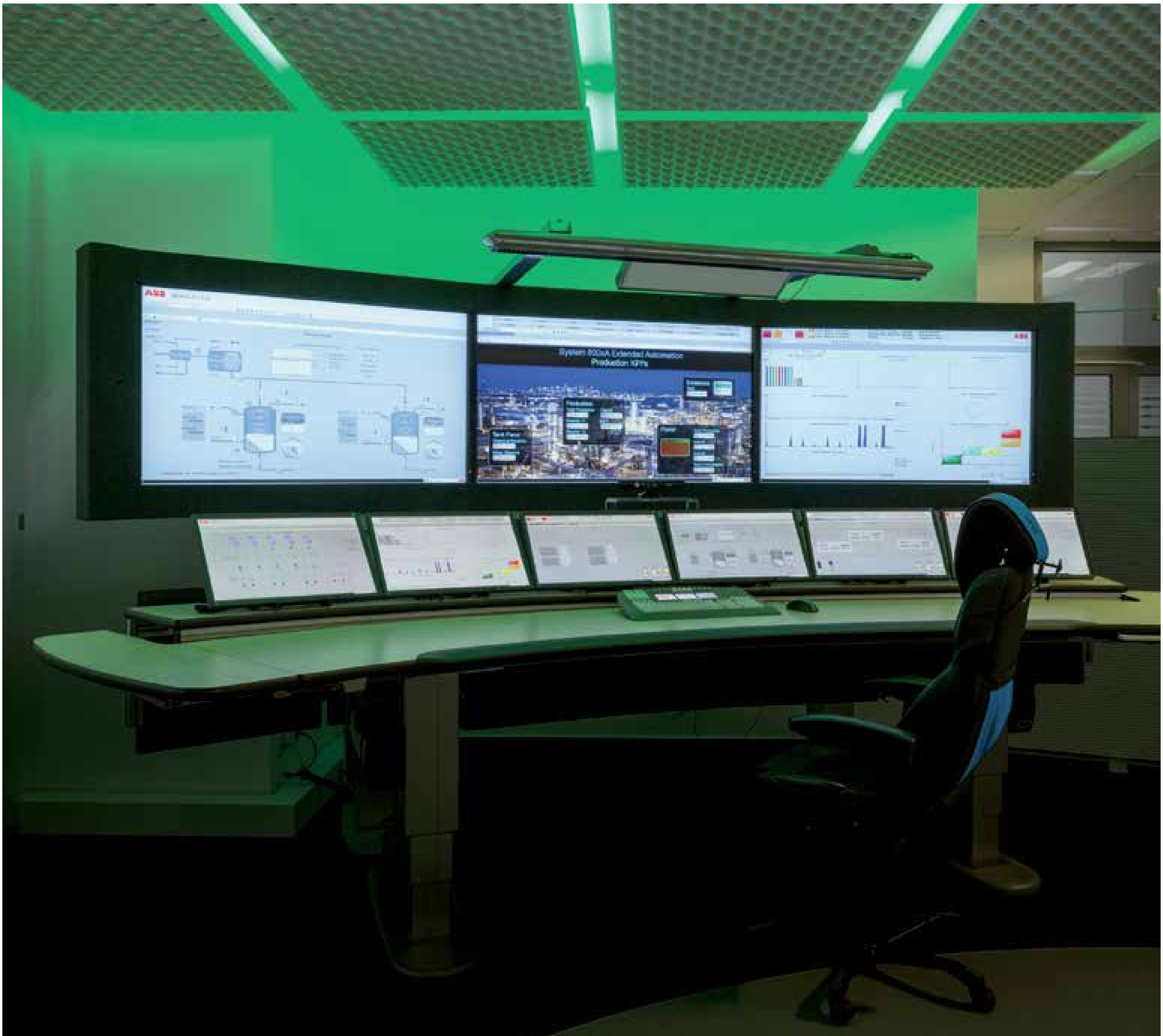


ABB Research Center Germany
Annual Report 2013

Power and productivity
for a better world™

ABB

Content

Christoph Winterhalter
Head of the ABB Research Center in Ladenburg (2010 - 2013)

Dear friends and colleagues,

Delivering breakthrough technologies and solutions, which have a significant impact for ABB's businesses, mostly requires interdisciplinary teams working together across organizational borders. In 2013, Corporate Research has started several large projects working on disruptive ideas for new technologies and businesses. The German research center took the lead for two of these highly visible projects in the areas of smart energy systems for active industrial sites and in exploring the opportunities of cloud computing for industrial automation systems.

In close cooperation with the German ABB we have strengthened our strategic university collaborations with the Karlsruhe Institute of Technology (KIT), the Technical University of Aachen (RWTH) and the Technical University of Dortmund by introducing mentors acting as key relationship managers for these universities. This will be key for continuously attracting a large number of highly qualified scientists from top universities and to ensure a world class competence profile in the desired areas.

In Germany we have put a strategic research focus on the topics "Industry 4.0" and "Building Automation". Industry 4.0 intends to enable future value creation networks for industrial production based on cyber physical systems. After having participated in this initiative from the very beginning, we are ramping up the related research activities to develop new automation technologies, solutions and corresponding business models. Some of our initial ideas about the interaction of humans with a future intelligent production system have been presented at the Hanover Fair.

A highlight in 2013 was certainly the inauguration of the new Automation Arena in our building in Ladenburg. In this area ABB business units showcase future automation technologies and their latest products around a central control room of the future. For our researchers it offers the unique opportunity to show and validate research results in a realistic environment and discuss its impact with our colleagues in the business units.

Finally, I got the opportunity to move back to an operational business responsibility, in which I am leading ABB's global PLC & Automation business from November 1st. Leaving Corporate Research, I would like to thank all our partners at the universities, the different ABB business units and our colleagues from the other Corporate Research Centers in ABB for the very constructive, productive and successful cooperation, and I would like to express my sincere gratitude to all our employees for their great contributions and dedication throughout the last four years. Last but not least I wish my successor, Dr. Jan-Henning Fabian all the best and good luck for his new assignment.

Christoph Winterhalter

Dr. Jan-Henning Fabian
Head of the ABB Research Center
in Ladenburg

Dear friends and colleagues,

As I join the German Corporate Research Center after 13 years in ABB's corporate technology organization, it is very exciting for me to become a part of the Ladenburg research team. "Leadership through Innovation" is our vision at Corporate Research. Our target is to be recognized as an excellent industrial research center and to create sustainable value for ABB business. This was the guiding theme for my predecessor Christoph Winterhalter. Christoph and the team delivered considerable results – for the year 2013 you will find a summary in this annual report.

Our mission is to deliver results – quickly, reliably, effectively and efficiently. In order to achieve these results, we are continuously improving the effectiveness and efficiency of our innovation process, while striving for a high level of operational excellence and stakeholder satisfaction.

After successfully having implemented a number of global changes in our project portfolio and academic network by the end of 2013, we started the next step in organizational development at Corporate Research. With the goal to maintain ABB's competence, knowledge and intellectual property in our core technology areas on a world-class level, we established nine global research areas corresponding to our core technologies. The research areas are complemented by nine research programs targeting on developing business oriented solutions based on new technologies. The German Corporate Research Center will play a key role in five research areas and programs, with a continued focus on automation technologies.

This annual report will give you an overview of our core activities in more detail. I am pleased and honored to present this report as a summary of the valuable work undertaken by the German Corporate Research team in 2013. I am convinced that it will raise your interest and that you will enjoy reading it. I also would like to thank all our partners at universities and different ABB business units for the constructive productive and successful project work with the common prospect to continue these successful collaborations in 2014.

Finally, I would like to express my sincere thanks to all employees who have created all our successful innovations by their dedicated work. I am very much looking forward to continuing this successful work during the upcoming years.

Jan-Henning Fabian

ABB Corporate Research Center Ladenburg

The German Corporate Research Center in Ladenburg is one of seven local research labs in the global ABB Corporate Research community. It is part of the Global Research Lab, which bundles the competencies and skills of ABB's 700 researchers in nine global research areas. With respect to local organization, the German research center is part of the ABB AG in Mannheim.

Our role in the in the global research community

Activities and Resources of ABB Corporate Research are globally managed and structured in a Global Research Lab comprising nine Global Research Areas, which are aligned to ABBs core technology areas.

The mission of a research area is to maintain worldclass competence in the respective field. This is achieved by strategically managing the global resource portfolio, as well as managing a portfolio of projects for competence development, basic research, and technology development within the research area. The German research center is providing resources and running projects in the following research areas

- Communication
- Control
- Mechanics
- Sensors
- Software

In order to provide the technologies needed for future ABB products and solutions, corporate research is running nine research programs. A research program is a portfolio of technology development projects, serving one or few business areas or product groups. Typically these projects require resources from several research areas. The German research center is running projects in five research programs with focus on automation and service technologies. In this way we are a key player in ABBs global research commity.

Our Business

As a local Research Lab, our core business is the execution of Research & Development projects. Our deliverables are project results, such as new technologies or technology platforms, hardware or software prototypes, industry-specific solutions or new processes. Our customers are the business units in ABB, which transform the results of the R&D projects into commercial products and solutions.

Our Vision and Mission

"Leadership through Innovation" – this is our vision. Recognized as an excellent industrial Research Center we create sustainable value for ABB business. We are striving for innovations, which means project results creating significant value for ABB's business units.

Our mission is to deliver results – quickly, reliably, effectively and efficiently. Results in this context are technological innovations with measurable, documented and confirmed value. In order to achieve these results, we are continuously improving the effectiveness and efficiency of our innovation process, while striving for a high level of operational excellence and stakeholder satisfaction.

Our Innovation Network

We drive the innovation process in a network involving all our employees, partners and customers in a way that emphasizes their strengths and competences in their respective roles. The innovation network is built on three cornerstones: customer focus, inventive culture and project management. The three main players in this innovation network are our focus areas, our senior researchers and our research groups.

Our organizational structure

The organizational structure of the German research center is shown in Fig 1. Scientific resources are structured in two departments and eight research groups, covering both hardware and software aspects of automation technologies.

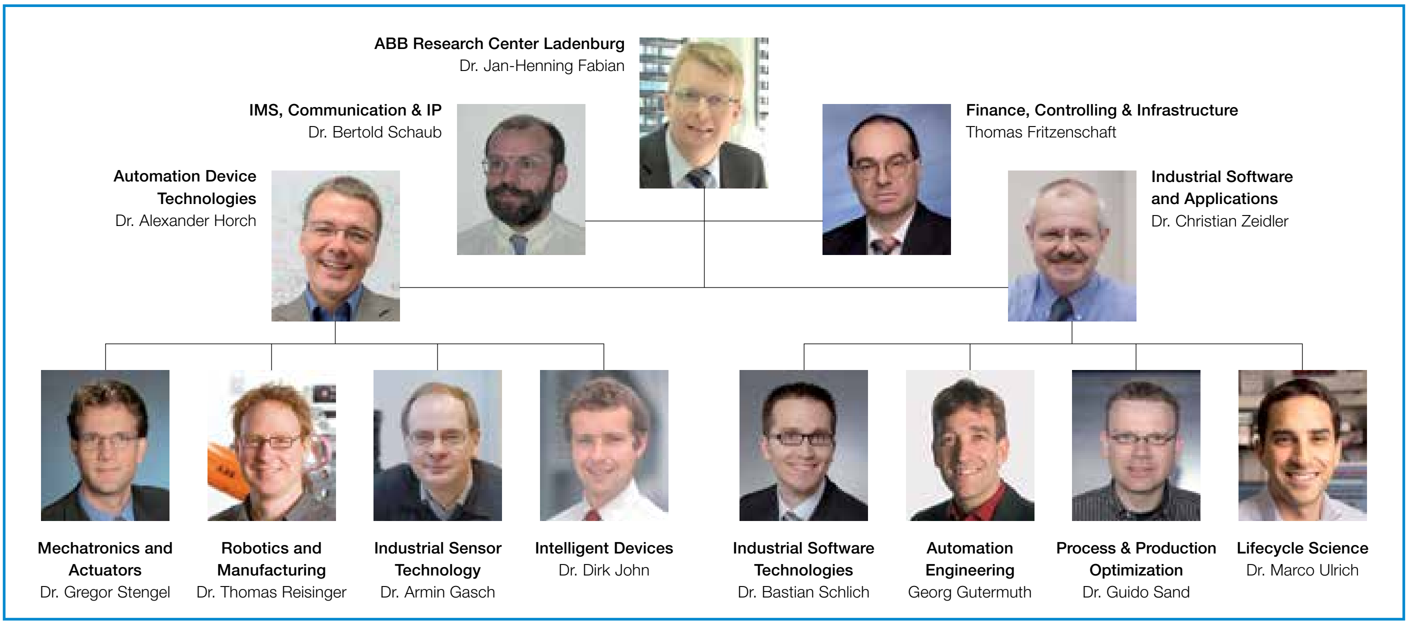
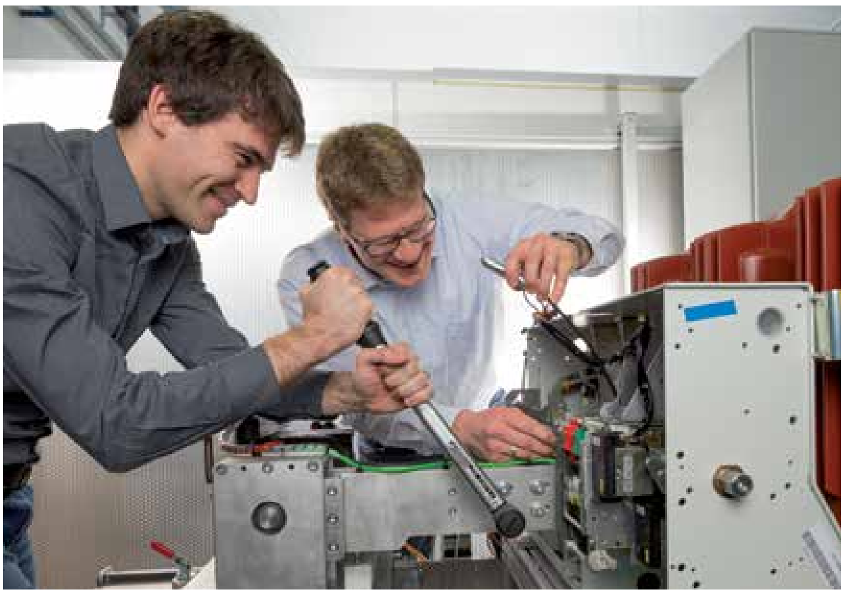


Figure 1: Organizational structure


ABB
FlexPicker



Our Focus Areas

In a focus area, we bundle our technical competence across research groups around the needs of our key customers. Each focus area addresses a well defined customer group with specific deliverables.

The focus area manager works closely with the customer in order to understand his business and his current and future needs. Together with other colleagues, such as senior principal scientists, he is deeply involved in the development of business strategies and technology roadmaps and the resulting portfolio of research projects. At the end of the innovation process, he takes care that the project results are implemented in successful products, thus ensuring that inventions from research are really turned into valuable innovations.

In the German Corporate Research Center we have established five focus areas addressing our key customers. The focus areas are:

Plant Automation

The scope of this area comprises next generation architectures and engineering methods for process automation systems from field to plant level.

Key deliverables are architectures for flexible, safe and scalable control systems and workflows and tools for efficient engineering.

Key customers are the ABB businesses in process automation, power plant automation and network management.

Factory Automation

The scope of this area comprises new technologies and engineering methods for efficient integration of key components in discrete automation applications.

Key deliverables are automation platforms, engineering tools and methods, as well as discrete automation applications.

Key customers are the ABB businesses in low voltage drives, PLCs and robotics.

Building Automation

The scope of this area comprises home & building automation enabling energy efficiency, ambient assisted living, E-mobility and grid interaction.

Key deliverables are sensing and monitoring solutions, integration solutions of electrical and energy building infrastructure, low-power device concepts, and energy management solutions.

Key customers are the ABB business in building automation and installation.

Service Solutions

The scope of this area comprises technologies, processes, and business models for industrial service automation.

Key deliverables are solutions for installed base management, service engineering, serviceability, process and production optimization, monitoring, diagnosis and sensor technology, as well as reliability management.

Key customers are the Service business units in ABB divisions and the ABB group service council.

Power Device Mechatronics

The scope of this area comprises new actuator and sensor solutions on device level for efficient and reliable transmission and distribution of electricity.

Key deliverables are reliable and scalable actuation platforms for switchgear and breakers, sensing and monitoring solutions, robust design & optimization of power devices, and methodologies for faster product and application development.

Key customers are the ABB businesses in high voltage and medium voltage power products.

Our Senior Researchers

In order to keep the competence in out cote technology areas on worlclass leven and to maintain a excellent academic network, we have a few dedicated senior reseasrcher. These are namely the senior pribciple scientists and corporate research fellows. These people are the highest technical authorites in their field of expertise. As renowned members of the academic community, they open the door to research partners and top talents at universities. They are involved in the development of technology strategies and roadmaps, and drive creation of new ideas and inventions as well as the protection of strategic intellectual property. With prestudies and technology evaluations, they prove the technical feasibility of new ideas and their value for ABB.

It is our goal to have senior researchers in all technology fields which are important to our focus areas. Currently we have six Senior Principle Scientists and one Corporate Research Fellow in the German Corporate Research Center.




SMART

Our Research Groups

Research groups are responsible for the effective and efficient execution of Research & Development projects. In order to fulfil this task, they establish and maintain an adequate quantity and highest quality of resources, both personnel and infrastructure. This includes in particular world class scientists and highly qualified project managers, as well as state-of-the art lab equipment and computing environments. It is the main goal of our research groups to maintain a high level of operational excellence.

Our resources and competences for efficient and effective project execution are organized in eight research groups and structured in two departments (Fig.1)

Department Industrial Software & Applications

Industrial Software Technologies

Software technologies play an important role in industrial products and systems, and are increasingly contributing to functionality and creation of added value. Seamless integration of powerful, high-quality software has therefore become a decisive competitive advantage.

Automation Engineering

Worldwide demand for the modernization or reconstruction of power and process plants as well as factory automation remains strong. A large proportion of projects in ABB's core areas of automation and electrical is design and engineering.

Process and Production Optimization

Production optimization covers diverse disciplines such as detailed production planning, quality optimization, control technology, diagnostics and decision support, which also influence each other. Therefore, the development of modern optimization solutions demands profound knowledge of the individual disciplines, as well as good knowledge of the areas of integration and software engineering.

Life Cycle Science

ABB offers comprehensive support services for its products, ranging from classic repair and spare-parts service to performance service for entire plants. Our research group supports these services with innovative solutions for the entire product lifecycle. ABB's particular goals in this area are increasing customer satisfaction, reducing costs and prolonging the lifecycle of products and plants.

Department Automation Device Technologies

Mechatronics and Actuators

Mechatronic systems are characterized by integrated aspects of mechanical engineering, electrical engineering and information technology. Mechatronics represents an inherently interdisciplinary field, and applies these three subject areas to extend the functionality of conventional components. This interaction of disciplines gives rise to a vast assortment of opportunities for the improvement of existing products and the development of innovative new technologies.

Robotics and Manufacturing

Automation solutions based on flexible programmable robots or machines for discrete manufacturing can be found in almost every assembly line today. However, the requirements for these solutions are changing continuously. For use in today's broad range of applications, modern automation solutions must be ever more flexible and more fully integrated into the different production environments.

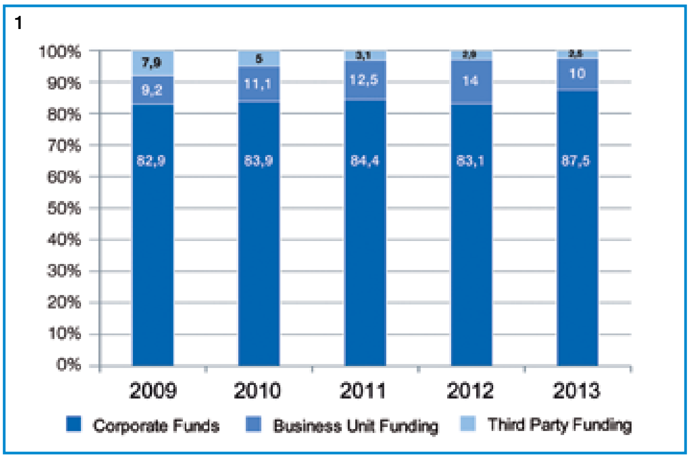
Industrial Sensor Technology

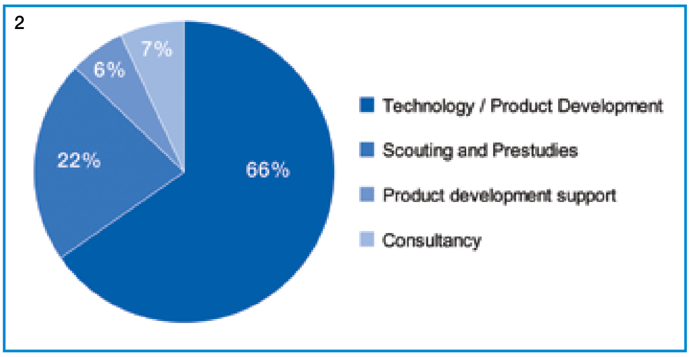
Sensors and field devices are key elements of automation and power systems. They supply the relevant information on processes and material properties in the form of measurement values, thus helping our industry customers to increase their productivity. The application areas of sensors range from process control and optimization, quality control and device monitoring right through to plant asset management.

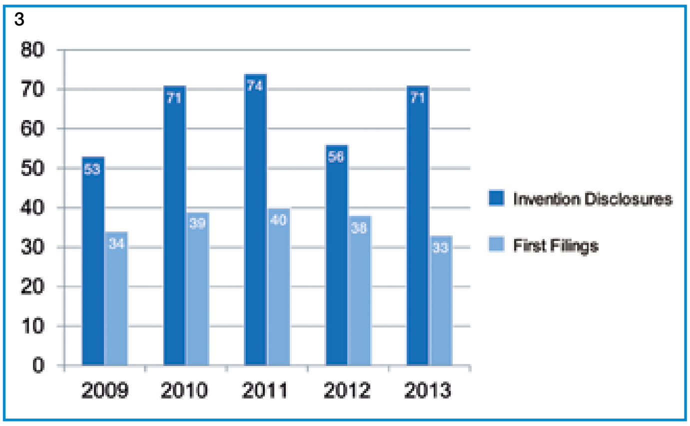
Intelligent Devices

Automation devices, which form the heart of all automation solutions, are expected to meet increasingly tough demands in terms of functionality, user-friendliness, communicative ability and integration into control systems. The required device intelligence is increasingly implemented in the form of software components that run as embedded systems in the devices, which inevitably entails increased energy consumption. As the energy available is often limited, measures for reducing energy consumption are set to be a key requirement for successfully designing intelligent automation devices.

Facts and Figures







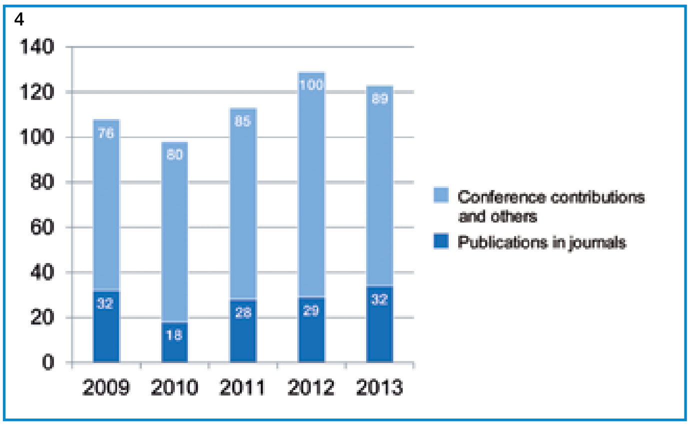


Figure 1: Funding split of research projects | Figure 2: Project revenues by project type | Figure 3: Inventions and First Filings | Figure 4: Publications

Key Figures	
Revenues	15,2 M€
Employees	104
Temporary employees, Students	82
Inventions	71
Patent Filings	33
Publications	123

Project Portfolio

The total project revenues in the German Corporate Research Center have been stable during the last few years, thus reflecting the installed project execution capacity. Although the funding split shoes a small shift towards corporate funds as the main source for our technology development projects, direct funding by ABB business units will remain important to keep close contacts with our customers. As a third source we will focus on public funded projects together with partners from the academic world.

Regarding project type a clear focus remains on technology development projects (see figure 2). The German Research Center is heavily involved in some of the large strategic technology development projects which have been introduced in Corporate Research in 2013. The share of prestudies and technology scouting projects has increased quite a bit, due to the larger amount of discretionary fund in the local centers, which is mainly used for exploring new technologies and for creating and following up new ideas. With product development support projects we make sure that the results of our technology development projects lead to successful products and solutions from ABB.

All of our research work is performed within our key technology areas. All technology development projects follow the ABB gate model. The Gate Model is a business decision model that helps to steer a project from the project customer's point of view. Furthermore, it enhances the communication between project team and customer, and it supports the transfer of projects results into business benefits. We continue to monitor the quality and efficiency of project execution based on the Gate Model with a special focus on transferring projects results into business.

Project Results

Project results are new or improved technologies, demonstrators or prototypes, which create value for ABB once they are implemented in new products, solutions or processes by ABB business units. In 2013 we achieved 14 well recognized technology transfers from our projects with a significant impact on ABB's business. Furthermore, we contributed to 4 technology transfers, which were created under the lead in other ABB research centers. Many of these project achievements are described in more detail in the Technical Results section of this report.

In addition to the primary project results, valuable intellectual property like patents, utility models or trade secrets is created in our projects. The number of inventions by our employees increased by 25% compared to the previous year, while the number of first filings could be maintained on a high level (see figure 3)

Publications in renowned journals and active contributions to conferences are important to demonstrate ABB's technology leadership. The total number of publications was maintained on a record level, while the number of publications in renowned journals could be significantly increased (see figure 4). This gives our researchers the opportunity to be highly visible in the academic community, and to contribute actively to future technology trends.

