Executive summary:

This project aims to reduce costs, time to market and required design expertise and to increase market share by setting up a development environment , assisting the designer and allows building of resonant operated power supplies applied for VLF-based true sinus HV-test systems (HVTS) and programmable dc-sources (DCS).

The structure of the development environment (CAD-HVTS- DCS) will be open and flexible. Its innovative methodology will in conjunction with using novel European power electronic simulator toolbox PLECS/MATLAB include and support the following functions:

a. A computer aided DC and AC analysis (CAA) of resonant operated power electronic circuitry based on a computer algebra system generating input for improved model libraries of PLECS,

b. Design of power electronic and control circuitry based on HV-cascade, R-controller models and generalized averaging techniques. It is supported by a.

c. Design of magnetic components, taking care of intra/inter winding and stray capacitances of high voltage windings and high-frequency effects, using (CAD-MAG)

d. Thermal design using approximate thermal modelling of power semiconductors and magnetic components.

e. The availability of novel macro models for power electronic circuits and characteristics for loaded HV-cascades (b) supporting small and large signal modelling should enable total VLF-generator simulation e.g. for control design, models for magnetic components with respect to electrical (c) and thermal behaviour (d) upgrades PLECS and simulation results.

f. Computer aided optimisation (CAO) of the power circuitry. with respect to selected cost functions which might be efficiency, weight, current and voltage stress of components by applying modern numerical optimisation algorithms.

Validation of models and the tool is by building of selected HVTS demonstrators and DC-sources

The afore mentioned objectives were achieved by implementation of tasks listed below:

-Develop the final specification and duties for HVTS, bidirectional HVTS, DCS and CAD-HVTS-DCS

-Compare various resonant converter topologies for HVTS and DCS-application in resp. to appropriate steady-state and dynamic characteristics, component stresses and efficiency and select the best suitable topology / topologies for each application.

-Built steady-state-, loss- and dynamical- models of the selected topology / topologies, validate those analytic models by utilizing simulation tools and experimental tests.

-Optimize the modulation strategy and output filter structure of the selected topology / topologies.

-Develop the model-based computer aided design and optimization environment and realize the multi-objective optimization.

-Develop model-based classical and modern control schemes for selected resonant converters, implement 3 prototypes and verify modeling by measurements on these prototypes

-Based on the 3 demonstrators the analytical models of the development environment are validated and they show good congruence. Major objectives concerning higher dynamics and high efficiency are achieved for the DCS. Due to the increased serial inductance volume and weight of magnetic components are higher than the current solution. But this can be cut down by switching frequency increase and optimization of magnetic components in the future. A novel bidirectional four-quadrant high-voltage converter was developed. A demonstrator was built to verify the investigation. This technology enables BAUR to reduce the power consumption and dissipation and thereby the goals of reduction of size, weight and costs are reached. The use of CAD-HVTS-DCS enables reduction of costs, design expertise and duration.

Project Context and Objectives:

Due to the soft switching characteristics and the potential to utilize parasitics of the real components and circuit resonant operated power supplies are more and more widely applied. However, in comparison with hard switched standard pulse width modulated (PWM) converters design and optimization of resonant converters is more complex. Hence, especially small and medium enterprises (SMEs) do not apply these converters due to the lack of a development environment.

The major objective of this project is to establish such a development environment aiding computer-aided steady-state and dynamic analysis for selected converter topologies. In combination with a multi objective optimization software (MOPO) the power circuit and control parameters can be designed and optimized.

Another objective is to apply this development environment to develop a new generation of DC source (DCS) with higher dynamics and high efficiency based on resonant converter. This includes topological pre-selection, design and optimization of pre-selected converter topologies. A final decision is made after a model-based topology comparison. A prototype is built to validate models of the development environment.

Testing of buried high-voltage cables becomes more and more important for reliable power grids. The VLF (very low frequency) 0,1Hz technology allows testing of high-voltage cables with much less energy due to a lower test frequency. But, it requires more technical test equipment. BAUR established this technology due to the last years. However the current technology is limited by power dissipation, scalability and weight.

The RPC-HVTS-DCS project aims to solve the challenges by a bidirectional high-voltage converter. A four quadrant high-voltage source is able to reduce power dissipation to a minimum. Energy that is used to load the capacitive cable to its maximum voltage can be feed back to an energy storage during unload of the cable. The polarity changes and the cycle restarts.

For verification and demonstration purposes a demonstrator is developed and built that eliminates the disadvantages of the current technology.

Summary of achievements split into HVTS, Bidirectional HV converter, DCS

HVTS

1)Final specifications, duties and responsibilities for HVTS are established, including the specifications of HVTS prototype, and the specifications of multi-objective design and optimization environment. (WP1/ D.1.b).

2)Compilation of resonant operated power electronic circuit topologies is executed. A comparison methodology is developed for unidirectional resonant converters, considering expected system steady-state characteristics, reactive power compensation capability, control characteristics, overall efficiency and resonant tank complexity. A preferable resonant operated topology among various resonant topologies is selected on the basis of the comparison methodology. (WP2.1.1, WP2.1.2 / D.2.1.1 b).

3)An equivalent circuit of an ideal and real loaded high voltage Cockcroft-Walton generator from power electronics point of view is derived. The corresponding loss model is built, which takes the influence from the boosting and smoothing capacitances, transformer resistance and diode dynamic resistance, diode forward voltage drop and stray capacitances into account. (WP2.1.2 a / D.2.1.1 a).

4)The large-signal model of the preferred resonant topology adopting generalized averaging method and extended describing functions are derived. Based on the latter, the steady-state characteristics, the optimum control-variable combination and the preferable resonant parameters are obtained. (WP2.1.2 b, d, e, WP2.2.1 a / D.2.1.1 b, D.2.2.1 a, b).

5)Loss model of the selected resonant converter including full-bridge inverter, AC inductor, high voltage transformer and Cockcroft-Walton generator is derived. The fundamental magnetic components design and the skin and proximity effect in winding conductors are also taken into account. (WP2.1.2 a, c / D.2.1.1 b)

6)The model-based computer aided design and optimization (CAD and CAO) environment for the selected resonant converter is realized based on the derived large-signal model and loss model. The resonant parameters study is executed for multi-objective optimization, the corresponding Pareto front regarding selected objectives are obtained. Such CAD and CAO environment can automatically realize the resonant converter design and optimization under given design specifications and is ready to be adopted by the manufacturer BAU. (WP2.1.2 f, WP2.1.3 / D.2.1.1 c).

7)Modular structure for compact HVTS is studied. Based on the compilation of various multiplier circuits, three preferable multiplier circuits with less component, improved steady-state and dynamic characteristics, are selected. Multi-module series-connected multiplier circuit for high voltage application and multi-module parallel-connected multiplier circuit for high power application are researched and concluded. (WP2.1.4/D.2.1.2).

8)Based on large-signal model, a linearized small-signal model of the preferable resonant topology is derived. An experimental test was successfully implemented to verify the derived small-signal model. (WP2.2.1 / D.2.2.1 a, b).

