Industrial IT and Automation Curricula and Experience at USN in the context of Industry 4.0

Hans-Petter Halvorsen, Nils-Olav Skeie, Morten Pedersen, Alexander Jonsaas, Saba Mylvaganam

Faculty of Technology, Department of Electrical Engineering, IT and Cybernetics, University of Southeast Norway, Norway

hans.p.halvorsen@usn.no; nils-olav.skeie@usn.no
morten.pedersen@usn.no
alexander.jonsaas@usn.no
saba.mylvaganam@usn.no

***Abstract*— Industrial IT systems form the backbone of almost all the industries covering process industries, bio- and medical informatics, all forms of energy related industries. The "marriage" of industrial IT and Cybernetics is unavoidable as automation (in a broader concept, cybernetics) involves monitoring, control and optimization of all types of systems in the fields mentioned above.**

The bachelor and master programme in Industrial IT and Automation (IIA) at University of Southeast Norway (USN) introduces basic and evolving technologies in IIA. Currently, at USN IIA curricula focuses on IoT (Internet of Things), Industry 4.0 and on open standards. In close collaboration with the industries, the curriculum in IIA tries to cover basics and current developments in sensors and measurement systems, data analysis, computer program design and programming, system design, automation systems, mathematical modeling and simulation, control algorithms, advanced control, including model-based predictive control (MPC). Key programming languages used are MATLAB, Python, LabVIEW, and various object-oriented languages. This paper presents some case studies based on this new curricula focusing on the results achieved in the context of some selected projects involving students, staff of USN and the industries in the context of growing focus on Industry 4.0.

Keywords—Industrial IT; automation; IoT; Industrial Collaboration; Industry 4.0

I. Introduction

When we traverse the path to today's technological capabilities, we find these as the cornerstones in the history of human aspirations and achievements:

- **18th Century** – Great strides in Mathematics and Physics by the polymaths , Pascal, Newton, Lagrange, Fourier, Leibniz, Gauss, Laplace etc. – **Maths and Physics Fusion**
- **Late 18th Century** – Early designs of steam engine – **Machine for Muscles**
- **Early 20th Century** – Great strides in automation and mass production – **Assembly line for the masses**
- **Mid20th Century** – Great strides in computing and data storage – **Data processing and storage for all**
- **NOW** – Ubiquitous smartness of objects and machines – **Mingling of machines and "things" with humans anytime and everywhere**

In this context, it is interesting to refer to the current exhibition in the Science Museum in London, "500 Years of Robots"! Recent literature, compresses these important developments into four decisive stages of revolutions, as shown in Table 1.

Table 1. Four stages of "technological revolutions" compressing the scientific and technological developments, discussed above into only four epochs [1].

	Time periods	Technologies and capabilities
First	1784-mid 19th century	Water- and steam-powered mechanical manufacturing
Second	Late 19th century -1970s	Electric-powered mass production based on the division of labour (assembly line)
Third	1970s-Today	Electronics and information technology drives new levels of automation of complex tasks
Fourth	Today-	Sensor technology, interconnectivity and data analysis allow mass customisation, integration of value chains and greater efficiency

II. Industrie 4.0

Although the accepted terminology is Industry 4.0, the current development encompasses men, machines, money and thoughts including even feelings. In the context of industrial development and innovations, German Chancellor Angela Merkel describes Industry 4.0 (in German Industrie 4.0) as follows: "Industry 4.0 is the comprehensive transformation of the whole sphere of industrial production through the merging of digital technology and the internet with conventional industry", [1].

SIEMENS, [2], in a presentation during Hannover Messe 2015, gave the following as decisive in the push towards the implementation of Industry 4.0: "sensors, computing power, storage capacities, data analytics, networking ability". The increasing automation and digitization in the energy sector is another example of the same trend with sharper focus in energy efficiency. Efficiency in the usage of different resources including energy will influence the competitive advantage and marketing potential of any product. The ubiquitous internet has transformed the usage patterns and modus operandi of the modern consumers, SIEMENS, e.g. from bookstore to e-book, from yellow pages to market place, from record store to streaming, from taxi to ride sharing. With these developments, "Industrie 4.0" is a German vision with time horizon reaching towards and extending beyond 2025, covering the entire value chain, and the life cycle of products even with good planning for recycling and related services. According to a recent report by European Parliament Research Services (EPRS), [1], "Industry 4.0" is based on these and other related evolving developments:

- **Information and Communication Technology (ICT)** inside and among companies;
- **Cyber-physical systems:** involving embedded sensors, self-configurable /autonomous robots, so called additive manufacturing more and more applied in diverse production facilities with 3D-printers;
- **Network communication** covering different aspects of Internet of Things enabling interaction of men and machines, between machines, among and between plants and different suppliers etc.;
- **Modeling and simulation** for design of components and systems and testing the results in the virtual world covering the conceptual stage to the final realization of the product.
- **Data acquisition, big data, cloud computing** for analyzing the process data, predictive maintenance and general analytics based on data fusion;
- **ICT based support** involving augmented reality and intelligent tools.

The product design and development with associated customer involvement and interaction have undergone major changes due to the above-mentioned technological revolutions and the innovations given above, as shown in Fig. 1. Due to these changes in customer expectations and behaviour, curricula addressing these issues are not only relevant but also urgent, as revolutions are very often disruptive and entail major changes in almost all aspects of any civilization.

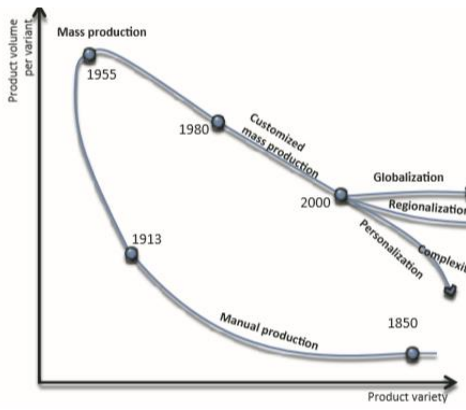

Fig. 1. Product variety and product volume during the technological "revolutions", Courtesy, [2].

The EPRS overview is succinctly represented in Fig. 2 in the overview of current technological status irrespective of the manufacturing sector involved as given in [1].

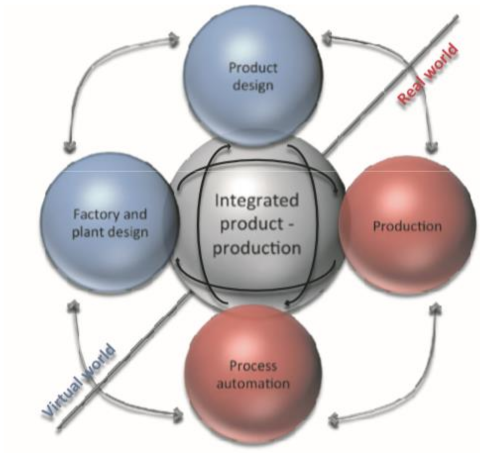

Fig. 2. Integrated Product – Production involving "virtual" and "real world". In the contect of this paper product can be hardware or software or both, courtesy [2]. Involves as a result horizontal integration covering the complete product cycle involving resources, raw materials, logistics and environmental considerations such as reuse of materials and environmentally friendly disposal of materials according to [1] and [2].

Fig. 3 and Fig. 4 show in a schematic way the different aspects of developments discussed in this section in relation to Industry 4.0.

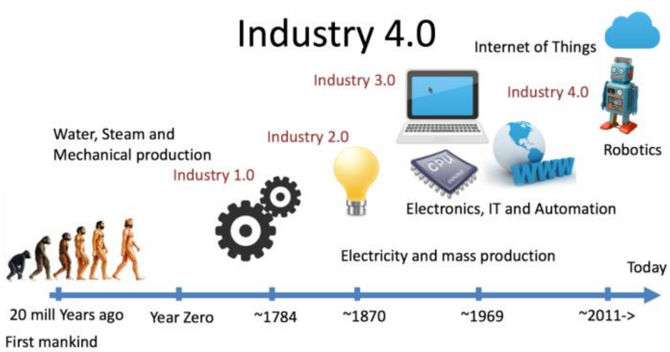

Fig. 3. An overview showing the technological devlopments discussed in this section.

Fig. 4. Industry 4.0 and its influence in the modern industries and societies. Handling vertical and vertical and horizontal integration.

III. Industrial IT and Automation

A. *Topics to be covered*

Based on the overview of EPRS and discussions with industrial actors like SIEMENS, IBM, Pepperl & Fuchs, Emerson Process Management, STATOIL, YARA, Norsk Hydro etc., USN has curricula at bachelor and master levels addressing Industry 4.0 and related topics. The courses are specially tuned to the process industries, with topics at times from other industrial sectors. Topics covered are selected from input form the industries and documents from the authorities and national and international expert groups. The following information on the curricula are from the website of USN, [3].