Human Resources

Our employees are the main assets of our research center. The average number of permanent employees has been stable during the last few years (see figure 5). In addition to our permanent employees, we employed a record number of 82 temporary employees like students or guest scientists, a 10% increase. This is a very appropriate measure to increase the visibility of the ABB Research Center as an employer towards students.

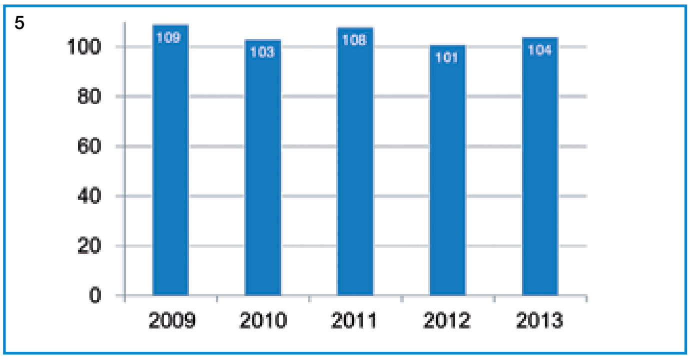
The world class competence level of our employees, including technical, social and management skills is a prerequisite for excellent research results. In 2013, 92% of the employees held academic degrees. The majority of these hold a PhD (see figure 6).

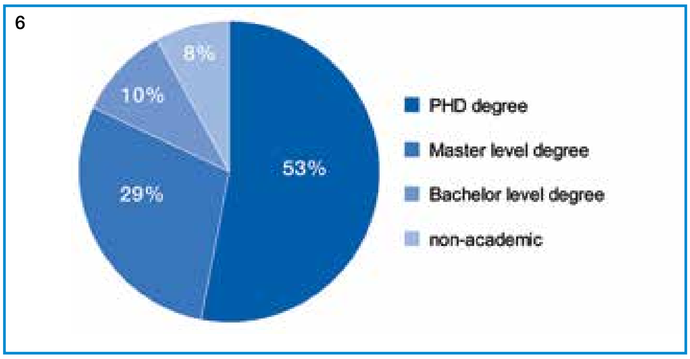
It is part of our mission to recruit talented young engineers and scientists, give them the opportunity to work for some years in corporate research and later offer them new career opportunities in ABB units. During 2013, 10 highly qualified new scientists were hired and during the same time period 6 employees were transferred into ABB business or took over full professorships at universities.

The unique academic environment in Germany, is still an important source of our new employees. 50 % of the recruitments in 2013 came from German universities in the closer region.

In the German research center we maintain an interdisciplinary, multi-national team with a high educational and cultural diversity. Our Human Resource portfolio currently consists of 16 nationalities. Regarding education the focus is on electrical and mechanical engineering, computer science and physics (see figure 7)

We emphasize strongly on the continuous development and education of our scientists, both by attending seminars and by on-the-job- training or job rotations. On average, we allocate approximately 5 % of the revenues for personnel training and development.





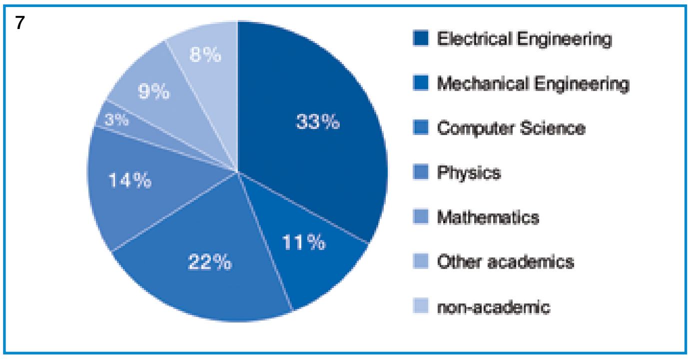


Figure 5: Personnel development | Figure 6: Educational level of employees | Figure 7: Branches of study of DECRC employees

Researcher diversity

Events and Highlights

1

2

3

4

January	February	March	April	May	June	July
			1 Augmented Reality App for Service at Hanover Fair		2 atp best paper award for Mike Barth, Jürgen Greifeneder and Peter Weber at Automation 2013	3 Annual DECRC Barbecue

5


6


7


8


August	September	October	November	December
4 New Workshop infrastructure		**5** Best PHD award from Karlsruhe Institute of Technology for Martin Krüger	**6** End customer seminar on HVDC light with exhibits by DECRC **7** Inauguration of the new Automation Arena	**8** Strategy Meeting of BU Industry Solutions with DECRC participation

Cooperations with Universities and Public Research Institutes

Successful innovation requires the combination of a range of competencies ranging from basic research to technology development and productization. In industrial research, our focus is on the development of new technologies for future products. In order to ensure the basic research and special skills we need for this development, we maintain a comprehensive network that includes leading universities and research institutes both in Germany and in other parts of the globe.

Particularly in Germany we have large number of excellent universities, where we maintain successful biliteral coop-erations on project level. Furthermore, since two years we put a focus on three strategic key universities in Germany: the Karlsruhe Institute of Technology, the RWTH Aachen University, and the Technical University of Dortmund. We are in a process to conclude frame agreements on research cooperations and general cooperation contracts with all three of them, which makes it much easier for us start individual cooperations and other common activities.

Bilateral Cooperations

Karlsruhe Institute of Technology (KIT)
Forschungszentrum Informatik
Prof. Dr.-Ing. J. Becker
Automation Devices

Karlsruhe Institute of Technology (KIT)
Forschungszentrum Informatik
Prof. Dr. H. Schmeck
Building Energy Management System

Karlsruhe Institute of Technology (KIT)
Prof. Dr.-Ing. M. Beigl
Internet of things and industrial applications

Karlsruhe Institute of Technology (KIT)
Karlsruhe Service Research Institute
Prof. Fromm
Industrial Servcies

Rheinisch-Westfalische Technische Hochschule Aachen (RWTH)
Informatik 11 – Embedded Software Laboratory
Professor Dr.-Ing. Stefan Kowalewski
Verification of PLC Software

Rheinisch-Westfalische Technische Hochschule Aachen (RWTH)
Lehrstuhl fur Prozessleittechnik (ACPLT)
Prof. Epple
Automation of Engineering

Technische Universitat Kaiserslautern
Automatisierungstechnik
Prof. Dr.-Ing. habil. Lothar Litz
Foundation Fieldbus Function Block emulation

Technische Universitat Kaiserslautern
Fachgebiet Mathematik
Prof. Dr. Sven O. Krumke
Production Optimization in the Metals Industry

Helmut Schmidt Universitat Hamburg
Institut fur Automatisierungstechnik
Prof. Alexander Fay
Engineering of Automation Systems

Universitat Kassel
Fachgebiet Mess-und Regelungstechnik
Prof. Dr.-Ing. Andreas Kroll
Advanced Process Control

Universitat Kassel
Fachbereich Maschinenbau
Fachgebiet Mehrkorpersysteme
Prof. Dr. Bernhard Schweizer
Co-Simulation

Technische Universitat Braunschweig
Institut fur Werkzeugmaschinen und Fertigungstechnik (IWF)
Prof. Dr.-Ing. Klaus Droder, Dr.-Ing Annika Raatz
Flexible Manufacturing Systems, Robotics and Mechanism Technology

TU Dortmund
Process Dynamics and Operations
Prof. Dr.-Ing. Sebastian Engell
Collaborative Production Optimization

TU Dortmund
Industrielle Robotik und Produktionsautomatisierung
Prof. Dr.-Ing. Bernd Kuhlenkotter
Robotics & Manufacturing, Human-Robot-Collaboration, Virtual Commissioning

TU Munchen
itm – Informationstechnik im Maschinenbau
Prof. Vogel-Heuser
Integration Technologies

Technische Universitat Berlin
Institut fur Prozess-und Verfahrenstechnik
Prof. Wozny
Support for training and education

TU Ilmenau
Fakultat Maschinenbau
Fachgebiet Entwurf mechatronischer Antriebe
Jun.-Prof. Dr.-Ing. Tom Strohla
Actuation Technology

TU Ilmenau
Fakultat fur Informatik und Automatisierung
Institute of Computer Engineering
Prof. Dr.-Ing. Detlef Streitferdt (JP)
Model-Driven Design

TU Darmstadt
Institut fur Automatisierungstechnik und Mechatronik – Fachgebiet Regelungstechnik und Mechatronik
Prof. Dr.-Ing. Ulrich Konigorski
Performance and Robustness of Industrial Motion Control

TU Dresden
Institute for Applied Computer Science – Industrial Communications
Prof. Martin Wollschlaeger
Integration Technologies, Automation Systems Design

TU Dresden
Institut fur Automatisierungstechnik
PD Dr.-Ing. Annerose Braune
Integration Technologies, Automation Systems Design, XML in Automation

TU Dresden
Institut fur Feinwerktechnik und Elektronik-Design
Dr. Ing. Holger Neubert
Simulation of Inductive Components
Magnetic Shape Memory Transducers

Universitat Mannheim
Lehrstuhl Wirtschaftsinformatik II,
Prof. Dr. Martin Schader
Software Failure Cost

Hochschule Mannheim
Institut fur Automatisierungssysteme
Prof. Seitz
PLC virtualization for education and training

Hochschule Mannheim
Fakultat fur Informatik
Prof. Sven Klaus
Multi-touch Application for Collaborative Enrichment of Engineering Drawings with Intelligent Data

Hochschule Mannheim
Fakultat fur Elektrotechnik
Prof. Martin Junker
Automated test case generation for ABB System800xA

Saarland University
Chair of Systems Theory and Control Engineering
Prof. Dr.-Ing. habil. Joachim Rudolph
Applications for Flatness-based Control

Hochschule Darmstadt
Automatisierungstechnik
Prof. Dr.-Ing. Stephan Simons
Knowledge Mapping & Prototype for Target Group specific Visualisation of an Automation Engineering process using Pixel Sense Technology.
Easy integration of signals from heterogeneous systems

Hochschule Ruhr-West
Wirtschaftsinstitut Lehrgebiet Wartungs- und Instandhaltungsmanagement
Prof. Dr. Katja Gutsche
Life Cycle Management

Hochschule Pforzheim
Fakultät für Technik – Bereich Informationstechnik
Prof. Dr.-Ing. Mike Barth
Workflow specific Engineering designation system

Hochschule Ingolstadt
Fakultät Maschinenbau
Prof. Markus Bregulla
Scalable Multilayer Integration Architecture

Duale Hochschule Mannheim
Fachbereich Mechatronik
Prof. R. Lemmen
Automation System Engineering

Duale Hochschule Mannheim
Studiengang Informationstechnik
Prof. Poller
Signalflußanalyse & Visualisierung in 61131 Umgebung

Fachhochschule Sudwestphalen Soest
Fakultat fur Elektrotechnik
Prof. Florian Dorrenberg
Knowledge Mapping & Prototype for Target Group specific Visualisation of an Automation Engineering process using Pixel Sense Technology

Beuth Hochschule fur Technik Berlin
FB 7 Elektrotechnik – Mechatronik – Optometrie
Prof. Peter Gober
iSurface Solution for Process Data Communication

Hochschule Ostwestfalen-Lippe
Institut für industrielle Informationstechnik (inIT)
Prof. Dr.-Ing. Jürgen Jasperneite
Automated test generation for industrial automation systems

Carnegie Mellon Universtity
Center for Advanced Process Decision-making (CAPD)
Prof. Grossmann, Prof. Hooker
Planning and scheduling methods

Carnegie Mellon Universtity
Center for Advanced Process Decision-making (CAPD)
Prof. Biegler
Optimization of polymerization processes

Imperial College London
Centre for Process Systems Engineering (CPSE)
Prof. Nina Thornhill
Plant wide disturbance analysis

Politecnico Di Milano
Dipartimento di Elettronica, Informazione e Bioingegneria
Prof. Roberto Ottoboni
DC Current Measurement for Circuit Breaker Applications

Politecnico di Milano
Prof. Loredana Cristaldi
Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB)
Reliability, diagnostics and prognostics

University of Bergamo
Prof. Sergio Cavalieri
Service processes simulation

Laboratório Nacional de Energia e Geologia IP, LNEG, Lisbon, Portugal
Department: Unidade de Modelação e Optimização de Sistemas Energéticos
Dr. Pedro Castro
Planning and Scheduling, Modeling and Optimization

University of Dubrovnik, Dubrovnik, Croatia
Prof. Vjekoslav Damic
Simulation of sensor systems

INGAR – Instituto de Desarrollo y Diseño (CONICET). Santa Fe, Argentina
Dr. Analía Rodriguez
LV Motors Stock Pooling – Supply Chain Design Optimization

University of Groningen, Netherlands
Prof. Dr. Paris Avgeriou
Software Architecture Methodology

University of Cambridge
Prof. Andy Neely
Service business development, Business model innovation

Kent Business School
Dr. Shaomin Wu
Senior Lecturer in Business-Applied Statistics

Hochschule Rapperswil
Fachgebiet Informatik
Prof. Dr. Olaf Zimmermann
Software Architecture / Cloud Computing

University cooperations within larger joint projects

Project PAPYRUS
Plant-wide asset management for large-scale systems
Aalto University: Prof. Sirkka-Liisa Jämsä-Jounela
Universität Duisburg-Essen: Prof. Steven Ding
University of Lorrainee: Prof. Dominique Sauter,
Prof. Christophe Aubrun

Project PINCETTE
University of Oxford, Prof. Daniel Kroening
Università della Svizzera Italiana, Prof. Natasha Sharygina
University of Milano-Bicocca, Prof. Mauro Pezzè
VTT Technical Research Centre of Finland, Dr. Boris Krasni

Project ROSETTA
Fraunhofer IPA (Germany)
K.U. Leuven (Belgium)
Ludwig-Maximilians-Universität Munich (Germany)
Lunds Universitet (Sweden)
Politecnico di Milano (Italy)

Project SiEGeN:
Silizium basierte Hochtemperatur-Thermogeneratoren auf 8“-Wafer-Level
Micropelt GmbH
ABB AG Forschungszentrum Deutschland
Christian-Albrechts-Universität zu Kiel
EADS Deutschland GmbH
E.G.O. Elektro-Gerätebau GmbH
Fraunhofer-Institut für Siliziumtechnologie
Fraunhofer-Institut Physikalische Messtechnik
MEMS Foundry Itzehoe GmbH

Project Energy SmartOps
Energy savings from smart operation of electrical, process and mechanical equipment
Imperial College of Science, Technology and Medicine London (UK), Prof. Nina Thornhill
Cranfield University (UK)
Swiss Federal Institute of Technology Zurich (Switzerland
Technical University of Krakow (Poland)
Carnegie Mellon University (USA)
ABB Research Center Germany

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Technical Results

The following technical papers describe the technical results and status of our research activities in more detail. As examples of major projects and research topics, they provide a good overview of the work in our research groups during the year 2013 to the technically interested reader. In particular, the topics are:

BMBF Project DIELASTAR: Exploring new actuator systems based on dielectric elastomers

Dr. Aaron Price

Summary
Dielectric elastomer actuators (DEAs) are an emerging technology that offers an attractive balance of work density and electromechanical efficiency relative to conventional actuators. While their functionality has been demonstrated through many laboratory scale prototypes and the first niche consumer products, the incorporation of DEAs within industrial products with stringent performance and reliability requirements has not yet been achieved. To this end, the DIELASTAR research consortium has been established to advance the state of technology for DEAs in industrial applications over a three year period beginning in 2012.

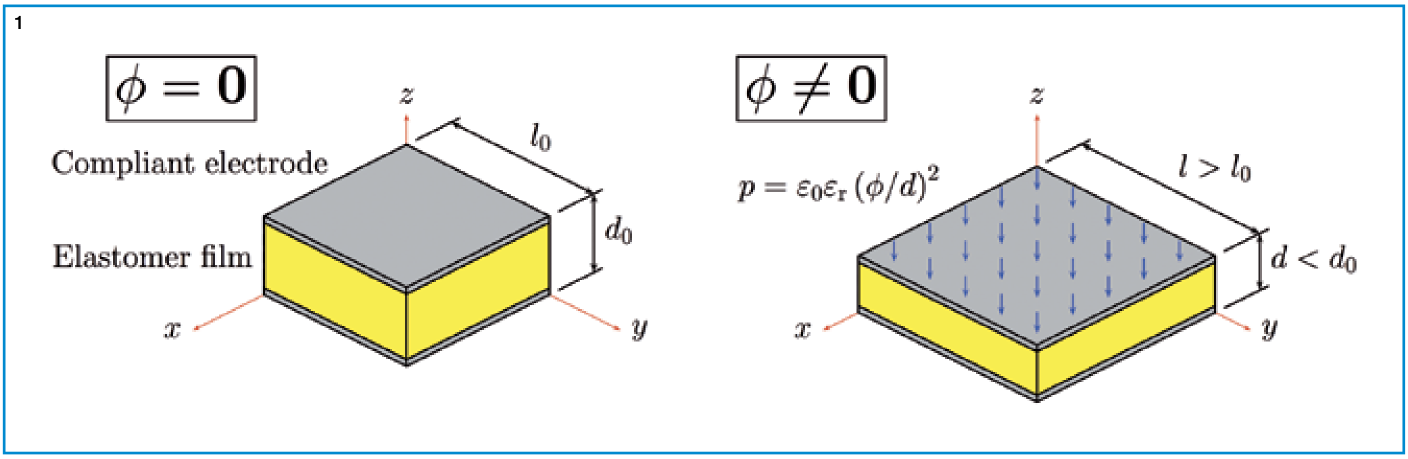
Introduction to the Research Consortium

The multidisciplinary research consortium is supported by the German Federal Ministry of Education and Research (BMBF) and consists of ABB's Corporate Research Center in Germany (DECRC), Bayer MaterialScience AG, Bayer Technology Services GmbH, the Fraunhofer Institute for Applied Polymer Science, the HS OWL University of Applied Sciences, and Festo AG & Co. KG.

As lead project coordinator, DECRC is spearheading initiatives to identify and overcome existing barriers to the application of DEA technology with support from leading partners in scientific research and academia. Topics addressed include significant improvement of dielectric elastomers by chemical modification, electrode materials and techniques, mass production technologies, modelling and simulation aspects, electromechanical system design and optimization, and finally power electronics and their corresponding control methodologies.

Dielectric Elastomer Actuators

As illustrated in Figure 1, DEAs consist of an elastomer film coated on opposing sides with a compliant electrode. The electroactive response is primarily attributed to electrostatic stresses defined by the Maxwell pressure across the membrane. This stress is related to both the electrical permittivity of the film and strength of the applied electric field. The mechanical deformations resulting from the application of this stress can be determined by the application of a suitable viscohyperelastic material law.



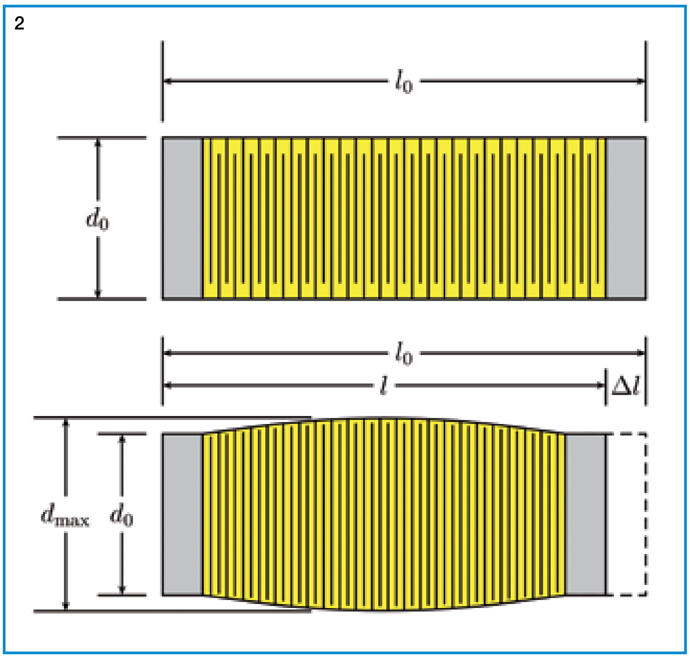


Figure 1: Principle of operation of dielectric elastomer film actuators
Figure 2: Stacked dielectric elastomer actuators offer a favorable balance of output force and stroke capabilities

As illustrated in Figure 2, stacked dielectric elastomer actuators consist of multiple layers of dielectric elastomer membranes stacked or folded on top of each other and terminated by relatively rigid end-cap fixtures. This configuration has been shown to exhibit a favorable balance of force and stroke (work densities approaching 13 J/kg) relative to alternative dielectric elastomer actuator configurations, and is therefore the basis for our ongoing research activities. At the onset of the DIELASTAR project, these actuators required kilovolt-level input potentials that inhibited their wide-spread commercial adoption (primarily due to the cost of high-voltage power supplies and the associated safety concerns). Hence, identifying optimized stacked actuator design specifications using improved elastomer materials and geometries has been a key objective for DECRC.

Performance Characterization, Modelling, and Simulation

DECRC has commissioned a custom-designed test-rig for the experimental characterization of DEAs. The highly-automated system is capable of conducting a variety of load-deflection tests in response to applied electrical input potentials. Material parameters garnered from these tests serve as inputs to specially formulated dynamic multiphysics simulation models that facilitate the evaluation and optimization of potential design candidates. In this manner, the impact of modified system design parameters can be fully quantified without incurring costly prototyping and unnecessary retooling of the DEA pilot production line.

Development of Specialized Electric Drive Circuits

DECRC is leveraging their extensive expertise in actuator drive circuit design to explore opportunities for high-performance electronic control units for use with DEAs. Multiple circuit topologies are currently being evaluated in parallel using specially constructed electronic components in order to satisfy the stringent performance requirements and design constraints.

Major Results to Date

Two fundamental barriers to the application of DEAs are the necessity of high voltages and the inherent risk of dielectric breakdown in the elastomer material. A key objective of this project aims to overcome these material-related barriers through the development of novel polymer formulations having improved dielectric and mechanical properties which significantly alleviate the requirement for high voltages. The consortium has realized these advances through the chemical modification of silicone and polyurethane elastomers, and by the systematic study of electrode materials and techniques that serve to improve energy efficiency while stabilizing long-term actuator performance. These advancements have been integrated by DECRC into a model-based design and optimization system for prototype switching devices that incorporate stacked DEA actuators.

Customer and ABB Internal Benefit

Conventional low-voltage switching products utilize electromagnetic actuators that dissipate significant amounts of energy in the form of heat while the control circuit is energized. Conversely, leakage currents are typically very small for DEAs and thus they offer superior electrical efficiency as a clear benefit. This improved efficiency cuts the electric power required to operate the device while simultaneously eliminating undesirable heat dissipation, and thus overall system costs are reduced.

Internal Customer

Division: Low Voltage Products
BU: Control Products

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Figure 3: Low-voltage switching products are prime candidates for high-efficiency DEAs.

Figure 1: Climatic Testing and Validation – ABB 3-phase GridShield® recloser

Hardware in the Loop Multi-Objective Optimization of Electromagnetic Actuators

Dr.-Ing. Octavian Craciun, Dr.-Ing. Gregor Stengel

Abstract

Medium voltage reclosers now represent an important grid protection device that connects different grid sources, increase the network/grid reliability and make possible implementation of self healing and auto reconfiguration schemes for overhead lines. With a high level of renewable energy penetration, medium voltage networks are becoming bidirectional. Therefore, the associated switching devices must ensure the protection of newer types of power systems as well as new types of loads. The optimal design of medium voltage reclosers is therefore important in order to enable the required switching capabilities.

The switching capabilities of medium voltage recloser can be influenced by various parameters such as actuation energy responsible for opening and closing the device. Therefore, to maximize the lifetime of the recloser, it is essential to establish an optimized control of the actuation energy. This project deals with hardware in the loop multi-objective optimization of an electromagnetic actuation unit integrated in a medium voltage recloser. The goal is to identify an optimal actuation energy control strategy for the opening operation.

Technology Overview

The ABB 3-phase GridShield® recloser is a well know medium voltage protection device in which single coil actuators are used main component driving the opening and closing the device. It has the ability to perform as a recloser, sectionalizer or automated load break switch. The proven design is rated for 10,000 full load operations.

The structure of the GridShield recloser is presented in Figure 2. The main subsystems are the stator, the two armatures (corresponding to the on and off positions), the coil, the permanent magnet and the opening spring.

In the closed position, the magnetic flux generated by the permanent magnets attracts the “on” armature. The open position is reached when the repelling opening spring is discharged. The permanent magnets generate magnetic short circuits at the rear side of the stator. During the closing process, a coil current generates an attractive force that overcomes the holding force due to the short circuits on the rear side of the stator and subsequently the repelling spring force. At the end of the closing process, the “on” armature is attracted by the stator pole faces.