9)Based on the small-signal model, three kinds of current-mode controller: conventional linear PI control, fuzzy PD control and model-based fuzzy control are developed for HVTS.

The expected simulated closed-loop results were obtained, and the comparison between them was implemented. (WP2.2.2 D.2.2.2 a, b).

10)Analogue R-Controller concept and its small-signal model and corresponding dynamic characteristics based on a given operating point are studied. A cascaded two closed loop is built for such model and executed in MATLAB-PLECS, bode plots and corresponding dynamic characteristics are obtained. Reliability of analogue R-controller is also discussed on a simplified bases, since failure data is not available by BAU. (WP2.4 / D.2.4).

DCS

Development environment: In order to achieve those objectives stated above a development environment incl. four fundamental functional modules (steady-state analysis, dynamical analysis, semiconductor loss analysis, model-based converter design and optimization) and two auxiliary modules (visualization, comparison) are developed. All function blocks are implemented in M-language under MATLAB. Modular and extensible structures facilitate the maintainability and extensibility of the development environment.

Development of a new generation of DCS: For developing the proposed new generation of DC sources models of all preselected converter topologies, incl. standard 2-level phase-shifted full bridge (2L-PSFB), 3-level phase-shifted half bridge (1P3L-PSHB), 3-phase 3L-PSHB (3P3L-PSHB), series-parallel resonant converter with LC output filter (SPRC-LC) and 2-stage bidirectional solution with series resonant converter and buck-boost converter operated in triangular current mode (SRC-BBC) are implemented in the development environment. Model-based converter design, optimization and comparison are performed. Comparison results show that SPRC-LC topology operated with optimized modulation strategy (combined frequency and duty-cycle to achieve zero voltage switching for one leg and zero current switching for the other leg) is the best suitable topology for the proposed application.

Due to the relative large deviation of the standard extended describing function (EDF) method according to E. X. Yang, a novel dynamical model considering the real discontinuous voltage waveform on   is developed, which is validated by simulations. Based on the novel dynamical model control parameters are designed and optimized using classic loop gain method in the frequency domain. Due to the strong nonlinearity of the SPRC-LC a gain scheduling method is adopted for control parameter adaptation.

Demonstrator and validation: Based on a demonstrator analytical models of the development environment are validated and measured results show good agreement in the electrical part. The major requirements of higher dynamics and high efficiency are achieved. However, due to the increased serial inductance volume and weight of magnetic components are higher than the current solution, resulting in higher costs. In order to improve its economical efficiency methods for methods for magnetic component cut down shall be investigated in the future.

Bidirectional HV-Converter

Summary of achievements

Comparison of different resonant power circuits for bidirectional HV-Converter: Different power converter schemes were evaluated for setting up a bidirectional VLF generator. For the selected topologies fundamental harmonic analysis (FHA) was performed. Further on time-based simulations verified the FHA. The best suitable topology was selected to design a novel bidirectional high-voltage four quadrant source.

Development of high-voltage and control components: In order to realize the selected converter topology in a demonstrator a large variety of high voltage components, auxiliary circuits for isolation, gating, symmetrizing, snubbing had to be adapted to realize the new concept, supplemented by the development of communication firmware for the microcontrollers and actuator and sensor addressing by a DSP system. Different mechanical designs were compared by a CAD system. The best suitable one was selected for the demonstrator as shown by photo.

Initial start-up and tests: Step by step the commissioning of the demonstrator was performed. The four quadrants of the voltage-current diagram were extensively tested in characteristic steady states. Controls were implemented in the DSP to enable the output of a sinusoidal 0,1Hz test voltage.

WP3 a) The largest markets for the HVTS-VLF technique are located in Far East/Asia and America followed by the Commonwealth of Independent States and Europe.

WP3 b) Most of the Transmission System Owners are in the USA (617) followed by Germany (950) and Switzerland (800).

The owners are all potential buyer of the HVTS-VLF technique. The biggest three competitors are Seba KMT (competitor worldwide), Megger (weak position in the German market) and High Voltage (dominant provider in the USA).

WP 3c) The price for the product should be less than 600.000 US$. An installation in a regular transporter should be desirable (equipment must be considerably lighter than the permitted payload). Voltage level up to standard high voltage cables (130 kV) has great prospects today and for the future.

WP 3d) HVTS modules like the TopCon power unit can be used in rail technologies, pulse test methods, magnetic sweeping or radar units.

WIT

The dependence of parasitics on second order parameters make them susceptible to dramatic variations when small changes in the underlying parameters are present. This is often brought on by the manufacturing tolerances of wires and isolation materials. To accurately model this requires an intimate knowledge of a large number of constructional parameters. This makes the models complex and computationally expensive if not impossible to evaluate. The proposed approach is to make use of experimentally determined coefficients for analytical models of parasitic capacitances. For losses the use simple 2D-FEM analysis of the magnetic distribution in a window cross section is recommended to determine coefficients for analytical loss models, where simple approximations no longer hold.

Project Results:

The main results are split into the 3 areas of application HVTS- DCS and bidirectional converters.

HVTS

WP 1 / D.1

Final specifications, duties and responsibilities for HVTS are established, including the specifications of HVTS prototype, and the specifications of multi-objective design and optimization environment (WP1/D.1.b). UPB-LEA coordinated these activities and provided the required documents.

WP 2.1.1 / D.2.1.1 b

Compilation of resonant operated power electronic circuit topologies is executed. Since resonant converters are well-known to be appropriate topology for high voltage application, the series resonant converter, parallel resonant converter, LLC resonant converter, LCC resonant converter and LLCC resonant converter are taken into account for the topology compilation regarding investigation of steady-state characteristics, parasitic integration capability, soft-switching operation region, control characteristics and topology complexity.

After detailed investigations and comparison, conclusions can be drawn that:

1) series resonant converter shows limited voltage conversion ratio and poor control characteristics for light load situation;

2) parallel resonant converter has poor control characteristics for full load situation;

3) LLC resonant converter has limited operating region in over-resonance zero-voltage-switching (ZVS) region;

4) LCC resonant converter has wide operating region regarding variable output voltage, power and load range; a well designed LCC resonant converter enables integration of the parasitics of transformer and multiplier circuit; LCC converter has an inherent short circuit protection;

5) compared with LCC resonant converter the more complex LLCC resonant converter has similar steady-state characteristics and operating region, the preferable local reactive power compensation capability unfortunately cannot be adopted for HVTS application; the suggestion of selecting the resonant frequency as the only operating point (e.g. fsn=1) is

infeasible, since the harmonics in the resonant current cannot be eliminated and the resulting increasing of n (transformer turns ratio) and k (CW stage number) are not preferable for HVTS application.

In summary, the LCC resonant converter has clearly turned out to be the most appropriate topology for HVTS application.

WP 2.1.2 a / D.2.1.1 a

An equivalent circuit of an ideal and real loaded high voltage multiplier rectifier circuit named Cockcroft-Walton (CW) or Greinacher cascade is derived from power electronics point of view. The corresponding loss model is built, which takes the influence from the boosting and smoothing capacitances, transformer resistance and diode dynamic resistance, diode forward voltage drop and stray capacitances into account.

