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POWER BALANCE CONTROL USING EVOLUTIONARY ALGORITHM

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ABSTRACT
Modern electric power systems are large-scale systems with a complex structure comprised of interconnected networks. The balance between the generation and consumption of electricity has to be maintained at any moment. Transmission System Operator (TSO) is responsible for keeping the domestic power balance. Power reserves used to control this balance are called "ancillary services". These services are performed both by automatic control and human operator. The task of the operator is to activate proper services and their amounts. A nonlinear optimization problem is formulated that enables the ISO to make least-cost decisions for activation of ancillary services. In this contribution the optimization problem is solved via the Self-Organizing Migration Algorithm (SOMA) which belongs to the class of evolutionary algorithms. This algorithm is based on the competitive-cooperative behaviour of intelligent creatures solving a common problem. Optimization of ancillary services via SOMA is tested on two scenarios that are based on real values obtained from the Czech TSO.

KEY WORDS
Optimization techniques, evolutionary algorithms, power system stability and control, ancillary services

1. Introduction

Modern electric power systems are large-scale systems with a complex structure comprised of interconnected networks. The Union for the Coordination of Transmission of Electricity (UCTE) coordinates the operation and development of the electricity transmission grid in 24 countries, including Czech Republic as depicted in Figure 1. UCTE transmission system is divided into control areas - typically by countries, although some subsystems are joined together to create utilities that are able to operate independently in case of emergency - e.g. CENTREL. Transmission System Operator (TSO) manages the operation of the power system within the control area and coordinates its activities with neighbouring utilities. The TSO is responsible for taking care of the safe transmission of electricity, the reliability and stability of the system and balancing supply and demand at any time.

Ancillary Services support the transmission of energy from resources to loads, while maintaining reliable operation of the power system. The provision of ancillary services is an economic and technical issue that must be addressed in all deregulated power market structures.

TSO works on behalf the users of the system and has to decide how much ancillary services should be bought. If there are not enough services then TSO cannot ensure the security of the system. However, the costs for the AS are passed to system user. To reduce the risk some ancillary services are available through long term contract and some are bought through spot market. AS also represent another business opportunity for generators.

The objective of the reserve dispatch in a multi-area electricity market is to minimize the expenses for the reserves subject to a number of constraints. In [1] the multi-criteria optimization problem is solved via Pareto-based evolution strategy. Chand and Sugianto in [2] used a heuristic based technique called horizon scan to find optimal solution for the reserves dispatch.

An expert system that has reliability requirement as the inputs and volume and composition of ancillary services as output has been developed in [3]. The optimization method proposed in this paper is intended to aid the TSO in calculating the necessary ancillary services for system security and reliability. An optimization problem is formulated that enables the ISO to make least-cost decisions for purchasing ancillary services.

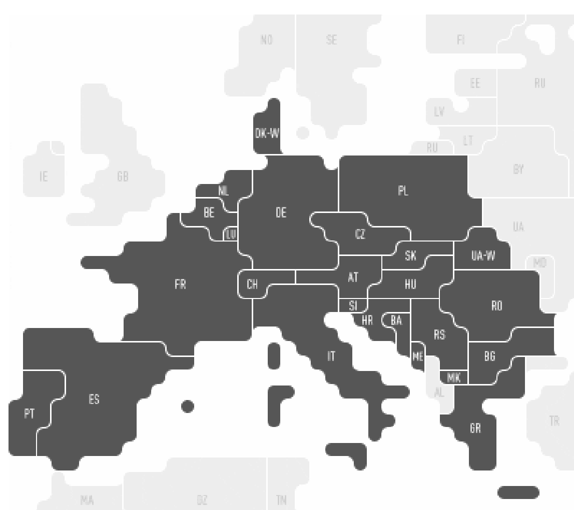

Figure 1. Synchronously linked grid of UCTE

2. Ancillary Services

Power systems are subjected to sudden and unpredictable changes due to changes of generation and fluctuations of loads. Supply of electricity is one critical infrastructure influencing function of a modern society. Other infrastructures such as traffic, transportation or production strongly depend on its performance.