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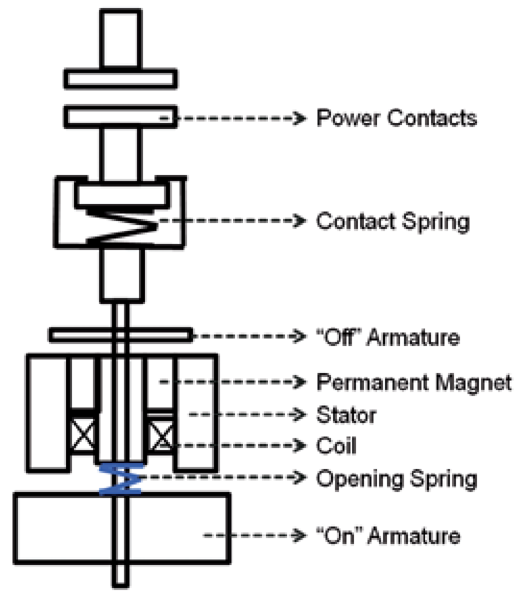

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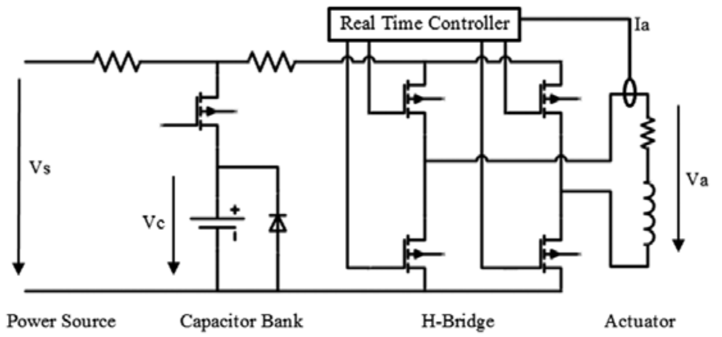

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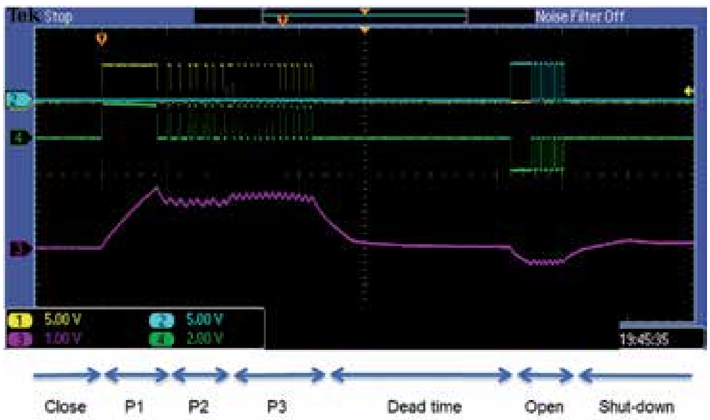


Figure 2: ABB 3-phase GridShield® recloser structure | Figure 3: Power Amplifier for Electromagnetic Actuator | Figure 4: Hardware in the Loop Test Bench Validation

For the opening operation, at the end of the stroke, the off armature will impact the mechanical components of the stator. Due to the abrupt stopping of the moving parts, the components of the actuator are subjected to large mechanical stresses. Additionally, once the on armature reaches the final position relative to the stator, the high kinetic energy generates a hard impact with the stationary structure. This leads to mechanical bouncing that generates an overtravel and a backtravel of the actuator which can influence the switching properties of the recloser over its lifetime.

By optimally controlling the coil current, the overtravel and backtravel at the end of the stroke can be significantly reduced. Increased product lifetime or reduced actuation energy are some examples of advantages when considering applying an optimized control algorithm.

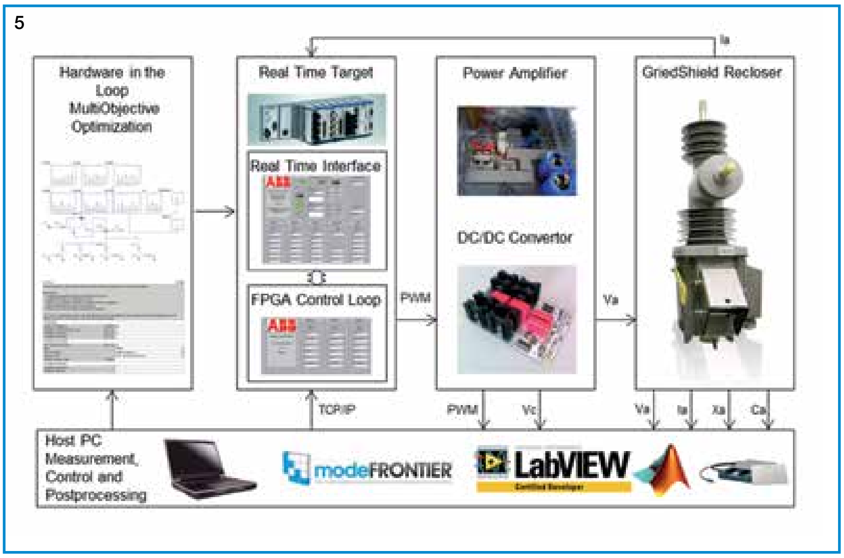
The next two sections will present the implementation of a dedicated Hardware in the Loop test bench allowing repetitive Closing-Opening cycles and the study and optimization of different actuator control schemes.

Hardware in the Loop Test Bench

The two main subsystems of the test bench are the hardware and software components. The hardware part consists of the device under test (medium voltage recloser) and of a suitable power amplifier allowing the driving of actuators up to 100 A, 400 VDC. The software part is represented by the implementation of the control scheme on a suitable real time target that can drive the coil current in a closed loop bandwidth up to 10 kHz.

As presented in Figure 3, the designed prototyping power amplifier consists of a capacitor bank that will supply the actuator via an H-bridge convertor. The capacitor bank is controlled by a suitable charging-discharging circuit.

The PWM actuator current control loop is implemented on the FPGA of the selected real time industrial control unit (CompactRio-9073). The corresponding Virtual Instrument is translated afterwards into VHDL code by using a Xilinx compiler.



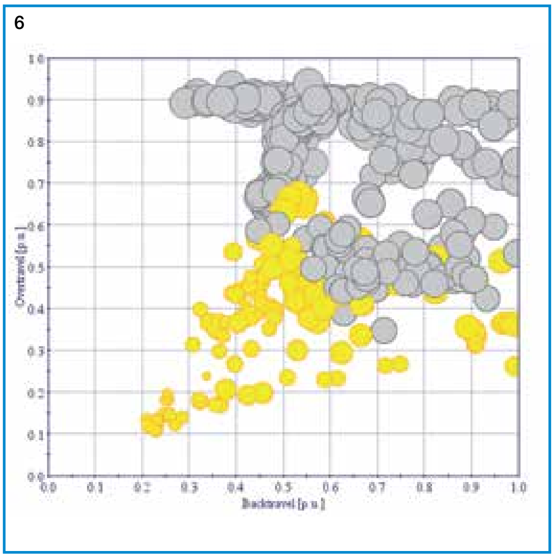


Figure 5: Hardware in the Loop Optimization Approach | Figure 6: Opening Operation Optimization of Medium Voltage Reclosers

In Figure 4, an example of closing - opening cycle is presented. At first, once the controller is switched on, the closing cycle is initiated (the controller is configured for three time periods, namely P1, P2 and P3). Then, the voltage is switched off and the actuator energy is released (dead time). Once the dead time is elapsed, the opening operation will be initiated (only one control period). The final stage consists of the shut-down procedure of the FPGA.

Hardware in the Loop Optimization

The implemented HIL testing and control test bench coupled with optimization software is described in this section. The goal is to optimize the controller parameters in order to achieve a low overtravel and backtravel, all by having the boundary conditions fulfilled (e.g. contact breaking, opening speed). This multi-objective optimization – based on Genetic Algorithm algorithm – is realized for the opening operation.

In order to perform the optimization directly on the prototype, the HIL test bench was coupled and controlled by the optimization software package (modeFRONTIER) that controls the complete testing sequence (as presented in Figure 5). The coupling is performed via the real time interface. Thus, all parameters that are normally set on the real-time interface are included as outputs from the optimization workflow.

Figure 6 presents an example of optimization output for one selected control algorithm. By optimally controlling the electromagnetic actuator, the overtravel and backtravel can be significantly reduced (up to 50%). For this case study, around 1200 closing-opening operations have been realized.

The 3D plot represents overtravel, backtravel and opening speed (represented by the size of the bubble. The solution is considered feasible (grey) if the opening speed is higher that the imposed limit. Otherwise, the solution will be considered as not feasible (yellow). As shown below, the Pareto frontier is located at the level of around 0.5 p.u.

Conclusion

This paper presents the set-up of a software and hardware study platform for medium voltage reclosers Hardware in the Loop (HIL) optimization. Based on the described methodology, the efficient reduction of overtravel and backtravel is proved. Increased product life time or excellent switching proprieties are some of the advantages of the method. This fully flexible testing and optimization infrastructure represents a valuable hardware-software interaction.

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Manufacturing Paradigm for Human-Robot Collaboration – Industrial Assembly in mixed Environments

Dr. Hao Ding, Dr. Björn Matthias

During the past decade, the interest in safe human-robot collaboration (HRC) for applications in industrial production has developed from a niche research topic [1] to a broad effort [2] encompassing activities from basic research to application profiles and from standardization [3][4] to biomechanics and ergonomics [5]. The driving force behind the entire effort is the vision that practically relevant industrial scenarios will include both human workers with their specific expertise and robotic production assistants with their characteristic strengths, combining forces to empower a production facility with superior productivity and flexibility [6]. A drawback of present prototypical HRC implementations is that the basic reaction in the event of an impending risk to a human worker is to stop robot motion, thus interrupting the application and curtailing productivity.

Enabling Industrial Robots for Small Lot Sizes

Present trends in production optimization for consumer products, such as 3C (Computing, Communication and Consumer Electronics) devices, are driving manufacturing paradigms away from mass production towards what is sometimes referred to as mass customization [7], the extreme at which each unit produced is unique to meet individual customer needs and taste. In this process to accommodate as much customer individualism as possible in modern technology products, manufacturers are striving to salvage as much as possible of the advantages of mass production. Relevant issues here are quality and reproducibility, as well as cost advantages in the economy of scale. In discrete manufacturing, one possible enabler for quality and reproducibility is the use of automation.

Fixed automation is the most inflexible choice, and does not allow for product variants in a cost-efficient manner. The introduction of robotic automation has opened an important dimension of flexibility for the past decades. Presently, manufacturers are at times facing the limitations of the fully automated robotic approach, since the automation of certain manufacturing steps in a sufficiently flexible manner still escapes economical realization. At present, only manual work is economical in this area. With the advent of safety-rated robot controllers, manufacturing now has access to a new dimension of flexibility in production processes. It becomes possible to realize partial automation by distributing manufacturing steps among robots and human workers in the mixed production environment, while still maintaining personnel safety [8]. Robots can be assigned to tasks for which they are best suited and in which they bring to bear their traditional strengths, such as precision and repeatability, and human workers handle the tasks that require understanding of context, adaptation to variability, and even manipulation tasks needing complex dexterity skills. For future production topologies, a new instrument to realize lean aspects in production thus has become available. The relevance of the different approaches to discrete manufacturing, depending on the production volume, is proposed in Figure 1.

The figure shows the dependence of unit cost on production volume in a schematic way, including manual assembly, fixed automation, conventional robotic automation, and HRC. Note that, depending on the production volume, different approaches will lead to the lowest cost per unit produced. Human-robot collaboration thus serves to extend the applicability of robots in industrial production to smaller lot sizes than is presently economical.

Improving Productivity by Collaborative Behavior Design

To analyze the collaborative application with regard to safety and productivity, this section introduces terminology and a descriptive formalism. Whenever specificity is required, the application type that we consider is industrial assembly in a collaborative setting.

- Production Behavior: Maintain productivity and avoid safety-critical situations
- Safety and Productivity (S&P) Exception: Irregular situation which either interferes with productivity or compromises workers safety
- Exception Behavior consists of:
  - Exception Reaction: execution of S&P functions to uphold productivity and to ensure worker safety
  - Exception Recovery: dedicated set of commands to restore regular productive operation after Exception Reaction

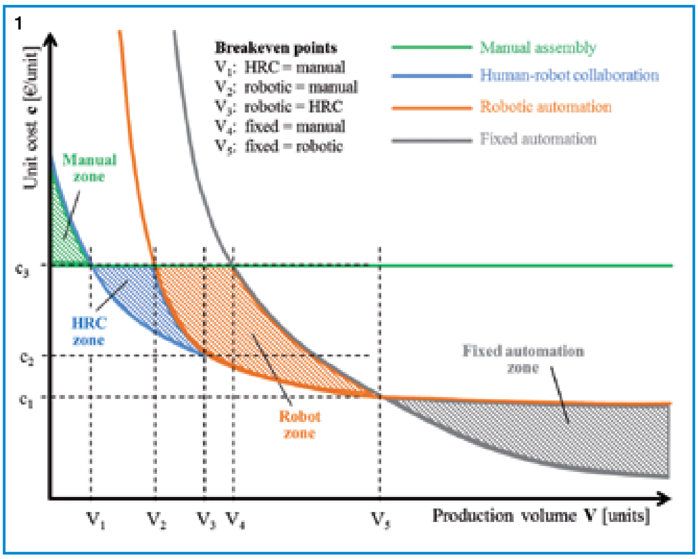
In the normal operation, collaborative robots run with production behavior. Safety and productivity exceptions which either interfere with productivity or compromise workers safety are caught by the corresponding exception reaction. A dedicated set of commands in exception recovery restores the regular productive operation after exception reaction.

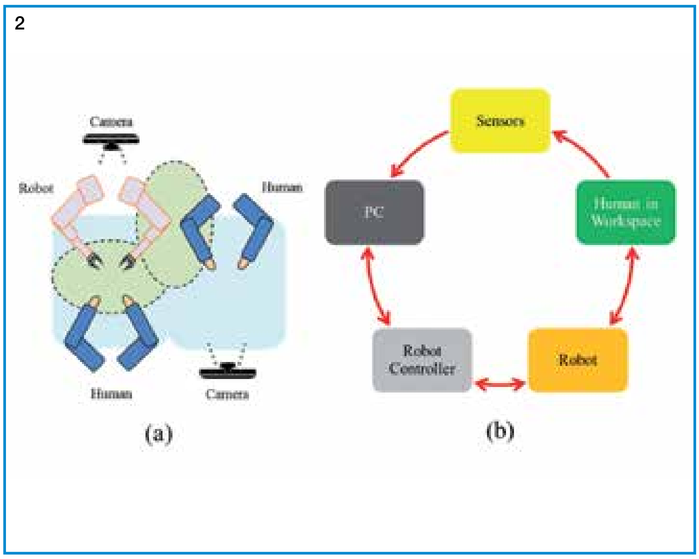
We proposed a concept for structuring the collaborative behavior using finite state automata [9][10], which has also been extended for multiple human-robot collaboration [11].

Collaborative Small-Parts Assembly Application

To experiment with the proposed concept, a demonstrator is set up. Figure 2 shows a scheme of an assembly station. It consists of a workbench with the ABB Dual-Arm Concept Robot [12][13]. The robot is designed as a harmless robotic coworker for industrial assembly. It consists of two robotic arms with 7 DOF in each arm, which can be controlled individually or synchronously. The robot is able to collaborate with a human worker on the assembly of a PLC I/O module as shown in the trade shows Hannover Fair 2011 and AUTOMATICA 2012.

Figure 1: Different manufacturing paradigms and their areas of relevance | Figure 2: Experimental setup for HRC in industrial assembly





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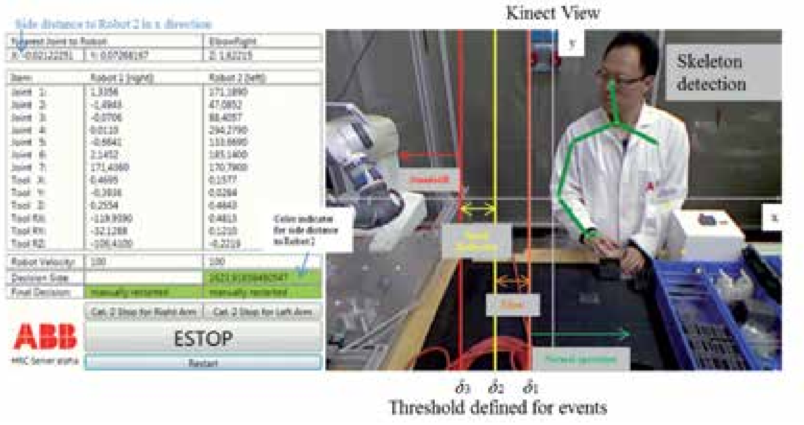

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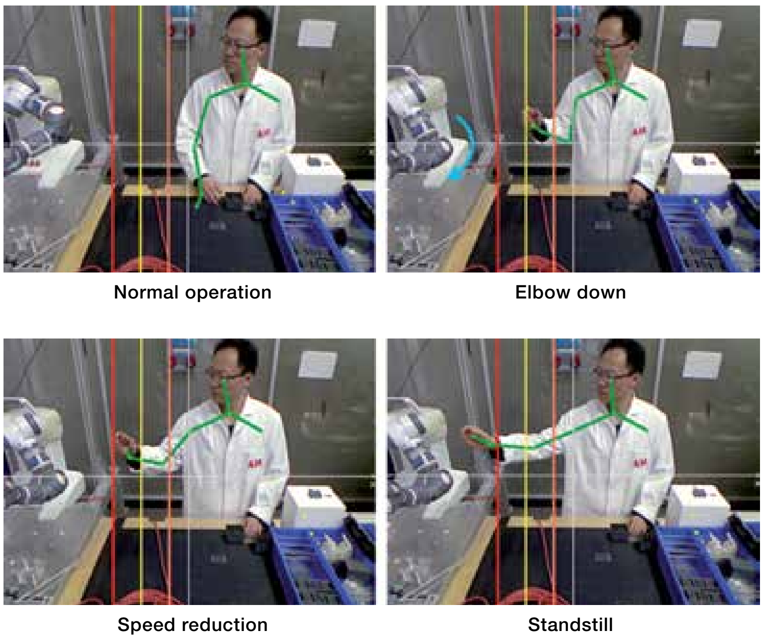

Figure 3: User interface for the HRC assembly station | Figure 4: Human-robot collaboration in different states

The assembly scenario is observed with two depth cameras, which detect the worker's positions, for workspace supervision. Two interaction zones in which direct contact between the robot and the human might occur are designated in this scheme. One zone is located between the robot and the human side-by-side, and the other face-to-face.

A user interface is implemented, shown in Figure 3. Distance thresholds δ_1, δ_2 and δ_3, specified in advance by the user, are introduced to define the events (like elbow-down, speed reduction, standstill) to be associated with the crossing of these thresholds.

When the human worker approaches the robot and crosses the distance threshold δ_1, this is interpreted as an exception. As a reaction, the robot moves its elbow down, keeping the position and orientation of its tool-center point to continue with its normal work. When the human worker approaches further and crosses the distance threshold δ_2, this generates another exception and the robot reaction is speed reduction. When the human worker crosses the distance threshold δ_3, this exception leads to the robot reaction of standstill. Once the distance increases beyond the threshold δ_1 again, the system automatically recovers to its normal production behavior.

In case of a failure in the robot system, this exception generates a protective stop regardless of the current system state. Only manual recovery, i.e. a manual reset of the controller system, is allowed in this case, since a check by a human operator is required to verify the safety of the system before a restart is allowed. The robotic behavior is in the assembly station is shown in Figure 4.

Improving Uptime of Collaborative Assembly

Experimentation with this setup has shown that the uptime of the collaborative assembly application can be improved by reducing the frequency of unintended contact events between worker and robot. This is achieved by triggering the appropriate choice of robot reactions from among “elbow down”, “speed reduction” and “standstill”, whenever needed to avoid an impending contact situation. As a result, the downtime of a collaborative application can be reduced and productivity increased.

Acknowledgement

The authors thank Jakob Heyn, Junjie Zhang, and Malte Schipper for their contributions to the setup of the assembly station for human-robot collaboration.

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Circulating Current Monitoring for Early and Precise Fault Detection in Synchronous Motors

Dr. Ulf Ahrend, Dr. Rolf Disselnkötter, Dr. Stephan Wildermuth, Pedro Rodriguez, Pawel Rzeszucinski

Abstract

Often found in critical, high power applications, synchronous machines require reliable condition monitoring systems. Reliability is not only important for the installed sensor system but also for the motor failure detection algorithm that analyses the acquired data. The ultimate goal is to detect and identify faults in an early stage and to avoid any false alarms. Synchronous motors represent large investments and typically drive processes where downtime results in significant capital losses. Predictive condition based maintenance schemes are therefore desirable. This report describes the development and verification of a specific method that employs a sophisticated current measurement scheme and allows an early and precise diagnostics.

Introduction

Large synchronous machines are an essential part of a process in various applications: They may drive large compressors in oil and gas applications, they are used to propel large cruise vessels with electric propulsion systems like ABB's Azipod or they can drive large refiners in paper mills (cf. title figure). The rated power typically ranges from a few megawatt to more than 60 megawatt.

Downtimes of critical assets can easily result in costs of several million dollars per day. Thus, detecting developing faults at an early stage can help to avoid catastrophic failures by scheduling timely maintenance actions.

There are various physical parameters like temperature, vibration etc. that could be measured to deduce the health status of an electric motor. Not all of them reach the desired level of precision and even the interpretation of the signals may be difficult. Motor currents on the other hand may be indicative for a number of different failures and they can be measured with high accuracy. Therefore, current sensors may be considered as an appropriate part of a continuous monitoring system for a high power machine.

In this paper, the usefulness of circulating branch currents as indicators for motor faults is proven through numerical simulations and real measurements carried out on a specially-designed synchronous motor. Circulating currents enable a more sensitive and accurate condition monitoring and protection of synchronous motors than methods based on the monitoring of stator currents or stray fluxes.

Technical Details

Large synchronous machines are typically designed with stator windings that are split in several parallel paths, thus reducing the branch currents while still delivering the same total power at the terminals. Under ideal symmetrical conditions, no currents will circulate between parallel branches of the same phase. However, when a motor fault breaks this symmetry, currents will circulate between the branches (cf. current IC in fig. 1), as the branch currents will no longer be equal. Thus, the circulating currents potentially represent a sensitive indicator of faulty conditions and they are often called a natural fault indicator.

The goal of our research project was first to prove the method through tests on a real motor and secondly to verify numerical models of a motor under faulty conditions and to derive conclusions based on the simulation results.

An ABB-proprietary simulation tool has been used in these investigations. Faulty conditions result in a loss of symmetry in the machine. In order to model the faulty machine and to calculate the circulating currents in all of the branches, it is necessary to consider the whole motor cross section in the model. A typical map of the calculated flux lines at a specific instant of time is shown in figure 2 for a motor that has a static rotor eccentricity of 40 %.

The extracted circulating currents are compared to the measured ones. The experimental arrangement with a specifically modified low voltage synchronous motor is shown in figure 3. The test motor (right hand side of fig. 3) was connected via a Cardan coupling to a driven motor which acted as a generator and transferred the generated power to a large resistive load.

Figure 1: Schematic representation of two parallel stator windings – if the two branch currents I1 and I2 are not identical a circulating current IC will result | Figure 2: Magnetic field distribution obtained from simulation on a 2D FE model with 40% eccentricity | Figure 3: Experimental test setup – synchronous LV test motor (right) and load generator (left)

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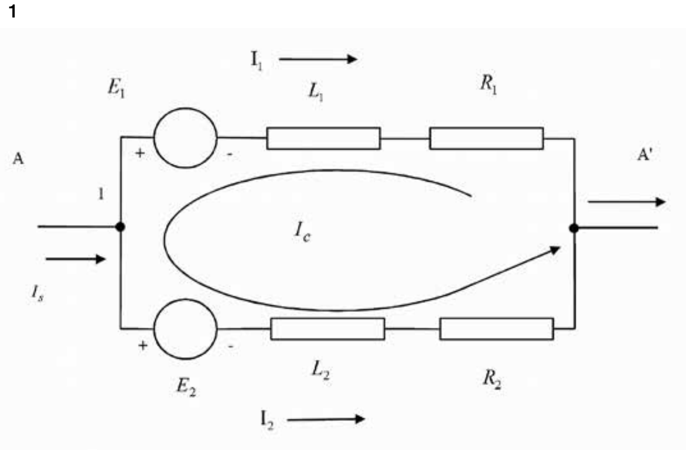

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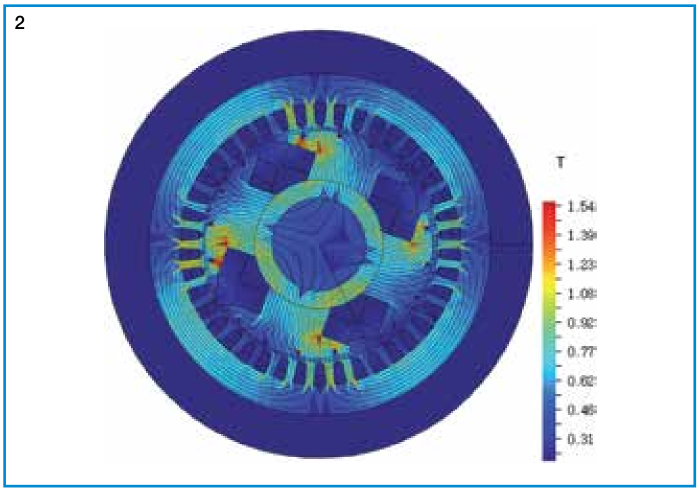

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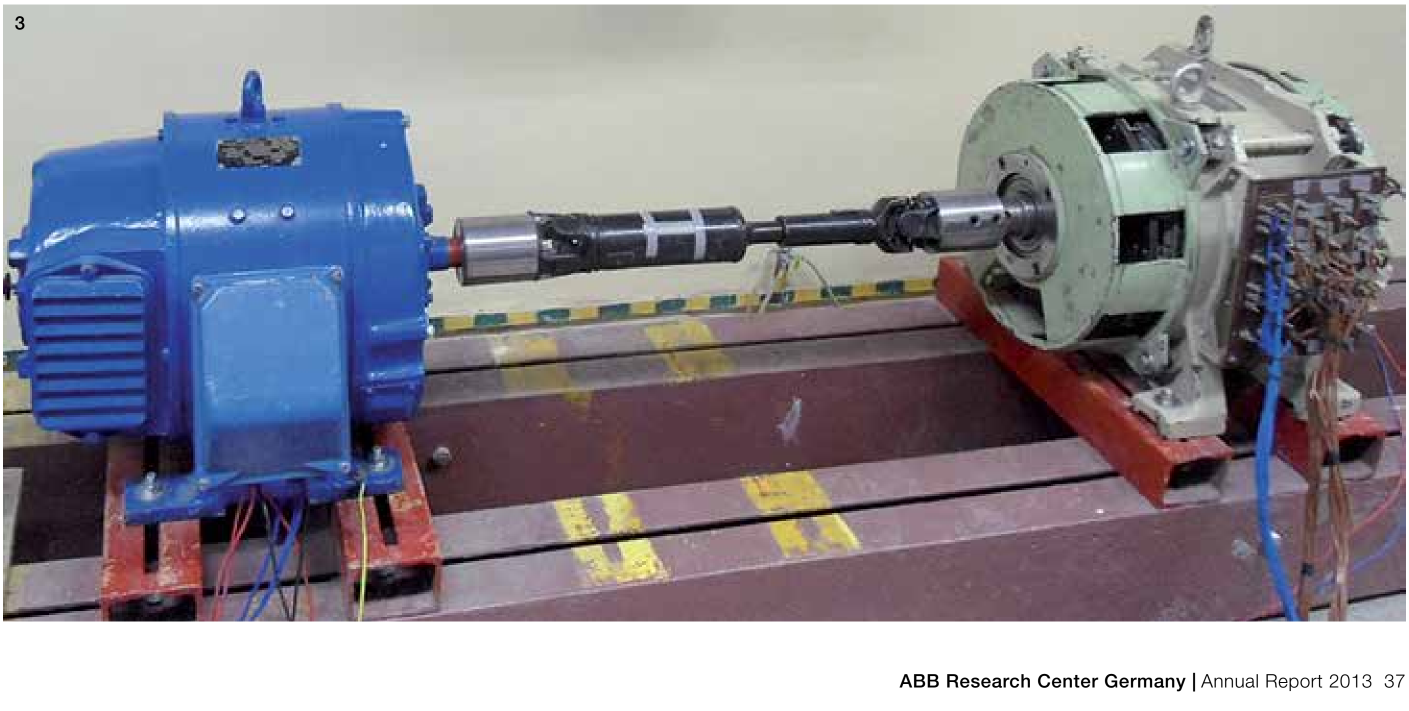

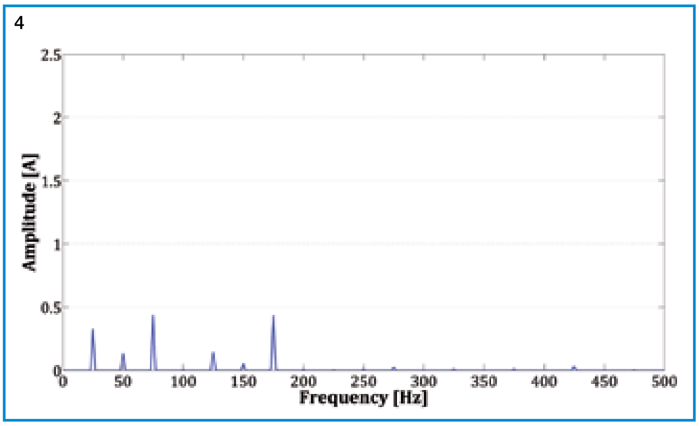

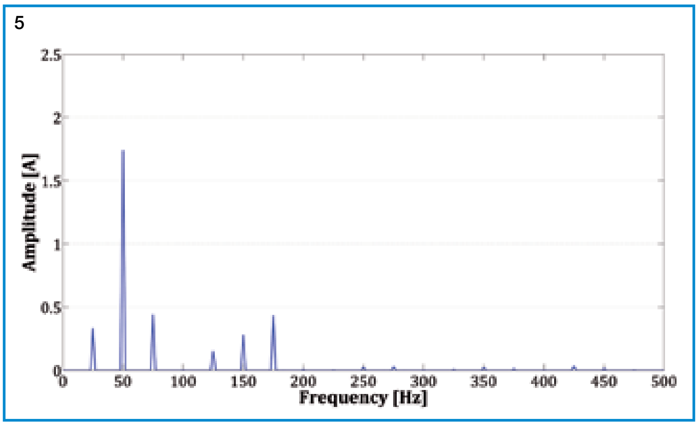

Figure 4: Measured circulating current spectrum at nominally healthy motor condition | Figure 5: Measured circulating current spectrum at 20% static eccentricity

Analysis of a Static Eccentricity Problem

The static eccentricity fault was realized with the use of special end-rings which were placed in the bearing lids on both sides of the machine. For fault identification it is important to compare the resulting current signatures with a healthy motor which is ideally symmetric. However, this ideal scenario cannot be expected for real motors. The one used in the experiments was assessed to have 8% static and 8% dynamic eccentricity already in the nominally healthy state.