The equivalent circuits of an ideal and real loaded three-stage ($k=3$) CW-multiplier are shown below, respectively. The input voltage of CW-multipliers are $U_p \cos(\omega_s t)$, among which U_p is the amplitude of the quasi-sinusoidal output voltage from the resonant tank, ω_s is the switching frequency. n is the voltage turns ratio of the high voltage transformer, k is the stage number of the CW-multiplier. U_o is the specified output voltage of the CW-multiplier. C_{si}, C_{gi} ($i=1,...k$) are boosting and smoothing capacitance for each stage. D_{igs}, D_{isg} ($i=1,...k$) are ideal diodes between boosting and smoothing route for each stage with conducting direction from smoothing to boosting, or boosting to smoothing, respectively.

Equivalent circuit of (left) an ideal and (right) a real loaded HV CW multiplier

WP 2.1.2 b, c, d, e / D.2.1.1 b, D.2.2.1 a, b

The large-signal model of the LCC resonant converter adopting generalized averaging method and extended describing functions are derived. The verification through simulation and the steady-state characteristics regarding normalized switching frequency f_{sn} and duty cycle d are shown below, respectively.

Circuit diagram of simplified LCC resonant converter

Voltage conversion ratio of LCC resonant converter vs. (left) normalized fs and (left) duty cycle d

The component stress depends on the specified operating point and resonant parameters. Figures below show the relationship between resonant capacitor's ratio   and the component stress with same operating point. It is obvious that larger resonant capacitor's ratio results in lower component stress for the same operating point.

Relationship between component stress and resonant capacitor's ratio with the same output power or same output voltage under optimum fs-d combination line (Us is the peak value of the voltage across series capacitor Cs, Is is the peak value of the resonant current through series inductor Ls, Cp is the parallel capacitor)

The loss model of the LCC resonant converter consists of four parts, such as full-bridge inverter, CW multiplier circuit, magnetic components (AC inductor Ls and HV transformer), and series capacitor Cs. In summary, they are briefly described below:

-Loss model of full-bridge inverter under optimum fs-d combination:

Among which, IMrms is the rms-current flowing through transistor, IDrms and IDavg is the rms and average current flowing through the parallel diode, RDSon is the transistor´s on-resistance and RD is the forward resistance of the diode, VF is the diode forward voltage, and Psw is the switching loss of the transistor.

-Loss model of CW multiplier circuit normally indicates the voltage drop in CW multiplier, which depends on the output current Io, boosting and smoothing capacitors, switching frequency fs, and stage number k. As an approximation, the voltage drop UCW_drop can be represented as (C is the equivalent capacitor for boosting and smoothing route):

-Loss model of series capacitor Cs. where tanδ is the capacitor´s loss factor.

-Loss model of magnetic components, such as AC inductor Ls and HV transformer, is derived according to basic magnetic knowledge. The following three aspects are considered: core loss Pfe, low frequency copper loss Pcu and incremental effect due to skin and proximity effect in high frequency high current application.

-Loss model of the series capacitor Cs. where tanδ is the capacitor loss factor.

WP 2.1.2 f, WP 2.1.3 / D.2.1.1 c

Based on the derived large-signal model and loss model of LCC resonant converter, a computer aided design and optimization (CAD & CAO) environment is developed in CAMEL-VIEW-MOPO (iXtronics Co.). Since resonant current amplitude ILP and voltage drop in CW multiplier UCW_drop are critical variables, which determines the component stress, losses and indicates the wasteful cost, both of them are selected as the optimization objectives. The resulting multi-objective optimization process is shown below.

Multi-objective optimization procedure of LCC resonant converter

Through resonant parameters study, the graphical results regarding decision variables and Pareto front regarding two-objectives are obtained, as shown below. For such research, the transformer turns ratio n and CW multiplier stage number k are fixed through preliminary study.

Such CAD and CAO environment can be directly adopted by customer (e.g, BAUR Co.) and are beneficial for product performance improvement, cost reduction, and time to market.

Graphical results, two dimensional illustration and Pareto front of LCC resonant converter in decision variables' range: Cs=100-800 nF, Cp=10-220 nF, Ls=100-1000 µH, n=7, k=2

WP 2.1.4 / D.2.1.2

After study of five different single units of multiplier circuits:

1) classical asymmetrical CW multiplier,

2) classical symmetrical CW multiplier,

3) simplified symmetrical CW multiplier,

4) Delon circuit and

5) bipolar CW multiplier, the simplified symmetrical CW multiplier, Delon circuit and bipolar CW multiplier circuit turned out to be the appropriate units for compact HVTS, since they need less components and show better steady-state and dynamic characteristics compared with the classical CW multiplier circuits.

And these three kinds of multiplier circuits are further considered for the compact modular structure HVTS.

Through the study of multi-module series-connected multiplier circuits, which is potentially applicable for high voltage application, the following conclusions are drawn:

1) Modular structure HVTS consisting of simplified symmetrical CW generator has lower transformer stress, but higher capacitance stress;

2) Modular structure HVTS consisting of Delon circuit has higher transformer stress, but lower capacitance stress;

3) Modular structure HVTS consisting of bipolar CW generator shows medium transformer stress and capacitance stress;

-4) Diodes stress of all three types of modular circuits are the same.

5) The output voltage in series-connected modular circuit is m (modular number) times of that in the single unit.

Through the study of multi-module parallel-connected multiplier circuits, which is potentially applicable for high power application the following conclusions can be drawn:

1) The component stress in parallel-connected modular circuit is the same as that in the single unit;

2) The output current in parallel-connected modular circuit is m (modular number) times of that in the single unit.

WP 2.2.1 / D.2.2.1

Based on the large-signal model, the linearized small-signal model of the LCC resonant converter is derived and experimentally verified.

Below shown are the small-signal equivalent circuit model of LCC resonant converter and the experimental verification results of control-to-output transfer functions.

Small-signal equivalent circuit model of LCC resonant converter and experimental verification of control-to-output transfer functions comparison: (blue) control variable is d. fs=40kHz, (red) control variable is fs. d=0.95.

WP 2.2.2 / D.2.2.2

Based on the small-signal model and the analysis of dynamic characteristics, a cascaded two closed-loop control is developed. The inner is a current-mode control for regulating the resonant current. Three kinds of controllers are investigated: conventional linear PI controller, fuzzy PD controller and model-based fuzzy controller. For the outer loop a conventional PI controller serves for output voltage regulation. Simulated results in a small operating region are provided below. For a large operating region, it is expected that the fuzzy PD and model-based fuzzy control show superior behavior compared with the linear PI controller. Because of space limitation, the experimental verification on the scaled-down prototype is not given here.

Simulated results of current-mode controller with square-wave or sinusoidal reference: (left) with PI controller; (middle) with fuzzy PD control; (right) with model-based fuzzy control.

From above given results the following conclusions are drawn:

-Linear PI current-mode controller has acceptable control performance considering the settling time, overshoot and steady-state error.