Therefore continuous regulation is essential in maintaining system frequency. If generation exceeds load then frequency rises. If load exceeds generation frequency falls. Continuous regulation is also important in controlling inter-area power flows. If generation exceeds load within one balancing area, then power will flow over the transmission line ties to adjacent areas. Normal system operations are infrequently punctuated by unexpected generator outages and transmission line failures. To be able to respond to contingencies without affecting overall reliability system operators have a coordinated set of operating reserves. If there is a generator outage the frequency has to return to its preset value of 50Hz within 15 minutes. These reserves dedicated for the balance control are called ancillary services. The Czech TSO operator ČEPS uses following ancillary services to balance contingencies:

- Primary frequency control
- Secondary frequency control
- Tertiary control
- Quick-start
- Dispatch reserve
- Emergency from abroad
- Balancing energy

Primary Frequency Control is an automatic response to frequency changes reacting immediately at the generation units. The primary regulation reserve **RZPR** must be released within 30 seconds.

Secondary Frequency Control is a process a regulated unit output change as required by the secondary frequency regulator. Dispatch centre at TSO is responsible for utilization of regulation reserves **RZSR**. The reserve must be available within 10 minutes with minimum rate of 2MW/min.

Tertiary control TR consists of a change of the operating point of the generation unit's output based on request sent to the power plant by the dispatch centre at TSO. The whole regulation reserve for tertiary control must be provided within 30 minutes at the minimum rate 2MW/min. The tertiary control is used to free up the exhausted secondary reserve so it can effectively balance the frequency fluctuations. The reserve denoted **RZTR-** is used to decrease the output and **RZTR+** to increase the output.

Quick-start reserve RZQS is a reserve that contains units capable of providing the reserves within 10 minutes. The main purpose of this reserve is the correction of power imbalances occurring as a consequence of a failure at a power plant or a significant load increase.

Dispatch reserve RZDZ is provided by units that are capable of reaching nominal or agreed value within 90 minutes. These reserves are activated upon request from TSO dispatch centre. The provider must guarantee minimum 24 hours duration of provision of dispatch reserve.

Emergency assistance HV from abroad is based on mutual agreement with neighbouring TSOs.

Balancing energy EregZ can be purchased from abroad. The inquiry to the source TSO must be submitted by the provider 2 hours before the scheduled supply of **EregZ**. It is possible to activate or terminate the supply of **EregZ** on a change of business interval, currently on the hour. This energy is not guaranteed and may not be obtained when it is needed.

3. Regulation Reserves

The volume of the contracted power reserves in the form of ancillary services has to be selected to ensure secure operation of the power grid. The expert system that has a reliability requirements and the composition of ancillary services as the output has been developed in [3]. This expert system helps the Czech TSO plan ancillary services purchase under the changing market condition. It uses historical records of ACE (Area Control Error) and activation of ancillary services, technical and economical characteristics of generation companies at market and returns recommended optimal set of ancillary services, expected costs and reliability indices that describes behaviour of the power grid controlled with such a set of AS.

4. Real-time power balancing

Regulation and Frequency Response requires generators to balance control area supply and demand, and maintain frequency and tie line flows at scheduled values. This ancillary service is procured competitively, by the ISO, for the shared benefit of all system users.

Dispatch is the real-time control of all generation and transmission resources that are currently online and available to meet load and to maintain reliability within the control area (Figure 2). ACE is a difference between the scheduled and actual foreign power exchange corrected with the effect of the primary control, which acts independently of the central controller, to avoid counter-regulation. The ACE should be kept at the zero level since negative ACE represents unscheduled export and positive ACE represents unscheduled import. The problem for TSO is how to use all the possible resources efficiently and in a coordinated way to ensure system security.