The current spectra obtained from simulations could be validated by comparison with the frequency content of the circulating currents generated during experimental measurements under similar conditions.

Figure 4 shows the spectrum of a circulating current recorded at the test machine under nominally healthy condition. As expected there is only little response from the supply frequency (50Hz and its harmonics) and the rotational modulation by the spinning rotor (25Hz and its harmonics). In the ideal symmetric scenario one would expect no response at all.

This behavior changes if a static eccentricity of 20% is introduced (cf. fig 5). A clear increase in the amplitude of the supply frequency and its third harmonic can be observed. This may be attributed to the fact that the rotor moves closer to one branch of a single phase while it is more distant from the second branch. As a result there is a larger difference between the currents in the two branches.

The reactions of the supply frequency components and their sidebands were verified to be of the same nature as those predicted by simulation. Components at the supply frequency and its third harmonic increase substantially in amplitude, whereas the amplitudes of the sidebands around these components remain relatively constant.

Conclusions and Benefits

The nature of diagnostic information contained in the circulating currents indicates that this approach is much more intuitive and easier to automate in that specific frequency components react to specific fault types. This in turn allows for unambiguous interpretation of the results and may lead to a reliable assessment of the exact type of fault present in the motor. In addition the background signal is reduced by its common mode component, as the circulating current is obtained via the subtraction of two branch currents. This results in an improved sensitivity and precision of the diagnosis. This type of system is supposed to find applications in high power synchronous motors and generators, where protection, condition monitoring and prognosis are very important to ensure the maximum availability of the drive system.

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Infrared Temperature Sensor for Generator Circuit Breaker Monitoring

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Abstract

An IR temperature sensor for generator circuit breakers has been developed with the focus on achieving the required performance while providing an economical solution. The sensor is based on a thermopile detector supplemented by a specifically designed package to maintain the performance even under harsh environmental conditions encountered in a high voltage generator circuit breaker. Simulations of the thermal layout of the sensor have been performed to optimize the package and the performance of the sensor system has been validated by experiments.

Introduction

ABB generator circuit breakers (GCBs) are suitable for application in all kinds of new power plants as well as for replacement or retrofit in existing power stations when they are modernized and/or extended. During normal operation of the power plant, the GCB has to carry the full nominal current (up to 30 kA) of the generator. Its main conductor is on high voltage potential, typically between 10-30 kV. At these high currents, even a small increase of resistance in the current carrying path leads to a high temperature increase. Misalignment of the connections, dust inside the GCB or damaged contact surfaces as well as deliberate overloading of the GCB can lead to a local temperature increase. Typical temperatures of the main conductor of the GCB under normal operation are in the range of 60 - 80 °C. Heat removal from the main conductor is partially done by radiation, thus paint with high emissivity is typically applied to the conductor. Exceeding these temperature limits may lead to loss of interrupting capability of the GCB or even provoke a flashover if components start melting.

Furthermore, supervision of the actual temperature of the GCB and continuous monitoring of the temperature behavior over time supports early and planned diagnostics and repair without unexpected downtime of the power plant. Beside temperature several different condition monitoring values are collected and interpreted in the central condition monitoring device GMS 600 (Figure 1) used to track the health condition of the GCB

Generally, the temperature supervision of HV components is challenging because the temperature sensor has to survive severe electromagnetic conditions and may also be exposed to strong temperature gradients (outdoor application under severe climatic conditions). No appropriate commercial tem-

Figure 1: Central condition monitoring device GMS 600

perature sensing system was on the market which fulfilled all technical, commercial and functional requirements. Therefore a new temperature sensor system was developed within a research project.

Sensor development and design

After a detailed analysis and testing of alternative methods a measurement scheme based on the detection of infrared radiation (IR) has been selected. The approach was to take a commercially available IR sensor element and enable it to operate reliably in the demanding GCB environment by developing a protecting package around the commercial sensor element that provides proper dielectric and thermal protection/shielding. Beside these physical requirements the IR sensor system had to be cost-efficient and robust. As central component a non-cooled Si-based thermopile detector was chosen due to its good cost/performance ratio. Beside the ASIC electronics of the detector itself an additional electronics was developed to convert the digital SMBus output signal to Modbus which had to satisfy demanding EMI requirements in the GCB application.

The layout of the sensor package therefore needed to fulfill three major objectives:

- Suppression of large spatial temperature gradients at the IR sensor element
- Suppression of large temporal temperature gradients at the IR sensor element
- Suppression of electromagnetic interferences, thus a good EMI behavior

In order to fulfill the first objective the housing of the IR sensor element needs to be surrounded by a material with high thermal conductivity (inner housing, Figure 2). This ensures that the thermal field around the sensor remains homogeneous.

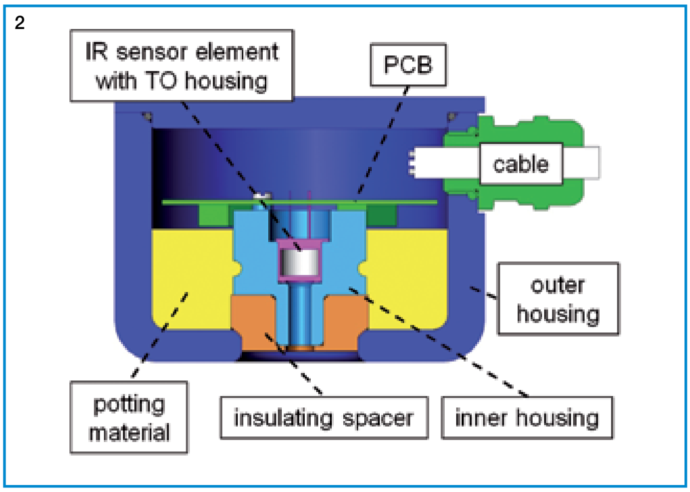
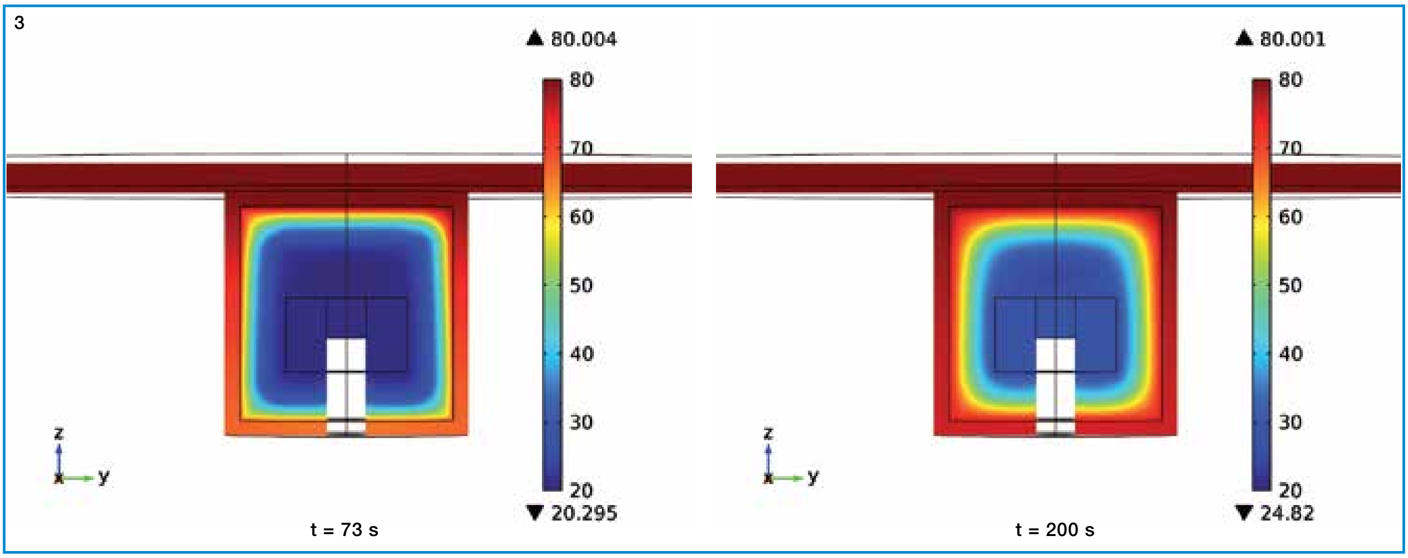


Figure 2: Schematic of the cross section of the sensor package showing the main functional components

The second objective can be satisfied by choosing a design that leads to a large thermal time constant (in the range of some minutes) by giving the relevant elements (sensor + aperture) a large thermal mass and by reducing thermal conductivity around the sensor.

A two-housing-concept has been implemented (Figure 2) consisting of a thermally weakly coupled outer and inner housing. This two stage approach inherently serves also the dielectric and EMI requirements: The outer housing acts as a Faraday cage and the thermally low conducting material effectively isolates the sensor also electrically. Additionally the outer housing is grounded through the GCB enclosure and the inner housing is connected to a local ground potential.



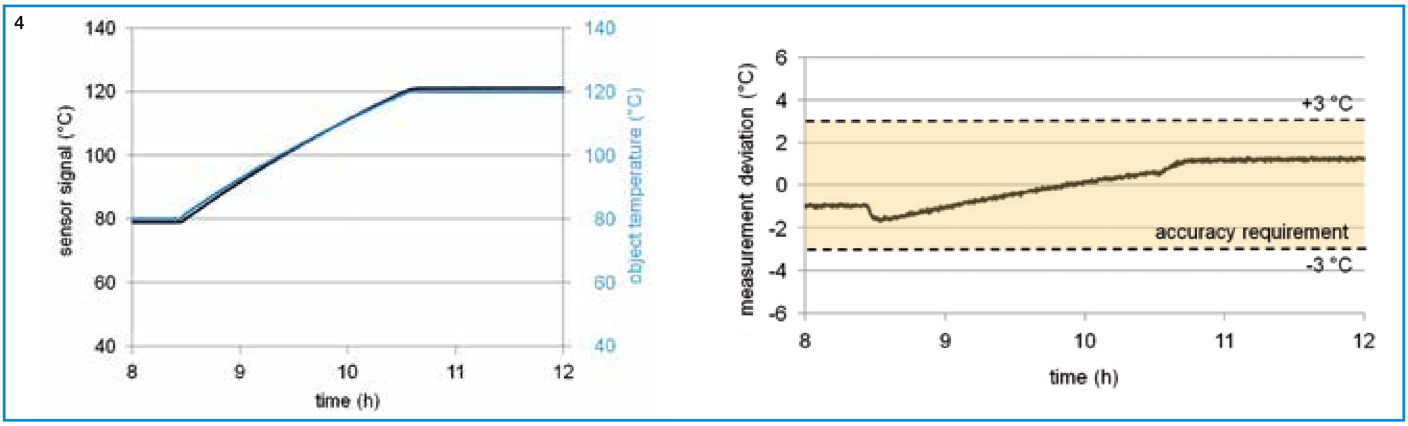


Figure 3: FEM simulation of the heat up of the sensor package: These simulations give a first estimate on the thermal time constant of the whole sensor package and were used to define the package dimensions | Figure 4: Overheating of a GCB conductor has been simulated in a climatic chamber by increasing the object temperature from 80 °C to 120 °C (left). This temperature change has been monitored with the IR temperature sensor over several hours. The measurement deviation (right) stays well within the required accuracy interval of +- 3 °C during the entire temperature ramp.

The dimensioning of the package has been defined through transient thermal FEM simulations of a simplified model (Figure 3). The design goal was to achieve a thermal time constant greater than 10 minutes. This was predicted through the simulation and later on verified by experimental tests.

Prototyping and testing

To verify the performance of the IR temperature sensor, a total number of 21 sensor prototypes have been built and extensively tested in a climatic chamber to simulate different external influences. Very good sensor performance (error smaller 2 °C) has been found during temperature shock experiments (temperature change from 25 °C to 70 °C at a rate of 5 °C/min) as well as repetitive temperature cycles from 5 °C to 60 °C at a rate of 0.1 °C/min to simulate typical day/night scenarios. To check the basic performance of the sensors, their response has been monitored for an object temperature range (black-body radiator) from 30 °C to 120 °C at a constant ambient (sensor) temperature of 25 °C. The sensor response followed a linear behavior with a linearity error below 3 °C over the entire temperature range.

A very important use case for the IR temperature monitoring system is the reliable detection of excessive heating due to overload operation of the GCB, i.e. when temperature of the main conductor approaches 120 °C. This scenario has been simulated by changing the object temperature from 80 °C to 120 ° (Figure 4). The IR sensor accurately captures this temperature change and the measurement deviation stays well within the required accuracy interval of +- 3 °C.

Additionally, the IR temperature sensors have been tested for influences typically encountered in a GCB environment. This includes extensive vibration testing to simulate mechanical shock during switching operations of the GCB. Furthermore, electromagnetic immunity of the sensor has been tested according to IEC 61000-4 and -6 addressing immunity to RF electro-magnetic fields and electrostatic discharges as well as electrical fast transient tests (required severity level 3). All tests were successfully passed and the sensor system thus qualified for operation in a GCB.

Conclusion and Outlook

The novel cost-effective and robust temperature sensor system described in this article enables reliable temperature monitoring of GCBs during operation. In combination with other sensor information (e.g. vibration or contact-ablation information) a clear picture on the devices health condition can be derived. There are two main aspects for the value proposition of these kinds of condition monitoring systems:

- The supervision of the actual device status helps to prevent fatal errors, e.g. the full drop out of the power plant resulting in high cost and potentially disastrous damage to equipment.
- In combination with smart analysis algorithms and methods from reliability engineering, predictive maintenance strategies are enabled, being the basis of novel service offerings to end customers

In addition the knowledge on the behavior of the equipment in the field is an important feedback into the design and development processes of new devices. Hence it helps to increase the overall product quality. Furthermore, the condition monitoring signals coming from a whole fleet of devices can be analyzed in a holistic way. Taking this step from the monitoring of a single asset to a fleet of assets opens up totally new opportunities and value propositions ABB can offer to end customers through its service portfolio.

One of the key activities during the development project was the early involvement of possible producers for the temperature sensor. Due to this fact, the design of the technology demonstrator delivered by ABB Corporate Research showed a high degree of maturity and was ready to be used in the final application in GCBs. To adapt the technology demonstrator into a product, only minor changes in the sensor design were necessary, to be compatible to the chosen production processes.

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Design Space Exploration
Designing devices for future Building Automation systems

Francisco Mendoza, Markus Ruppert

Abstract
Building automation systems rely on smart interconnected devices responsible for the operation of HVAC, lightning, security, and infotainment systems. Designing such devices is a challenging task since these should be able to cope with constantly evolving technologies and functionalities of future smart homes and buildings. A solution inspired from the automotive domain relies in the use of state-of-the-art model-based design tools. This article describes up to which point such approach can be used in the building automation domain.

1. Problem description

The design constrains of smart devices for building automation systems are mainly cost, power consumption and size (footprint). These constraints are highly relevant since more and more functionality and communication capabilities are expected from such devices. At the same time, devices should be able to cope with constantly evolving technologies and new use-case scenarios.

Engineers can benefit from design tools that can help evaluate possible design alternatives in an efficient manner. In particular, we see a need for design tools to evaluate technical tradeoffs, such as cost, size and power consumption, of design alternatives in order to find the most optimum ones. These results must be available as early as possible in the design phase in order to decrease technical risks and accelerate the time-to-market of devices.

The process of evaluating design alternatives under certain constraints in order to find the most optimum ones is referred to as design space exploration and is illustrated in Figure 1. The design space is defined as the set of all possible combinations of different features and requirements of a device. The subset of the design space containing all consistent and valid solutions is called the solution space. The motivation of design space exploration is to find design solutions close to the origin (utopic solution). These solutions represent the Pareto frontier. Finding design solutions along the Pareto frontier can be too complex and requires computer-aided support.

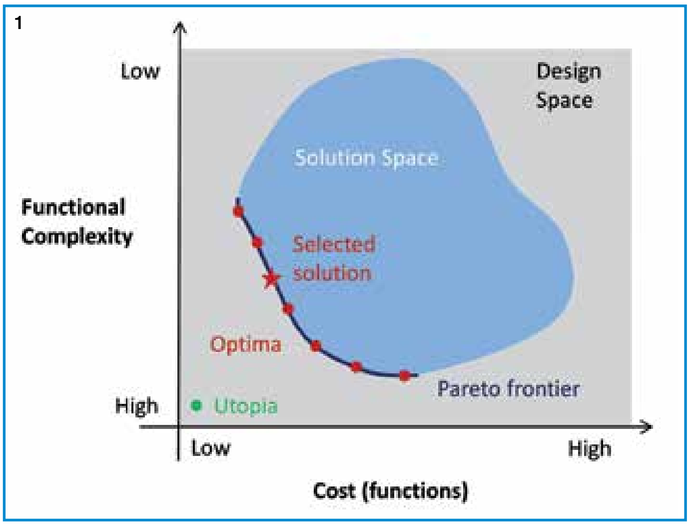

Figure 1: Design space exploration overview

The primary use case for exploring the design space of devices is to find optimum design alternatives for supporting function distribution. The motivation is to design devices that enable flexible, scalable and robust future building automation solutions. For example, a building automation system that can scale according to user needs (e.g. add a new light control scenario function without having to install a new device) or that can adapt to device failures (e.g. move a temperature control function of a digital thermostat to another device in case it fails). Figure 2 shows two scenarios for function distribution. Functions are labeled as actuating, sensing, control an logic (A,S,C,L in the figure) and are separated into distributable and non-distributable functions. Distributable functions do not rely on specific hardware and can execute in any device or externally on some cloud service. On the other hand, distributable functions rely on a particular hardware (e.g. a light switch) and must execute locally on a device.

2. Solution approach

The main challenge for performing design space exploration is to formalize the design aspects that need to be explored. Model-based design approaches provide a way to do this. A good example from the automotive domain is PREEvision [1]. This is a model-based design tool for electric/electronic architectures and is currently being used by all major car manufacturers. The most interesting aspect of this tool is that all design aspects can be described and their relationships mapped. For instance customer requirements can be traced down to the Electronic Control Units responsible for them, their location in a car and the wiring used to interconnect them. We see an opportunity to apply similar concepts for the design space exploration of devices in the building automation domain.

Our approach for design space exploration in the building automation domain is shown in Figure 3. It assumes that functions and the architectures of the devices implementing them can be separately considered [2]. We assume that a function or a set of functions can be implemented in different device architectures. The simplest way of thinking of these functions is as software components that can be executed in different devices.

The product catalogs from ABB Stotz Kontakt and Busch-Jäger devices were analyzed as a starting point for identifying potential distributable functions. The search was limited to KNX devices and resulted in 550 devices with various functionalities. Their functionalities were afterwards classified into basic function blocks such as actuating, communication, control, logic, sensing, and user interface. We identified 133 different basic functions blocks, 80 of these being potential distributable functions.

A similar search was done to identify the electric/electronic component used in KNX devices. This resulted in thousands of active, passive, and mechanic components. Their relevance for the basic function blocks described above was afterwards investigated. Digital ICs such as microcontrollers and logic circuits (e.g. binary operation chips, timers) were identified as the most important components since they are responsible for the device's intelligence. Discrete semiconductors (e.g. diodes, transistors and optical interfaces) come in second place, followed by Analog ICs (e.g. amplifiers, comparators, power management chips) and RCL circuits. This demonstrates that each electric/electronic component has certain relevance for the functionality of a device and must be considered in holistic way for the purpose of design space exploration.

3. Assessment

Only a set of design alternatives from Figure 3 are physically realizable after mapping functions and device architectures. Each of these mapping solutions must have some sort of measurable cost function that can be used to evaluate them. For instance, a function defined as a software component can be executed in a high-end microcontroller (32-bit) or in a low-end microcontroller (8-bit). The tradeoff between both implementations can be measured in terms of a cost function that quantifies the ratio between required versus provided processing performance. The same applies for a function requiring a given amount of memory. It can be mapped to any architecture which has at least that amount of memory available.

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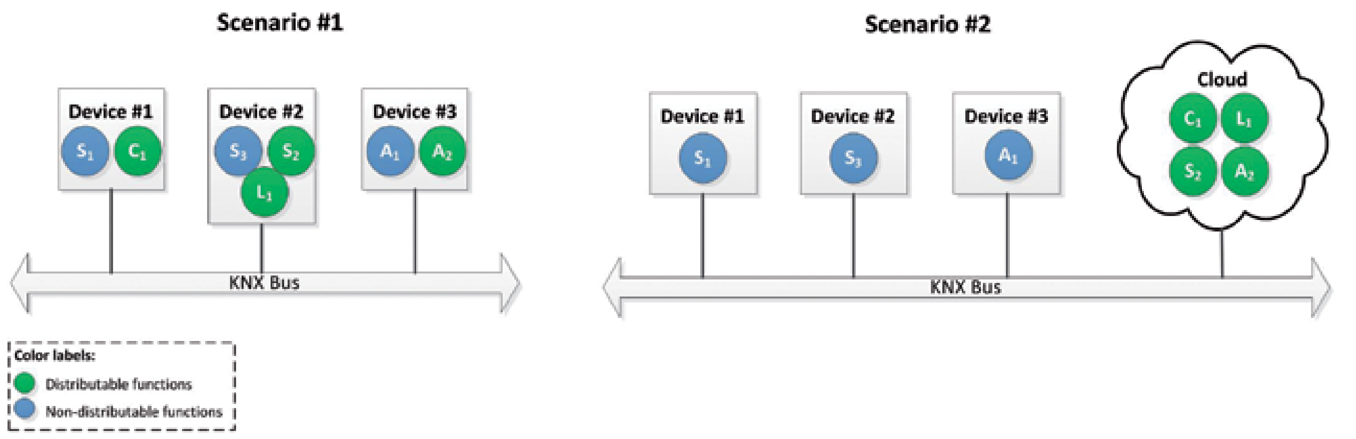

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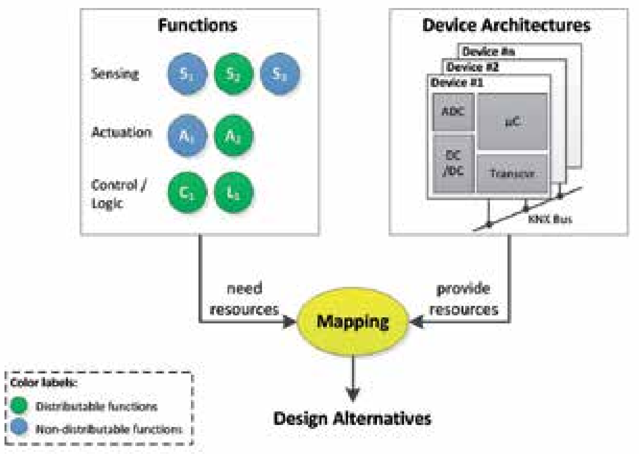

Figure 2: Scenarios for function distribution | Figure 3: Mapping of functions and device architectures

Calculating some of the cost functions above seem trivial, such as memory size (results from the sum of memory requirements from all aggregated functions in a device). However, it is not clear how to calculate some cost functions, especially qualitative ones such as robustness, scalability, safety and security. It is also not clear which cost functions can be aggregated in a linear fashion.