-Fuzzy PD controller has an obvious steady-state error, but it can be avoided using an adaptive gain in large operating region.

-Compared with linear PI controllers, model-based fuzzy controller has no overshoot, shorter settling time and it shows better performance in large operating regions.

Photography of scaled-down HVTS prototype

WP 2.4 / D.2.4

Analogue R-controller concept and its small-signal model and corresponding dynamic characteristics based on a given operating point are studied. In order to get a sinusoidal output voltage, the R-controller consisting of series-connected transistors is adopted and operated as an electric load for discharging the output voltage.

According to the datasheet of the selected transistor and specified operating point, the capacitances, transconductance of the transistor are known. Referring to unified transistor model and Miller's theorem, an equivalent small-signal circuit model is derived. A cascaded two closed loop control is built for such model and executed in MATLAB-PLECS, bode plots and corresponding dynamic characteristics are obtained.

Reliability of analogue R-controller is also discussed, but such research should base on an experimental test or enough field data, which is not available at BAU. Supplementary work on the R-controller concentrates on the appropriate transistor selection, optimal number of series connected transistor determination.

DCS

Overview and Objectives

Due to the soft switching characteristics and the possibility to utilize parasitics of components and circuit resonant operated power supplies enable higher dynamic performance and efficiencies at light to medium loads. These properties qualifies them to be applied at todays requirements. However, in comparison with standard pulse width modulation (PWM) converter design and optimization of resonant converters are more complex. Especially for small and medium size enterprises (SMEs) it is very difficult to carry out optimal designs for resonant converters without a development environment.

Hence, a major objective of this project is to establish such a development environment. Under this development environment computer-aided steady-state and dynamic analysis for selected converter topologies can be performed. In combination with MOPO the power circuit and control parameters are designed and optimized.

The 2nd main objective is to apply this development environment to develop a new generation of DC source with higher dynamics and high efficiency based on resonant converter, incl. topological pre-selection, design and optimization of pre-selected converter topologies. Final decision is made utilizing a model-based topology comparison. A demonstrator is finally built to validate models in the development environment and experience the latter.

Development environment

Over view of the development environment

Four fundamental function modules are involved in the development environment:

-Steady-state analysis

-Dynamical analysis (large-signal and small-signal analysis)

-Semiconductor loss analysis

-Model-based converter design and optimization

Besides those fundamental modules two auxiliary modules for visualization and comparison are developed.

For each particular converter topology and its operation condition (incl. parameters, operation point) the electrical steady-state and dynamical characteristics are calculated firstly. The calculated electrical values (e.g. mean and RMS current through transistors and diodes, instant current and voltage at turn-on and turn-off instance, etc.) are input to semiconductor losses models. All computation results can be saved and visualized by the visualization module. Objective function can be built from those computational results and input to the multi-objective parameter optimization tool MOPO, which optimizes the converter parameters numerically using quasi Newton method. It should be noted that the optimization results are strongly depending on the selection of objective function. However, sometimes it is not so easy to decide which objective function suits best the individual design requirement. Hence, a comparison module for comparing specified characteristics (e.g. switching frequency, semiconductor losses, etc.) of different designs or different converter topologies is provided in this development environment.

All function blocks are implemented in M-language under MATLAB. Modular and extensible structures are applied to ensure the maintainability and extensibility of the development environment.

Implemented converter models

Within this project steady-state, dynamical and semiconductor loss models for standard 2-level phase-shifted full bridge (2L-PSFB), 3-level phase-shifted half bridge (1P3L-PSHB), 3-phase 3L-PSHB (3P3L-PSHB), series-parallel resonant converter with LC output filter (SPRC-LC) and 2-stage bidirectional solution with series resonant converter and buck-boost converter in triangular current mode (SRC-BBC) are developed according to the following state-of-the-art modeling techniques:

*For PWM converters:

-Steady state models: current balancing of inductors and voltage balancing of capacitors

-Dynamical models: state space average

*For resonant converters:

-AC fundamental analysis and extended AC fundamental analysis

-Extended describing function (EDF) method

*Semiconductor loss models:

-Conduction losses: interpolation of linearized output characteristic of IGBT and forward characteristic of diodes at particular junction temperatures

-Switching losses: look-up table (LUT) using instant current and voltage at switching actions for hard switching, neglecting soft switching losses, rough calculation of losses by hard switching with regenerative snubber by using a loss reduction factor

Model-based converter design under this development environment

The main objective of this work block is to develop a new generation of DC source (DCS) with higher dynamics under this development environment. . This work block is performed in two phases:

-Model-based converter design and comparison

-Small-signal analysis and control design

Model-based converter design and comparison

Comparison and selection of topology for a specific application is one of the most critical works for power converter development. Unfortunately this work is mostly done through a qualitative comparison based on experiences of engineers and/or published references. This comparison is usually efficient for a topology pre-selection, but not sufficient for a final decision, because a successfully applied converter topology in one particular case does not mean that it is also the best solution in another one. For a final decision a quantitative comparison is required in a rigorous design procedure.

Before a quantitative comparison all candidate converter topologies shall be designed and optimized according to an identical objective, in order to achieve a fair comparison. For simple converter topologies, e.g. hard switched PWM converters, their design and optimization is relatively easy using manual or simulative approach. For resonant converters, due to its design complexity a CAD-approach In conjunction with a numerical multi-objective multi-parameter (MOMP) optimization is required. This optimization cannot be performed based on simulations, because such simulations of are too time-consuming. Hence, an analytical model-based converter design, optimization and comparison are required.

Step 1: Pre-selection of converter topologies and strategies for operation

This critical stage is initiated by an analysis of technical requirements and current solution, the latter serving as reference. Limitation and drawbacks of the current solution and improvement potential through applying new circuit topologies and/or new operation strategies are studied.

Partner REG requires higher dynamic performance compared to the reference solution, good efficiency and power density. The boundary condition resulting from DCS-applications is the extreme wide operation range of and. In order to achieve higher dynamics the determining output filter must be reduced by increasing the switching frequency or using interleaving technique. Unfortunately using the current 2L-PSFB topology it is not possible to increase the switching frequency without loss in efficiency, because zero voltage switching (ZVS) is lost at light load conditions and regenerative snubbers cannot be employed for the lagging leg. The reduction of switching losses is thus a major objective for topology selection.

The first possible topology is 1P3L-PSHB, which operates identically like the 2L-PSFB. Due to its 3-level structure IGBTs with lower reverse voltage can be employed and turn-off losses can be reduced. However, due to the doubled current conduction losses are increased. The question arrises, whether the increased conduction losses can be completely compensated by the reduced switching losses even at a higher switching frequency?

The second possible solution is to apply interleaving technique, e.g. 3P3L-PSHB. Since the filter frequency is three times the switching frequency it is possible to reduce the output filter without increasing the switching frequency. Another advantage of this topology is that the current of each phase is only one third of 1P3L-PSHB, which reduces the overall semiconductor conduction losses. Disadvantage of this variant is the more complex power circuitry (power electronics, transformer, etc.) and much higher installed semiconductor apparent power, yielding higher costs.

