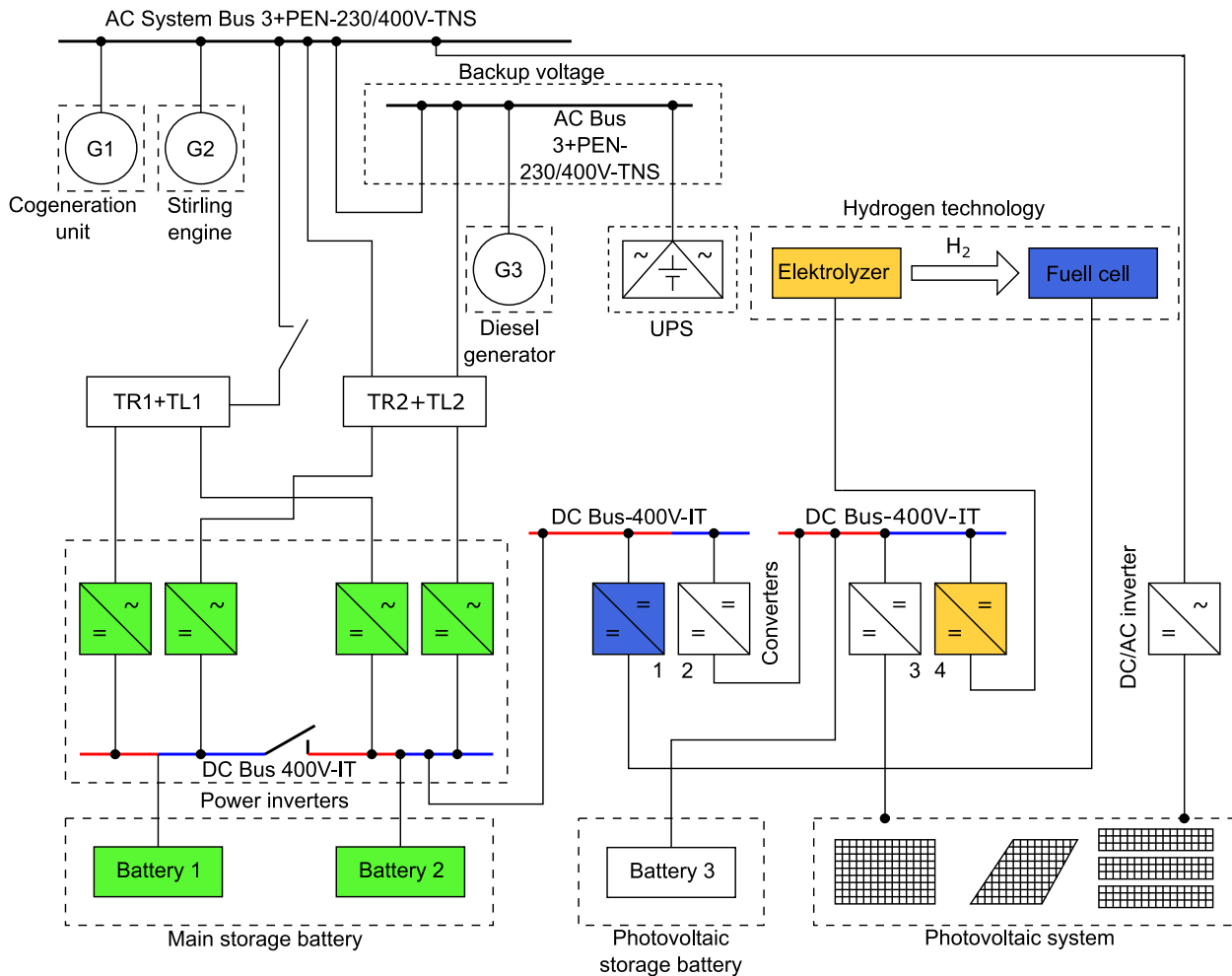
Fig. 1: Connection of individual power sources in TCO to technological blocks.

fully depleted, it is still fitted with a diesel generator and the UPS unit to ensure stable supply of power and safe shutdown of all technologies, especially the thermal cracker [1] and [2].