The challenge of finding and evaluating consistent combination of electric/electronic components that can implement all possible design alternatives seems too complex to be described with available model-based design tools. Not even PREEvision from the automotive domain is able to do this since the level of detail required is too fined-grained.

4. Conclusions

It seems unfeasible to perform design space exploration on the electric/electronic architectures of devices. It seems more reasonable to simplify the design space exploration challenge by discarding such fine-grained aspects. Instead, a small set of common device architectures (also called common platforms) can be used to find the tradeoffs of function distribution. The exploration can be done initially by specialized tools during commissioning in order to know the number and type of devices needed for a certain application and a metric of the robustness and scalability of the possible solutions. Similar explorations can be done after commission, for example, to increase the robustness of a building automation system in case of device failures or to add new functionalities into existing installations.

Internal Customer

Low Voltage Products and Systems

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Cloud-Enabled Automation Systems Using OPC UA

Dr. Johannes Schmitt, Dr. Thomas Goldschmidt, Dr. Philipp Vorst

Abstract

Emerging data-intensive applications like smart grids and the internet of things pose new challenges to industrial monitoring systems. Data has to be transferred not only within plant networks but also through the internet, across firewalls, proxies etc.

OPC UA is a modern industrial communication standard that is getting more and more adopted in various industries. A drawback of OPC UA related to a cloud-based application is its client-server based communication concept. Following this communication principle, OPC UA has to handle hurdles caused by firewalls, proxies, dynamic IP-addresses, NATs and client-lookup strategies. While web and cloud technologies have successfully been used for various enterprise applications, their maturity for industrial applications with higher requirements for responsiveness and robustness is largely unknown. Widely used technologies for communication from a cloud application towards client-side services are XMPP and Websockets.

The purpose of this work is to bring OPC UA together with web and cloud technologies in order to enable the use of OPC UA in cloud environments. We have extended the client-server concept of OPC UA and provide an evaluation of the applicability, reliability and performance of various web-based communication protocols that serve as an additional transport layer underneath OPC UA. We have therefore extended the OPC UA communication stack with XMPP and Websocket support and we analyzed the performance of these extensions.

1. Introduction

The targeted scenario focuses on the area of automation systems, where an application (or service) in the cloud has to communicate and interact with field-devices on a site (e.g. a building or plant). One or more of the following exemplary applications can be assumed:

– Remote control: As far as requirements like delay constraints and reliability are met, a remote logic in the cloud can be used to control elements on site. The advantage of a cloud-based approach is the global view of aggregating the information of multiple sites and virtually unlimited CPU power. Another benefit is the easy integration of mobile devices like smartphones.

– Cloud historian: A data historian in the cloud is of special interest when a virtually infinite amount of data should be stored and/or data should be stored securely in a remote location because of (legal) data backup requirements.

– Service platform: The PaaS (Platform as a Service) concept, where a modular software concept and common interfaces provide a basis for additional services or to obtain an extensible system architecture. Here the advantage of a cloud consists in its flexibility to provide virtually unlimited resources for the platform and its services.

OPC UA defines a meta-data model and interfaces to the data model. Using an OPC UA based communication between the cloud and a site provides full access to the information of the OPC UA Server(s) at the site. Without any media breach like mapping or protocol conversion a cloud application can make use of the functionality of the OPC UA server on the site.
As OPC UA is powerful in terms of extensibility of its data model and semantic self-description of the information – this approach is flexible and future proof.

A cloud application needs an OPC UA Client in order to access the data provided by an OPC UA Server deployed locally at a site or building. As a major extension to its predecessor OPC, OPC UA provides binary or XML-encoded messages over TCP or HTTP(S) [1]. This makes OPC UA routable, platform-independent and much more flexible – especially for internet- or cloud-based applications [2]. Since OPC UA uses a client-server based communication concept, the client starts the connection to the server (as depicted in Figure 1 with “A”). Following this communication principle, OPC UA has to handle hurdles caused by firewalls, dynamic IP-addresses, NATs and client-lookup strategies.

The common approach of the protocols XMPP and Websockets is the ability to establish the connection from the local-side and re-use this existing connection from the cloud-side “backwards” in order to access services decentrally [4] behind firewalls (as depicted in Figure 1 with “B”). While XMPP follows an asynchronous message-queue based principle using an intermediate message broker, Websockets are employed for synchronous direct calls.

3. Concept / Prototype Design

We have extended the client-server principle of the OPC UA stack by mechanisms which allow for bidirectional communication. This extension enables a cloud to local-side communication over a previously established local to cloud-side connection (as depicted in Figure 1 with “B”).

As another extension we developed a prototype for an “OPC UA Proxy Server” which provides transparent access (e.g. for other cloud applications) to multiple client-side OPC UA servers through the cloud-side OPC UA client (comparable to the concept of an “Aggregating Server” [3], but without replication). This proxy server concept targets to provide in the cloud a central point for communication for both the OPC UA Servers connecting to the cloud and the cloud applications requiring access to the information on the OPC UA Servers. The prototyped OPC UA Proxy Server shown in Figure 2 provides multiple mechanisms to manage the access to remote OPC UA Servers as they are commonly available for local servers. These mechanisms comprise connection management, remote node management, subscription and alarm/event management as well as access management.

Figure 1: New communication concept in OPC UA | Figure 2: OPC UA Proxy

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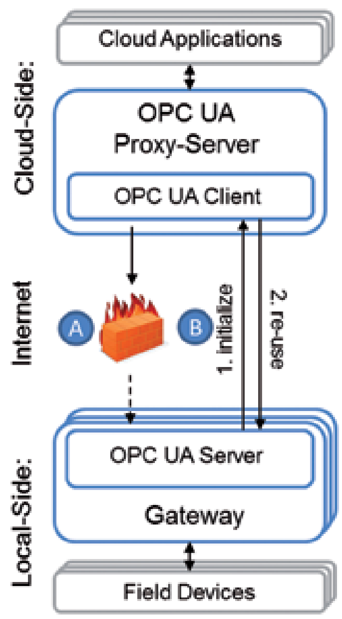

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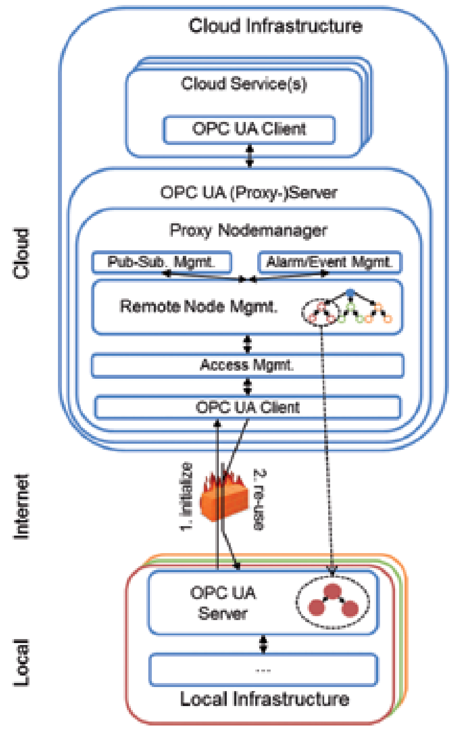

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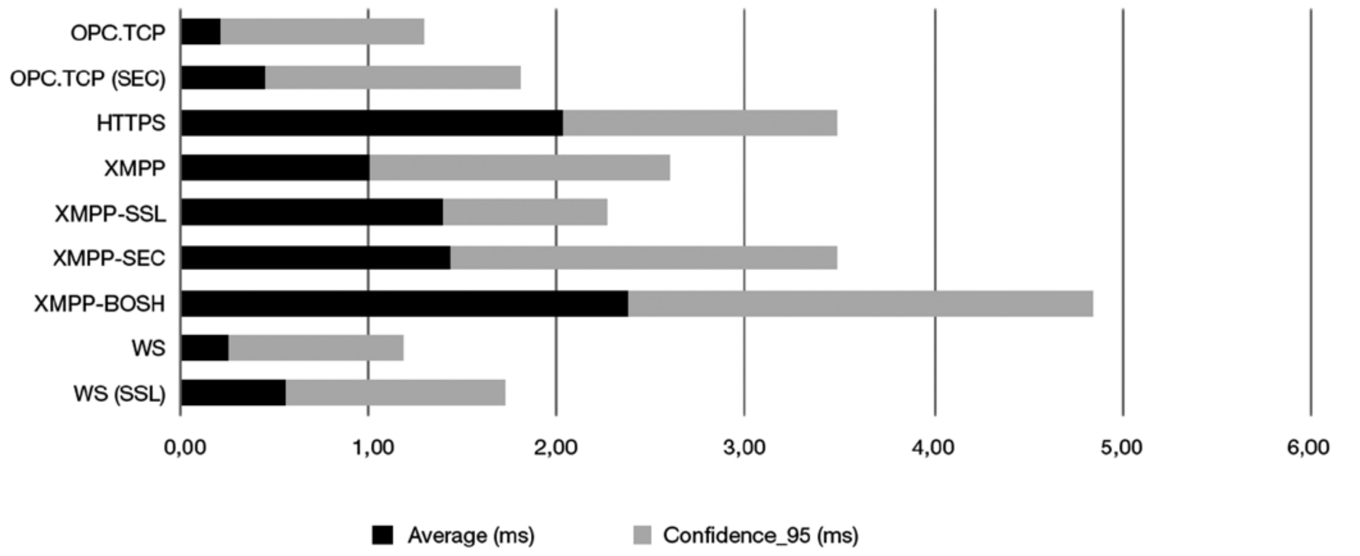

Figure 3: Delay for an OPC UA request-response

4. Performance Evaluation

As a proof-of-concept and for a performance analysis we have integrated and tested our system on local machines, private clouds, embedded devices, mobile devices and public clouds. The analysis comprises a comparison of traditional OPC UA over TCP and HTTPS with the new approaches of OPC UA over XMPP and Websockets. In addition, we analyzed also the impact of parallel requests, different security configurations and also the usage of XMPP over BOSH which allows traversing HTTP proxies. As an excerpt Figure 3 shows as comparison of the different transport means on a local machine, focusing the plain protocol overhead. OPC.TCP (SEC) with a delay of about 0.45ms can be seen as a reference value, which will typically be applied in OPC UA based systems. The OPC.TCP (SEC) is using its own mechanisms for signing and encrypting the data (similar to but not based on SSL). HTTPS is the other "basic-OPC UA protocol" included in the OPC UA Stack. It is using regular HTTP over SSL. Like typical http based approaches this protocol also uses a new connection per request and base64 for encoding, which makes it slower than OPC.TCP. Pure HTTP was not tested – OPC UA uses pure HTTP only in combination with the currently not supported XML encoding. XMPP uses also a binary TCP transport mechanism – but with the necessity to use a base64 encoding in order to wrap the binary data into an XML container. This and the additional hop over the XMPP Server (on the same PC) make XMPP slower than OPC.TCP. In comparison to HTTPS this approach is faster – which may be because it re-uses previously established connections. XMPP can be used in two secure modes: XMPP-SSL uses a (deprecated) approach by applying a SSL connection to the XMPP server, while XMPP-SEC uses an XMPP internal mechanism to provide a secured transport (maybe with end-to-end encrypted body). Both approaches have a similar delay in this scenario. XMPP-BOSH is using a BOSH based transport. BOSH itself is using a HTTP-long polling approach. The communication over base64+XMPP+BOSH has the highest latency – but the ability to work also over HTTP proxies, NATs and Firewalls. WS transports the data quite similar to native OPC.TCP – but with the bidirectional communication strategy. Both wrap the payload in their protocol which provides additional mechanisms for transport management. This results in a similar delay during the communication: The unsecure approaches need 0.25ms (WS) compared to 0.21ms OPC.TCP; the secure approaches WS (SSL) is also comparable to OPC.TCP (SEC) with enabled signing and encryption mechanisms.

5. Conclusions

The goal of the presented performance evaluation and some additional tests in combination with embedded systems and clouds was to give a proof of concept and to provide an order of magnitude for the average delay which can be achieved: the additional overhead for Websockets/XMPP compared to opc.tcp is in most cases about 0-5ms; the average delay for one request on an embedded device in the local network is between 5 and 15ms. But the basic delay for the communication over the internet to a cloud instance has to be taken into account in any case e.g. the same request towards a system in the (Amazon) cloud needs about 200ms. The delay might depend on multiple factors like the cloud provider, the physical distance, the DSL provider, the load of the cloud instance, and the current daytime – usually this value is between 50 and 350ms.

Additional results also show that by re-using already established connections a reduction of the latency can be obtained – e.g. while HTTPs needs around 2ms per request, Websockets over SSL need only about 0.6ms. Also, the delay of synchronous calls over XMPP and the indirection through the message broker can be relatively low, so that XMPP can be considered as an alternative to Websockets. XMPP also provides additional features such as asynchronous calls and multicast which could be interesting for future extensions.

The proof-of-concept shows that it is possible to engineer automation systems for the cloud, satisfying abovementioned requirements, by using an OPC UA based architecture in combination with extended transport mechanisms. With this approach it is also possible to manually instantiate "classic" OPC UA connections to OPC UA Servers with a Stack without Websocket-Support but with the necessity to manually address all connection issues like firewalls, NAT, etc.

Because the network connection to the cloud typically introduces the largest part of the communication delay, a fundamental decision should be made before enabling an automation system for the cloud: Can the constraints for communication delays be met by the network link to the remote instances/cloud infrastructure?

This allows exploring the limits of today's technical solutions for industrial applications and serves practitioners as a reference so that other applications can be compared to our performance measurement results.

Internal Customer

All the listed contributions where sponsored by the "Software" and "Communication" Research areas of ABB.

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Automation Cloud

Dr. Thomas Goldschmidt, Dr. Philipp Vorst, Dr. Bastian Schlich

Cloud computing is one of the recent game changers in IT. It is revolutionizing the way resources such as servers, storage, or entire applications are made available via the Internet – easily for resource consumers and cost-effectively for resource providers. In the automation domain, today it is hardly understood which types of applications actually benefit from cloud computing, what limitations they are exposed to, and which technology to employ. We present insights gained during the first year of our interdisciplinary, cross research area (Software, Control and Communication), cross research center (Germany, Sweden, Switzerland and India) project.

Problem Description

While cloud technologies have been successfully used for selected enterprise applications, their applicability and especially their maturity regarding the requirements for industrial applications is largely unknown. Additionally, as customers in the automation domain have higher standards regarding security, availability and safety cloud solutions in automation have to present a mature concept for these qualities.

At the same time, competitors are pushing with considerable investment in cloud R&D. For example in 2013, General Electric invested 105 MUSD into Pivotal, a cloud technology developing company, and heavily pushes what they call the Industrial Internet [6].

An important first step is to realize what the cloud – or, cloud computing – actually is. For many people, "the cloud" is often a synonym for "the web", and even developers often confuse a "cloud service" with a "web service". So, how to distinguish the two of them? Cloud computing essentially is a model for giving easy access to scalable computing resources (e.g., networks, servers, storage, applications, and services) over a network, typically the Internet. This is the widely accepted definition [2] by the National Institute of Standards and Technology. NIST also claims five essential characteristics:

- On-demand self-service: A consumer can unilaterally provision computing capabilities as needed, without requiring human interaction with each service provider.

- Broad network access: Capabilities are available over the network and accessed through standard mechanisms.

- Resource pooling: The provider's resources are pooled to serve multiple consumers (tenants). Different physical and virtual resources are dynamically assigned according to consumer demand.

– Rapid elasticity: Capabilities can be elastically, rapidly provisioned and released, on demand. To the consumer, the capabilities available often appear to be unlimited.

– Measured service: Cloud systems automatically control and optimize resource use by leveraging a metering capability. Resource usage can be monitored, controlled, and reported, for both the provider and consumer.

For cloud consumers, this essentially results in easy access and provisioning with on-demand elasticity and pay-per-use. For cloud providers, this results in resource-efficient service providing, while scalability and multi-tenancy (the ability to concurrently provide several users and organizations the same service securely and without undesired interference) have to be ensured.

Cloud services exist on three different layers: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). IaaS deals with the management of virtual resources such as virtual machines or storage facilities. PaaS concerns the lifecycle, i.e., deployment, monitoring, and scaling of applications and services. Finally, SaaS is the end-customer facing service providing domain-specific functionality.

The development of a cloud solution is a complex undertaking. Especially, the increased complexity of the technology stack has to be handled, which might incur higher initial costs that only pay off for a sufficient number of customers. Security and privacy concerns have to be thoroughly addressed as a single breach might have a huge impact on the customer's confidence in the service provider. Furthermore, business models and organizational readiness have to be adapted to support the Software as a Service concept. Finally, engineering of a customer's logical system in the cloud has to be streamlined. Cloud services only scale to the required large number of customers if customers can do the provisioning and configuration of their systems in an easy-to-use, self-service manner.

The goal of our project has been to analyze the opportunities and offerings of available cloud technology, to understand applicability and limitations, and to tackle the listed challenges.

Solution Approach

The research project "Automation Cloud" is an interdisciplinary research undertaking, involving researchers in the area of software architecture, cloud computing, engineering, control, optimization, security, service business, and user interfaces.

We tackle the problem from two different angles. First, we analyze candidate applications from existing as well as new ABB businesses and define ways to transform them into a cloud-based solution. Second, we take a technological point of view and analyze cloud technology regarding their benefits in automation applications.

What automation applications to bring into the cloud?

For selecting the right automation applications that actually benefit from being transformed into a cloud-based SaaS solution, we analyze them regarding the NIST criteria for cloud computing. There is often a misunderstanding which target features really deserve a cloud solution and which ones simply benefit from using an underlying cloud infrastructure. The NIST criteria enable us to identify applications of the former type.

For example, we analyzed whether the remote monitoring of big photovoltaic power plants, which is existing ABB business, would benefit from a cloud solution. However, we identified that the properties of this case do not fit the cloud properties very well. For example, there is only a limited number of customers and thus no rapid scaling is required. Furthermore, the engineering effort for each new plant is rather high and often done by ABB engineers, thus the self-service aspect is not fulfilled. Finally, the load of the system, such as the data being transferred from each plant as well as the analysis being done are rather constant, thus the system does not require elasticity. However, if the scope would be extended to include all kinds of asset management and service data for transformers, switches, panels, etc., a cloud service for centrally managing service for this equipment would benefit from the cloud properties.

Another example of where a cloud solution for automation does make sense is the monitoring of solar inverters for small installations or private households. In this scenario thousands of customers want to use an easy-to-use, self-configurable access to the monitoring data of their inverters. Thus, the solution requires cloud capabilities like, elasticity, scalability, self-service, and broad network access.

Finally, we investigate how we can apply cloud business models to automation SaaS. Not all application cases fit the cloud business model and therefore, it does not make sense to analyze them technically. On the other hand, cloud business models can also inspire ABB business and extend it to markets that we currently do not address.

How to apply cloud technology in automation?

ABB will probably not be a cloud provider in the future. However, we need to understand the technologies in order to move our applications into the cloud. Therefore, for certain ABB software a migration path starting from a virtualized environment based on IaaS and probably moving to a PaaS, which also manages application lifecycles, scalability, and deployment, is important for short term progress.

However, as a long term focus, we envision an ABB Automation Platform as a Service that targets domain-specific solutions for various areas that are missing in general purpose cloud platforms. As depicted in Figure 1, example solutions are: robust, scalable, cloud-native historians (events & time series data), secure and reliable device connectivity, easy self-service provisioning and engineering, a collaborative engineering platform, web and mobile automation, control in the cloud as well as a platform for big data analyses. In this area, ABB has most expertise and knows the customers' needs and other domain constraints. Therefore, we should build on existing technology at the IaaS, PaaS layer and create domain specific, tailored solutions that will enable ABB to deliver multi-tenant Software as a Service to the customer.

Technical Accomplishment

During the first year of this project, we accomplished various insights into technology, created cloud operation concepts, and developed proof-of-concept prototypes. A few highlights of this work are given below. One of the technical accomplishments is presented in a separate article "Cloud-Enabled Automation Systems Using OPC UA" on page 64.

Conceptual Architecture

We created a conceptual architecture for an automation platform that offers automation domain specific services such as reliable, industry standard communication as well as tailored databases. As a proof-of-concept, we implemented an end-to-end prototype based on this architecture. The prototype is able to collect data from various sources, distribute and store it internally and visualize it using web-based dashboards. Along the development path of this prototype, we evaluated cloud technologies for IaaS (e.g., OpenStack, Amazon Web Services), PaaS (e.g., Azure, CloudFoundry), cloud databases (e.g., Hadoop, Redis), communication protocols (OPC UA, Websockets), security (e.g., SAML2, OAuth) and many more.

The combination of the conceptual architecture with the evaluation prototype delivers reusable architecture decision points and quality attributes for specific scenarios. Furthermore, we gathered lessons learned about maturity and risky steps within the technological range of cloud computing.

Scalable Historian Database

Scalable storage of all kinds of data is a vital part of a cloud solution. In the area of automation, the largest part of the data is time-series data representing sensor measurements, setpoints, and production data over time. In contrast to a traditional historian where the storage capacity is mostly limited to one industrial plant, a cloud system would have to scale to orders

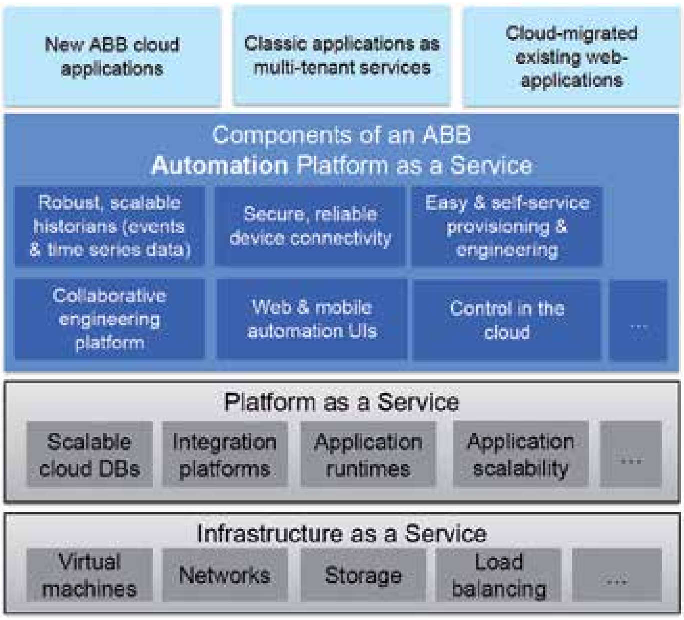

Figure 1: Automation Platform as a Service.

of magnitude more than that. In order to identify which cloud technology is the best fit to handle this kind of data, we performed an evaluation of cloud-native time series databases regarding their scalability and robustness. To assess these qualities, we defined two representative workload profiles from the smart grid domain. For example, one of them simulated the data coming from millions of smart meters measuring the energy consumption of utility customers. Furthermore, we observe how graceful the databases handle loads beyond their current capabilities. Based on these profiles, we evaluated three different open-source time series databases (OpenTSDB, KairosDB, and Databus). In particular, we aimed to determine the scalability and reliability of the technologies.

The results of the evaluation indicate that a near-linear scaling behavior is possible. The best candidate, namely KairosDB, was able to handle both workloads to an extent which would result in realistic cluster sizes, i.e., a 24-node cluster could handle the smart meters of a large city, i.e., more than 6 million smart meters. Regarding resiliency, the solutions could, even with one or two instances down, continue working. Even though, response times partly went beyond the specified timeouts.

Conclusion and Outlook

The Automation Cloud project aims at evaluating as well as developing automation domain specific cloud technology to facilitate the creation of an ABB Automation Platform as a Service.

IaaS providers already provide matured systems whereas PaaS frameworks are still maturing. Especially, the support the requirements of the automation domain such as high security and availability need to be explored further.

Customer and ABB Benefit

Our project enables ABB business units to deliver automation software as a service by creating an architecture framework for cloud computing in automation. Therefor we come up with functional prototypes, technology evaluations, architecture decisions, and demos validating high-potential business cases.

This way, we help ABB to grow business and stay competitive in the area of SCADA/DCS/MES software, a multi-BUSD market.

Customer / Internal Customer

Process Automation Division, various business units
Power Systems Division, various business units
Group Function Service R&D

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Static Analysis for IEC 61131-3 – Automatic Detection of Programming Errors

Dr. Stefan Stattelmann, Dr. Bastian Schlich

Testing software manually is a cumbersome and error-prone process. Static code analysis is a well-established approach to reduce the manual testing effort during software development. However, programming languages (i.e., IEC 61131-3) used for controllers in plant and factory automation are barely supported in commercially available static code analysis tools. In collaboration with RWTH Aachen University, we adapted a sophisticated static analysis tool for ABB control software to bring the efficiency gains of static code analysis to the automation domain.