A completely different solution is the use of resonant converters. A pre-comparison of steady-state control characteristics yields the SPRC-LC as the most qualified among different resonant converter topologies. Due to its ZVS character in the total operation range the switching losses can be strongly reduced, especially if regenerative snubbers are employed for reducing the switch-off losses. Compared to 3P3L-PSHB the power circuit of SPRC-LC is much simpler. However, a big challenge of classical frequency-controlled (duty cycle equals one) SPRC-LC in this particular application is the extreme wide operation range, which implies a very large variation of switching frequency is required. If we use duty cycle control (at fixed switching frequency) ZVS condition cannot be ensured in the total operation range. Hence the questions arise: Can this critical problem be solved by an optimized modulation strategy? And can the known disadvantage of a relative higher amplitude of the primary current, which increases the conduction losses be compensated by the reduced switching losses even at a higher switching frequency?

Obviously all those questions listed above cannot be answered by performing a qualitative comparison. A model-based quantitative comparison is required for a final topology selection.

Step 2: Model-based converter design and comparison

For a quantitative comparison both PWM converters (1P3L-PSHB and 3P3L-PSHB) are designed to operate at the same switching frequency (20 kHz) as the reference 2L-PSFB. Parameters of passive components and semiconductor switchers are designed according to the technical specification.

The SPRC-LC is designed using analytical models of the development environment. The worst case for the converter design is maximum output power fed by a minimal input DC voltage. Hence, the following objectives are considered in the converter design and optimization:

a)The converter can operate in the whole operation range by a minimum input voltage of. Two critical operation points are and, which are checked in the optimization routine.

b)Minimize the semiconductor losses and resonant current stress.

c)Maximize the switching frequency for achieving the higher dynamics requirement.

Since b and c are conflicting objectives a trade-off optimization shall be conducted.

As a SPRC-LC can be controlled both by switching frequency and duty cycle, we obtain an additional freedom to achieve a better steady-state and dynamical characteristics through optimizing the modulation strategy. Compared to the classic frequency modulation we can achieve ZVS in one leg and zero current switching (ZCS) in the other leg by using optimized modulation strategy. Hence, the switching losses of ZCS-leg and the turn-on loss of ZVS-leg can be almost eliminated. Since the ZVS switching condition in ZVS-leg can be ensured by a special state machine implemented in a field programmable gate array (FPGA), the turn-off loss of ZVS-leg is also strongly reduced by employing purely capacitive snubbers. A switching frequency range of about 45 kHz to 210 kHz is required by using classic frequency modulation, which is unrealistic for practical implementation. While by using optimized modulation only a switching frequency range of about 40 kHz to 90 kHz is required. Another advantage of the optimized modulation strategy is the reduction of resonant current and semiconductor loss. Hence, optimized modulation strategy is selected as key feature for our application.

After design and optimization of all candidate topologies a model-based comparison is performed under the development environment. Comparison results show that SPRC-LC has low semiconductor losses and low RMS resonant current even at much higher switching frequency.

Step 3: Final power circuit design

In the final power circuit design the parameters are slightly adopted considering the component availability. After parameter adaptation converter characteristics are checked again using the development environment and analyzed in more detail using simulation tool PLECS.

Innovative dynamical modeling and control design for SPRC-LC

By developing a dynamical model for SPRC-LC it turned out that the classical EDF method according to E. X. Yang shows a large deviation, if the voltage across   is discontinuous. The reason is that the standard EDF method assumes all current and voltage waveforms of the resonant tank to be sinusoidal. In continuous   voltage mode (CVM) all current and voltages in resonant tank are of nice sinusoidal shape. However, in discontinuous   voltage mode (DVM) the voltage across strongly deviates from the sinusoidal shape. Results in design optimization show that in order to reduce reactive power, resonant current and switching losses a large part of the operation range should be operation in DVM.

In order to solve this problem and to describe the dynamical behaviors more accurately, a novel EDF model for SPRC-LC is developed. Here the voltage on is not assumed to be sinusoidal and is not considered as an independent state variable, but a function of and. Instead of an approximated output voltage, in the novel model it is calculated by the real voltage waveform across, which is suitable for CVM, boundary condition and DVM. Simulative comparison results show a big deviation of the classical EDF model and a very good agreement of the novel EDF model.

Perturbing the novel large-signal model at steady-state operation a small-signal model is deduced. Control parameters are design and optimized using classic loop gain method in the frequency domain. Due to the strong nonlinearity of the SPRC-LC gain a scheduling method is adopted for control parameter adaptation.

Prototyping and validation

Based on a SPRC-LC demonstrator analytical models of the development environment are validated. As an example the validation of the control characteristic, which shows a very good agreement. Optimized modulation is realized in both operation modes.

Conclusion and outlooks

Within this project a model-based development environment for converter design, optimization and comparison was developed, which was successfully applied in developing a new generation of DC sources. The major requirements of higher dynamics and high efficiency are achieved. However, due to the increased serial inductance volume and weight of magnetic components are higher than the current solution. In order to improve its economical efficiency methods for optimization of magnetic component shall be investigated in the future.

Table 1: Converter parameters of 2L-PSFB, 1P3L-PSHB and 3P3L-PSHB

Topology	n = N2 / N1	Ls	Lout	Cout	IGBT module	Rec. diode
2L-PSFB	19:17	3.5 µH	0.3 mH	82 µF	1200 V / 200 A	1200 V / 100 A
1P3L-PSHB	38:17	0.875 µH	0.3 mH	82 µF	600 V / 400 A	1200 V / 100 A
3P3L-PSHB	38:17	7.875 µH	0.1 mH	37 µF	600 V / 150 A	1200 V / 50 A

Table 2: Optimized SPRC-LC parameters

Passive component	Commutated parameter	Implemented parameter
n = N2 / N1	9 : 10	9 : 10
Ls	49.068 µH	46 µH
Cs	482 nF	484 nF
Cp	214.2 nF	220 nF
Lout	120 µH	120 µH
Cout	32.8 µF	33 µF

Bidirectional HVTS (WP 2.1.5, WP 4, WP 5)

Overview and objectives

Testing of buried high-voltage cables becomes more and more important for reliable power grids. The VLF (very low frequency) 0,1Hz technology allows testing of high-voltage cables with much less energy due to a lower test frequency. But, it requires more technical test equipment. BAUR established this technology during last years. However the current technology is limited by power dissipation, scalability and weight.

The RPC-HVTS-DCS project aims to solve the challenges by development of a bidirectional high-voltage converter. A four quadrant high-voltage source is able to reduce power dissipation to a minimum. Energy that is used to load the capacitive cable to its maximum voltage can be fed back to an energy storage during unload of the cable. The polarity changes and the cycle restarts.

For verification and demonstration purposes a demonstrator is developed and built that eliminates the disadvantages of the current technology.