3. Transients Modelling Software

The dynamic model considered in this paper has been built using the software available and currently in use at the Department of Electrical Power Engineering of VSB–Technical University of Ostrava. This software is formed by the program environment of EMTP-ATP (Electro Magnetic Transients – Alternative Transients Program) that is designed mainly for modelling of transients and creation of alternate diagrams of electric machinery, distribution lines and components. The specialty behind development of this program is the opportunity to simulate transients of electromagnetic and electromechanical nature. It is adapted for design of circuits using algebraic, partial and differen-

tial equations. This program also helps with design of extensive and complicated electric grids as well as control systems. The calculation process itself makes use of simplified modifications of the Newton-Rhapson method [6].

4. Dynamic Model

This section describes the partial dynamic model in the EMTP-ATP environment, see Fig. 2. This model is based on the block diagram showing individual electric power sources within the TCO.

The topology of this model with individual sources of electric power in the TCO comprises the AC power supply bus rated for $3 \times 230/400$ V and the back-up AC bus rated for $3 \times 230/400$ V, for development of voltage on the main supply AC bus rated for $3 \times 230/400$ V. This bus is connected to the main power supplies, as the cogeneration unit delivering 100 kW, the Stirling engine with power of 10 kWe. In case the TCO is disconnected from the power supply in mains and the internal accu-
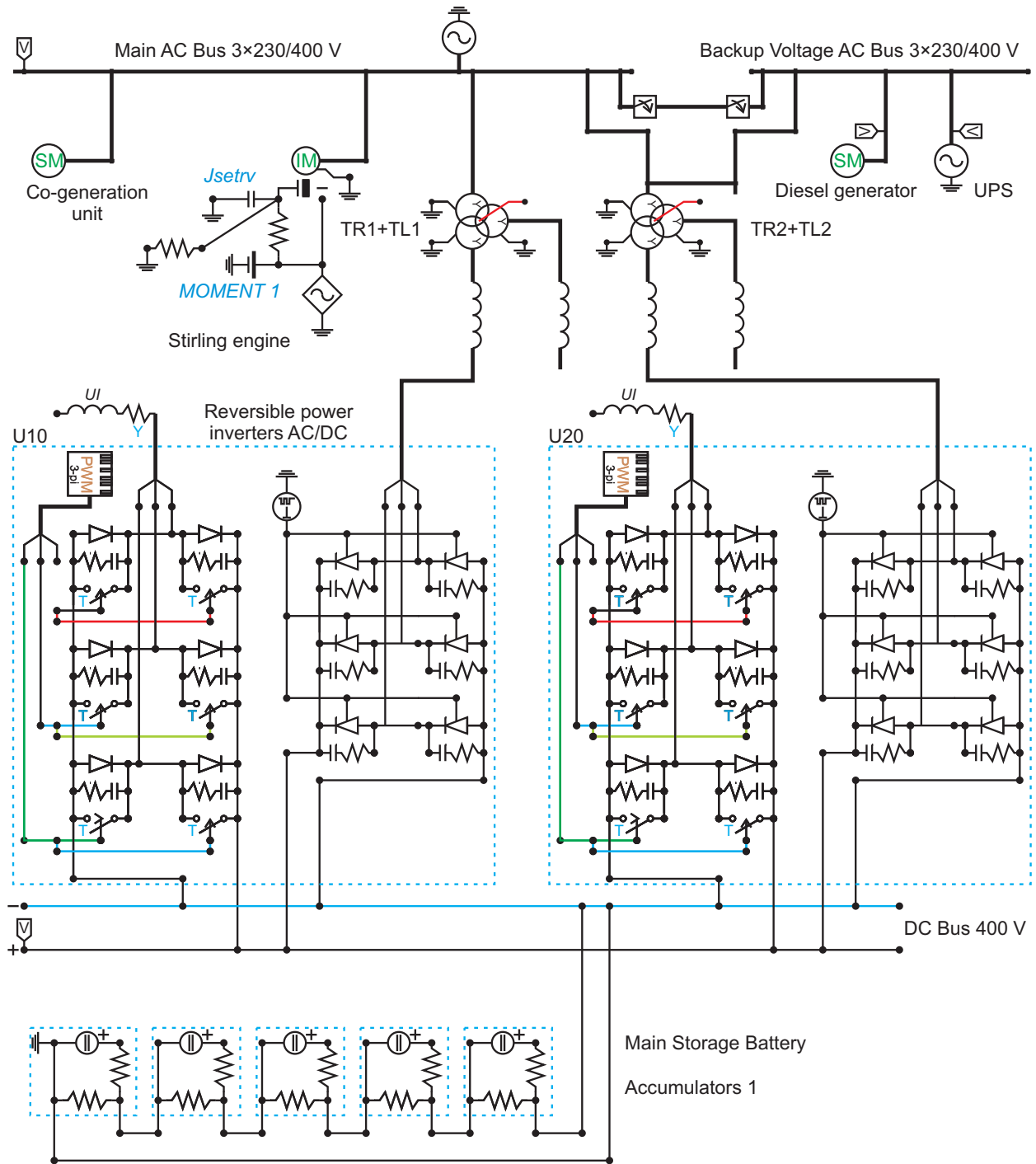
Fig. 2: Part of model created using the ATP Draw program [3], [6] and [7].

