SIMULATION OF MANAGING THE GENERATION OF ECOLOGIC ENERGY IN LOCAL ENERGY MARKET

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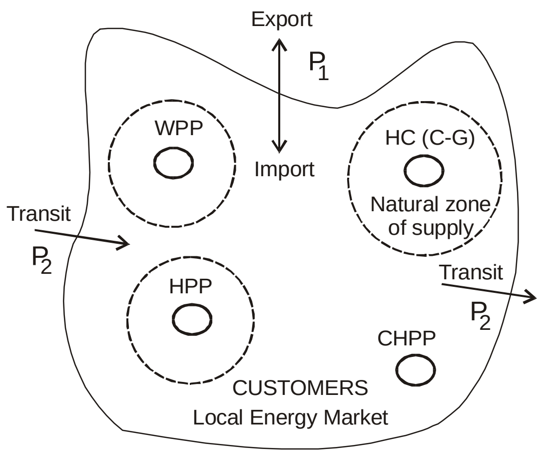
Power system, energy management, simulation, neural network, ecologic energy, decision support

ABSTRACT

The main aim of this paper is to describe strategy of decision taken by power system manager to minimize costs of energy in terms of spot market. The proposed attempt takes into consideration some problems of ecologic sources of energy, which are committing with conventional power plants. In the given circumstances of demand and load of power plants and networks simulation of expected values of energy is realized in an interactive mode. There are discussed some results of the simulation for the model of power system, including conventional thermal power plants, hydropower plants and wind farm. Neural network technology is applied to define load frame for set of committing thermal power units, hydropower plant and wind power plant.

ECOLOGIC SOURCES OF ENERGY AND LOCAL ENERGY MARKET

Sources of renewable energy effect the load of committing thermal units in accordance with theirs mode of operation. Hydro-plants cover the peak load or base load of power system, that mode of operation depends on disposed volume of water inflow. Complex of wind turbines effects equally when velocity of wind is proper, but the power system is loaded additionally when energy of wind exceeds rated values. Local Electric Energy Market (LEEM) allows producers (sources) and providers (networks) to sell energy to consumers nearby the sources. The commitment and competitions among producers and providers (transmission and distribution networks) should assure the interests of energy consumers. The crucial problem is to balance between energy production and its demand with regard to stated prices and power flow in a local power system expecting varied set of energy sources. The main aim of this paper is to simulate decision making strategy of power system manager (operator) in order to minimize costs of energy in terms of varied weather, different customers behavior and influence of spot market. The proposed attempt is based on fuzzy neural networks and algorithm applied to calculate values of energy in the given circumstances of demand and load of different kinds of power plants and networks.



Figures 1: The Structure of Local Energy Market– Energy Sources; WPP-wind power plant, HC(C-G)-heat central (co-generation mode), HPP-hydro power plant, CHPP – conventional heat power plant

SIMULATION OF COMMITTMENT OF ECOLOGIC ENERGY SOURCES

Electric power demanded by final consumers of energy reflects changes in the level of generation, transportation and distribution costs (Chowdhury at al. 1990, Ringlee and Wiliams 1963). Determined and undetermined volume of power demand in the power system (PS) involves the procedures of peak load covering by set of power units. The set of committing

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power units, operated in an optimal mode, effects the real costs of transaction made on the energy stock (spot market or balancing market). The response of final customers and energy distributors on varied costs of energy depends on tariff's prices. In case of increasing costs of energy the power demand will be decreasing in the near future. Therefore the income of energy provider does not change, however the costs of purchasing sales are higher. Fluctuation of hourly loads should be minimized as low as possible to obtain the optimum constraints of energy generation (Chowdhury at al. 1990, Sroczan 1996, Baltierra at al. 1998), but it is only possible when energy management system (EMS) is applied by consumers and demand side management (DSM) is operated by energy providers respectively. Therefore the power system manager should carefully balance the habits either of energy consumers and distributors or power plants and network requirements (Sroczan 1999). If procedures of local optimization are omitted, costs of delivered energy would be increased more then necessary, from theoretical point of view.