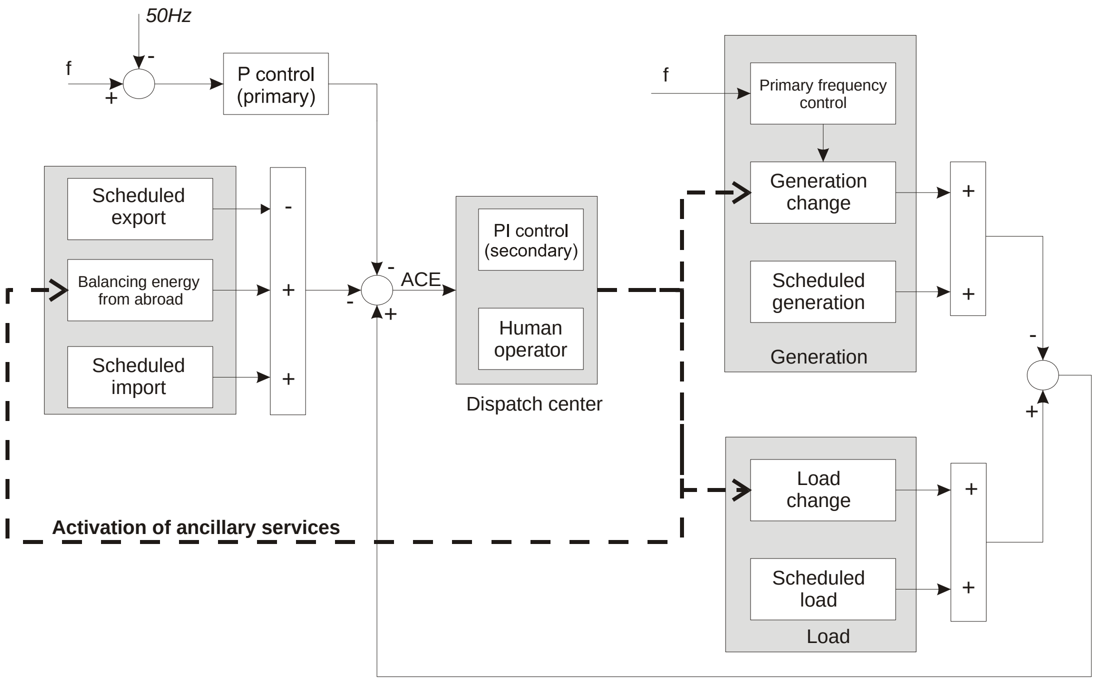

Figure 2. Power balance control

To test the proposed algorithm it is assumed that the dispatch control has the following information:

- 6h-prediction of ACE
- capacity of reserves in the form of ancillary services
- prices of AS for each generating blocks

The sampling period is set 15 minutes. Thus the 6h-prediction is represented as row vector with 24 columns. The task of the predictive dispatch control is to minimize ACE and minimize operating costs. The overall costs are given as sum of costs for ACE and costs for ancillary services:

$$Costs = Costs_{ACE} + Costs_{AS}$$

The costs of AS are given as

$$Costs_{AS} = TR.P_{TRi} + QS.P_{QS} + DZ.P_{DZ} + HV.P_{HV} + EregZ.P_{EregZ}$$

where

$$TR = \left[TR_1, TR_2, \cdots, TR_{24}\right]$$

represents the vector of activated tertiary control reserves at each sampling point and

$$P_{TR} = [P_{TR1}, P_{TR2}, \cdots, P_{TR24}]$$

is the vector of prices of TR at each sampling point. Other ancillary services use the same notation.

The secondary control reserve is not included in the plan for ACE balancing and is used to balance the uncertainty of the prediction vector. The outputs of the optimization process are the time vectors of particular ancillary services.

5. Self-Organizing Migration Algorithm

Evolutionary algorithms (EAs) are a less analytic approach to optimal solution search in discontinuous space, which have also had success in combinatorially immense problems. EAs mimic the natural mixing and occasional mutation of genes in heterozygous reproduction. Through many rounds of reproduction, in which more favourable solutions are the dominant reproducers, natural selection is mimicked, and optimal solutions are approached.

The Self-Organizing Migrating Algorithm - SOMA is based on the competitive-cooperative behaviour of intelligent creatures solving a common problem. Such behaviour of intelligent creatures can be observed anywhere in the world. A group of wolves or other predators may be a good example. If they are looking for food, they usually cooperate and compete so that if one member of the group is more successful than the previous best one (e.g. has found more food) then all members change their trajectories towards the new most successful member. It is repeated until all members meet at one food source. In SOMA, wolves are replaced by individuals. They ‘live’ in the optimized model’s hyperspace, looking for the best solution. It can be said, that this kind of behaviour of intelligent individuals allows SOMA to realize very successful searches.

Table 1
Available reserves for period from 10:00 till 16:00

Block No.	Type of Reserve	Capacity of a block [MW]	Price [Kc/MWh]
1	QS	200	3800
2	QS	300	3800
3	QS	100	3000
4	TR+	10	4500
5	TR+	10	4000
6	TR+	41	4500
7	TR+	41	4500
8	TR+	40	3000
9	TR+	13	3300
10	TR+	10	4500
11	TR-	10	400
12	TR-	15	390
13	TR-	10	700
14	TR-	10	50
15	TR-	20	410
16	DZ	60	3500
17	DZ	43	3500
18	DZ	20	3700
19	DZ	70	6000
20	HV	300	4000
21	EregZ	300	5000

6. Simulation Results

To test the optimization properties of the SOMA algorithm two 6h-datasets that represent prediction of error between production and consumption were used. The characteristics of the ancillary services as stated in Section 2 and the capacity of the AS at each generating block at each sampling interval (Tab. 1) that is available for particular AS were used as system and operating constraints for optimization. History values obtained from the TSO operator were used for simulation. If two generating units have the same price they are replaced by a dummy source with the capacity of both sources, since the choice between these sources does not influence the value of a cost function.

