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Long term evolution for control system applications in a smart grid context

Ljungberg Per [1], Donovan Craig [1]

1 : Ericsson Research
Ericsson Research
164 80 STOCKHOLM
http://www.ericsson.com

Long Term Evolution L.T.E., marketed as LTE 4G, is a global standard for wireless communication of high-speed data based on the GSM/WCDMA network technologies with increased bandwidth and low latency specially designed for machine-2-machine (m2m) applications. The success and rapid roll-out of LTE 4G in many countries have lead to an increased interest to use this technology for different application domains. In the smart grid context system characteristics such as resilience, availability and latency are important factors. In this presentation we share our insights on experiments conducted in a virtual smart grid lab environment where selected smart grid functions use LTE for distribution automation. The studied use-case is Distributed Fault Location Isolation and Service Restoration (FLISR) using a subset of IEC 61850 control signaling. Early results demonstrate the technical feasibility of using LTE 4G for a wide range of m2m communication needs in a smart grid context.

Electrified Vehicles as Platforms for Complex System Control

Esen Hasan [1*], Adachi Masakazu [1]

1 : DENSO INTERNATIONAL EUROPE
* : Corresponding author

Automotive systems are evolving continuously and they are becoming more complex to control. The number of control units, program size, and number of functions are increasing. Electrification of the powertrain introduces new challenges especially concerning energy management and fault-tolerance. Moreover, via smart-grids, electric and plug-in hybrid vehicles are being integrated into the electric power networks. Thus, the scale of automotive systems is growing larger, relating to infrastructure, energy production and storage, tele-communication, and so on. This presentation will give an overview of DENSO's approach and respected research work on those emerging challenges from control engineering point of view. Fault-tolerance of different high-voltage battery configurations will be discussed as an example.

The Use of Real-time Prices, Stability, and Volatility in a Smart Grid Market

Kiani Arman [1*], Annaswamy Anuradha [,2*], Samad Tariq [,3]

1 : Technical University of Munich
2 : Massachusetts Institute of Technology
3 : Honeywell Automation and Control Solutions
* : Corresponding author

The recent paradigm shift in the architecture of a smart grid is driven by the need to integrate renewable energy sources, the availability of information via advanced metering and communication, and an emerging policy of a demand that is intertwined with pricing. By using communication technologies that offer dynamic information, the ability to use electricity more efficiently and provide real-time information is expected to significantly improve. The introduction of both renewable energy sources as well as efforts to integrate them through an information-processing layer brings in dynamic interactions between the major components of a smart grid. In this presentation, a dynamic mechanism of the wholesale energy market that captures the effect of uncertainties of renewable energy sources and real-time pricing with demand response is derived. Beginning with a framework that includes real-time pricing, an attempt is made to capture the interactions between generation, demand, locational marginal price, and congestion price near the equilibrium of the optimal dispatch. Conditions under which stability of the market can be guaranteed are derived. We will show that price volatility can occur when demand elasticity and market latency are not suitably linked together. These results show that the proposed dynamic mechanism can provide guidelines for a stable and non-volatile real-time pricing strategy and accommodate power systems security and reliability concerns.

On power sharing and stability in autonomous inverter-based microgrids

Schiffer Johannes [1], Anta Adolfo [1,2], Duc Trung Truong [1], Raisch Jörg [1,2], Sezi Tevfik [,3]

1 : Control Systems Group, TU Berlin
2 : Max-Planck-Institut für Dynamik komplexer technischer Systeme
3 : Siemens AG

We consider the problem of voltage and frequency stability for an autonomous inverter-based microgrid. Given a desired power distribution for the network, we provide a design procedure that accounts for uncertainties in line impedances and loads. An LMI-based decentralized feedback control design is derived that stabilizes the system. We further analyze the trade-off between decentralized stability and power sharing.