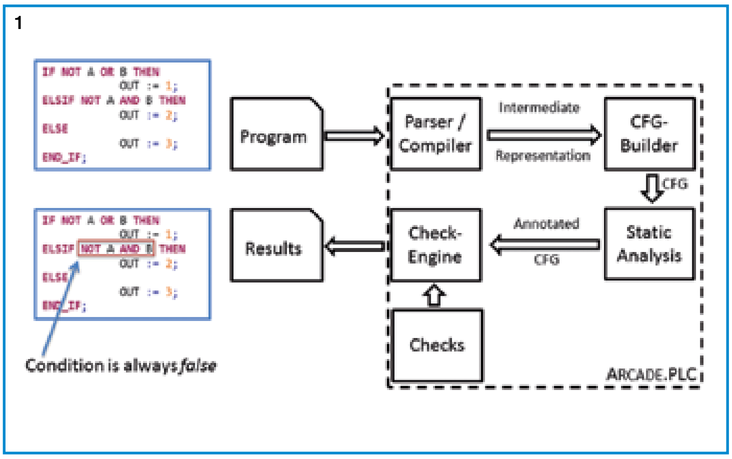
Problem Description

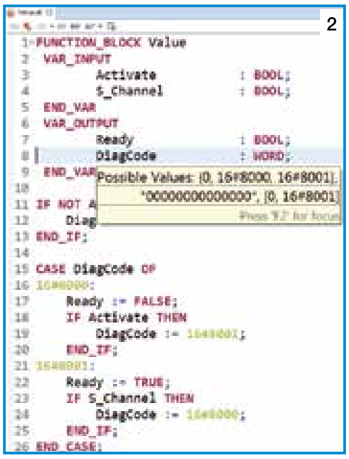
In the area of general purpose programming, e.g., for programming languages like Java, C# or C++, static code analysis is in widespread use to detect coding errors automatically during software development. Such tools can reason about certain properties of a program, e.g., runtime errors, without specifications or test cases provided by the software developer. As the use of static code analysis reduces the effort needed for manual testing, it can reduce the overall cost of software development significantly. However, there is very little support for static code analysis of IEC 61131-3 languages in commercial solutions.

IEC 61131-3 languages are used within many engineering tools for ABB products, including Control Builder Plus, Control Builder M, and Control Builder F. These tools allow users to develop control logic and test the control program using an included simulator (soft controller). However, there are little to no automated mechanisms to detect potential coding errors.

Solution Approach

As a part of a university collaboration with RWTH Aachen University, the ARCADE.PLC PLC [1] static code analysis tool has been adapted for ABB controllers and applied to control programs for the AC500 and AC 800M controllers. The overall analysis work flow is depicted in Figure 1. As the static code analysis is implemented as an external tool, no changes to the programming environment or the engineering tool are necessary. The software developer simply loads the program to be analyzed into the analysis tool, and the tool automatically reports potential problems using its own graphical user interface. Internally, the tool reads the program to be analyzed, transforms it into an internal representation on which the actual analysis is performed. Based on the results of the static analysis, additional checks are executed and the results are presented to the user.





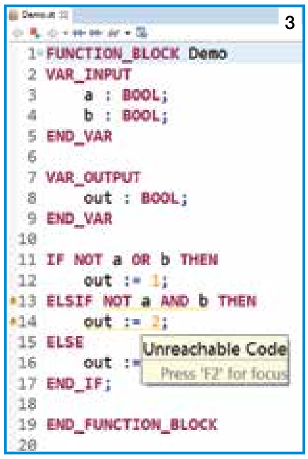


Figure 1: Static Analysis Work Flow | Figure 2: Results of Value-Set Analysis | Figure 3: Warnings in ARCADE.PLC Code View

The first step of the analysis work flow is parsing the program to be analyzed and transforming it into an internal intermediate representation on which all following analyses will be based. This transformation steps allows the static analysis to be independent from the actual engineering tool and the 61131-3 dialect used. Based on the intermediate representation, the control flow of the program is extracted and represented as a control flow graph (CFG). The actual static analysis step is implemented as a data-flow analysis on the CFG using abstract interpretation [2]. The core of the static analysis is a value-set analysis, which determines the potential values of all variables in the program. Simply put, the ARCADE.PLC tool performs a symbolic execution that approximates the calculations of the program independent from the inputs fed into the program. Internally, this works by simulating the computations on variables using abstract values like intervals, bit vectors, and finite sets of concrete values. Thus, the analysis can determine the possible output values of complete programs or function blocks in a way that is independent from the actual inputs and without executing the program. The value-set analysis by itself can already be very useful, e.g., to demonstrate that a function block implementing a state machine can reach all required internal states. As shown in Figure 2, the ARCADE.PLC tool displays the results of the value-set analysis using an enumeration of possible values, a bit vector, and intervals for each program variable.

The results of the value-set analysis are also annotated to the control flow graph during the analysis and used for further checks. For instance, the possible values of variables can be used to statically evaluate the outcome of conditional statements (IF/ELSE). If a certain condition always evaluates to TRUE or FALSE, some program lines which are surrounded by a conditional statement will either always be executed or not executed at all. Since this is independent of the input variables, it most likely constitutes a programming error. Further checks based on the results of the value-set analysis include checking for a potential division by zero, verifying that all possible runtime values are handled by a case statement or detecting that the value of a variable is constant although it is written to by the control logic. The tool can also check if output variables are written more than once within on execution cycle or if firmware functions are used inappropriately.

An example of how the analysis results are presented is shown in Figure 3. The analysis was able to prove that the combination of input variables specified in line 13 can never evaluate to TRUE. As a consequence, the statement in line 14 is unreachable and thus can never be executed. The results of all the analyses implemented in ARCADE.PLC are available through a nice graphical user interface. This enables the developer of control code to analyze individual function blocks or entire projects with multiple applications at the push of a button.

Technical Accomplishment

In the course of the project, static code analysis techniques have been successfully applied to real-world control code for the AC500 and AC800M controllers. The ARCADE.PLC tool was able to analyze entire control projects consisting of multiple controllers, while considering the potential interaction between the applications running on different controllers. The static analysis provided very good results with little to no false warnings.

In a case study for the AC500, several development versions of the PLCopen Safety library were analyzed. By applying the tool to different intermediate versions, we could show that ARCADE.PLC would have been able to automatically detect some of the coding errors which were only discovered after extensive manual testing. Thus, applying ARCADE.PLC already during the development of the library would have simplified its safety certification.

As part of another case study, ARCADE.PLC was used on a complete automation system with multiple AC 800M controllers. Some of the results for this case study are shown in Table 1. Even for larger programs with multiple function block instances, the time to analyze the code remains in the order of seconds. The tool was also able to analyze the entire project consisting of about 55,000 lines of code in less than one hour on a laptop computer. By applying the analysis tool on a complete process automation project, its scalability could be demonstrated. Despite the complexity of the project, the tool produced sensible results with little to no false warnings.

Program	Lines of Code	Function Blocks	Time for Analysis	Warnings
Controller 1 / Program 1	233	3	< 1 s	6
Controller 1 / Program 2	61	5	< 1 s	0
Controller 1 / Program 3	2196	121	9 s	8
Controller 2 / Program 1	2776	100	11 s	0
Controller 2 / Program 2	169	5	< 1 s	0
Controller 2 / Program 3	2684	100	63 s	0
Controller 2 / Program 4	206	12	< 1 s	0

Table 1: Selected Results of AC 800M Case Study

Customer and ABB Benefit

The ARCADE.PLC static code analysis tool supports ABB developers equally well during the creation of individual function blocks, function block libraries, and complex, networked control applications. By applying automatic analyses during software development, the efforts for testing and debugging can be reduced and the development time can be accelerated. As the employed static code analysis covers all possible program executions, i.e., it achieves full test coverage, the quality of the software is improved at the same time. This allows streamlining the certification process of safety-related components. Ultimately, applying static code analysis enables ABB to provide customers with better, more reliable and less error-prone software systems and components. By integrating a static code analysis tools like ARCADE.PLC into the engineering work flow, the same benefits could be made available to customers.

Customer / Internal Customer

Division Discrete Automation and Motion
Division Process Automation

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Engineering Cockpit – Tying system projects together

Andrew Cohen, Georg Gutermuth, Armin Wallnöfer, Dr. Mike Barth

In engineering project execution, many different processes, tools, and people are involved. To reduce the effort and complexity of Process Automation engineering projects within ABB, the project Curry was undertaken. One of the solutions developed within Curry is a workflow-based engineering cockpit. It was built with the aim to better facilitate coordination of information and engineering in distributed projects, and to have a better overview of all of the moving parts within a project. The project workflow itself is used as a base for this, and it connects several different processes which are normally only connected via documents or in the minds of experienced engineers. This cockpit visualizes the workflow, and acts as an intermediary and loose coupling between different processes and tools, giving all project participants information in a consistent, unified view. This view hides away much of the complexity of the different systems and tools and gives a project-specific view which is adaptable to different domains and tool landscapes. It aggregates information from several disparate systems and data sources into a searchable and easily navigable entry point to engineering.

Problem description

Throughout ABB, engineering projects are executed by several different local units. Each unit has its own manner of executing projects, its own tool suites that have been developed over the years, its own unit-wide standard libraries, etc. The reasons for these differences are specific to domains (processes & regulations), customers (best practices and legacy hardware), and countries (local standards).

Unifying all engineering project execution workflows across the entire ABB organization to one uniform process has failed in the past due to the aforementioned differences. On the other hand, having all units with wildly different workflows and processes is inefficient, and fails to reuse the best practices from other domains.

Additionally, there are several different tools in use within a single project. There are systems for documentation, change management, standard procedures, templates, project management, etc. These systems are often disparate entities with no common thread to connect them. To further complicate matters, large engineering projects usually go beyond national boundaries, and even beyond company boundaries, with several

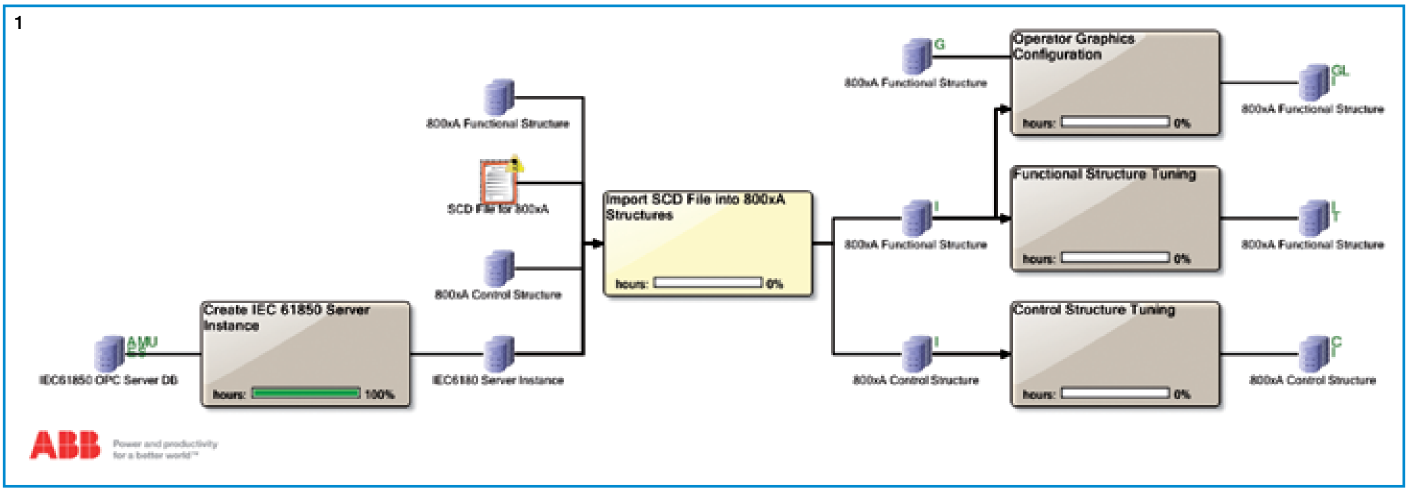

Figure 1: A simple sub-workflow which is part of a larger project. Objects form the connections between activities, and are defined in a directed graph model. The objects are linked to real artifacts in engineering, allowing queries, quick access, and impact analyses. In this case, the object 'SCD File for 800xA' was changed by another user and checked into a version control system. The change is shown instantly in the current user's cockpit view. The activities are linked to real users, tools, notes, knowledge management sources, and can automatically query other systems in the background to give progress metrics.

companies working on different parts of a large plant. For engineers, it is difficult to know where their work fits within the context of the overall project, or where to find help or guidance if they need it. Existing Operational Excellence (OpEx) information for standard procedures is usually static and decoupled from the project, and requires additional human interpretation. For managers of such a project, it can become quite difficult to keep track of what the different parts of the project are.

All of this can add up to a complicated situation where engineers must spend a lot of time getting used to processes and systems, and keeping track of project-specific information. With projects becoming increasingly distributed in nature, the engineers need to have a good overview and, at the same time, keep track of the different tools, data sources and project details they need to work with.

To try to reduce the overall complexity in engineering, and to try to streamline processes which lead to wasted time, the Curry Corporate Research project was undertaken.

Technical Approach

Curry's solution included a concept of an engineering cockpit that shows the project-specific workflow. This overview gives the engineer tailored guidance along the way, while also hiding away complexity and unnecessary information. The engineer can access as many things as he or she needs from one single interface that is organized in the way that he or she thinks: activities and objects (e.g. documents, hardware or software).

According to [1], we model the workflow as a directed graph with alternating activity and object nodes. Activities are tasks which are completed within a project (such as "Allocate IO"), and the objects are the inputs and outputs to activities (such as an "IO List"). The connections between activities and objects are made explicit in a computer-readable form (and not just within documents which require human interpretation). This graph model is queryable, and queries on this model return sub-workflows (themselves directed graphs in the same form as the workflow itself). The project-specific workflow can be generated (semi-)automatically at the beginning of the project from project bids or supplier master document lists (SMDLs), and can be dynamically changed to fit changed requirements during project execution.

The nodes in the workflow can provide additional static metadata (such as links to manuals, internal wikis, tools or document management systems) as well as additional configuration metadata which allows automatic aggregation of data such as cost or status. For example, progress providers can be added to activities to make a coarse estimation of progress in terms of real engineering artifacts (such as the existence of output documents in a document control system, or a number of objects allocated in 800xA or even external tools).

In Curry, this workflow model was refined and implemented. Additionally, a prototype of the engineering cockpit was implemented. The engineering cockpit is a software application which visualizes and takes advantage of the workflow model in an approachable software tool for engineers.

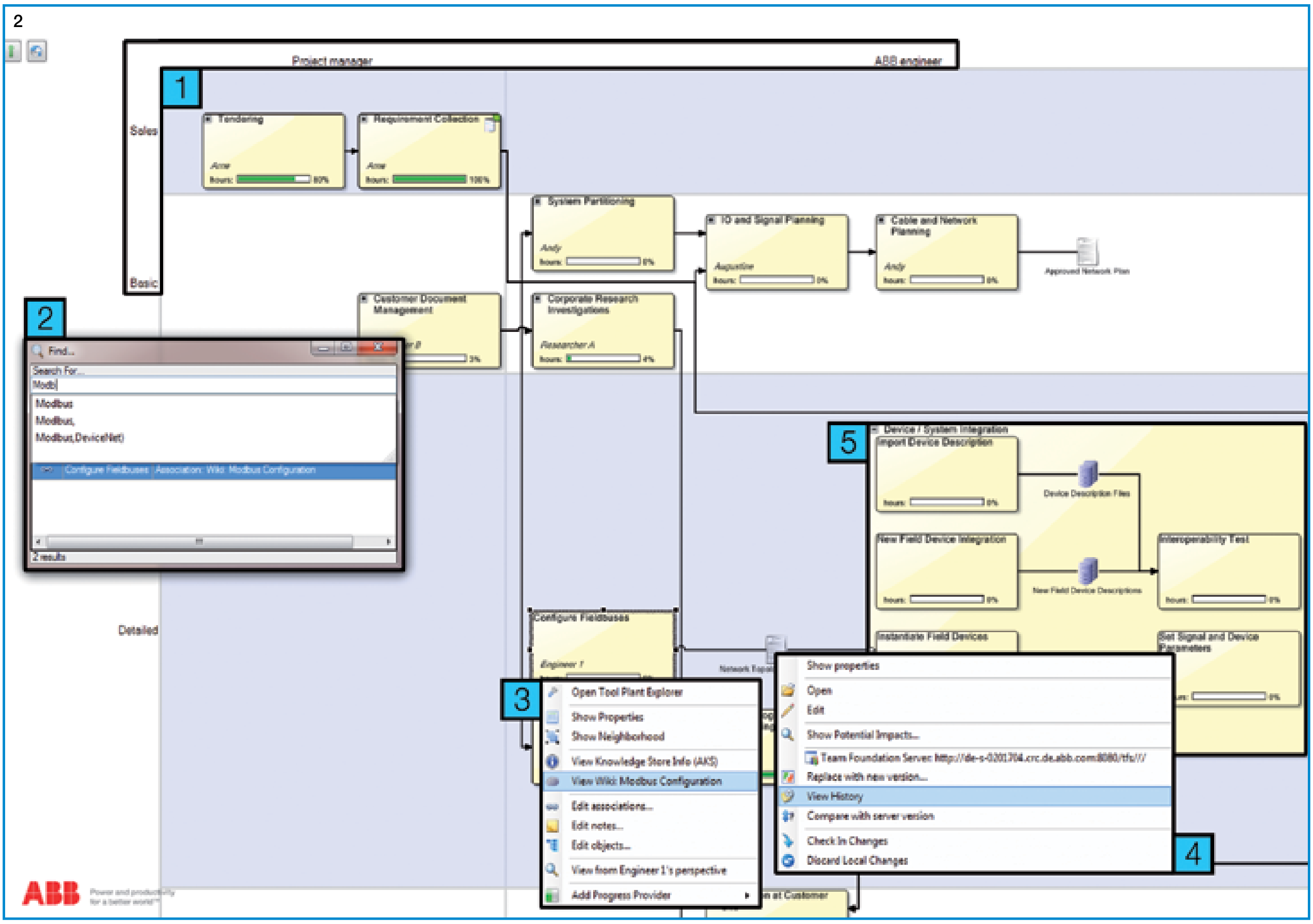

Figure 2: The engineering cockpit puts many different things in the hands of engineer within a click, including customizable swimlanes [1], project-wide search [2], context aware menus [3: Activity, 4: Object], and hierarchical levels of Granularity [5].

Project Overview: Users have a multitude of viewing options; for instance, the activities can be laid out in swimlanes based on arbitrary categories such as project phase, subcontractor, role, country, etc. Groups of activities can also be built, expanded or collapsed to show or hide details, and user-centric (what is relevant for me) and activity-centric (what is this activity waiting for, and what other activities need the outputs) views are also available. This helps the engineer to understand: "What are my tasks?," "When are my contributions needed?," "Whom do I deliver to?," "What is the status of activities I am waiting for?," or "Who worked on the requirement spec?"

Guidance: Users have immediate access to linked information (such as templates, manuals, or guidelines) directly from the activity or object they are working with. Team members can see their next task and project managers can, by viewing the progress, react early to bottlenecks or problems.

Navigation & Search: The engineering cockpit connects different pieces of information together visually for the engineer without interfering with the tools. The cockpit is searchable (with autocompletion), and distributed; meaning that several different engineers can see, query, and update the project simultane-ously in a distributed manner. The cockpit automat-ically connects with project-specific repositories and systems in the background.

Change Management: Impact of changes during project execution can easily be seen and discussed, as can other information about a change and follow up on the implemen-tation status of changes. Even the overall workflow can change with new project requirements during project execution.

Learning across projects and locations: At the end of a project, valuable data about the execution can be retrieved and used for the next project, since it was collected automatically during project execution. Examples are:

- Real effort data to be used in the next project bid
- Proven sub-workflows to be evaluated in other locations
- Best practice execution in one location to be considered for outsourcing in another project
- Sharing of lessons learned across projects and attached to the activity (not somewhere in separate documents)

In order to flexibly work with different systems, the prototype is extensible, allowing individual units to add connectivity to other tools they may need to access. There are hooks available to extend invocation of objects, tools associated with activities, progress estimation, import/export features and connections to documentation and version control systems for the objects.

Business Approach

Curry is a PA-wide initiative aiming for engineering improvements. The industries participating are Control Technologies, Oil and Gas, Pulp and Paper, Minerals, Metals, Marine, Food and Beverage, and Pharmaceuticals. Beyond the workflow support, further solutions were developed in a joint effort, e.g. to improve knowledge exchange, reuse of solutions, and the general engineering tool architecture and usability.

Results

- Design and implementation of a workflow model to store all relevant data in a computer optimized form.
- Prototype implementation of an engineering cockpit, with most of the user-requested features implemented.
- Piloting the cockpit with NO OGP. Project engineers, lead engineers, and OpEx groups gave positive feedback, and improvements were implemented.
- Demonstration of the method and tool to the PAIS Global and Country Management Team, resulting in inclusion in their strategy.
- The method and tool is being used to document workflows within Corporate Research, including the power, process automation, and building automation domains.
- Handover to productization (PAIS) is planned for mid-2014

Internal Customers

Division: Process Automation – BUs PAIS
(O&G, P&P, Minerals, Metals), PAMA and PACT

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The Extended Cause & Effect Editor
about capturing customer requirements in a structured way

Katharina Gohr

The engineering of process plants involves a variety of people of different domains with individual and specific engineering tools. The handover of data from one engineering step to the next implies two major challenges – the transfer of information between corresponding tools as well as people, e.g. between the domains of process and control engineering. While the process engineer works with P&IDs and control narratives to describe his requirements, the control engineer works with control logic sheets. But neither P&IDs nor control logic sheets are optimal in requirement discus-sions between the domains. Hence, requirements are written in documents – but verbal text is a known source for specification errors. For safety applications, this is solved by cause & effect matrices. This contribution extends the cause & effect matrix towards a common interface between process and control engineering, simplifying the exchange of requirements between tools and people. It is proposed to be common, structured, formal and human-readable requirement format, especially for discussions of requirements between different domains, such as process and control engineering. A formal description of requirements in an extended cause & effect matrix is a sound basis for a variety of further applications.

Problem description

The project was triggered by an end customer in the chemical sector – wishing to improve his engineering process. The problem there is mainly that the process engineer and the control engi-neer have no common language in which they can discuss the automation engineering of a plant. While the process engineer thinks in form of P&IDs and control narratives, the control logic engi-neer creates function block diagrams. But as the control engineer gets the input for the function plan engineering from the process engineer, he has to understand his languages as well. This manual step of creating the control logic is feasible as long as the information on the P&IDs and control narratives is complete, clear and detailed enough. But as this is often not the case, misunderstandings arise and questions back to the process engineer are frequent. As the P&IDs do not show all the required details and the control narratives are not easy to grasp, the control engineer would try to discuss his questions with the process engineer on the control diagrams and might forget that the process engineer is not used to them. More than ever when it comes to specialties as negative logic, the process engineer might not be willing to take the time to understand the control diagrams. The same problem typically arises during the hand-over of requirements from the customer towards ABB.

In the area of safety logic, this problem is already solved by using cause and effect matrices. These are configured by the customer and handed over to ABB. This format is usually understood by both disciplines – control and process engineering. Unfortunately, the normal cause and effect diagram is limited to simple shutdown logic and not capable to represent the more complex process logic. Thus, it was only used in the area of safety logic.

Extending the cause & effect matrix

The idea of this contribution is to extend the concept of the cause & effect matrix towards storing normal process logic in a cause and effect format. It should be possible to not only bring actors in a safe state (shut-down) as it is the case in a typical cause and effect matrix but also to control the actors according to the process needs. Thus, a simple tick or cross in the matrix that combines a sensor with an actor is not enough to reflect this logic. Instead, process command like 'open', 'close' or 'on' or 'off' should be inserted in the connecting cell. Also interlocks should be included so that these commands could also be understood as input ports of an effect-typical, e.g. a valve or a pump. Additionally, a section for combining signals through interlock logic is added upfront the connection area as shown in Figure 1. By the price of increased complexity of the format, this enables to cope with/comprise complex process logic in a flexible way.

According to the proposed extensions, in this interlock section, not only boolean logic like 'AND', 'OR' and 'NOT' can be modeled but also logic for analogue values like timers, selectors/switches and mathematical operations. They handle the preprocessing of the incoming signals from the sensors before affecting the actors. In case three levels of interlock logic do not suffice, either more columns could be added to the format or instead of connecting the outcome to an actor directly, a variable could be used instead. If this variable is then used again as a cause, the processed signal can be further manipulated.

In order to support the user in case the interlock logic becomes more complicated, a graphical preview (see Figure 2) shows the logic for one effect in the today's common form of a function block diagram. The extended cause & effect matrix can hence be transformed into control code.

This concept has been implemented in a prototype: logic previews are generated out of the information in the matrix and updated on the fly. These graphics are not planned to be editable as editing a matrix is usually quicker than editing a graphic once the user gets used to it. For documentation purposes, the graphics could still be printed.

Results & Benefit

The extended cause and effect editor (xCE) combines the advantage of the simplicity of the cause and effect diagram with the capability to also represent complex process logic. Requirements can be exchanged between process and control engineering without misunderstandings and thus save time, reduce the need for clarifications and help to improve the quality.

Furthermore, with this human and computer readable format, a huge part of the control configuration can be generated automatically which again reduces cost, increases quality and brings down the time needed for the control engineering allowing shorter project cycles. Ideally, the customer uses the xCE internally to configure the requirements of his plant. But with this compact format and autogeneration capabilities, it could even make sense for the control engineer to use it as a configuration tool in cases where the process engineer (customer) does not use it.

Currently, a product is being developed by the business unit PA-CT.