B. *Bachelor curricula*

Bachelor degree programme in Computer Science and Industrial Automation at USN strives to facilitate the acquirement of the following knowledge and skills:

Knowledge in the following areas:

- Electrical Engineering
- Mathematical methods
- Control systems
- Analogue and digital signal processing
- Automation systems
- Data communications
- Design and programming
- Project methodology
- Scientific research methodology
- Technical documentation
- Research and development within their field of study
- Social, environmental, ethical and economic implications of technological solutions
- Innovation and entrepreneurship

Skills in the following areas:

- Electrical Engineering: circuit analysis, filter design, amplifier circuits, digital technology
- Control technology: controller tuning, choice of control structures, modelling and simulation
- Analogue and digital signal processing: selection of filter types, filter design
- Automation systems: design of industrial control systems and selection of components such as PLC
- Data communication: configuration and operation of networks and bus systems
- Design and programming: design, programming, documentation and testing of software systems
- Project methodology: organization, planning, report writing and presentation
- Scientific research methods: literature search, data evaluation, quality assurance and the use of references
- Technical documentation: technical drawings, wiring diagrams, technical flowcharts, protocols and data presentation
- Social, environmental, ethical and economic implications of technological solutions: copyright issues, HSE (Health, Safety and Environment), the use of directives and regulations
- Innovation and entrepreneurship: brainstorming, networking, market research, business plans

As indicated in the vision of Industry 4.0 for the mastery of subjects, the bachelor curricula contain in addition to general topics in science and mathematics, courses in sensors, measurements and instrumentation, automation technology, industrial computer communications and networks, electives such as dynamic simulation and control design etc.

C. *Master curricula*

The master programme in Industrial IT and Automation at USN provides a broad knowledge in monitoring, control and optimization of all types of technical and industrial systems based on cybernetic methods and computer engineering with the following learning outcomes and skills:

Knowledge

- In hard and soft sensors including data fusion with basics of artificial intelligence

- in developing both mechanistic and empirical models with focus on technical processes,
- of system behavior based on simulation,
- in designing and/or analyzing computer based systems for solving industrial problems or challenges,
- in developing data acquisition systems based on state of the art measurement and instrumentation systems,
- in system identification and model-based control methods such as Kalman filtering, Model Predictive Control (MPC), and inferential methods.

Skills

- Ability to apply adequate methods and techniques in solving problems within Industrial IT and Automation,
- Ability to work as an individual, as well as in teams, in planning and conduction of experiments and technical projects,
- Ability to work safely in laboratories, in accordance with HES procedures,
- Ability to use programming languages e.g. MATLAB, LabVIEW, Python, C++, C#, Aquasim, MODELICA etc. to solve technical problems,
- Ability to analyze and critically review different sources of information, and is able to use such information in structuring and formulating technical problem descriptions and goals,
- Ability to conduct independently a defined research and development project under supervision, according to prevailing ethical norms.

The master degree curricula in Industrial IT and Automation has among others the following modules satisfying the Industry 4.0 framework of expertise:

Modelling of Dynamic Systems, Scientific Computing, Control Engineering, Multivariate Data Analysis, Hard/Soft Sensors in Process Measurement, Industrial Information Technology, Object-oriented Analysis, Design and Programming, System Identification and Optimal Estimation, Model Predictive Control, Object-oriented Modelling of Hydro Power Systems, etc.

Students successfully completing the master studies in IITA can work in different sectors, e.g. manufacturing, process industry, energy systems, vehicle control, building automation, or in the oil and gas industry etc.

IV. Interaction with Stakeholders

YARA, one of the dominant fertilizer manufacturers has continuous collaboration with USN and is strongly involved in the process of implementing some aspects of Industry 4.0 vision. Experts from YARA are involved in defining and supervising student projects. In the modeling of granulates involved in the final stages of the fertilizer production, YARA is supporting a PhD candidate. YARA has also adjunct professors working in the USN.

YARA and Emerson Process Management are involved in trying out various new programming strategies using the industrial Distributed Control System (DCS) program DELTA V. USN, YARA, Emerson Process Management in collaboration with the research institute Tel-Tek (to be merged with the largest research organization SINTEF from 01.07.2017) have collaborated in various projects in the field of powder technology.