Today's technology

Two separate high voltage sources for each polarity load the capacitive cable through the current controllers. The current controllers consist of cascaded transistors with a direct current control. During unloading of the cable the energy stored in the cable will be dissipated in the current controllers. Since the current controllers are high-voltage components they are placed together with the high-voltage sources in a high voltage tank built of steel or aluminum. The tank must be able to dissipate the heat generated in current controllers. These facts result in heavy generators. If the energy stored in the cable could be recycled to the low-voltage side (back to the DC link) it could be stored for the next test cycle. This is the goal for the HVTS bidirectional part in project RPC-HVTS-DCS.

Research on bidirectional HV-converter structures (D2.1.3a, b, c)

Known high- to low-voltage converters are used in high-voltage direct current transmission. Due to its extreme high power ratings this technology is not applicable for VLF generators. VLF generators need a small converter facilitating high voltage but at low current. For this reason different power converter schemes were evaluated for use in a high-voltage environment. For the selected topologies fundamental harmonic analysis (FHA) were performed. Further on time-based simulations verified the FHA. The best suitable topology was taken to design a novel bidirectional high-voltage four quadrant source.

Research and development of HV-components (D4c, D5a,b,c)

Since the novel bidirectional topology differs completely from today's VLF generators a variety of new components and functional blocks had to be designed and tested. This relates to all components placed in the high-voltage tank. Firmware had to be implemented in a few microcontroller based boards for control and measurement purposes. Even a new high-voltage tank was designed after mechanical design studies performed by a CAD system showed its advantages compared to the current VLF generators.

Initial start-up and tests (WP6, D6)

Step by step the initial start-up of the demonstrator has been performed. At first the communication firmware for the microcontrollers has been tested. All actuator and sensor signals are processed by a DSP-system. The four quadrants of the voltage-current diagram were extensively tested at characteristic steady states.

UHV in kV	IHV in mA	UZK in V	IZK in A	Pin in W	Pout in W	η in %
10	1,4	93	0	14	0	0%
10	5	39,6	0,89	50	35	70%
10	10	36,8	2,11	100	78	78%
10	15	34,9	3,32	150	116	77%
10	20	33,1	4,5	200	149	74%
10	25	31,2	5,77	250	180	72%
10	30	29,5	6,94	300	205	68%
10	35	27,7	8,14	350	225	64%
10	40	25,7	9,45	400	243	61%

An external high-voltage power supply was used to feed a constant voltage of 10 kV to the bidirectional converter. Through variation of the load on the low-voltage side different power points of the converter could be tested. A maximum efficiency of 78% was reached as compared to zero of the current solution.

Based on the properties of the chosen converter type the relation of the input to the output voltage should be constant. This can be explained by the resulting equivalent resistance.

In spite of the non-linear behavior of the output voltage versus HV-current the output current is nearly linear-dependent of the HV-current. The gradient implies the conversion ratio of the selected converter type. This relation is used for the control structure to generate a sinusoidal high-voltage output voltage.

A maximum efficiency of 78 % was attained at a high-voltage input current of 10 mA. At a lower input current the voltage-depending losses dominate. At higher input currents the resistive-depending losses dominate. The efficiency can be increased by a better selection of components. For this demonstrator only standard components were used.

Tests with VLF output (WP5, WP6, D6)

Initial tests have been conducted with controls being implemented in the DSP to enable the output of a sinusoidal 0,1Hz test voltage. The tests have been performed with a 600 nF capacitive load. The red line is the voltage at the test object. Its maximum is at about 10 kV. This line is almost sinusoidal. The current (green) has some deviations to the desired current (blue). Shown deviations can be minimized by improvements of the control strategy.

Summary

A novel bidirectional four-quadrant high-voltage converter was developed. A demonstrator has been built to verify the investigation. This technology enables BAUR to reduce power dissipation and thereby the goals of reduction of size, weight and costs are met.

WIT

Parasitic models for the magnetic components used in the HVTS and DCS applications were envisioned for this work package.

Capacitance models

The presence of very high voltages and the use of large numbers of turns to achieve large winding ratios, leads to a rise in the significance of the parasitic capacitances in the wound magnetic components

A literature survey of models for parasitic capacitance of wound components yielded no models suitable to accurately predict the parasitic capacitance of a winding based only on material, geometrical and constructional parameters. An investigation into the reason for this yielded the insight that the total parasitic capacitance is extremely sensitive to geometrical variations and constructional variations. This effect is compounded by the large numbers of turns required in high voltage applications. Normal tolerances in the material geometries (eg. wire diameter) alone, can easily lead to more than 40% variation in the predicted capacitance values. This effect was confirmed by extensive parametric FEM analysis.

Additional constructional tolerances, arising from process and material variations, compound this effect even more. This effect was again confirmed by extensive parametric FEM analysis. The wide variations reported in the literature between experimentally measured values of parasitic capacitances and the values predicted by the proposed models, is hereby readily explained.

Only accurate knowledge about the exact geometrical placement of each wire-turn in the wound component will make accurate calculation possible. It is therefore impossible to derive an analytical model, based on only a small number of parameters, to accurately predict parasitic capacitance. An FEM approach for capacitance calculation where large numbers of turns per winding are involved is computationally too expensive to employ in an optimisation loop where repetitive evaluation is required.

The suggested approach to deal with this problem is to assemble samples from the same materials and employing the same construction methods as in the final components. From the samples coefficients can be derived that can be used to calibrate the published models.

Loss models

In all high-frequency switch-mode converters the high-frequencies currents lead to additional losses over and above the DC losses. This impacts the efficiency of the converters and gives rise to heating which requires additional cooling of the final product. Designers of such equipment are always seeking for simple analytic models that will correctly and accurately predict the losses under various operating conditions.

A literature survey turned up some promising methods. These were used to predict losses in various wound magnetic components. This was undertaken for various permutations on small (E-30 based) wound components. This included foil and solid-wire windings as well as transformer and inductor configurations with and without air-gaps in the core. The predictions from the models were validated experimentally and in many cases satisfactory correspondence was achieved. Analytical models were/preferred chosen because of their relatively low computational requirements. This is important as the intended application is to include the loss models in the overall optimisation loop. This comes at the price of accuracy due to approximations required to keep the mathematics tractable.

This was repeated on wound components for the prototype bi-directional converter. Again the analytically predicted losses were validated experimentally, under both high and low excitation conditions. For the cases where the magnetic components can be considered to be operating primarily as an inductor or a transformer, the models show satisfactory performance. For the cases where the component operates as transformer-inductor combination, i.e. more of a coupled inductor, then the simple analytic loss models are no longer very good and a different approach needs to be applied.

In such a case a 2-D finite element model approach should be applied to obtain a rough understanding of the complex field distributions and then this used to determine the eddy current loss in the windings.

The results are best summarised in the table below.

Foil windings Litz wire windings

Inductors with air gaps Inductor Ls

Empirical factor approach completed

2D magnetostatic FEM based outstanding

Transformers HV transformer Tx

Wide and low frequency approaches completed

Undriven shield layer effect HV transformer Tx

Wide frequency approach completed

Transformers with air gaps Inductor Lp

2D magnetostatic FEM based and air gap outstanding Inductor Lp

2D magnetostatic FEM based and air gap outstanding

Suggestions for improved loss modelling are summarised in the previous table. With the increased processing power of modern computing devices it will in the future be feasible to do a simple 2D FEM analysis of a basic window cross section, in order to derive coefficients for analytical models. This will significantly enhance the accuracy of the loss predictions beyond what can be obtained from purely analytical methods.