mulation capacities have been depleted, there is always the diesel generator with the UPS unit.

The main DC bus rated for 400 V is connected to two accumulation units formed by five batteries connected in series. Since the EMTP-ATP software does not allow connecting any idle sources in series, each source of electric power had to be connected to a load [1] and [2].

4.1. Co-Generation Unit

The technological centre is connected to the co-generation unit rated for 100 kW that is supplied from the thermal cracker burning the pyrolyzed gas. Power output from the co-generation unit depends on the input material subject to testing in the thermal cracker, which is subject to testing. The co-generation unit is based on combustion engine linked with a synchronous generator. The synchronous generator in dynamic

Tab. 1: Parameters of synchronous generator at co-generation unit [2].

Co-generation unit			
Synchronous generator			
Voltage	400 V	Cos φ	0.8
Active power	100 kW	Moment of inertia	1.082 kg·m^2
Apparent power	125 kVA	Phase	3
Current	180 A	Connection	D (star)
Frequency	50 Hz	R.P.M	1500

Tab. 2: Parameters of asynchronous machine for the Stirling engine [2].

Stirling engine			
Asynchronous generator			
Voltage	400 V	Cos φ	0.85
Active power	11 kW	Moment of inertia	0.065 kg·m^2
Apparent power	14.5 kVA	Phase	3
Current	21 A	Connection	D
Frequency	50 Hz	R.P.M	1470

model is processed directly from the 'Machine' menu, type SM59_NC per the machinery values entered, see Tab. 1.
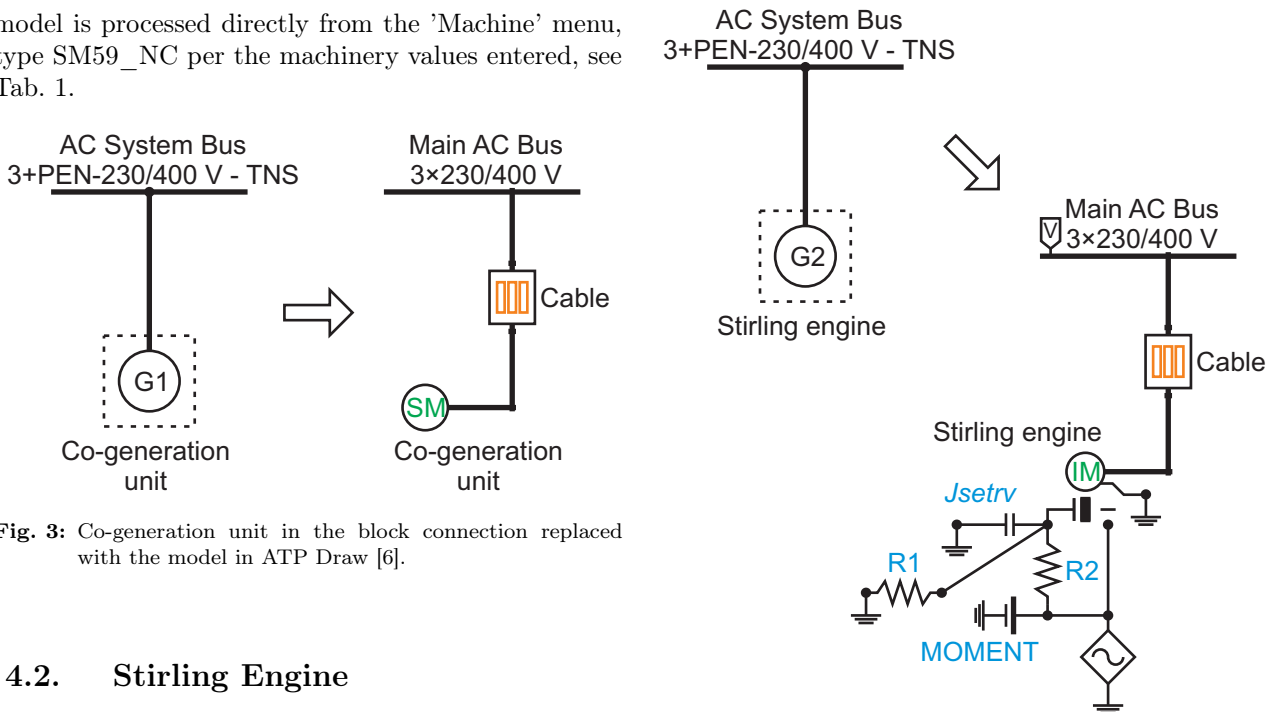