STATKRAFT one of the large actors in the Norwegian Energy Sector is funding many large and small projects, including PhD research fellows.

STATOIL is supporting a project SEMI-KIDD dealing with increasing autonomy in the monitoring and control of drilling fluids with 4 PhD research fellows collaborating with many industrial actors, with the main funding from the Research Council of Norway.

Pepperl & Fuchs (Norway branch) finds the proximity of USN advantageous for synergy effects and organizes guest lectures on sensors, explosion safety, RFIDs, use of PLC including recent developments in Industry 4.0.

In the field of sensor technology and MEMS, USN has developed many systems earlier, which are in use in many industrial sectors. USN is currently involved in the development of ultrasonic sensors for industrial and medical applications in collaboration with many industrial actors.

V. Projects Related to Industry 4.0

Table 2 contains selected projects with some relevance to topics related to Industry 4.0. These projects are carried out partly in campus and in the industrial collaborators. The topics covered reflect the key elements of Industry 4.0 shown above in Fig. 2.

Table. 2. Selected projects with some relevance to Industry 4.0 from the recent past at USN

Project	**Partner(s)**	**Topics**	**Industry 4.0**
Flow metering of non-Newtonian Fluids	STATOIL	Flow, ,	sensor data fusion, autonomous operation of rigs
Intelligent manhole cover	Ulefoss Jernværk	Continuous monitoring of water with wireless data transmission	Networked sensors
SMART HOME	NI, Local Health and Social Units	Ambience, security, care of elderly	IoT
Automatic Bottle Filling	FESTO	Sensors, PLC,	Autonomous operations

These and other student projects are briefly presented in the next section with self-explaining illustrations.

VI. CASE STUDIES

A. SMART production line

Students taking a bachelor degree in the Computer Science and Industrial Automation programme must take part in a project during the 5th semester that gives the students practical skills in commissioning a production line with Industry 4.0 approach. The production line itself consists of four MPS (**M**odular **P**roduction **S**ystems) stations from the German company Festo. The purpose of the line is to produce plastic jars of various colors and sizes filled with water and sealed with a cap. The Handling Station fetches the jars to be produced – tall transparent jars or small red, black or transparent jars – and transfers them to the Bottling Station. This station fills the jars with the specified amount of water before passing them on to the Capping Station, which seals the jars with a plastic cap. Finally, a Mitsubishi industrial robot in the Transfer and Quality Station puts each jar on a weighing cell to ensure that the amount of water in each jar is within ±2σ relative to a full jar. If the jar passes the test, the robot puts the jar on a transfer tray; otherwise, the jar is discarded. Fig. 5 shows the sequence of operations.

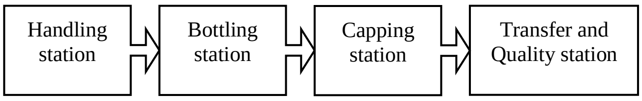

Fig. 5 Sequence of operation of an automatic jar filling station

Each jar is equipped with an RFID tag with read/write capability. When a jar is fetched from the Handling Station, the following information is written to the RFID tag: tare weight (the weight of empty jar, unladen weight), order id, jar type, and ordered weight. When the jar reaches the filling position, the amount of water to be filled is read from the RFID tag. Equally, the tare weight and ordered weight will be read from the tag in the Transfer and Quality Station and compared with the measurement of the weighing cell. Finally, the jar information (order id, measured weight, deviation, type of jar, passed/not passed, time and date) will be transferred to the SCADA system and stored in an SQL database for later analysis. The system is shown in Fig. 6.

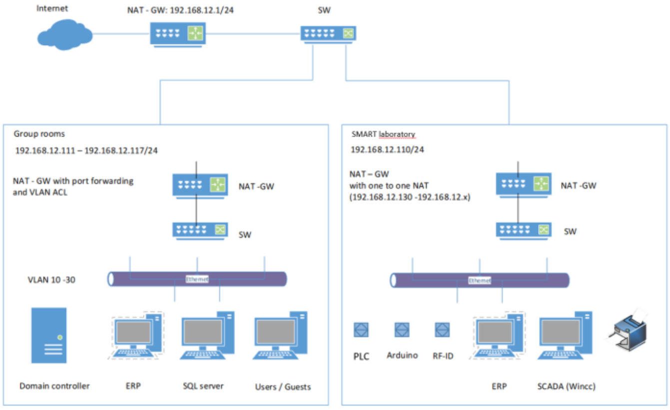

Fig. 6. SCADA operation and overview of communication in the SMART production line

The Handling, Bottling and Capping stations are controlled by one S7-1500 PLCs each. These PLCs are connected to a network using the Profinet protocol. Other protocols used are Profibus DP and AS-interface. The weighing cell in the Transfer and Quality station is controlled by an Arduino microcontroller. The robot controller communicates with the Arduino and the Capping station PLC with digital handshake signals. Some of these stages are shown in the programming structure shown in Fig. 7.