The structure of local energy market (LEM) in many countries is similar - some levels of competitions among conventional heat power plant (CHPP), transmission and distribution networks (TDN) allow the producers (sources – CHPP, HPP, WPP and H-C) and providers (TDN) to sell the energy at the actual market price. In developing countries this kind of energy management effects the possibility of growing either power plant capacity or power and energy flow in networks (providers and distributors) - from point of view of modernization or developing the production possibilities. Some aspects of these very involved and essential problems, especially including PP with limited energy production, are discussed in this paper.

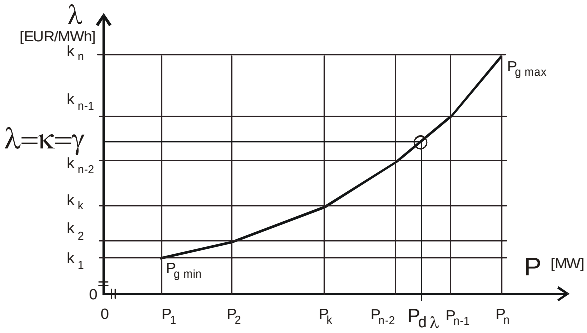
Limitation of energy generation refers especially to ecologic energy, which additionally depends on wind and hydro resources. There are decision support system and classical load dispatch algorithm applied to solve the problem of cost's minimization of generated energy. Obtained quality of power and energy balance effects the expected income of energy providers.

The proposed model of managing the LEM (Sroczan 1999) is based on maximization of expected delivery income (EDI) calculated for the k-*th* energy provider, which is described as Ω – a set of committing power plants including renewable sources and final distributors. Expected income, calculated for this set considers following relationships: power plant, energy stock, provider, distributor, consumer, in j-*th* hour of considered time period of calculation T:

$$max\{EDI_k\} = max\left\{\sum_{i,k\ni\Omega}\sum_{j\ni T;}\begin{bmatrix}\left(a_{jk} + b_k P_{ijk} + c_k\, P_{ijk}^2\right) + \\ -\left(a_{ij} + b_i P_{ijk} + c_i\, P_{ijk}^2\right)\end{bmatrix}\right\} \tag{1}$$

$$\sum_i P_{ij} = P_{PSj} + \Delta\, P_{FLij} \tag{2}$$

where: EDI_k - income of k-*th* energy provider which is contracted power and energy from i-*th* power source (PP), belonging to set Ω; a_i, b_i, c_i, a_k, b_k c_k – characteristic's factors describing the relationships between hourly exploitation costs of i-*th* power plant and k-*th* distributor, defined for set Ω; P_{dS} – demanded power of PS; ΔP_{FL} – power losses in given network branch *ij*.



Figures 2: Calculation of Incremental Cost for the Set of Conventional Thermal Power Plant, Hydropower Plant and Wind Farm; λ – increment of generation costs which is balancing the power demand P_d=P_g, γ – cost substituting the increment of water consumption, κ – wind power cost substituted by current cost of power generation in PS and balancing $Pg\kappa$.

Equation (2) describes constraints of power balance in PS including power losses in transmission and distribution networks. The structure of considered PS is shown in the fig.1. Sources of energy defined as ecologic are classified as wind (WPP) and hydro power (HPP) plants. Both class of energy sources depend on weather constraints. All sources are operating with respect to natural distance between plant and consumers. It means that long distance transmission of energy is unprofitable but sometimes is necessary. The final price of delivered energy is calculated as average value, defined in the contract between power plant and wholesale energy provider, but in reality it should be calculated or modified in the real-time mode by PS energy operator office in accordance with weather constraints.

The equation (1) includes also some impact of ecology constraints in form of decrement or increment of the costs yielded by the operation of hydroelectric plants, transmission and distribution networks as well as environment protection costs.