Fig. 3: Co-generation unit in the block connection replaced with the model in ATP Draw [6].

4.2. Stirling Engine

The Stirling engine, installed as a non-traditional source of energy, is a hot-air or even heat-gas engine working with an external source of heat. The range of such external sources could comprise various primary sources as coal, petroleum fraction, biomass, solar energy, etc. The Stirling engine installed in the centre is the PCU35 solar/gas type with the power output of 10 kWe and the heat output of 25 kWt. Employed as the co-generation unit, this engine combusts the mix of pyrolyzed and natural gas or pure natural gas only. The Stirling engine is designed for being driven by its asynchronous mechanism connected to the grid. The asynchronous engine in the dynamic model has been selected from the 'Machine' menu, type UM_3 per the machinery values entered, see Tab. 2.

The Fig. 4 shows further values for definition purposes [3].

Fig. 4: Stirling engine in the block connection replaced with the model in ATP Draw [3] and [6].

1) Rated Machine Load (Torque)

M (N·m) in the ATP Draw is respected by the direct current source.

2) Moment of Inertia (Jsetrv)

J (kg·m^2) in the ATP Draw is respected by connection of a capacitor to the circuit in parallel. The capacity measured in Farad units corresponds with the moment of inertia measured in kg·m^2. Since the capacity value is entered into the ATP Draw using µF units, the capacity value is designated as C (µF).

Tab. 3: Parameters of diesel generator required for the model [2].

Diesel generator			
Synchronous generator			
Voltage	400 V	**Cos** φ	0.8
Active power	84 kW	**Moment of inertia**	1.078 kg·m^2
Apparent power	105 kVA	**Phase**	3
Current	152 A	**Connection**	S
Frequency	50 Hz	**R.P.M**	1500

3) Shaft Friction and Start-up

The circuit is fitted with the resistor marked with the index R_1, which simulates shaft friction, this is a mechanical parameter. The magnitude of this resistance depends on the mechanical losses, i.e. ventilation losses and losses caused by friction in bearings. Its value expressed in N·m/(rad·s^{-1}) is entered as the conductance parameter for this value. This value corresponds with R (Ω).

The other resistor marked with the index R_2; together with the electric current source, I represents the machine start-up mechanism with the usual value of 0.1 Ω, whereas its size is not important for the circuit behaviour.

4.3. Diesel Generator

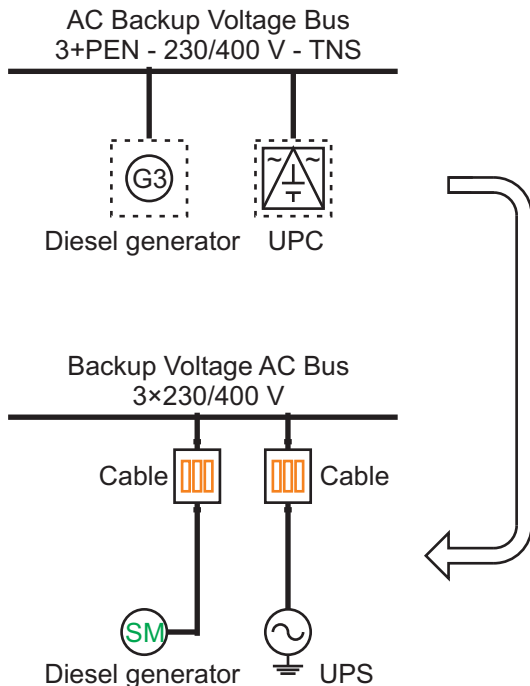The power back-up unit installed in the technological centre is formed by a diesel generator coupled with an UPS unit. The UPS unit is simulated as a 3-phase voltage supply unit.