Port-Hamiltonian Model of the Full Electrical Power System

Ortega Romeo [1]

1 : Laboratoire des signaux et systèmes (L2S)
Univ Paris-SudSUPELECUMR8506 CNRS
Plateau de Moulon 3 rue Joliot Curie 91192 GIF SUR YVETTE CEDEX
http://www.lss.supelec.fr/

In this paper a port-Hamiltonian model of the full, nonlinear, electrical power system is derived. The system is composed of synchronous generators, transmission lines and loads, which are all represented via first principle models. No simplifying assumptions - like linearity of the loads, nor neglecting losses and transient phenomena on the network or the generators stator - are made. This leads to an energy-based description of the full system, where all elements preserve their original physical interpretation. The model is derived proceeding from a bond-graph representation of each of its components, which are then integrated via standard power-preserving interconnections.

Stochastic MPC for optimal real-time power dispatch and bidding on the energy markets under uncertainty

Patrinos Panagiotis [1*], Bernardini Daniele [1], Puglia Laura [,2], Bemporad Alberto [1]

1 : IMT Institute for Advanced Studies Lucca (IMTL)
Piazza S. Ponziano, 6 55100 Lucca
https://www.imtlucca.it/
2 : University of Trento (UNITN)
Via Belenzani, 12 I-38122 Trento
http://www.unitn.it/
* : Corresponding author

In this talk we show the effectiveness of recently developed model predictive control (MPC) techniques based on stochastic optimization for solving complex decision problems that arise in managing smart distribution grids. After quickly revising the general stochastic MPC setup, we consider two concrete application cases related to the Dutch energy market. The first application concerns the problem of real-time power dispatch of Balance Responsible Partners (BRPs), in which a hierarchical stochastic MPC algorithm is presented to minimize generation costs while economically tracking the assigned E-Program, coping with various types of uncertainties such as wind power, loads, imbalance prices, and delta power signals received from the Transmission System Operator (TSO), and taking into account the constraints imposed by the physics of the generators. In the second application, we describe multi-stage stochastic optimization algorithms for enabling BRPs to optimally bid on the day-ahead and ancillary service markets, explicitly taking into account in the formulation the risks associated with the incurrence of economic losses.

Energy and CO2 efficient scheduling of smart home appliances in the Stockholm Royal Seaport

Sou Kin Cheong [1], Sandberg Henrik [1*], Johansson Karl Henrik [1]

1 : ACCESS Linnaeus Centre, KTH Royal Institute of Technology
* : Corresponding author

This talk considers the minimum electricity cost and CO2 emission scheduling problem of smart home appliances in the Stockholm Royal Seaport. The Royal Seaport is a new urban district in eastern Stockholm which will house 10,000 new apartments and 30,000 new office spaces where modern living is combined with environmental thinking to create sustainable living.
Operation characteristics of the smart home appliances, such as expected duration and peak power consumption, can be adjusted through a power profile signal. The optimal power profile signal minimizes cost and CO2 emission, while satisfying technical operation constraints and consumer preferences. Constraints such as enforcing uninterruptible and sequential operations are modeled in the proposed framework using mixed integer linear programming (MILP). Several realistic scenarios based on actual spot price are considered, and the numerical results provide insight into tariff design. Computational issues and extensions of the proposed scheduling framework are also discussed.

Robust transient synchronization of power networks

Fradkov Alexander [1,2], Furtat Igor [3], Pchelkina Irina [2]

1 : Institute of Problems in Mechanical Engineering (IPME)
61 Bolshoy ave V.O., 199178 Saint Petersburg, Russia
www.ipme.ru/ipme/labs/ccs/
2 : Saint Petersburg State University (SPbSU)
28 Universitetsky Prospect, 199504, Peterhof
www.tklab.ru
3 : Institute of Problems in Mechanical Engineering (IPME)
61 Bolshoy ave V.O., 199178 Saint Petersburg
www.ipme.ru/ipme/labs/ccs/