Conclusion

The dependence of parasitics on second order parameters make them susceptible to dramatic variations when small changes in the underlying parameters are present. This is often brought on by the manufacturing tolerances of wires and isolation materials. To accurately model this requires an intimate knowledge of a large number of constructional parameters. This makes the models complex and computationally expensive if not impossible to evaluate. The proposed approach is to make use of experimentally determined coefficients for analytical models of parasitic capacitances. For losses the use simple 2D-FEM analysis of the magnetic distribution in a window cross section is recommended to determine coefficients for analytical loss models, where simple approximations no longer hold.

HNI

Within the work package WP 3.1 the following results were achieved:

a. The worldwide market volume at a voltage level from 150-250 kV is relatively low: about 100.000 km cable run in the ground. At a voltage range beyond 50 kV the market volume is much higher: in this range about 500.000km cables are in the ground worldwide. These high voltage cables are mainly tested with resonance testing equipment which is sold for approximately 800.000 EUR. A test including the personnel costs, the mounting and dismounting of the device is offered by KEMA or IPH Berlin (service providers) for about 20.000 EUR. The resonance testing equipment enables to test cables up to 200 kV with each of these devices. Typical tests of high-voltage power lines (110 kV) with resonance testing equipment: In factory at 3 x U0; after construction at 2,5 x U0; tested cable length vary between 40 m and 11 km.

b. The regional distribution of the worldwide high and extra-high voltage power lines

The largest markets for the HVTS business are therefore located in Far East/Asia and America - followed by the Commonwealth of Independent States and Europe with a considerable margin. Far East/Asia and America own the most high-voltage cables. In addition to that they are also still most active at building new ones.

c. Nine resonance testing equipments (technology to be substituted) are in use in Germany, two in the USA and two in Switzerland. The USA has the most Distribution Network Owner (2440) followed by Germany (950) and Switzerland (800). The owners are all potential buyer of HVTS-VLF technique. In this overview china is missing because of its centralized organization and structure.

d. The competition analysis focuses on three market segments which are important in respect to the HVTS technology for the considered company. These are the market segments cable fault detection (CFD), cable testing and diagnosis (T&D) and services regarding cable testing (service cable). The companies which were part of the competitors' analysis are differing a lot concerning their regional appearances and their market performance portfolios. C1 and C2 are the current main competitors in the business area of cable fault location and testing and diagnosis. Half of the competitors are expected to increase their degree of competition.

e. The two competitors C13 and C14 are groups of companies: C13 covers cable manufacturers and C14 includes service providers. These groups are considered because these companies could expand their business and become strong competitors. Companies manufacturing resonance testing units will become competitors when the HVTS-VLS technique is ready for the market.

f. A useful method to visualize trends is a trend radar. Altogether 24 relevant trends were identified. The trends with the highest probability of occurrence and impact on the energy industry are "Smart grids", "E-Mobility", "Electricity from renewable energy" and "Availability of resources".

g. Regarding test and diagnosis using the VLF technique voltage levels of approximately 130 kV have been approved. Generally VLF tests and diagnostics are practicable from 69 kV as there are no standards or restrictions. The regarded company could be a pioneer in this section and could set the standards based on their own competences.

h. The result of the trend and technology mapping shows, that the HVTS VLF technology has a good chance to be a market success. Using the list of requirements, the considered company is qualified to develop a promising product.

For work package WP 3.2 the following tasks have been completed:

a)Above all, for the power units next generation new scopes of application were identified.

b)Creativity techniques were used within workshops to identify ideas for "diversification".

c)A portfolio "benefit for the customer" to "effort for the regarded company" is the result of a systematic idea- and innovation-management process. We used this method for instance to structure new requirements for the power units in order to widen the scope of application:

WP 7/ D7

A workshop for know-how transfer of the development environment and training of SME (Regatron) was done on 25th and 26th May.

Two workshops for know-how transfer of the development environment and training of SME (BAUR) were conducted on 10th of February 2011 and 26th of July 2011.

Potential Impact:

Exploitation Report BAUR

Background

In 1995 BAUR introduced the VLF technology for cable testing starting with 70 kV (later 80 kV) application and generators for cable test vans into the market. Since 2005 the product range has been expanded to lower voltage portable devices. In 2009 the measurement of the loss factor was introduced for the portable devices as well.

In the meantime, the VLF method has been established in various national and international standards and has been copied by our competitors. The advantages of the VLF method are that the devices are much smaller and have less weight thus enabling greater mobility.

On the market side two trends can be observed. On the one hand there is a trend towards increased length of cables. This trend which is mostly related to off-shore wind farms, leads to higher capacitances of the cables and therefore the required currents are rising. On the other hand there is a trend from the usage of underground cables instead of overhead lines. For these applications test equipment for cables with higher voltages is demanded.

For both trends measurement equipment with much higher output power than today is needed. In order to develop such products restrictions concerning weight, volume and heat dissipation have to be taken into account. To optimize all these parameters exact modeling and more use of simulation tools are required as well as new concepts for the topologies and circuit design.

Achievements

Product Strategy

A clear view to the applications and market figures was worked out. Those were in detail the required voltage levels and buried cable lengths and ages differentiated towards the countries worldwide.

Modeling and Simulation

Models for the different system parts, mainly power module, high voltage cascades and control circuits were built up and evaluated. With those tools the choice of suitable configurations for the realization of the prototypes was carried out. A feedback from measurements on real circuits to the simulation was partly realized.

Topologies and circuit design

With the bidirectional cascade a very promising new topology for the entire system was introduced. This approach offers a very high potential for the reduction of the outer dimensions, the weight and the thermal losses of the VLF generator. Besides it also minimizes the power consumption, which is of value if lower rated power for mobile devices is required.

The work on optimization of the conventional R-controller circuits has been started. Approaches for large improvements could not been found. Also design hints for up scaling the actual design without loss of reliability have not been given. For the auxiliary power supply of the R-controllers control circuit a novel switching mode power supply for very low current consumption has been developed. This improvement is ready to be transferred into series development.

Prototyping

The partial improvements at the power modules and the connected control strategies with the prototypes based on the existing R-controller design do not lead to significant enhancement of the overall performance of the VLF generators and therefore do not enable new approaches for generators with higher power output or voltages.

The first evaluation of the bidirectional cascade proves the principal feasibility of the concept and confirms the high potential. Nevertheless the concept has to be expanded with modules, which enable a smoother zero crossing of the output voltage. First concepts for the bidirectional HV converter were presented however they need to be verified.

That is why the SME ´s BAU and REG are interested in the research program for SME's on demonstrators in order to exploit project results. Especially the bidirectional HV converter is of large interest for BAU since it has a huge impact on volume, weight and costs of VLF-generators but also REG is largely interested to mature the new DCS based on resonant topologies and minimize the volume and weight for inductive components, since the major objective to improve the dynamic performance was achieved.