The synchronous generator in this dynamic model is generated from the 'Machine' menu, type SM59_NC. For machine values, see Tab. 3.
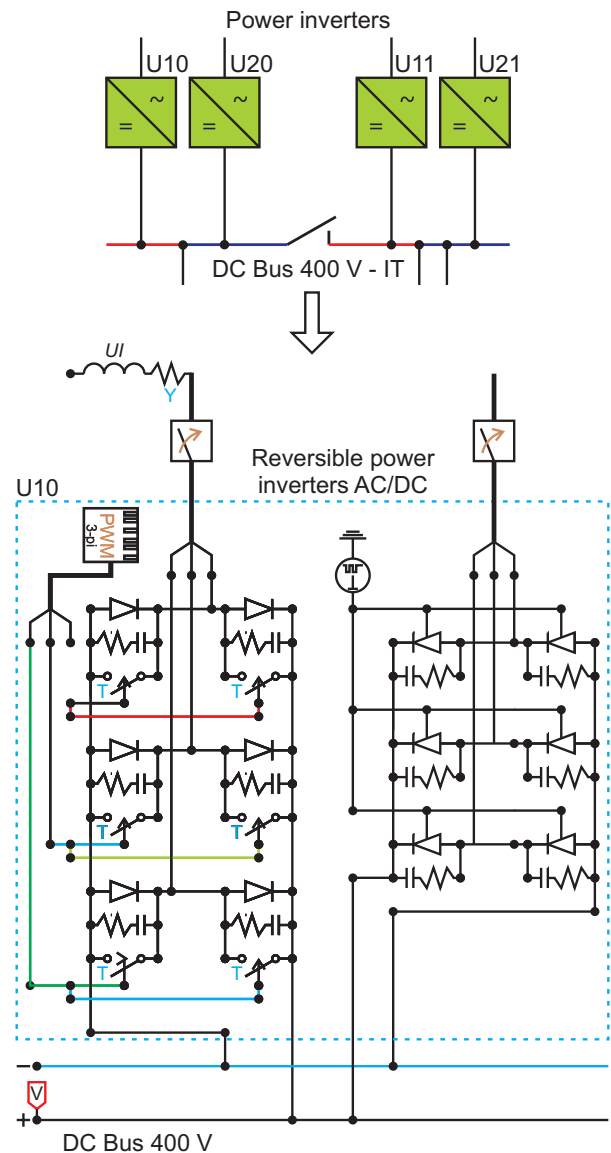

Fig. 5: The diesel generator with UPS within the block connection have been replaced with the model in ATP Draw [3] and [6].

Fig. 6: Reversible inverter in block connection replaced with the model in ATP Draw [4], [5] and [8].

4.4. Reversible Power Inverter

The one of four AC/DC inverters simulated in the model is a 6-pulse controlled rectifier with over-voltage protection features at thyristors with the voltage DC 400 V at inverter output. On the contrary, the three-phase inverter DC/AC in the model has been simulated by transistors fitted with over-voltage protection features. Actuation of transistors is handled by means of PWM (Pulse Width Modulation) and the output phase values referring to voltage and current are shown in the Fig. 7 and Fig. 8 for better reference.
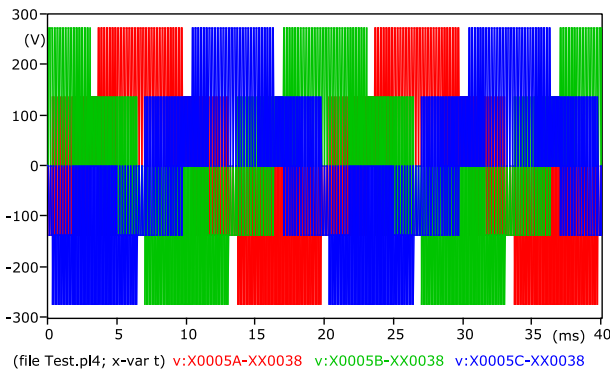