Two approaches to the controlled synchronization of electric generator network are considered. First approach is devoted to synchronization of the network of electric generators where the model of each generator is described by the differential equation of third order with known parameters. The solution is based on the speed gradient method. The control law depends on the power angle, relative speed and the quadrature axis internal voltage for each generator.
The second solution is based on application of the robust algorithm of disturbances compensation. Each generator of the network is described by third-order differential equation with algebraic constraint equations between subsystems network. Parameters of the network are unknown. The control algorithm depends on relative speed of each generator in the network. It is shown that the proposed algorithm ensured synchronization of the network with the required accuracy both in normal and fault modes when the reactance of one transmission line is changed.
The efficiency of the proposed control algorithms are illustrated by numerical examples.

Coordinated control of distributed energy resources in the power distribution grid

Zampieri Sandro [1], Bolognani Saverio [1]

1 : University of Padova

We consider the problem of optimal reactive power compensation for the minimization of power distribution losses in a smart microgrid. We first propose an approximate model for the power distribution network, which allows us to cast the problem into the class of convex quadratic, linearly constrained, optimization problems. Then, we design a randomized, gossip-like optimization algorithm based on that model. We show how a distributed approach is possible, where agents have a partial knowledge of the problem parameters and state, and can only perform local measurements. For the proposed algorithm, we provide conditions for convergence together with an analytic characterization of the convergence speed. The analysis shows that the best performance can be achieved when we command cooperation among agents that are neighbors in the electric topology. Numerical simulations are included to validate the proposed model and to confirm the analytic results about the performance of the proposed algorithm.

A receding horizon approach to intraday electricity markets

Joe Warrington [1]

1 : Eidgenössische Technische Hochschule Zürich (ETH Zürich)
ETH Zurich
Hauptgebäude Rämistrasse 101 8092 Zürich Schweiz Telefon: +41 44 632 11 11 Telefax: +41 44 632 10 10
http://www.ethz.ch/

The incorporation of uncertain and rapidly-changing quantities of intermittent renewable energy is arguably the major challenge of the coming decades for the operators of electrical grids in those countries where the renewable share is expanding. This is because ever greater flexibility from the other market participants is needed in order for power production and consumption to be shaped around the exogenous power infeed. The difficulty of ensuring this flexibility is provided efficiently is compounded by the need for the solution to be compatible with market-based operation of the power system. A strategy explored in this work is the re-negotiation of prices and power volumes on a receding horizon basis, borrowing from predictive control principles. The aim of this approach is to ensure that the newest forecasts of exogenous power injections into the network are available at all times. This should improve efficiency by allowing market participants to adjust power consumption or production plans at the earliest possible stage.
We report on the application of Lagrangian relaxation techniques to finite horizon (multi-period) power flow problems with diverse market participants, such as generators, storage devices, aggregated household appliances, and other consumers. The methods are demonstrated in the presence of network constraints, firstly for linearised «DC-approximated» grid models, and then on full AC grid models via a tight semidefinite relaxation of the power flow problem. We discuss the computational issues arising from attempting to solve the multi-period optimization using distributed methods.
Finally, since these optimization techniques respect principles such as privacy of information and can therefore be interpreted as iterative market clearing mechanisms, their potential adaptation for use in real intraday electricity markets is discussed.

Site-wide energy management

Kramer Stefan [1]