In the fig. 2 there are shown the incremental costs of power generation in PS. Relationships among the thermal, wind and hydroelectric unit costs of generation are shown as the increment related to actual PS power demand. The varied value of γ and κ enables balancing the generated and demanded power with regard to kind of renewable energy source and power generation limits

(2) The optimal increment of power generation costs is equal:

$$\lambda_t = \frac{\partial C_{i,n,t}}{\partial P_{i,n,t}} = \gamma \frac{\partial W_{j,n,t}}{\partial P_{j,n,t}} = \kappa \frac{\partial C_{k,n,t}}{\partial P_{k,n,t}} \qquad (3)$$

for all committing units.

Each of the increments of power P_{i+1} - P_i , for i=1,2,..,n describes a part of units' characteristics for generation costs or total plant costs . Comparison of generation costs of different kinds of power sources allows to sort the set of committing units with regard to increment of the λ (or γ or κ) coefficient.

The essential problem of the price of power and energy with regard to ecologic sources depends on PS manager decision and LEEM operator (Sroczan 1996, Malko 1997). If the decision is optimal the costs will be fulfilled in each time *t* the relationship:

$$C_t \rightarrow min\left\{\sum_{i=1}^{n} C_i\left(P_{gi}\right)\right\} \qquad (4)$$

where: $C_i(P_i)$ – cost of generation in i-*th* PP at partial load of P_g.

The proposed criterion function based upon decision algebra, supports the decisions made for optimization of power flows in considered PS to meet the constraints of contracts:

$$EMV(C_i) = \sum_{i=1}^{n} EDI(S_i) \cdot P(S_i) \qquad (5)$$

where: EMV(C_i)- expected monetary value of decisions in a given probability P(S)of power demand; S_i - probability of achieving the real value of the given power demand.

NEURAL NETWORK AS A TOOL FOR SUPPORT MANAGER'S DECISION

Structure of neural network consists of balanced adder, dynamic module realizing the linear function and non-dynamic module, which is performing a non-linear function. Task of identification is based on estimation coefficients and also the weights of the neuron's network based on the error processing e(t) between the output of the model y^m(t) arrangement and the output of the object *y(t)*.The module of the linear dynamic function is described by the transfer function, in this case realizing given relations between inputs v_i and outputs y_i.

The AI network, implemented in the loop of manager decision support system, consists of three layers within one hidden layer. The first layer is similar to input signals, which are obtained from real-time system. Evaluation of considered parameters is realized in the hidden layer. Output signals of neuron network describe the current state of discussed power system, defined for chosen parameters, negligible for operator's decision. Process of training the NN is described as iterative tuning of coefficient w_i of each inputs x_i to meet the value *y(k)* at the output of NN. Relationship between input and output is established by defined constraints.

The weight coefficient w_i is calculated, for the k-th step of learning as:

$$w_{ij}(k+1) = w_{ij}(k) + \Delta w_{ij}(k) \qquad (6)$$

where: *i,j* – number of joined neurons, *k, k+1* – old and new number of w_i.

The process of learning may be tuned by operator, each input vector x(k) is compared with stated vector s(t) and they are defined as:

$$x(k) = [x_1(k), x_2(k), \ldots x_n(k)]^T \qquad (7)$$

$$s(k) = [s_1(k), s_2(k), \ldots s_m(k)]^T \qquad (8)$$

The data learning NN are given for each group of input vector *x(k)* and *s(k)*, for *k=1, 2,...,p*, where *p* describe the learning pattern. For each pattern the error *e(k)* is defined as:

$$e(k) = y(k) - s(k) \qquad (9)$$

where: *y(k)* is a current response of NN for input signal *x(k)*.