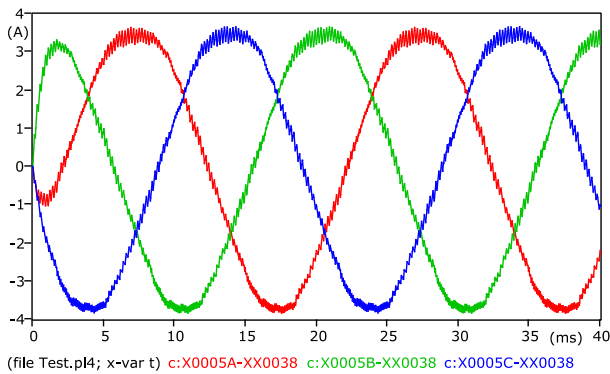**Fig. 7:** Phase projections of voltage at the inverter output in ATP Draw.

Fig. 8: Phase projections of current at the inverter output in ATP Draw.

The Fig. 7 and Fig. 8 shows the simulation results of the phase voltage and current values of said process vector PWM. The inverter has worked to RL load on the parameters $R = 50$ Ω and $L = 30$ mH, the switching frequency was set at $f_{PWM} = 5000$ Hz, output frequency was $f_{OUT} = 50$ Hz. The top part of this picture shows development of voltage at the individual phases for better legibility. These are mutually shifted by 120°. On the other hand, the bottom part of this picture shows the values of phase current. Also mutually shifted by 120°.

1) Simulation and Transient on the Power Inverter

The following simulation of the energy transfer is performed by software EMTP-ATP, where in the simulation is used connection DC source (battery), controlled DC/DC converter controlled by the DC/AC inverter and then connect to the AC network. In this simulation flow of power between the AC and DC power source is monitored. The values for the simulation are shown in Tab. 4.

$$R = \frac{U^2}{P} = \frac{400^2}{160 \cdot 10^3} = 1 \ \Omega. \tag{1}$$

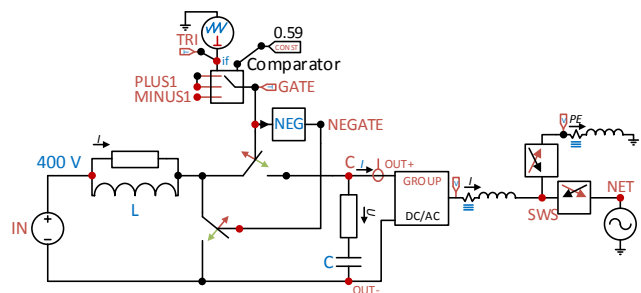Overall scheme sources which have been modified and simplified in blocks are shown in Fig. 9.

Fig. 9: Adapted scheme for transfer of energy.

The energy balance of DC power sources is calculated for $t = 50$ ms (using 1 microsecond step), the power of the DC source is the product of the DC source voltage (400 V) and the DC source current. The battery supplies 780 kW power to the grid at the steady state. The transient occurs at 60 ms. After the transient stabilization, the battery will supply 160 kW power to the 1.2 Ω star connection load. This 1.2 Ω load is higher than 1 Ω in the Tab. 4 due to higher voltage on the load.
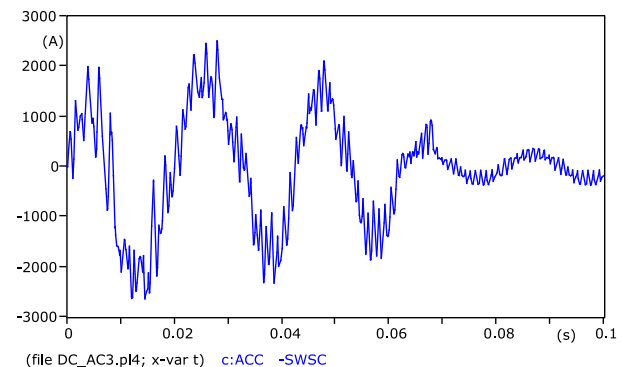

Fig. 10: Current waveform in phase A at the output of the DC/AC inverter.