Internal Customer

Chemicals and Control Technologies

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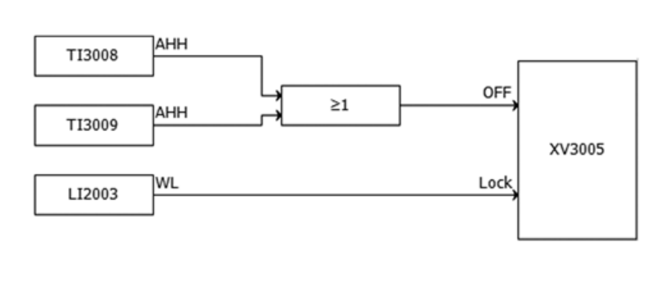
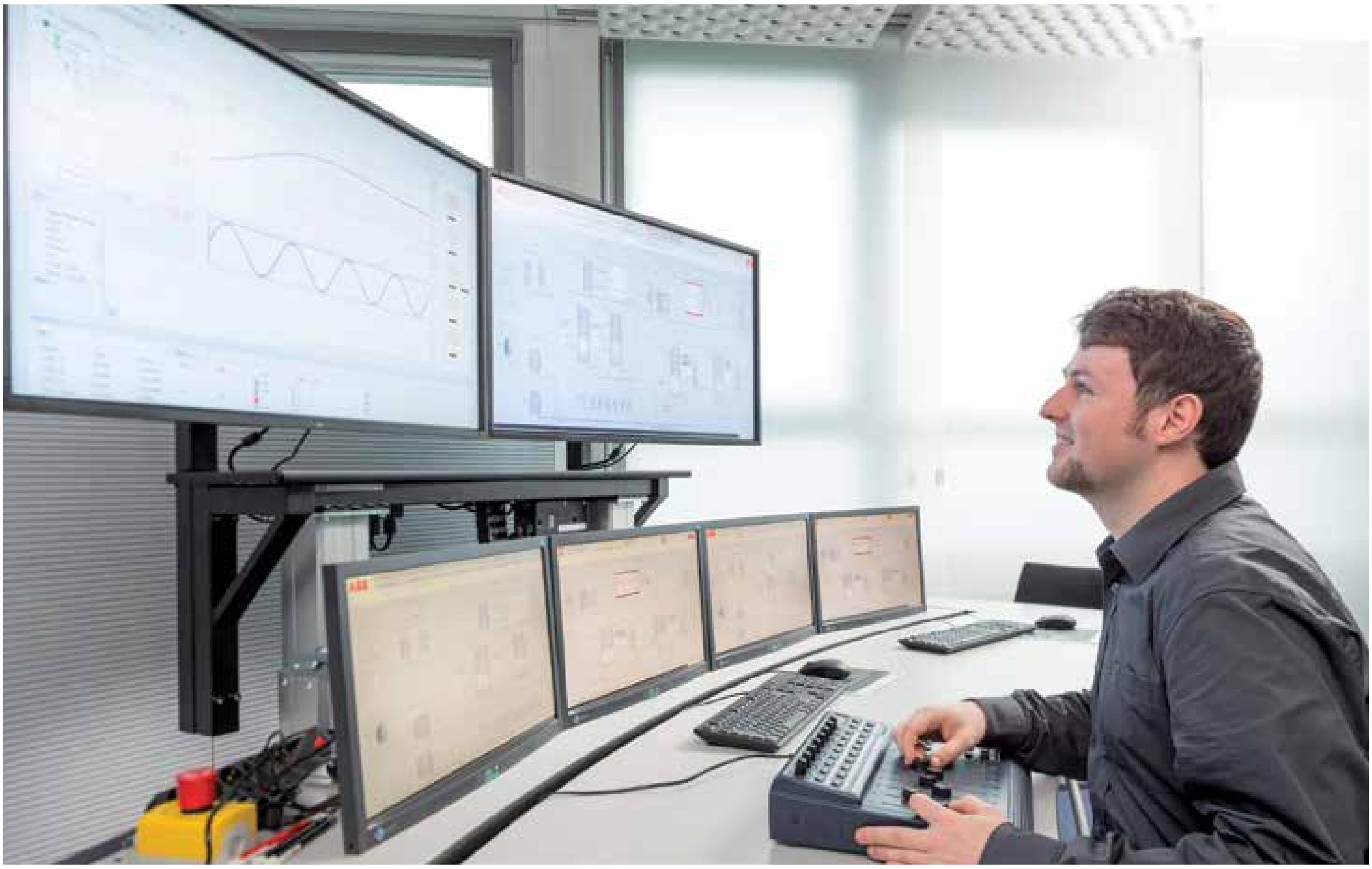
Figure 1: Extended cause and effect matrix | Figure 2: Logic of effect 'XV3005' as function diagram

1

Name	Type	Trip Point	Interlock 3	Interlock 2	Interlock 1	Name: XM3008, Type: MOT	Name: XS3001, Type: MOT	Name: XV3005, Type: MOT
LI2003	LT	WL				Lock	OFF	OFF
TI3009	TT	WH				Lock		
TI3009	TT	WL				Lock		
TI3009	TT	AHH			OR1			OFF
TI3008	TT	AHH			OR1			

2





Engineering Testing Support
Easy integrated instant testing of control applications

Christian Messinger, Andrew Cohen

The engineering of automation systems is a complex process that combines a wide variety of tasks. In the project Engineering Lab, we investigated different levers in engineering in three short phases, each consisting of three stages: idea creation, prioritization and agile implementation. This approach helps to quickly exploit the core of an idea and come up with a prototype to evaluate the value of the ideas in an efficient manner. One of the three ideas, which is presented in more detail, is the Engineering Testing Support: a way to easily and intuitively test control code during development to avoid cost of poor quality in later phases such as factory acceptance test or even onsite commissioning.

Problem description

The development of control code is one of the core aspects of automation engineering. Tools for the programming of PLCs or DCSs are considered to be core tools in the workflow of engineering projects. Once the logic has been implemented as defined in the customers' requirements and according to project guidelines as well as safety considerations, the applications are tested. Today, the testing is done either by the manual forcing of individual variables, one at a time, and observing the behavior of the potentially emulated system or later in the factory acceptance test (FAT) by forcing the signals at the IO-hardware by using potentiometers.

Both ways are limited in one way or another. Simultaneously changing inputs are hard to simulate using the forcing methodology and the FAT is rather late in the project, so finding a problem at that stage is already quite costly. A common disadvantage is the manual effort needed to execute the tests. Once a test is passed, it will most likely being considered as "done" and ready to proceed even though a change in the application may have a side-effect, changing the behavior of the already tested applications.

In literature, one can find that the cost of poor quality rises exponentially as the project progresses; problems found later are considerably more expensive than those found earlier. Therefore, one of the main goals was to create a low-effort testing solution that introduces testing as early as possible in the workflow of control code engineering.

Figure 1: A MIDI controller that can be used to control multiple signal values live during simulation

Technical Approach

The challenges in early testing can be summarized by two questions: How can we easily simulate the sur-roundings of an application in test to observe their behavior, and how can we reduce repetitive effort of the tests to keep the time between tests low and therefore the quality high?

Easy Simulation of Input Values

Today, the testing of an application, function block or sequence is done by simulating the inputs by forcing the variables in the engineering tools while an emulated controller is running and observed. Since the behavior of the applications is not a simple input to output mapping without state, we also need to simulate the signal change over time. Even that is not enough to mimic the surroundings of the tested entity; we need to simulate multiple signals over time.

To get inspiration for signal behavior in the time domain, we looked into a different area that is specialized to these kinds of problems: the music production domain.

Changing the set points and parameters of audio equipment over the timeline of a musical piece has similar requirements to testing the behavior of an emulated system:

- It has to be easy and intuitive to control (since it is done in real time).
- The setup changes often, so it needs an easy integration and setup procedure.
- The control of the parameters over time should be reusable along with the recording.

The predominant interface technology to control parameters in music production is the MIDI standard, a way to transport parameter changes in a live setup. It is a well-established standard, and the market for MIDI controllers, like the one shown in Figure 1, is large and therefore there is a broad variety of control-lers in terms of features and price.

The wiring of a connected MIDI controller to the signals of an engineering tool can be very simple and intuitive using a method called “MIDI learn”. The engineer selects the signal to be simulated and moves the fader or knob on the controller. Our implementation now automatically associates the hardware con-troller with the signal and the engineer can control the signal behavior of multiple channels over time like an audio engineer does while mixing of a band during a concert.

Record and Automate Tests

To be able to change the signal values live is a helpful addition, but a larger benefit comes from the possibility to record, save and replay signal curves over time. We implemented this in our engineering lab prototype and once again used music production software as a source for inspiration. Once a signal is recorded, the signal curves can be edited, for example by cutting, shifting in time or even adjusting the speed of the recorded pieces. Additionally, a library of predefined signal curves provides standard and often used functions like sine curves, sigmoids, or first- or second-order exponential rises / decays. These predefined signals have parameters which can be adjusted to the needs of the test. For example, the flow after opening a valve could be approximated by a first-order exponential rise. Figure 2 shows the user interface of the record, edit and replay functionality inside of the example engineering tool. A second, more detailed waveform editor also allows the direct manipulation of the recorded data points.

Once one or more signal samples have been recorded, adjusted and combined with predefined signalfunctions, the engineer can save this setup for later replay of the test. This helps to concentrate on the behavior of the control system since the test is fixed and can be reliably executed over several test runs.

To automate the testing even further, we took the concept of Unit-Tests from the software development domain: An auto-mated test with so called assertions that formulate some expected results.

For that, we can place assertions directly in the timeline associated to a signal and define the expected behavior like “Signal5 is below 42” or “Emergency Stop is True”.

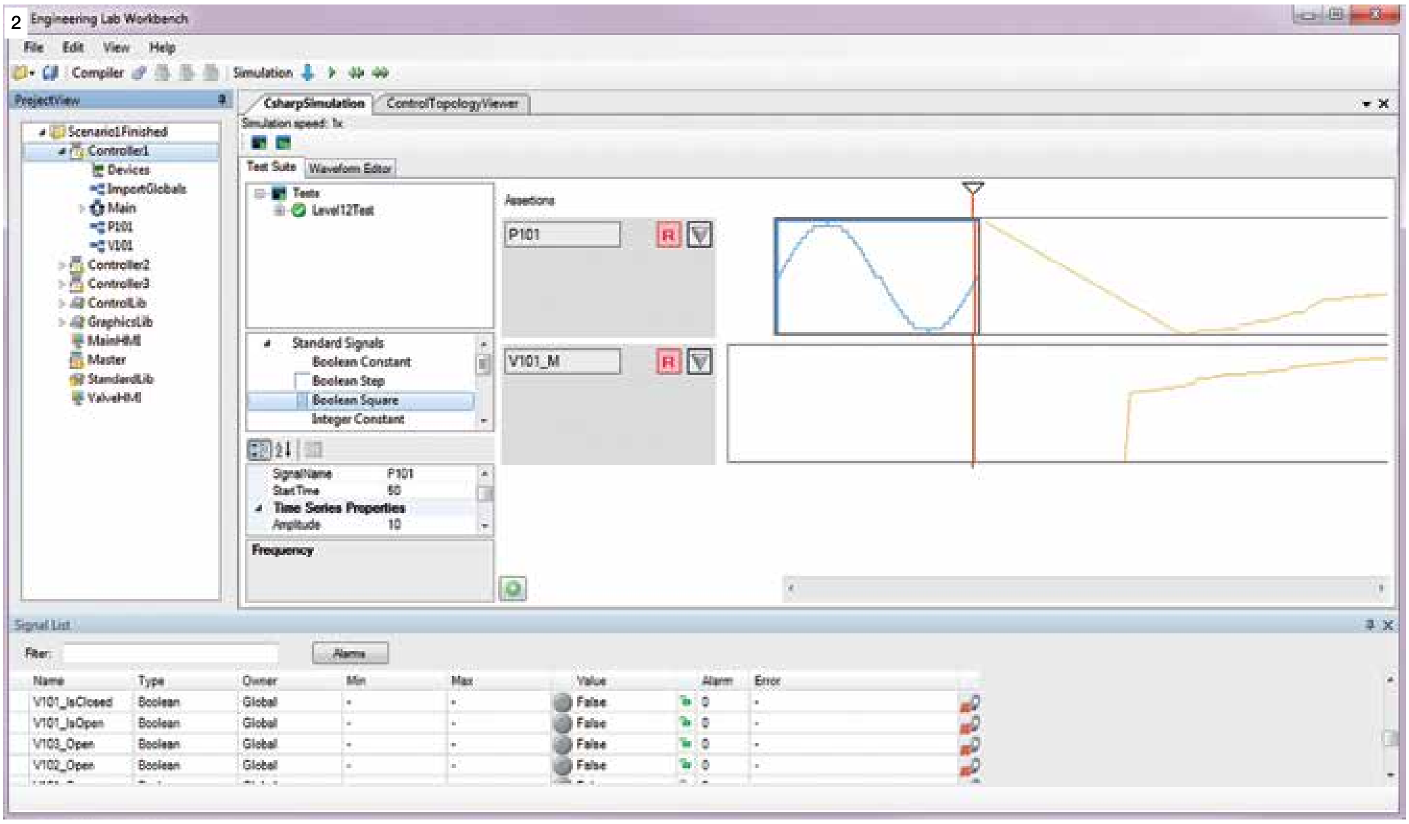


Figure 2: Signal recording and edit functionality in the engineering tool

These assertions are stored together with the signal recordings and enable a completely automatic run of the test or even a large number of tests in sequence. A real world project could build a test suite that checks that the main important logic is working once a day. Problems resulting from later changes can be found and solved early before they become costly.

Results

We created a working prototype showing the workflow with early testing in control code engineering. It features an easy integration of standard MIDI controller hardware and live changing of signals during simulation. Recording of signals, editing and replay can be combined with assertions to build test suites. The prototype was shown to the reference group consisting of product managers of three different BUs and got a very positive response. The Engineering Lab project was meant to create and validate ideas that are worth spending more effort on. Testing support has shown its potential and is considered for follow up activities in the near future.

Internal Customers

Division Process Automation, BU Control Technologies
Division Discrete Automation and Motion, BU Drives and Controls PLC
Division Power Systems, BU Power Generation

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“Sequence Analyzer”, From Process Data Analysis to Customer Benefits

Dr. Moncef Chioua, Dr. Chaojun Xu, Axel Haller, Heiko Petersen

Abstract

Batch processes are commonly used in industries like pharmaceuticals, polymer, semiconductor etc., for specialty chemicals and high quality products. Today, large amount of processes data are collected during the batch operation are stored in process historians. These large process dataset are not systematically used because of the lack of dedicated tools and methods to extract valuable information from them. Detecting unintended deviations from the normal operation and identifying the root cause of these abnormal behaviors by visual analysis of the process variables trends becomes difficult with the increased amount of stored data. A semi-automated batch process monitoring tool was developed. This tool is based on a multivariate data analysis technique: the Multiway Principal Component Analysis (MPCA). This tool will serve as a troubleshooting and performance analysis support system for ABB service process optimization engineers.

Keywords: Root Cause Analysis, Batch Process, Monitoring, Fault Detection and Isolation, Multivariate Data Analysis.

Introduction

Changing market needs require agile operations of industrial processes [6]. Batch processes are a suitable configuration for manufacturing multiple product types. Additionally, modern advanced control systems enable automatic or semi-automatic transitions between multiple process operating points corresponding to multiple product types. For instance, polymer and paper industries manufacture products of different grades each requiring different operating conditions.

In both cases batch process or transition phases of a multigrade continuous process, the process operation is dynamic i.e. the process variables are continuously varying. This particular feature makes the detection of a process disturbance and the isolation of its root-cause a challenging task.

The Sequence Analyzer project aims at developing an analysis tool for the performance evaluation of such sequences (batches, transitions) for various applications and to help our customers increasing the added value of their stored historical process data, thereby leading to the increase of the quality of ABB advanced services.

Major Results

ABB Corporate Research developed in collaboration with the Process Automation sub Business Unit Life Cycle Service and the Global Competence Center Chemical and Petrochemical a semi-automated tool for the monitoring of batch processes. A first prototype was tested at an industrial pilot site of a major consumer chemical company. The obtained results were successfully validated by the end customer and justified the triggering of an improvement action plan for their batch production plant.

Data-based monitoring of batch processes

The approach relies on the use of historical data to learn the expected behavior of the batch process under nominal conditions and constructs a statistical "gold batch" model automatically.

The data driven technique named "Multiway Principal Component Analysis" (MPCA), (see e.g. [1, 5] and reference therein) is used to monitor batch processes. This method requires the collected process data to be preprocessed in order to convert it to a suitable format.

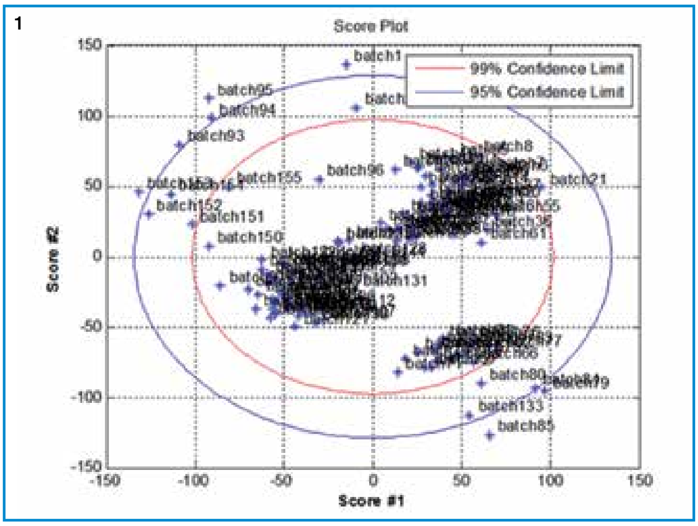
Batch durations differ from one batch operation to the next. A time alignment technique (Dynamic time Warping) [3,4] is used to stretch or to compress the datasets in order to make them comparable without losing/changing the dynamic characteristic of the data (see Fig 5).

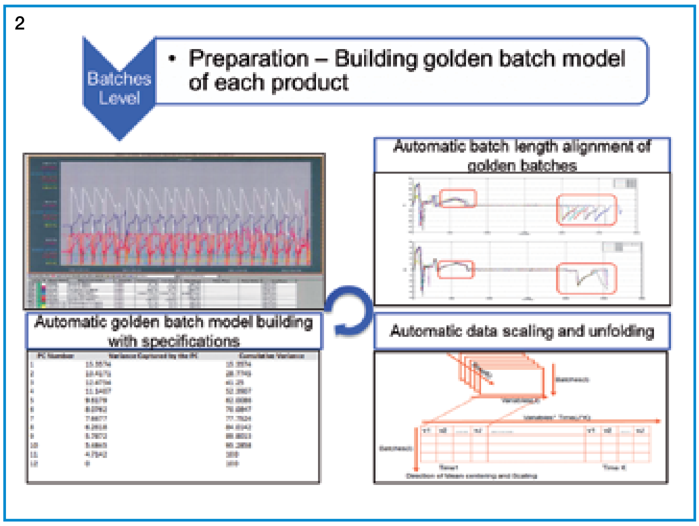
After the preprocessing phase, a statistical model is computed.

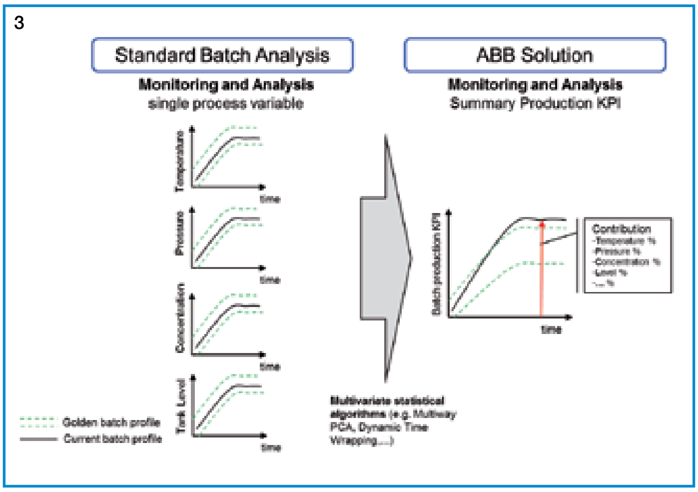
Once the MPCA model is built over the set of nominal batches, it is ready to be used i.e. to systematically monitor new batches.

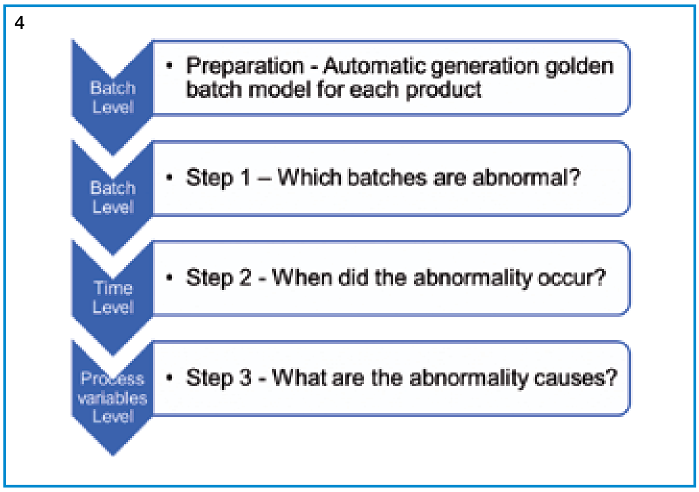
The Workflow which is adopted for of the new test batches comprises three major steps (Fig 4).

Figure 1: 2D Representation of the data driven monitoring model | Figure 2: Steps in the MPCA analysis | Figure 3: Using the MPCA techniques reduces the complexity of process monitoring by aggregating the multiple process variable deviations into a univariateindicator | Figure 4: General Workflow of the Batch Analysis









The first step is to identify the faulty batches from the set of batches under examination. For this purpose, two univariate indicators denoted Q and T^2 are computed with respect to the nominal model for each of the batch. If any batch is identified as being faulty, the workflow moves to the second step of the analysis, where the condition of the identified faulty batch is further analyzed. In other words, the time at which the batch deviated from its expected nominal behavior is identified. This is done by computing the Q and T^2 indicators at each time of the faulty batch evolution and checking these values against the admissible limits derived from the nominal model. Once the fault occurrence time is identified, the third step of the workflow illustrates the contribution of different process variables to the detected fault see e.g. [2].

Figure 5: Process variables before (above) and after time alignment (below) using Dynamic Time Warping (DTW) | Figure 6: Test batches clearly violate the admissible limits (horizontal red lines) | Figure 7: The computed Univariate indicator shows a limit violation (top left side) explained by the contributing process variables on the right side

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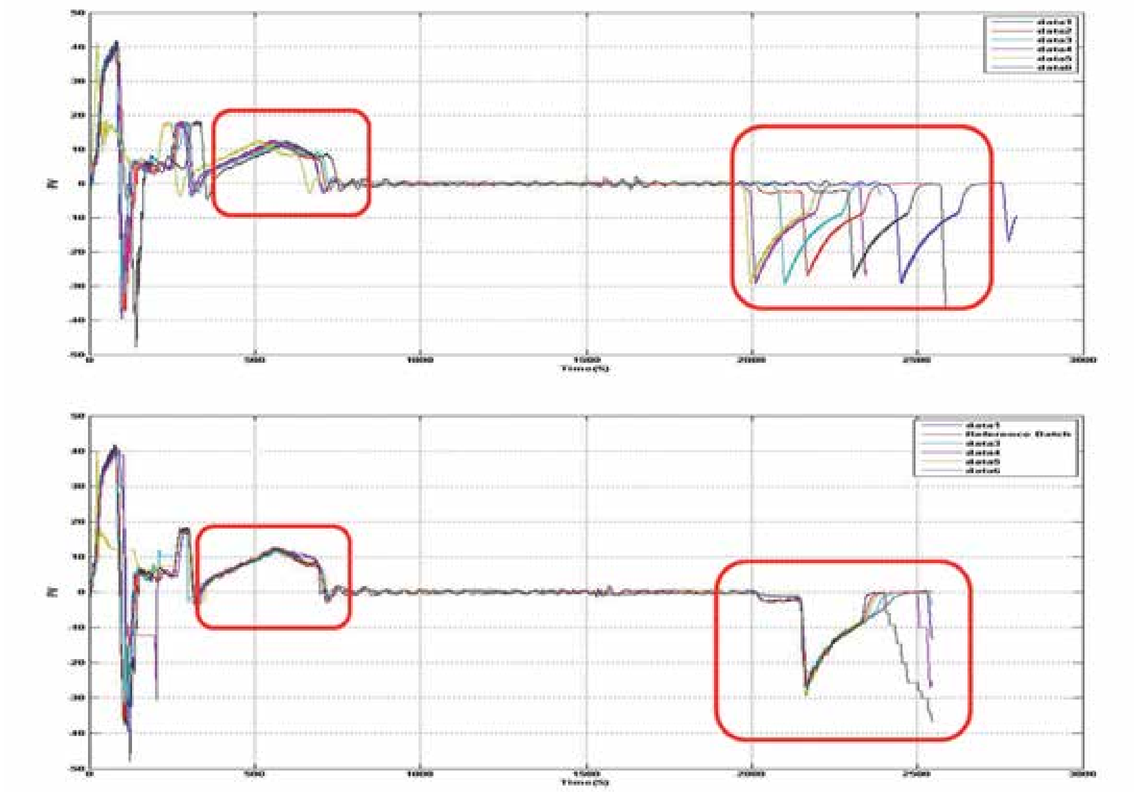

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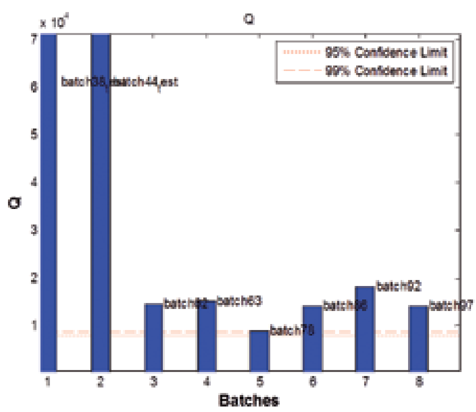

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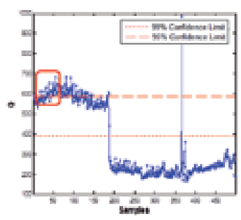
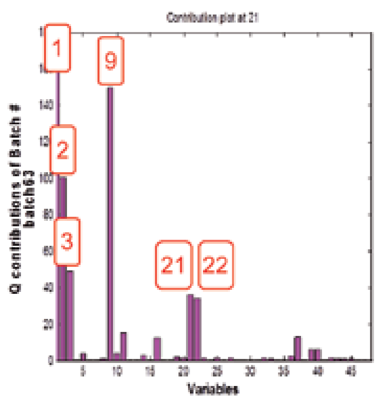


ID	PLT-Stellen	Beschreibung
1	PC11341.SP	Spray gas Pressure Setpoint
2	PC11341.PV	Spray gas Pressure Sensor
3	PC11341.CO	Spray gas Pressure Controller Output
9	F11341.IN	Spray gas flow lance 1 Sensor
21	L19310.IN	Tank B931 Level Sensor
22	L28340.IN	Tank R834 Level Sensor



Case Study: Fluidized-bed drying and granulation process monitoring

- **Nominal Model Building:**
  The nominal model is built using 149 golden batches datasets. The model building involves the steps shown in Figure 1.
  After a suitable preprocessing of the data, an MPCA model is built. This nominal model is represented in Figure 2 where each cross represents a single batch and the red and blue ellipses the admissible limits.