The pattern vector s_p is calculated a priori from data imported from SCADA system of PS for given states of committing CHPP, WPP and HP. It is possible to build the pattern matrix for the simulator structure. The procedure of learning the NN by the operator-expert enables to minimize the error gained by the NN. For *m* neuron output and *p* patterns the error is described as:

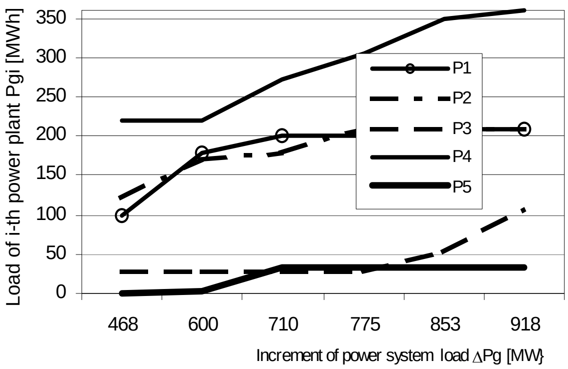
$$E = \frac{1}{2}\sum_{k=1}^{p}\sum_{j=1}^{m} e_j^2(k) \qquad (10)$$

The assessed impact of PS manager within the strategy of load the hydro-power plant depends on value of γ– system equivalent price of water, volume of water that is consumed in each hydro-power plant and κ– wind power cost.

RESULTS OF SIMULATION

The assumed principles of commitment include time and power gain without limits and occurred from short and long planning term. Power plant framework optimization is made using linear or dynamic programming. The impact of manager's decision on natural environment is defined by different values of γ, and κ coefficient that are substituting cost of wind power and the increment of water consumption in accordance with increment of generations cost in CHPP. The γ coefficient is responsible for hydropower plant allocation in the queue of load covering in accordance with disposed water volume. The κ coefficient is responsible for the WPP scheduling. Ther are considered the procedures of cost optimization: weather and load forecast of the PS on different time horizon, power demand as the response on DSM policy, actual and predicted states of PS. In the Table 1 ther are shown results of simulation for assumed values of PS power demand and different value of γ and κ- system values (price) of ecologic energy.

The assessed impact of the PS manager on the strategy of load the hydro-power plant depends on value of water system equivalent price, defined for water which is consumed in each hydro-power plant. Loading the wind farm depends on weather and PS demand, too. The value of κ as well as γ change the power range of generated energy, so the hydropower plants and wind farms are committing with thermal plants.



Figures 3: Simulated Load Characteristics for Given Set of Power Plants – CHPP, HPP, WPP; γ= 0,2 [$/m^3] and κ= 0,0223 [$/MW]

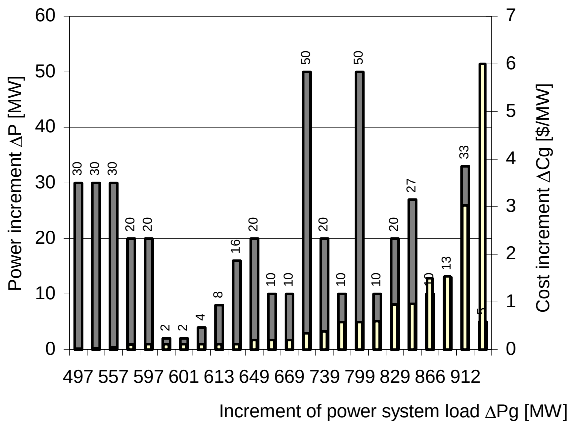
The value of EMV calculated for each PP and for both values of γ and κ shows that for low γ hydro power plant the load comes as the first one. If the value of γ is increasing the load is covered by power plant WPP. It means that the cost of emission the combustion gases are similar because of steady load of CHPP. Therefore the decision of PS manger effects the natural environment in two aspects: if the energy is generated by HPP or WPP the renewable energy is utilized and total amount of CO_x, SO_x, NO_x and H_2O is decreased.

Some results of simulation the manager's impact for energy generation cost are shown in the tab. 1.