1 : INEOS

INEOS Köln operates a large integrated petrochemical site in Cologne. The energy network of such a site is rather complex and provides a number of discrete and continuous degrees of freedom such a network optimisation leads to a complex problem.
Additionally, in the coordination of the energy network with production and other utilities, different timescales must be considered: the first scale refers to the online load/demand balancing, longer time scales concern decisions on an hourly, daily, and monthly scale.
In short-term planning, the optimal operation strategy must be computed for a small number of days. This approach offers the opportunity to compensate day/night effects, e.g. high steam demand of compressors of a plant during day time due to high ambient temperature while other plants could be operated in an anti-cyclic way, saving steam at the same time. The expected rate of production of every unit has to be taken into account. The idea is to change the production rate of single units during the day while ensuring that the defined daily production goal is reached. Those units have to be identified and described properly in a simplified model.
The planning system has to be linked to the production planning system which provides the planned production rates (products and steam) and the energy requirements of the site. For a specific planning horizon the optimal choice of units to be operated has to be determined. A particular challenge is the balancing of the daily production within this horizon while fulfilling the requirements of the production forecast. Additionally, the goal is to identify the benefits of alternative solutions which can be realized if production rates are adapted, i.e. if a reduction of the production rate of a certain unit offers the opportunity to shut down a boiler of the power plant and to reduce inefficient usage of steam, e.g. to run a condensation turbine.
In the medium-term optimization the challenge is to consider long-term constraints, e.g. that a boiler cannot be switched on or off on a daily basis. Hence, de-commissioning and commissioning requirements of equipment and minimum outage or running periods have to be considered. The solution of the medium-term planning problem will provide the basis for long-term planning.
In long-term planning, plant turn-arounds (TAR) are an issue that have to be chosen properly such that central assets, such as the power plant, are able to fulfil the energy demand of the running plants or during commissioning/de-commissioning.
The goal in this application is to develop and implement technology for medium-term optimization, long-term planning, and plant load balancing to achieve energy-optimal production. This will be a major step towards reducing the energy needs of the site and can be extended to other INEOS integrated sites.
Energy networks need to be run in a resource-optimal way in order to avoid a waste of energy, for example by steam let-down, or the loss of production due to steam shortages.
A small part of the general idea has been realised in the crackers which form the heart of the site. A steam cracker employs steam; high pressure steam that is converted into work and low pressure steam that is used for heating, for example in the reboilers of distillation columns. As high pressure networks are often expensive to maintain they do not exist site wide and the crackers have to run their own auxiliary boilers to drive large machinery such as compressors. Thus, they produce excess low pressure steam which can only be used for heating. In order to maintain the pressure in their internal steam networks let down stations are often used as they regulate the pressures much more quickly than a load change on an auxiliary boiler could. This let down wastes steam and thus energy because the low pressure steam cannot be converted into higher value work or electricity. The aim of minimizing the steam production within a processing plant is therefore to run the let down stations at their lowest allowed capacity, while maintaining steam pressure and thus plant availability.
At INEOS Köln's Crackers this was achieved by formulating an optimization problem. Compiled MATLAB code is connected to the DCS using the communication system ACPLT/KS and gives a suggestion every two minutes to the control room operator as to how to run the auxiliary boiler most economically.

Energy control and optimization in petrol refineries

Gonzales Rafael [1*]

1 : Petronor - Repsol
* : Corresponding author

Increased market pressure and the need to comply with new environmental regulations have led petrol refineries to undertake structural transformations as well as to improving efficiency in the operation of the processes using advanced control and economic optimization. Moving further in this direction, the talk present some current projects and challenges, based on the use of models and optimization methods, oriented to improve the high level operation of the refinery with the aim of improving the use of energy and other resources.

Unit coordination for energy saving in the steel plant

Xu Chaojun [1], Engell Sebastian [,2]

1 : Process and Production Optimization, ABB AG Corporate Research Center Ladenburg, Germany
2 : Process Dynamics and Operations Group, Biochemical and Chemical Engineering, TU Dortmund, Germany