"Order data" are entered into the system through an ERP application that the student must develop. The order data are stored in an SQL database. These data are fetched by the SCADA system and presented to the operator.

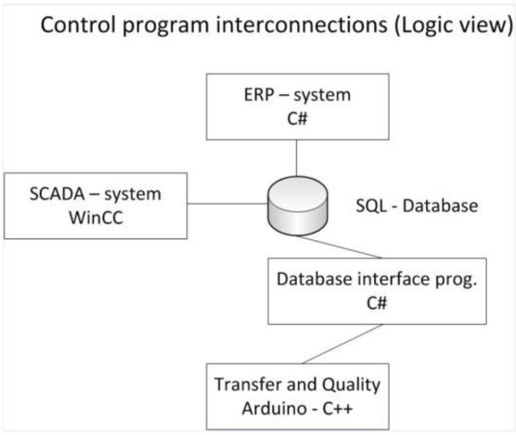

Fig. 7. Different programs interacting for the sequential operation for the filling of jars.

The first three modules were purchased in 2011, the last one in 2013. Since then, the line has undergone several modifications in order to prepare it for Industry 4.0 activities. The line can easily be used to test various IoT solutions. The fest system can be modelled to a digital twin, as portrayed in Fig. 2. The complete system can produce data from various sensors and actuators for analysis ("big data") and for optimization purposes, just to mention a few possibilities. This system has been used with courses in bachelor level and can be used by master level students too.

B. IoT laboratory for BSc. and MSc. students

The SMART research group at USN has developed an IoT device with switches, potentiometers, LEDs, and voltage outputs. The Modbus TCP protocol is used to interconnect the switches and the LEDS, and the potentiometers and the LEDs (voltage outputs). Software using the Modbus TCP protocol will read the "sensor" devices, switches and potentiometers, and write to the "actuator" devices, LEDs and voltage outputs. The system developed by students is shown in Fig. 8.

Fig. 8. Modbus TCP control in SMART HOME applications developed by master students

The bachelor and master students will have laboratory exercises to learn 1) about IoT, 2) how to use protocols or services on top of the TCP/IP protocol to communicate with IoT devices, 3) use Modbus TCP as one protocol for IoT device, and 5) implement a C# application for communication with the IoT device. An external software application must be used to interconnect the switches and the LEDs, and the potentiometers and the LEDs.

C. Cloud Based Data Logging, Monitoring and Analysis

Industrial cloud base data logging and analysis using windows running in the cloud is shown in the following figures, Fig. 9 -11 [4].

Fig. 9. Cloud hosting with different vendors

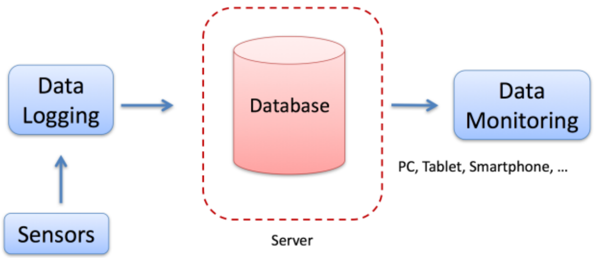

Fig. 10. Industrial cloud based data logging

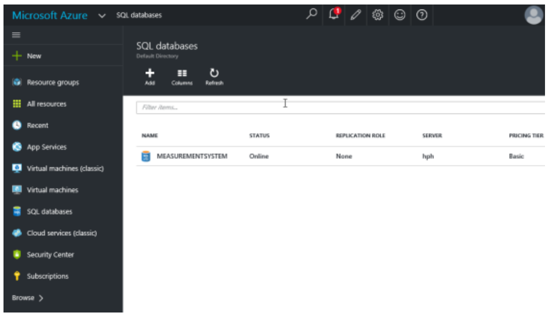

Fig. 11. Microsoft Azure – Cloud Platform (Windows running in the Cloud)

D. Next Generation OPC: OPC UA

Problems with standard/classic OPC (**O**pen **P**latform **C**ommunications) are mainly the following: it works only on Windows; cumbersome to use OPC in a network due to COM/DCOM.

