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Simulation of Integration of Distributed Generation into Power System Control

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Abstract. The paper deals with modeling of the integration of distributed generation into the central dispatching system with regard to the electricity market environment. Due to the large number of the relative small unit power of distributed generation the resulting reserve power can achieve a remarkable quantity. However the utilization of these reserves is not obvious because of several technical issues like the cogeneration of heat power, lack of proper informatics, bounds of law about electric energy (LEE) in Hungary etc.

An agent based simulation model was developed to discuss the problem. The model consists of the distributed generation units (DG-s) and the DG-concentrator (DGC) which is an interface between DG-s and the independent transmission system operator (TSO). All of them are simulated as autonomous software units suitable for decision making, learning and multi-direction communication. This is a multi-agent system, where the service, control and simulation of stochastic demand variation are easy to study.

Several scenarios were discussed regarding the contracts between DG-s and TSO. The financial paragraph of the contract should ensure the willingness of private owned DG-s to provide their reserves for the central control. The results of the simulation help to find the minimum loss operation of the system.

Key words

distributed generation, cogeneration, central control, multi-agent system, simulation

1. Introduction

Growing number of high efficiency, environment friendly, relative low unit power cogeneration is in operation due to the government financial support. The unit power of a high-efficiency DG is not on the same level as the power of a conventional power plant but all DG-s together are capable for providing 10-15% of the power-consumption nowadays in Hungary [1].

DG-s considered in the paper are planned basically for cogeneration. Producing heat-energy and electrical energy they achieve high efficiency (>75%) necessary for the advantageous financial conditions guaranteed by LEE. On the other hand TSO is obliged to take over energy produced by DG-s.

The primary obligation of TSO is controlling the balance of production and consumption in the power system. For this purpose several methods are available as controlling contracted power plants, energy exchange with neighboring power systems, using energy storage etc. Because of growing number of DG-s a new possibility arises with better economic and energetic features employing their reserves.

Controlling the balance of power system is a serious problem in Hungary. The old type, not suitable for frequent control nuclear plant in Paks gives the 40% of the total production. The LEE supports installations of renewable and other environment-friendly technologies and obliges the TSO to take over energy produced in these generation units. As their number is growing the controllable units are losing ground so the disposable reserves are decreasing.

As their primary function all of DG-s considered in this paper provides heat-energy for district-heating services. Part of energy evolved from burning fuel is transformed to electricity with different technologies (gas-engine, gas-turbine) and supplied into electricity system. Due to the aggregated efficiency of cogeneration (70-85%) building and operating this kind of generating units is highly supported. Thus the number of low-powered – but totality with significant reserves – DG-s is going to increase admittedly in future.

The paper is focusing on the agent-based modeling of the above mentioned problems and presents some results of the simulation.

2. Technical Limits of Integration

Priority of heat-energy means the uppermost trouble in integrating DG-s with cogeneration into central control. While generation units are regulated towards meeting the actual demand of heat-energy it influences the electrical power production. Certain technologies give more freedom in controlling electric and heat power production separately at the expense of lower efficiency and profit.

Contracts with thermo services obligate DG-s to satisfy emerging heat-energy demands which has a seasonal nature, therefore – as the electric and thermo energy cannot be produced entirely separately – the electrical energy reserves available for TSO control has also a seasonal nature.

Because of low demand of heat-power in summer most of unit blocks of DG-s are out of operation and thus decreases the amount of downloading. Conversely electricity production can be increased only with ensuring of by-passing or storing the heat-energy evolved. Storing obviously a better solution because by-passing lead to decreasing of efficiency. In winter uploading reserves are minimal because the units are running on maximal power. Decreasing of electrical power is limited by the heat-power demand however a storage-heater can reduce this bound.

On the other side the amount of produced heat-energy in a year (or sometimes seasonally) is declared in the contract with the thermo-service. The tolerated deviation depends on the contract; in Budapest 5% deviation is allowed.

Furthermore regular servicing causes planned outage of generators that influences the amount of reserves even if most of these is performed in summer when blocks are usually out of operation. TSO (in fact the DGC, we discuss it later) also must be prepared for not planned outages of DG-s.

Last but not least the gas-consumption of DG-s is limited by the gas-service. Only 8% deviation from the previously declared amount is allowed daily.

Level of established informatics system is another important factor of integration. Continuous monitoring of electrical power is essential condition of an integrated DG. Robustness and safety of communication and control of the units can be increased with proper remote control system. Presently the model presumes the needed level of infrastructure.