This work addresses the coordination heuristics of two large-scale flexible multi-stage batch (flow shop) scheduling problems, which are currently solved independently by tailored algorithms that consist of mixed-integer linear optimization and heuristics due to the complex production constraints in different production sections. The approach is motivated by an industrial-scale steel making process that consists of a melt shop as the first production section and a hot rolling mill as the second production section. The first section produces intermediate products, i.e. slabs, which are stored in a slab yard and which are consumed by the second section. Huge amount of the reheating energy is wasted in the second section to warm up the cold slabs due to long storage time in the slab yard. The aim of coordination is to arrange the entire production complied with the technical constraints of both sections as well as to ensure the timely delivery of finished products with minimum resource and energy consumption. A bottom-up coordination approach is presented to coordinate existing multi-stage batch schedule optimization solutions. A coordination level is introduced above the level of the existing scheduling solutions, where an upper-level coordinator is formulated as an optimization problem initially based upon the technical constraints of the identified bottleneck stages within the distributed production sections. The optimal solution of the coordinator is used as the coordination inputs for the lower-level schedulers. Additionally, the coordinator will be updated iteratively based on the feedback from the lower-level schedulers by adding integer cuts into the optimization model. A prototypical software architecture is proposed to maintain configurability and flexibility of the coordination approach by using the ISA95 standardized web-service interface to the existing steel production schedule solutions. The simulation results based on real production data from a stainless steel plant reveals that the coordination approach may help the steel company to increase the total productivity about 7%, reduce the slab yard inventory about 23% and reduce the natural gas consumption in the reheating furnace about 9% compared to the uncoordinated schedule. In other words, the coordination benefit for the plant with the annual production of 1.3 million tons steel is the total production cost saving about 1 million Euro p.a. without any additional hardware investment.

Wide-area Monitoring in Control for Electric Power Systems

Larsson Mats [1]

1 : Corporate Research, ABB Switzerland (ABB-CH)

Phasor measurement and Wide-area Monitoring,Control and Protection (WAMCP) technology represents a major improvement in the automation and control infrastructure in comparison to the traditional network supervision systems (SCADA/EMS) that allows active monitoring and management of fast dynamics in power systems. The talk will introduce wide-area monitoring and control and explain current commercial state of the art as well as outline a few active research topics in the field. Special attention will be given to recent advances in applications for monitoring power oscillations of large continental power networks, based on the example of the European ENTSO-E interconnected power grid.

HVDC grid: from actuators distributed control to global stability of the network

Benchaib Abdelkrim [1]

1 : Power Electronics Activities
ALSTOMGRID
102, avenue de paris, 91300 Massy
www.alstom.com

The increasing of world population as well as environmental issues will brought new needs and restrictions to the society, which will be addressed from the nergetic point of view, where the widely deployed AC power system will present limitations. The integration of wind as well as photovoltaic energies will create growing instabilities in power network tending to restrict the power amount integration. High-voltage direct current (HVDC) technology has become a credible alternative for transmitting power over long distances through submarine or underground cable crossings. Due to their capabilities of providing reactive power support and controlling the active power flow, VSC-HVDC systems have been recently the subject of several interests. Indeed, as AC/DC power conversion involves no inertia, power flow through HVDC-links can be modified quasi-instantaneously, and part of the transmission capability of HVDC-link could be used to improve system responses in the face of sudden disturbances such as loss of load, generation, or transmission devices. These systems will play a key role in increasing renewable energy penetration in power networks. In fact, interconnecting such DC links, will results on radial and then meshed DC power networks, able to absorb demand modifications and to damp disturbances even in the AC side. In this presentation, a modelling and control of SVC-HVDC two terminals transmission system will be shown, followed by an extention on how to globally control a MTDC transmission grid from associated distributed control based actuators. Our aim is to obtain a plug and run DC power grid.

Unified System-Level Modeling and Predictive Optimization of Virtual Power Plants for Control Services

Koch Stephan [1], Andersson Göran

1 : ETH Zurich, EEH - Power Systems Laboratory

In this talk, a novel modeling method for generation, load, and storage units in power systems, referred to as "Power Nodes Modeling Framework", is presented. The concept is based upon the notion of common system-level properties of grid-connected units in spite of diverse underlying physical processes. The chosen nomenclature enables the compact representation of coordinated flexible unit portfolios and an easy formulation of predictive optimization problems for control service provision (such as frequency control, balancing, capacity firming, etc.) by Virtual Power Plants. A number of simulation examples with focus on high-renewables-penetration power systems will be shown to illustrate the approach.

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