Tab. 4: Information about sources for simulation.

Information about sources				
DC source		**3 phase source**		**Load 160 kW**
UDC	400 V	**U**$_{fm}$	327 V	**R** 1 Ω
TRI period	2.5 µs	**PWM period**	1 ms	
		Constant	0.59	

Tab. 5: Parameters of asynchronous machine for the Stirling engine [2].

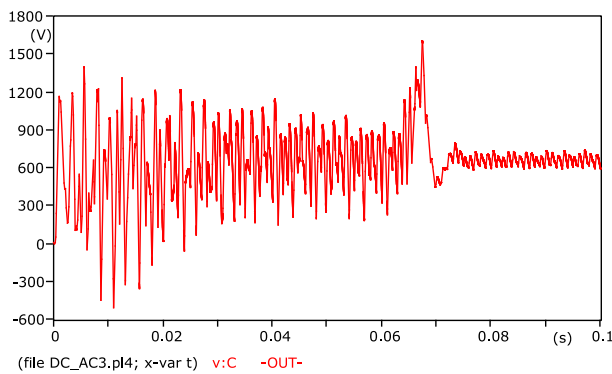| Main storage battery			
Nominal block voltage		80∼V	
Capacity		C5 930∼Ah	
Minimum cell voltage	1.65∼V	**Minimum block voltage**	66∼V
Nominal cell voltage	2.05∼V	**Nominal block voltage**	82∼V
Maximum cell voltage	2.44∼V	**Maximum block voltage**	98∼V
Nominal capacity of energy W = 381.3∼kWh			

Fig. 11: The output voltage in phase A on condenser (DC link).

4.5. Main Storage Battery

The existing requirements resulted in suggestion to store power in a battery that allows connection to the alternating grid rated 3×400 V via reversible power inverters.

The battery room is divided into two sections and fitted with two battery banks separated by operation means. Both battery banks supply the electric power at 400 V voltage level. Each section comprises five battery blocks on either side of the room. Each block is formed by 40 lead cells connected in series. The voltage per block is 80 V with the capacity of 930 Ah, see Tab. 5. These batteries stand for the main power storage capacity of the centre and they also define the basic reference voltage level for direct-current buses in TCO.

Fig. 12: Major batteries in block connections are replaced with the model in ATP Draw [6] and [10].

5. Conclusion

This paper describes connection of the TCO using the block diagram that shows all the power sources within TCO laboratories. The second part of this paper provides a description of the software used for modell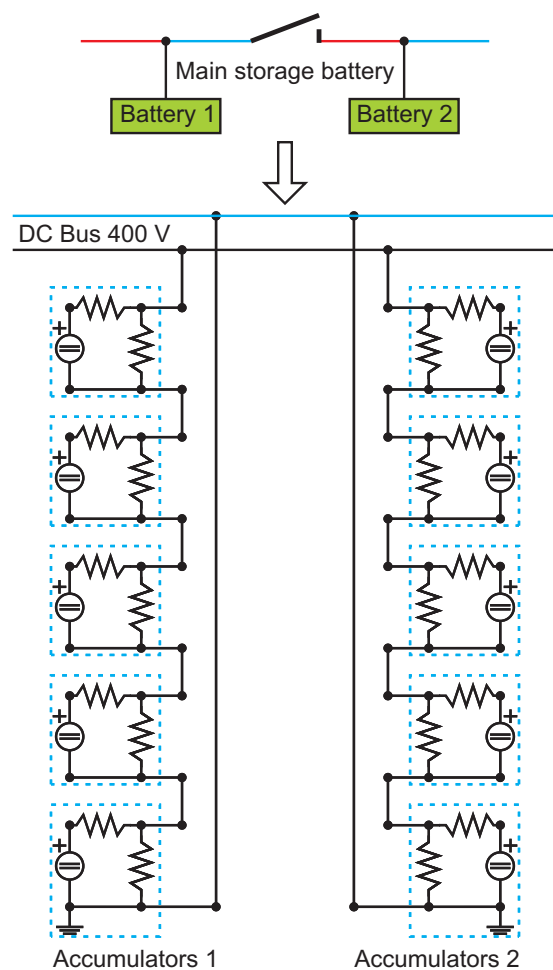ing of the technological centre in Ostrava–Vitkovice. The next part shows the existing dynamic model created within the ATPDraw environment. There are pictures showing individual sources of power. The values produced by ATPDraw have been plotted into the graph for reference. A complete dynamic model requires modelling of DC/DC inverters, photovoltaic cells and hydrogen technologies. The dynamic model will serve the purpose of research and observation of the entire

technological centre with respect to transients at individual sources of power.