3. Description of the Agent Technology

Studying the problem a multi-agent simulation model was established. Below the agent technology is briefly introduced. [2],[3]

A. Agents and Environment

Agents are always accompanied with their environment. Agents have input and output ports. Environment provides inputs which affect agents to respond with an adequate action as their output. Using term of software-agent assumes a code-environment where inputs and outputs are represented as variables.

Agents usually perceive a quite complex, continuously varying situation (percept) as input which means steadily altering variables in the case of software-agents. Output of an agent is its chosen activity conditioned by the entire percept theretofore (perceptual sequence).

B. Properties of Agents

Expecting the agents to settle upon the most suitable action requires measuring their performance adequately. Performance measure determines numerical value to be maximized in the case of software-agents. The exact effect of each action on the performance is rarely definable therefore agents merely attempt to determine the right act with approximation. An agent who is suitable for rating actions by performance measure is called rational agent. At any given time the action of rational agent depends on:

- the performance measure
- the agent's prior knowledge of environment
- possible actions of agent
- perceptual sequence of agent

C. Properties of the Environment

Agents serve as tools for studying different questions which is represented essentially by the environment. Agent-environment provides several properties to model diverse problems:

- fully or partially observable
- deterministic or stochastic
- episodic or sequential
- static or dynamic
- single agent or multi-agent

As our model applies multi-agent environment this term should be paraphrased. Multi-Agent System (MAS) contains several agents to model and simulate a question. In competitive MAS increasing performance of one agent results in decreasing of performance of the other agents; contrarily in the cooperative MAS agents tend to maximize their performance by helping each other. Structure of MAS influences the autonomy of agents. In centralized system, where master-agent gives orders, possible actions of slave-agents are restricted while all agents have the same priority and level of autonomy in the case of distributed MAS. Due to complexity of problems hybrid MAS is usually applied where all characters detailed above are included.

4. Review of the Established Model

A. MAS Environment

Studying the questions of integration requires a partially observable, stochastic, sequential and dynamic multi-agent environment. Precisely the MAS is partially competitive (between DG-s) and cooperative (seeing the relation of DG-s with DGC). Without centralization of MAS, agents are autonomous; they restrict their actions by themselves.

The environment realizes all parameters which affects the agent to act but are not modifiable by them. The more important environment parameters are:

- temperature (affects the required thermo energy)
- electric energy reserve demands
- prices of electric energy and reserve

For the temperature and reserve demands stochastic generators are implemented. Different energy prices are constant as declared by the Hungarian Energy Office.

B. DG Concentrator Agent

Basically two types of agent have been established in our model: DG agent and DGC agent. As dispatchers of TSO should not communicate with numerous DG-s a DG Concentrator (DGC) established to hide the complexity of generation units. DGC is responsible not only for handling the outages but for the optimal distributing the demanded reserve.

C. DG Agent and State-space Method

Due to survey about the Hungarian system [1] agents of DG-s are aware real technical properties.

Different cogeneration technologies means different operating strategies but same deciding algorithms should be implemented in DG agents to the effect of easily understandable and expandable model. To make it clear: gas engines can reach their nominal power in five minutes however starting a stoker needs hours. Demand of same intelligent algorithms in both cases can be served only with an interface. This interface is the state-space: several states were generated for each agent depending on the operating strategies.

Figure 1 shows a state-space of a DG with four gas-engines. Operating with different number of gas-engine can be recognized: dot with zero electric and thermo power is the operating state when no units runs, dot in the bottom-right corner means the state with maximum power.

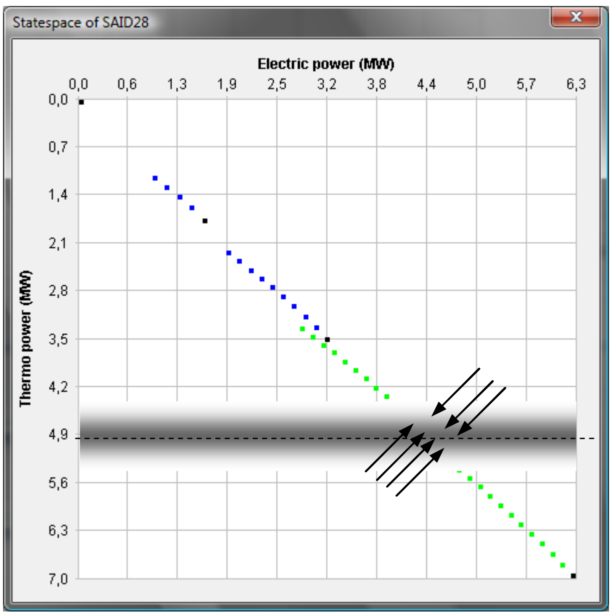

Fig.1 Method of state-space (DG with 4 gas-engines). [4]

As the states have the same attributes (electric power, thermo power, control time, number of operating units, profit and costs…), which are independent from operating strategy, same algorithms could be implemented in each DG agent.