Exploitation

The development of a new generation VLF generators with low risk based on the realized prototypes is not possible at the moment. The R-controller design shows only slight potential for improvements and the bidirectional approach needs future pre-development work before staring a series development.

The potential of the new bidirectional approach is so high that BAUR intends to follow up investigations on this concept and patent the bidirectional HV- converter scheme. At present BAUR is at the planning phase of this project. A rough estimation of the further steps is given in the following.

2012: Completion of the concept of the bidirectional cascade. Executing further investigations on the existing prototype concerning the control stability in the whole working area. This requires simulation work as well as measurements on prototypes. This will lead to an employment of 2-5 engineers.

2013-2015:If the predevelopment phase is successful, a series development phase of 2-3 years will be required with at least 5 engineers.

Outlook

As seen from today's standpoint a positive result of the development could change the market for cable testing at higher voltages from the currently used technique of the resonant generators at 50 Hz to the much smaller VLF technology, thus enabling access to locations where it is impossible to perform measurements today. There will not only be a market for selling these products but also a possible market for offering the measurement as a service.

After the possible start of production beginning 2015 a market volume of more than 5 Mio Euro per year after ramp-up seems to be realistic. This will lead to an employment of approximately 20 employees in production (at BAUR direct) and more than 5 employees in the service area.

Exploitation Report HAB

Background

The HABEMUS electronic + transfer GmbH was founded in 1995. The company is a development and manufacturing service provider, supporting its customers from the initial idea and feasibility up to the final product. Essentially, HABEMUS develops processor-based circuits and the required firmware for measuring, controlling and regulation tasks. For the solution of measurement and control technology tasks, HABEMUS mainly uses microprocessors and DSPs. HABEMUS provides its know-how sector-independent and already operates in different industrial fields. One exemplary product has to be mentioned in the following: "Mavolog 20P" (proprietary of HABEMUS; sales and distribution by Gossenmetrawatt) to analyze and evaluate the quality of supply voltage according to EN 50160. With its compact design (most compact device at present), the measuring device enables real-time analysis and evaluation of voltage characteristics like overvoltage, transients, balance, harmonics, voltage, flicker and frequency.

Exploitation of new control and simulation technology

The demand on efficient and economic solutions/devices and the pressure to shorten time-to-market, requires the ability to create, implement and validate efficient and complex algorithms for the signal processing and control strategies.

For a fast and efficient development of the filter- and control algorithms, without building up complex and time-consuming hardware, HABEMUS needs development tools and the ability to use them unerringly.

Several control concepts as adaptive control, robust control, fuzzy and neural network control have been evaluated and show well promising characteristics.

It was the main aim of the project to enhance the know how on control strategies and after project duration also on FPGA-based control and specific sensor acquisition (collaboration with UPB-LEA).

Achievements:

-Control scheme selection and design tool for different customer's demands: achieved

-Faster controller structures: achieved

-Product Strategy, Market Requirements and diversification: achieved

Exploitation:

Habemus will perform further studies with the provided tools and the proposed topologies in the near future.

Exploitation plan:

2011 Extended studies on the HVTS prototype (together with Baur)

Extended studies with the provided tools for other areas/customers

Industrialization of HVTS (together with Baur)

2012 FPGA-based control and filter design to implement complex and fast algorithms. (collaboration with UPB-LEA).

PLEXIM

New insights gained during the Project:

The requirements and the discussions during the project have led us to several implementations into the product PLECS Standalone:

Analysis Tools Implemented:

The steady-state analysis enables the user to determine the periodic steady-state operating point of a switching system without having to simulate the startup transients.

Transfer functions play an important role in controller design. PLECS enables the user now to determine open-loop transfer functions or closed-loop gains of switching systems without having to revert to averaged models.

Scripting Interface Implemented

PLECS Standalone allows to write simulation scripts, for example to perform parameter sweeps. Alternatively, one can configure PLECS Standalone as an XML-RPC server in order to run simulations and evaluate the results from within other applications.

DLL Block Implemented

PLECS Standalone allows to include an external DLL (dynamic library link) into the simulation. This makes it possible to use the same C-code in the simulation as in an external DSP.

Machine Models Revised

Now, the Permanent Magnet Synchronous Machine model offers a voltage-behind-reactance implementation that permits open-circuited stator windings. This makes it easy to interface with arbitrary external circuits such as rectifiers.

In addition to these we have seen further requirements such as rotational mechanics which we intend to implement in future releases.

Exploitation report REG

Background

In 1999 REGATRON joined the market of high power programmable DC power supplies with a first approach to a full digital fast switching family of TopCon power units. By stepwise upgrading the processor power and associated electronics, a real versatile and powerful version TopCon QUADRO was launched on the world market in 2004-2006.

Due to the unique AAP (application area programming - a REGATRON invention), TopCon allowed as first power system worldwide the simulation of 2-pole electrical networks in real-time mode. This was the break-through for the simulation of mid-sized to large scale solar panel arrays, allowing the user to simulate the behavior of big solar 'farms' enabling extended tests of solar inverter technologies.

Today, REGATRON delivers some 25 Megawatt of controlled DC power per year to all around the world.

Exploitation of new resonant switching technology

Although TopCon QUADRO technology represents outstanding qualities, todays requirements are growing steadily in terms of controller dynamics, filter capacities as small as possible, high overall efficiency and compact, lightweight construction. Because most of the possibilities of present phase-shift technology are already fully utilized, new approaches were studied.

Resonant inverter designs show well promising characteristics in terms of minimized switching losses, thus allowing for much higher switching frequencies. This in turn permits faster controller structures and smaller DC output filter designs.

It was the main aim of the project to investigate the characteristics of several resonant inverter topologies, focused on power efficiency, dynamics and compact construction.

Achievements:

-Low loss circuits: achieved

-Faster controller structures: achieved, significant higher effort necessary

-More compact design: not achieved due to bulky magnetics

Exploitation:

REGATRON will perform intense studies on the proposed topologies in the near future and clarify the qualification of resonant structures for a full industrial design.

Exploitation plan:

2011: Extended studies on deliverable prototype DCS, actually at LEA Paderborn

Low power operation area

Studies on more compact magnetics (WITS) outside of the project

After-project meeting at LEA Paderborn related to industrialization of RPC-DCS

2012 Industrialized prototype: constructional aspects, general EMI concepts and tests

Investigations on a novel cooling system allowing for both air convection as also liquid cooling.

2013: Manufacturing of a preliminary series of 'TopCon V' version, development of test and calibration procedures

Field test series at selected customers for further input and modifications

After last modifications: Launch of 'TopCon V' series DC power supplies

Outlook

As seen from a todays standpoint, resonant inverter topology will mark a further step towards very reliable and powerful DC power sources in the mid-sized or big-sized DC power market.

Based on recent calculations, this market will be of some 20 to 35 MW annual power for REGATRON, exhibiting a business volume of some 20 Mio EURO and place of work for some 30 employees in REGATRON's domain.

List of Websites:

http://ww.eu-rpc.de