Acknowledgment

References

[1] MINARIK, D., S. RUSEK and R. GONO. Implementation of accumulation technologies of electric energy to hybrid energy system. In: *13th International Scientific Conference Electric Power Engineering*. Brno: IEEE, 2012, pp. 759–762. ISBN 978-80-214-4514-7.

[2] MOZDREN, T., S. RUSEK, R. GONO, D. MINARIK and P. MOLDRIK. The Input Analysis of Parameters and Expected Operation Modes of Energetic Technologies in Technological Centre ENET. In: *16th International Scientific Conference Electric Power Engineering*. Prague: IEEE, 2015, pp. 32–36. ISBN 978-1-4673-6787-5. DOI: 10.1109/EPE.2015.7161161.

[3] STOJKOVIC, S., M. BJEKIC and Z. JARDA. Educational simulation model for studying the impact of distributed generation on distribution networks using ATP-EMTP software. *International Journal of Electrical Engineering Education*. 2014, vol. 51, no. 4, pp. 292–305. ISSN 2050-4578. DOI: 10.7227/IJEEE.0002.

[4] SALOMONSSON, D. *Modeling, Control and Protection of Low-Voltage DC Microgrids*. Goeteborg, 2008. Dissertation thesis. Chalmers University of Technology. Supervisor Lenart Soder.

[5] HAN, J., M. BJEKIC and Z. JARDA. Modeling and Analysis of a Low-Voltage DC Distribution System. *Open Access Resources*. 2015, vol. 4, no. 3, pp. 713–735. ISSN 2079-9276. DOI: 10.3390/resources4030713.

[6] Introduction to ATPDraw: version 5. In: *ATP Draw* [online]. 2015. Available at: `http://atpdraw.net/docs/ATPDraw%20v5%20Presentation.pdf`.

[7] MILANO, F. *Power System Modelling and Scripting*. Castilia: Springer-Verlag Berlin Heidelberg, 2010. ISBN 978-3-642-13669-6.

[8] BLUHM, H. *Pulsed Power Systems-Principles and Applications*. Berlin: Springer-Verlag Berlin Heidelberg, 2006. ISBN 978-3-540-26137-7.

[9] MEDVED, D., M. KOLCUN, Z. CONKA, P. HOCKO and M. NOVAK. Simulation of faults in the power system and their elimination in the EMTP-ATP. In: *7th International Scientific Symposium on Electrical Power Engineering*. Kosice: IEEE, 2013, pp. 484–487. ISBN 978-80-553-1441-9.

[10] DEGNER, T., A. ENGLER and O. OSIKA. Modelling of Distributed Energy Resources with ATP-EMTP. In: *European ATP-EMTP Users Group Meeting and Conference*. Warsaw: IEEE, 2005, pp. 1–9. ISBN 82-471-0177-7.

About Authors

Tomas MOZDREN was born in Ostrava, Czech Republic. He graduated from the Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava in 2013. He is currently Ph.D. student at the same university. His research interests include in generate Dynamic model in Technological center.

Stanislav RUSEK was born in Havirov, Czech Republic. He received his M.Sc., Ph.D. and professor from VSB–Technical University of Ostrava in 1981, 1989 and 2002 respectively. His research interests include electrical transmission and distribution, control of electrical distribution systems and power system reliability.

Radomir GONO was born in Bilovec, Czech Republic. He received his M.Sc. and Ph.D. from VSB–Technical University of Ostrava in 1995 and 2000 respectively. His research interests include renewable sources and electric power system reliability.

Veleslav MACH was born in Ostrava, Czech Republic. He received his M.Sc. and Ph.D. from VSB–Technical University of Ostrava in 1975 and 1997 respectively. His research interests include High Voltage and EMTP-ATP.