Figure 1 explains the method of state-space. If DG is demanded to provide 5MW thermo power then it searches all states in a defined zone of the demanded thermo power (marked with arrows) and choose the optimal one with maximizing the performance measure.

Performance measure is a function of profit, but several bounds are implemented as efficiency, gas, thermo energy (e.g. gas-bound punishes the states which lead to break the limit of gas-consumption.) Above the bounds there are strict bounds ruling out the unreachable states. (e.g. if a gas-engine is under service states running all engines must not be chosen.)

State-space of other technologies can have totally different character and thus gives more freedom to choose different electric and thermo power. A more complicated state-space is shown on Figure 2.

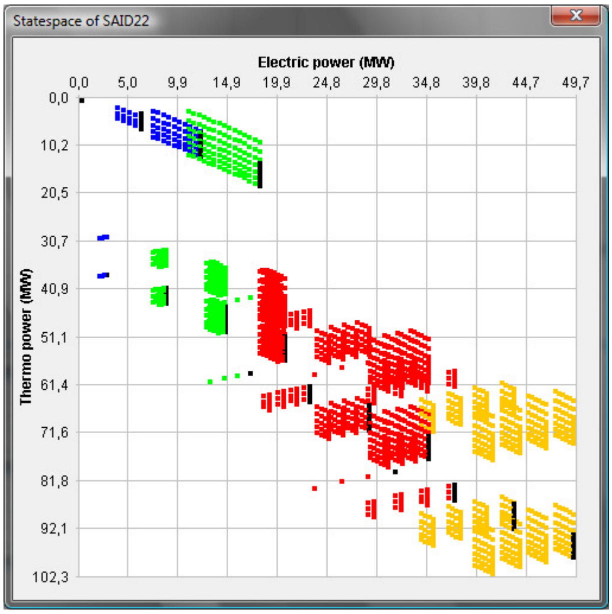

Fig.2 A more complicated state-space
(DG has gas-engines, stoker and steam-turbines also)

D. Initial conditions of simulation

As the model is continuously developed presently some simplifying assumptions have to be taken:

- amount of electric energy reserves are always the 10% of the actual total DG production
  - not realizable reserve demand has no consequence
  - outage during reserve service has no consequence
- gas-bounds are not so strict (experience of [1])
- content of thermo-service contracts is estimated
- cost of reserve is determined from the loss of profit.

5. Results of Simulation

Because of several input and output parameters of simulation a lot of questions can be studied. In this paper only the topics are picked out: amount of disposable reserves, effect of different parameters on cost and finally the optimal number of DG to be integrated.

Before studying different questions the model has been verified: 4 Wednesdays in 2008 the modeled production of DG-s approximates the real one in a 5% deviation.

A. *Amount of Reserves*

Firstly the amount and parameters of the reachable reserves were studied in order to prove the integration of DG-s is going to help on the controlling problem of the Hungarian power system. Bounds of gas-consumption, efficiency limit, usual thermo service demands and expectations were taken into consideration. Figure 3-4 represents the downloading reserves during a winter period and uploading reserves in summer if all DG in Hungary were integrated (~400MW). DGC managed to realize almost all reserve demands in both case. There are some unperformed demands which can be explained with too frequently reserve demand.

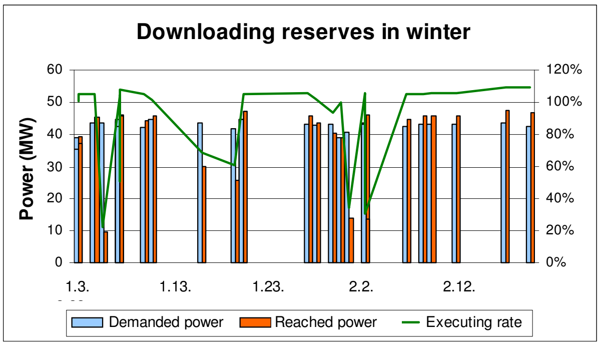

Fig.3 Reserves demand and achievements in winter [4]