- **Validation of Sequence Analyzer based on known fault batches**
  The validation is performed using a set of six known faulty batches of the same type "product A". In the operation protocol these faulty batches are reported with manual set point changes during the batch process, e.g., set points of spray gas pressure, product temperature etc., or have been restarted. We assume these faulty batches could be identified by using Sequence Analyzer without precognition in the operation protocol.

  - **Step 1: Which batch is deviating from the nominal behavior?**
    The first step is to identify the faulty batches within a given set of test batches. For this purpose, the Q and T^2 indicators of each test batch is computed with respect to the nominal model. If any batch is identified as being faulty, the workflow moves to the further steps of the analysis. As shown in Fig 6, all the batches reported by the operator to be faulty were successfully identified by the model.
  - **Step 2: When did the batch fail?**
    In the second step of the analysis (Fig 7), the time at which the batch deviates from its expected nominal behavior is identified. This is done by computing the univariate Q and T^2 indicators over the time index. In Fig 7, one of the faulty batches (Batch 63) is taken for further analysis. The Q indicator computed for this batch is clearly violating the control limits depicted by the red horizontal lines in Fig 7. It is clear that this batch is faulty in the beginning of the batch run. Later the batch becomes normal due to the corrective actions by the operator.
  - **Step 3: Why did the batch fail (Variables causing the fault)**
    The batch is identified as faulty at the beginning of the batch run. The main process variables contributing to this deviation are isolated at the time of the fault occurrence.
    These contributing variables are identified as the spray gas pressure SP and spray gas pressure PV.

Figure 8 compares the spray gas pressure SP and spray gas pressure PV variables of the faulty batch to the corresponding trajectories of the same variables of the average of the golden batches included in the nominal model.

It could be seen from Figure 8 that the value of the spray gas pressure SP and PV was lower at the beginning (3.5 Bar) compared to the average spray gas pressure in the nominal batches. The operator reported this batch to be faulty as the granulation is not fine enough, and the corrective action reported by the operator was that the, spray gas pressure was increased to 3.8 Bar. Another observation here is that, the spray gas pressure PV changed before the spray gas pressure SP, indicating that the loop was put on manual mode during the batch run.

From Figure 9, it can be seen that the spray gas to the spray lance flow for the faulty batch is smaller than the average value of the nominal batches, which could be a consequence of a clogging spray lance. The small spray gas flow could result to a poor granulation. The operator was intended to increase the spray gas pressure in order to increase the spray gas flow.

Additionally, the difference in the flow between lance 1 and 3 are high, which indicates also a clog problem in lance 1 and 3. Furthermore, the signal quality of the spray gas flow in lance 1 suggests a sensor problem.

Next Steps

The results of this project will be productized by sBU Life Cycle Service and integrated to the ABB Service Port remote service delivery platform.

This will enable a new advanced service offering by BU Industrial Solution – Global Competence Center Chemical and Petrochemical.

Extension of the proposed workflow to the monitoring of continuous process transitions e.g. paper machine grade changes are currently being investigated at ABB DECRC and promising preliminary results have already been obtained using industrial data.

Summary/Conclusion

A data driven methodology has been developed for batch process monitoring and analysis. Two level of analysis are made available. A batch to batch analysis able to detected the occurrence of an abnormal batch. And a temporal analysis able first to detect the time of the abnormality and then to isolate the process variables that contribute most to the detected process or operation abnormality. The proposed methodology can be

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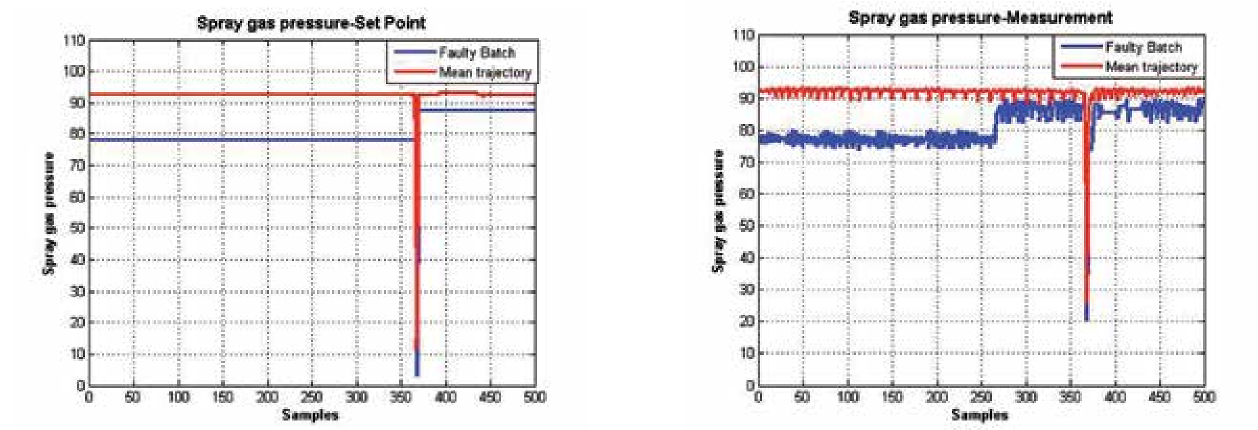

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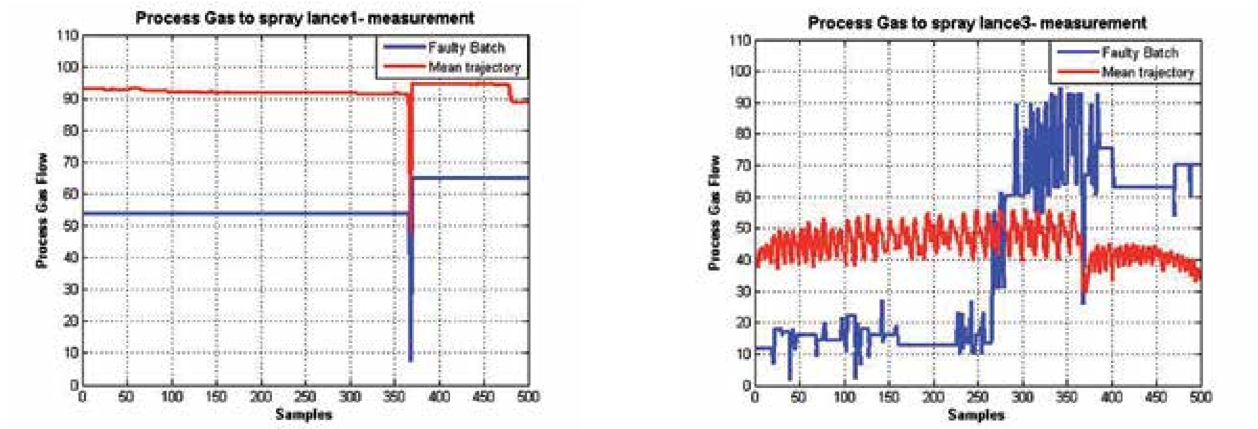

Figure 8: The spray gas pressure Setpoint (left figure) and measurement (right figure) of the faulty batch clearly deviates from the average trajectory of the nominal batches | Figure 9: The spray gas flows in lance 1 (left side) and lance 3 (right side) of the faulty batch clearly deviates from the average trajectory of the nominal batches

a useful troubleshooting tool that can be used both by ABB process optimization service engineers as well as by ABB end customers.

Acknowledgment

Ken Praprost, Ted Matsko and Tim Murphy from ABBs BU PA Life Cycle Service are acknowledged from bringing their process expertise through fruitful discussions and for providing the process test data.

Project Partners

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Stock Pooling Optimization – Take Advantage of the Stock Pooling Effect to Optimize the Supply Chain

Dr. Iiro Harjunkoski, Dr. Ralf Gitzel , Lennart Merkert, Werner Schmidt, Dr. Jan Schlake, Anant Urala

Abstract
An efficient supply chain management is crucial for good customer service. It reduces cost, increases the availability, prevents downtimes and decreases reaction times to customer requests. In the process of supply chain optimization the stock pooling effect can be used to enable new service business and to reduce stocking cost. Therefore, the Stock Pooling Optimization project team used methods for mathematical optimization to support the strategic decision process when setting up or modifying a supply chain. Three use cases were used for reference: Low Voltage Motor Stock Pooling, Wind Generator Pooling and Coil Shop Location Optimization.

Motivation
When looking at supply chains the following situation can often be encountered: A receiving unit has to decide if an item has to be kept on stock close to the intended site of operation or if it can be ordered in time from a distribution center when needed. Then, a similar situation arises at the distribution centers. Should the item be kept on stock or should it be ordered at the moment when it is needed. The situation is depicted in Figure 1 (left). An item in this context could be anything ranging from spare parts for LV Motors, wind generator to coils used in the production of motors.

Low Voltage Motor Case
In many industries, motors form a crucial part of the production equipment. Due to the myriad of sizes and specifications, many ABB customers end up having a broad collection of various motors in their plant, some of which are extremely critical for the production. The consequence of this variety is that the customer needs a large number of spare motors to cover potential failures. Especially in older facilities, where many motors are way beyond their intended life span, special care must be taken to at least cover the mission critical equipment.

Investing in spare motors means non-productive spending and results in bound capital. On the other hand, too few spare motors pose a significant risk to the operability of the plant. The Stock Pooling Optimization project has worked on a solution which can lower customer cost without increasing the risk of downtime.

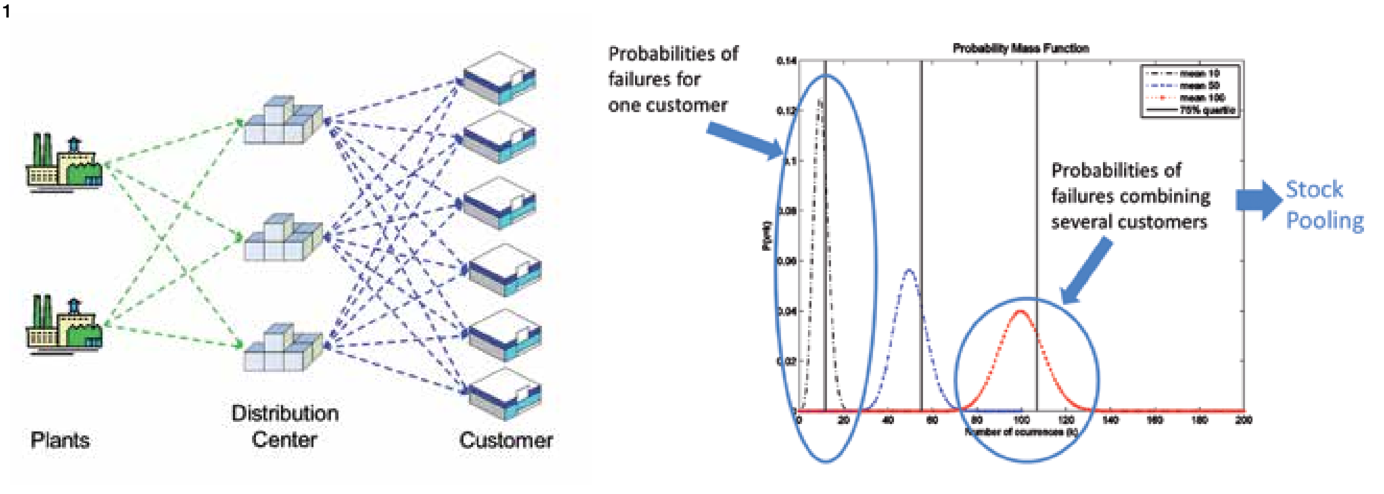

Figure 1: left: Structure of a Supply Chain: Distribution Centers order items at production plants. These items are delivered from the distribution centers to the customers. Right: Visualization of the Stock Pooling Effect – Lower risk to run out of stock

Wind Generator

ABB is manufacturing generators to be used in various wind turbines. The production time of such a generator is relatively long. On the other side customers who need a new generator for a new installation or as a replacement may not have the time and money to wait for the production or to keep a generator at stock for future use.

The Stock Pooling Optimization solution can lower the lead time/ time a customer has to wait for a new product by intelligent stock location planning.

Coils

In various regions in the world ABB production plants have a demand for coils to produce/repair motors. This demand is satisfied by external suppliers and ABB coil shops. Non-ABB wire vendors supply these coils shops with the raw product wire. Since the number of coil shops world-wide should be limited a need for finding the optimal location for these coil shops arise.

The Stock Pooling Optimization solution can maximize the efficiency of coil shops in delivering the ABB customers in the regions.

Taking Advantage of the Stock Pooling Effect via Demand prediction

The room for cost-effective improvement by an individual customer is limited – either the items are available or not. ABB, on the other hand, is in a unique position to help its customers by offering a new service where the customer and ABB can benefit of the so called stock pooling effect. Some careful considerations are needed to take advantage of the stock pooling effect. First of all, customer demand of items is based on rates (of failure, demand…) and will vary individually according to industry and imposed requirements. This means that a careful prediction is required. Second, when not all items are stored on site, an optimized supply chain is needed to ensure that items are available within a specified time.

The Stock Pooling Optimization project at ABB Corporate Research Germany addresses these two challenges. A multidisciplinary team of researchers working in cooperation with Carnegie Mellon University (CMU), Pittsburgh/USA, has developed algorithms to reliably predict customer demand and to optimize the supply chain in order to meet this demand while realizing cost saving potentials for the customers.

The black curve in Figure 1 (right) shows the item demand of a single customer in one year (black curve). The red curve shows the same demand for a fleet of ten identical customers. There is a distinctive difference between planning for a small amount of items and for a larger fleet. For example, a single customer has a roughly 25% chance to need more than 12 items of that particular type in a year. However, the chance for ten customers to need more than 120 items is far below 25% as indicated by the quartile. Colloquially speaking, the flatter and wider red curve is less prone to unexpected behavior than the black curve multiplied by ten. This implies that the required safety margin for the red curve is lower than the sum of all safety margins needed by single customers.

The Stock Pooling concept bases the demand forecasts for items on the customer demand data. For example using maintenance-related data in spare parts demand, it is possible to calculate an annual failure rate and to make predictions using

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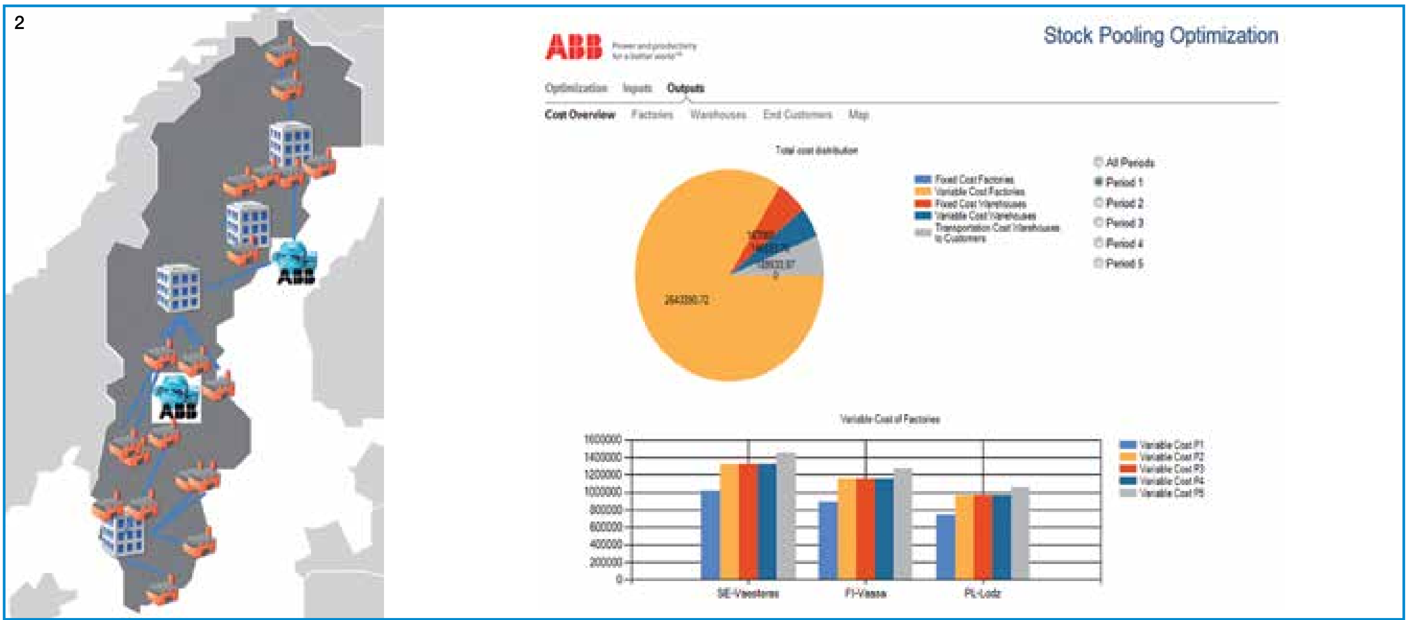

Figure 2: Optimized Supply Chain - left: Results are presented visually in the prototype; right: Cost overview for optimized supply chain

a Homogeneous Poisson Process (HPP). Two key parameters are determined by the prediction: (1) The expected number of failures describing the average case and (2) a safety margin to avoid the risk of out-of-stock, which is calculated based on the probabilities provided by the HPP.

Optimization of the Supply Chain Design Model

To address the problem of guaranteed and timely item availability, an extensive optimization problem needs to be solved. Based on the criticality specified in contracts, the items must be delivered before their respective deadlines. To reach this goal, a sufficient amount of items must be stored in the correct locations without overstocking. In other words, the algorithm has to determine the optimal network of factories, warehouses and the required stock levels at the warehouses. Figure 2 (left) shows a screenshot from the browser based software prototype. It displays a possible solution to a supply network problem with customers in red and warehouses in gray.

Figure 2 (right) shows the visualization of the expected cost for the possible solution. Detailed analysis of the optimized solution is possible using table based visualizations. In the context of the Stock Pooling Optimization project, Mixed-Integer Linear Programming (MILP) is used to find the optimal solution. The definition of the MILP model has to be done carefully; too many variables may result in an unsolvable problem due to the large size. On the other hand, if the problem model is too simple, the mathematically optimal solution might no longer reflect the reality. Tests of the developed model demonstrate that it is flexible and can be adapted to various use cases. The prototype allows non-optimization experts after a short training period to use the optimization capabilities of the supply chain design model.

Conclusions

The Stock Pooling Optimization results show the great potential of a scientific approach to the problem. Trustworthy demand predictions based on established methods and supply chain optimization using state-of-the-art algorithms enable a cost-effective pooling concept and more responsive spare-part service. For the customer, stock pooling means less capital bound in stored items without an increase in risk of downtime. The stock pooling is of great benefit to a wide range of plant operators.

Business Impact

The development of the Stock Pooling Optimization Tool was done together with DMMG PG Service R&D, Anant Urala, Hetal Lakhani, Cajetan Pinto. Results were transferred end of 2013. In the future, the tool will support the strategic decision process when choosing the optimal location of coil shops. This will help to reduce ABB's operation costs of coil shops and enable fast reaction times to ABB customer requests.

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Wearable and Mobile Computing for Improved Service Delivery

Dr. Markus Aleksy, Dr. Marco Ulrich

Abstract
Recent advances in mobile computing and sensor technologies have enabled new types of innovative solutions, such as mobile apps and wearable computing. Mobile devices provide the mobile worker with the opportunity to create, access, process, store, and communicate information without being constrained to a single location. Furthermore, sensor technologies enable us to measure information about the environment and provide it to a mobile or wearable device for closer inspection.

Motivation

Today, field service engineers and trades have on-site limited information available to perform service tasks. For instance information is needed to find the right equipment on-site, to analyze the application environment, to diagnose the root-cause of the problem, and to repair the faulty equipment. In addition, safety is becoming more important due the increasing complexity of industrial plants.

Wearable and mobile computing promises to gain efficiency improvements in industrial applications due to augmentation of the device as well as improved interaction between the user and the device [1]. Moreover, they can be used to improve the safety of workers by automatically sensing the environmental data as well as the personal health data of the worker.

Solution Approach

Augmented Reality-Based Localization

Localizing the equipment that needs to be serviced may be a challenge in a big industrial plant. In this case utilizing an augmented reality system together with an object localization approach can be a proper solution to support field service workers to find the location of the corresponding equipment. Augmented reality (AR) adds information and meaning to real objects. According to [2], an AR system supplements the real world with virtual objects that appear to coexist in the same space as the real world. AR features can be used to overlay real world images with additional information, such as equipment- or safety-related information or work instructions. Moreover, AR can be combined with localization technologies. This approach relies on a positioning system together with a digital compass. The positioning system helps to identify the objects' and the user's position while the compass provides required information to the orientation of the user.

Basically, it can be differentiated between two localization approaches based on an outdoor or an indoor positioning system. The Global Positioning System (GPS) can be used for the recording of the current location of the mobile device or the user while being outdoors. Moreover, it provides a

Figure 1: The prototype for demonstrating how devices can be localized within a plant or factory to provide more information | Figure 2: Main screen of the mobile app presenting wearable sensor data

low-cost and reliable approach, since many mobile devices and increasingly Head-Mounted Display's (HMD's) are already equipped with this technology. Although GPS has gained wide acceptance out-of-doors, there are different approaches, which try to cover the areas in which GPS does not (reliably) work due to missing intervisibility. Therefore, different approaches to indoor positioning exist, which fall back on other technologies, such as utilizing existing communication infrastructures, e.g. GSM (Global System for Mobile Communications) radio masts, WiFi or Bluetooth access points.

The developed prototype can be utilized for demonstrating how devices can be localized within a plant or factory to provide more information (see Figure 1). In a first step, the service worker can use a filter to limit the number of devices to a particular category. This feature might be helpful if a large number of devices are installed on site. Afterwards, the camera of the mobile device is used to capture the real world, which is augmented with additional information, such as the type of the device, its serial number, commissioning date, life cycle phase, the distance to the device etc. The user can obtain more information about each device by touching the corresponding virtual object. This information might be related to the product itself, available services, or contact information. Additionally, the augmented reality app can be combined with a remote access system to make use of real-time data from the device. The prototype was successfully presented at the Hanover Fair 2013 to the audience. Today, it is used for presentations at the Automation Forum in Ladenburg.

Automated Safety Suit

The vision of wearable computing is to provide an unrestrictive system that shows right information at the right time and supports sharing of context with others. Wearable devices can range from commercial off-the-shelf products, such as smart watches up to specialized solutions that incorporate sensors into clothing. The corresponding technological components include input devices (e.g. wrist-worn keyboards), output devices (such as HMD's), context sharing systems (e.g. video camera), and context sensing systems (e.g. acceleration sensors or image processing).

The developed wearable system (cf. [3] and [4]) consists of two major components: An automated safety suit and a mobile device (smartphone). The automated safety suit integrates several sensors and actuators, such as a body temperature sensor, a carbon monoxide sensor, an environmental temperature & humidity sensor, and a heartbeat sensor. A Bluetooth connection is used for transmitting the data to the smartphone.

The purpose of the mobile application is to collect sensor data, display alerts and notifications on the device when abnormal conditions are detected. First of all, some user preferences have to be specified beforehand to ensure that the wearable safety suit will perform the right actions in case of abnormal situations. The alert preferences include time-out specification, alert actions, and information related to contact data, such as e-mail address, phone number etc. Additionally, thresholds for utilized sensors have to be set up. The main screen of the application presents real time data transferred from the safety suit via Bluetooth (see Figure 2). It allows the user to monitor his vital signs and sensor data in a graphical manner. In case of an alarm, the application will automatically send SMS and/or e-mails to the supervisor of the worker including information of the field worker's location and type of alert.

Safety Observations

Safety-related forms are utilized to avoid hazards as well as to ensure and improve safe industrial environments. There are various safety-related forms that reflect different safety-related activities. Last minute safety assessments, such as Take 5 (mini risk assessment) are performed shortly before an activity, such as maintenance is performed. Safety-based observations are regularly carried out inside a plant to check and ensure safety-related behavior of the staff as well as condition of the industrial environment.

Migrating from paper-based safety forms to their digital counterparts, especially if they are executed on mobile devices, provides additional opportunities. First of all, it follows a non-invasive approach since no additional device is needed. Field service workers are usually equipped with mobile phones, thus replacing them with a smart phone and tablet respectively, doesn't make the introduction of new mobile device necessary. Additionally, mobile devices, such as smart phones or tablets provide several sensors that can be used to obtain and document safety relevant data. The capability to capture the location of a safety-related observation via the GPS enables the opportunity to gather and identify potential hotspots during the analysis of the observations made over a period of time. Moreover, the documentation of the observation information quality can be improved as well, if multimedia information, such as photos, videos, or sound recordings made during the observations can be recorded to emphasize the findings.

The purpose of the safety observation app is to support safety observations carried out inside a plant. It is designed to collect four types of safety information: General safety information, a safety-related checklist, safety-related notes, and multimedia information such as photos. The general information consists of information captured automatically by the device, such as date or location and information that have to be entered or selected manually by the observer. The checklist includes a list of observation categories that have to be assessed by the observer if they are safe or at-risk. Additionally, it is possible to add context-related notes to provide details with regard to the observations made. Finally, the observer can add some multimedia information, such as sound recordings or photos to the observation record to emphasize his findings. The collected safety information can be stored locally on the device in case of missing connectivity or transferred to a back-end system if the connectivity is re-established.

Conclusions

The availability of a variety of wearable and mobile computing technologies has enabled the creation of new support tools for improved service delivery. Relevant information about the environment, process, and personal health can be accessed on the move and shared with others. The developed prototypes may help to ensure safe working environment as well as help to increase efficiency in service delivery.

Internal Customers

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