OPC UA (**O**pen **P**latform **C**ommunications **U**nified **A**rchitecture) overcomes these problems, by eliminating the need to use a Microsoft Windows based platform of earlier OPC versions. OPC UA combines the functionality of the existing OPC interfaces with new technologies such as XML and Web Services (HTTP, SOAP) [5]. OPC UA is cross-platform and no dedicated OPC Server is no longer necessary because the server can run on an embedded system. Fig. 12 and 13 shows the features of OPC UA and OPC Classic and shows the various programming options available with OPC UA.

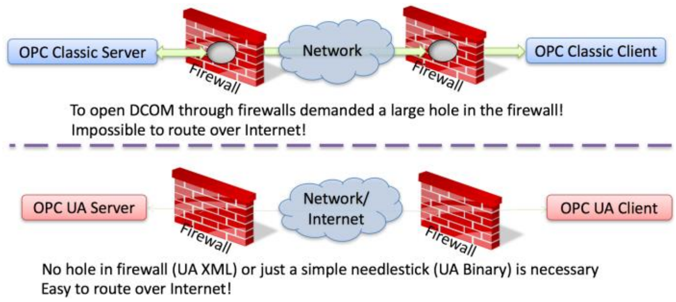

Fig. 12 OPC classic server vs. OPC UA

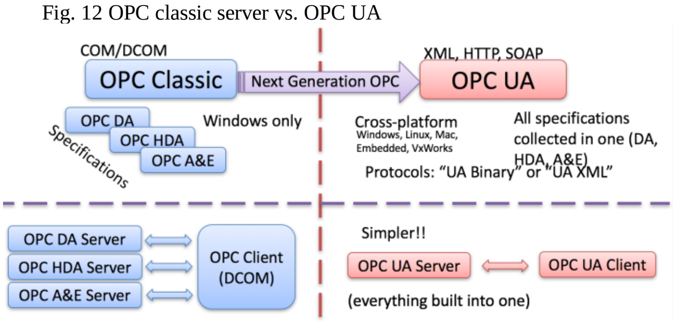

Fig. 13. OPC UA – The Next Generation OPC used in Industry 4.0 Applications

E. DeltaV and Industrial Wireless Communication

A transportable DeltaV training station was built by student groups for simplifying learning and research using hardware and software from Emerson Process Management. A complete DCS system is mounted on the rig, with several single-wire sockets for including physical models for e.g. temperature and level control.

In 2014 the rig was expanded with a WirelessHART gateway from Emerson Process Management to enable connection of wireless instruments. The training station with the DeltaV system and wireless gateway is shown in Fig. 14. WirelessHART (IEC 62591) is an industrial wireless communication protocol using mesh network topology [6]. With a rapid increase of smart instruments and wireless communication in the industry, the DeltaV training station allows students to learn and gain hands-on experience with commissioning and usage of wireless instrumentation. A bachelor project studied the viability of wireless instrumentation for use in the Yara fertilizer plant. Commisioning and training was first performed at the training station, before installation and testing at Yara [7]. Fig. 10 shows the initial planning of the WirelessHART network at USN.

Fig. 14. Emerson Smart Wireless Gateway installed on the DeltaV training station at USN.

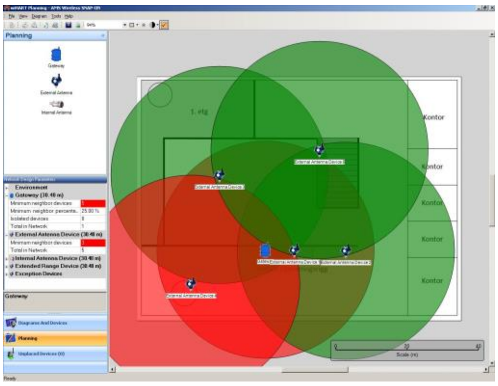

Fig. 15. AMS Wireless SNAP-ON used for planning the WirelessHART network [7].