The SOMA algorithm then searches for solution that minimizes the cost function [4]. The following parameter values to guide its search: population size of 200 and 100 migrations. The first scenario is for the short outage of a large generating unit. Figure 2 shows the results of optimization where dP_0 represents the error between the production and consumption in the open loop, i.e. without any control and dP_c represents the error between the production and consumption with ancillary services being applied. The results show the immediate activation of the Tertiary Control Reserve and Quick-start Reserve to balance the lack of power in the system. To balance the excess of the power in the grid from 13:00 to 16:00 only negative Tertiary Control is available and thus is activated. The second scenario represents a longer outage of a large generating unit. At the beginning Quick-start reserve as the fastest ancillary service is activated to balance the lack of power. The dispatch reserve and emergency assistance from abroad are also activated but due to their time delays they are not available immediately. Later the set-point for Quick-start reserve can be reduced and Quick-start reserve can be spared for another generation outage.

7. Conclusion

An evolutionary algorithm SOMA is developed in this paper for the purpose of optimal selection of standing reserve to minimize the imbalance most economically. The research concerning the tool that could help the operation centre at TSO to select proper ancillary services with optimal costs is still in development. However, the optimization of ancillary services via evolutionary algorithms shows possible solution how to optimize power balance problem with operational and system constraints.

Acknowledgments

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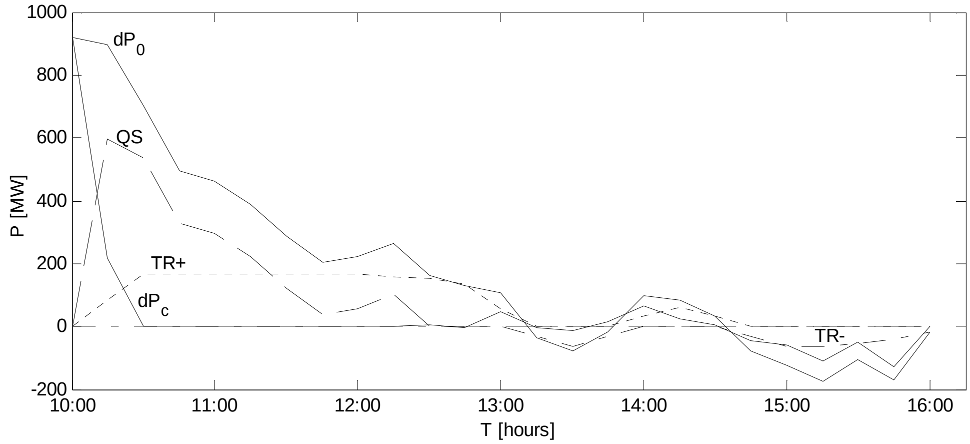

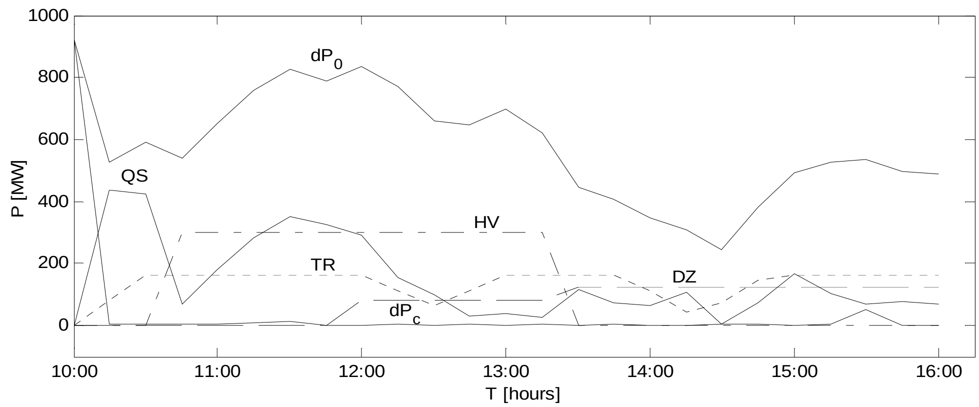

Figure 3. Optimized ancillary services for Scenario 1 and 2