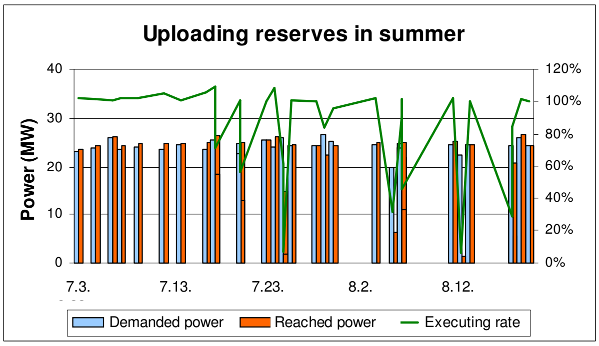

Fig.4 Reserves demand and achievements in summer [4]

Opposite cases (uploading in winter and downloading in summer) were also studied [4]. Because of high thermo-energy consumption in winter almost all DG run on their maximum power so uploading reserves are not achievable. Downloading reserves in summer show similar characteristics as uploading reserves in summer.

B. *Cost of Reserves and Dependencies*

Elementary purpose of simulation is finding the financial environment suitable for DG-s to be integrated. Therefore costs of controlling need to be studied in order to determine right financial parameters of contracts between TSO and DG-s. In these simulations price of reserves is counted from the loss of profit of DG in consequence of up- and down control. Figure 5 represents the cost of reserves in the function of time and the number of controlled DG-s.

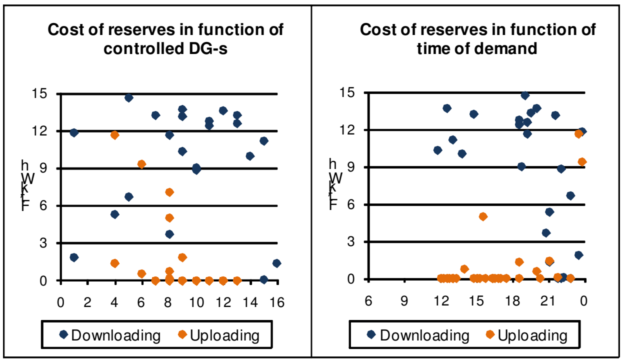

Fig.5 Cost of reserves in function of time and controlled DG-s [4]

Cost of uploading reserves is usually at lower or zero prices because of growing profit. (Model assumes that increased power of DG is paid as scheduled power, e.g. in case of 1MW uploading DG gets the same amount as it would have run on this increased power by schedule. This assumption shall be revised in the near future.)

Several parameters can influence on the cost. This paper shows graphs of influence of the number of controlled DG-s (Fig. 5. graph on the left) and of the time of demand (graph on the right). Other dependencies were also studied in [4].

C. *Optimal Number of DG to be Integrated*

The third study in the paper is focused on the optimal number (and power) of integrated DG-s. Obviously more DG-s are integrated, lower cost is reachable. Conversely the needed communication is growing and surprisingly the reliability of control is decreasing. Table 1 shows results of integrating the 6, 12 and 24 highest power DG. (Econtrol means the sum of performed reserves, Comm. is the average number of DG DGC has to communicate to fulfil a reserve demand and Reliability is the average of the executing rate (green line on Fig.3-4))

Table 1. Results for integrating 6, 12 or 24 DG [4]

	6 DG	**12 DG**	**24 DG**
P_{total}	233 MW	338 MW	456 MW
P_{avg}	39 MW	28 MW	19 MW
$E_{control}$	1429 MWh	2130 MWh	2803 MWh
Total cost	10,97 MFt	14,19 MFt	16,50 MFt
Rel. cost	7,67 Ft/kWh	6,66 Ft/kWh	5,88 Ft/kWh
Comm.	1,65	3,21	6,08
Reliability	77%	75%	69%

6. Conclusion

Above studies in paper vast questions of integrating DG-s were discussed to show the complexity of the problem. Implemented a state-space method same algorithms can work on different cogeneration technologies and other technologies (wind, water) are also implementable.

By the time of the ICREPQ'10 conference several contracts model will be studied to find the optimal financial conditions for integrating DG-s. Contracts can determine costs of various services: disposability charge of reserves, fee of applied reserves, compensation of waste heat-energy in summer, etc. TSO can inflict a punishment on DG-s in the event of satisfying reserves too slow, omitting or refusing contractual obligation, modifying amount of reserves out of allowed time, etc. Results will guide us which scenarios should be studied deeply with an intelligent model in the future.

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