F. International Project – Remote Control of a Robotic Arm

Student groups from Norway and Poland worked together on a collaborative project with the main goal of achieving remote control of a robotic arm using NI LabVIEW and Emerson DeltaV [8]. The robotic arm was located in Lodz University of Technology, Poland and controlled from USN. OPC was selected as the interface between the two systems and the sotware was connected over internet. The dataflow from the DeltaV control program in Norway to the robotic arm in Poland is shown in Fig. 16.

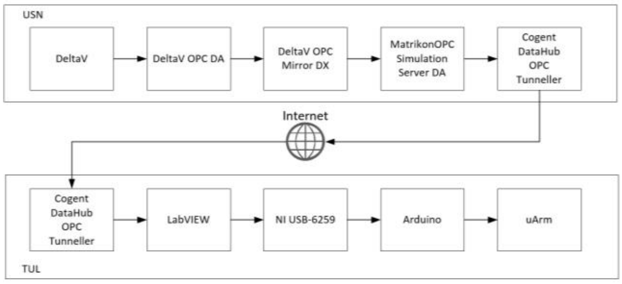

Fig. 16. Dataflow for remote control of the robotic arm [8]

G. Simulation and tests – load and fault studies in power systems

Wind and hydro power systems are the predominant sources of energy in countries like Norway and Iceland. The power supply from these resources are very much dependent on the prevailing weather conditions. Simulation studies can be performed using specially designed software and lab-scale facilities emulating selected behavior patterns. At USN, in collaboration with Iceland, models of the transmission systems in Westfjords Hydro Power stations were tested with OpenIPSL [9]. From this digital twin studies, the models help to stabilize the system without disconnecting loads. The models also help to keep bus voltage levels stable and high. Waterway models using Hydro Power Library in Dymola help to find optimal (minimizing) closing time of guide vanes/nozzles of generators to alleviate water hammer effects due to fast and unexpected fluctuations of penstock flow rate.

In an ongoing project with Jade University of Applied Sciences and German wind energy concern Enercon, USN is studying windmill stability in conjunction with feeding of power to grids using simulation and lab-scale studies, which are then tested in the field, [10].

VII. CONCLUSIONS

To cope with the industrial push coming from Industry 4.0 initiatives, academic institutions need to match the technical content in the curricula. USN has tried to do this in collaboration with industrial partners both national and international. The core content of Industry 4.0 is reflected in the courses/modules as well as in projects involving individual or group of students. Lot of academic and industrial activities are currently going on right now with vendors even delivering IoT/Industry 4.0 solutions tailored to customer needs.

ACKNOWLEDGMENT

The authors thank the industrial partners STATOIL, YARA, EMERSON PROCESS MANAGEMENT, National Instruments, Jade University of Applied Sciences, Enercon of Germany and others in supporting our curricular development and in providing us with equipment and software for some of the modules described above and for their continuous collaboration with USN. Morten Borg of USN provided us the details of the automatic filling station presented here.

References

[1] R. Davies, EPRS (European Parliamentary Research Service), Members' Research Service EN PE568.337)

[2] K. Heimrich, SIEMENS; Industry 4.0, Presentation, Hannover Messe. 2015.

[3] https://www.usn.no/english/ , accessed on 02.06.2017

[4] http://www.halvorsen.blog/ , acessed on 02.06.2017

[5] https://opcfoundation.org/about/opc-technologies/opc-ua/ , accessed on 02.06.2017

[6] https://fieldcommgroup.org/technologies/hart , accessed on 02.06.2017

[7] DeltaV-Prosessautomasjonssystem, http://128.39.35.248/DeltaV/TrainingCenter/PDF/DeltaV_IA6-1-14_Hovedrapport.pdf - accessed on 02.06.2017 (main report on DELTAV portable training center developed by students of USN)

[8] H. Halvorsen et al., Remote control of a robotic arm – A cross-platform study using LabVIEW and DeltaV –ITEN Conference publication, 978-83-7283-735-6, EEA (European Economic Area) Project report, Project Number FSS/2013/IIC/W/0028/U0046, In press

[9] K. Aars "Simulation of load and fault scenarios in a hydro power system with island grid", Master Thesis, University College Southeast Norway, 2017.

[10] H. Lorenzen, J. Timmerberg, S. Mylvaganam, "Risk assessment of stability loss: Experimental investigations of weak bus bars", Conference: 12th IEEE International Symposium on Electronics and Telecommunications (ISETC), 2016, Romania DOI: 10.1109/ISETC.2016.7781112