Table 1: Cost of Energy Generation for the Model Power System

Case number	Value of coefficient		Cost of energy
	γ [$/m^3]	κ [$/MW]	C_g [$/h]
1	0,2	1	2101,4
2	0,2	0,0223	1868,9
3	0,2	1,5	2181,4
4	1,5	1,5	5804,4
5	1,5	1	5648,0
6	1,5	0,0223	5311,5
7	0,0223	0,0223	1345,8
8	0,0223	1	1526,2
9	0,0223	1,5	1601,2

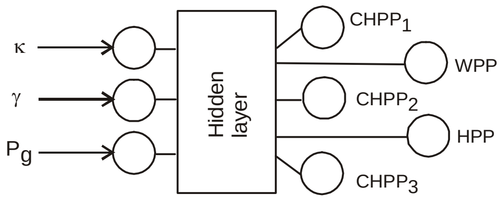
The considered model of PS includes: 85% of rated power in CHPP, 11,5% in HPP and 3,5% in WPP.



Figures 4: Results of Calculation the Incremental Costs for the Set of CHPP, HPP, WPP; γ= 0,2 [$/m^3] and κ= 0,0223 [$/MW] ; $\Delta Cg = \{0, 6,2\}$ [$/MW] – increment of generation costs which is balancing the power demand $\Delta P_{g\lambda} \in \{468, 918\}$

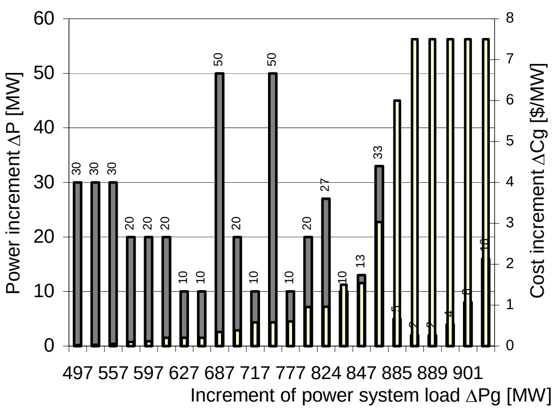
The simulated power system consists of three sets of aggregates; the first one contains the thermal sources of energy (CHPP), the second one hydroelectric (HPP) and wind units (WPP) as well power-limited (WPP) as energy-limited (HPP).

In the figures 3. and 4. there are shown the schedule of loading the modeling power plants and allocation of load increment ΔP_i versus power system load P_g. It is assumed that increment of cost of the power P_d generated in PS approximate λ (fig. 2) for the conventional thermal plant (CHPP). The cost's increments of energy generated by ecologic sources are calculated with regard to an equivalent cost factor γ for hydropower plants (HPP) and factor κ for energy generated by wind farms. The load schedule is obtained by using a neural network (fig. 5.) with three inputs – load's and manager's preferences; and outputs for each unit in the given power plants.



Figures 5: The Structure of Neural Network Dedicated to Define the Power Unit Load

The figures 6. and 7. presents the results obtained for γ=0,2<<κ=1,5. The HPP are loaded earlier then WPP and the cost groves about 16,7% of the previous one.



Figures 6: Results of Calculation the Incremental Costs for the Set of CHPP, HPP, WPP; γ= 0,2 [$/m^3] and κ= 1,5 [$/MW] ; ΔCg = {0, 7,5} [$/MW] – increment of generation costs which is balancing the power demand $\Delta P_{g\lambda} \in$ {468, 918}

Quite different preferences of energy manager are illustrated in the figures 8. and 9. The relation between γ=1,5>>κ=0,0223 shows that WPP set is loaded as the first one, before the HPP units, but the cost of energy increases considerably – about 243,5% in relation to case 3 (tab. 1.).

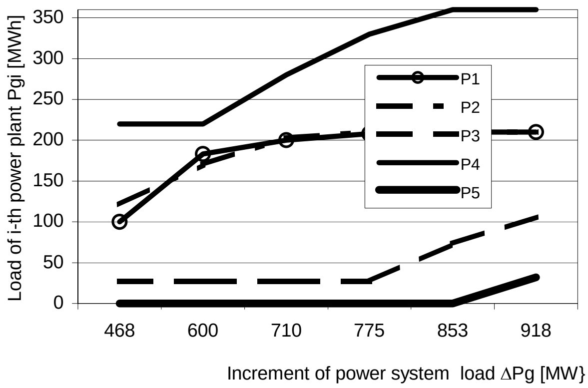
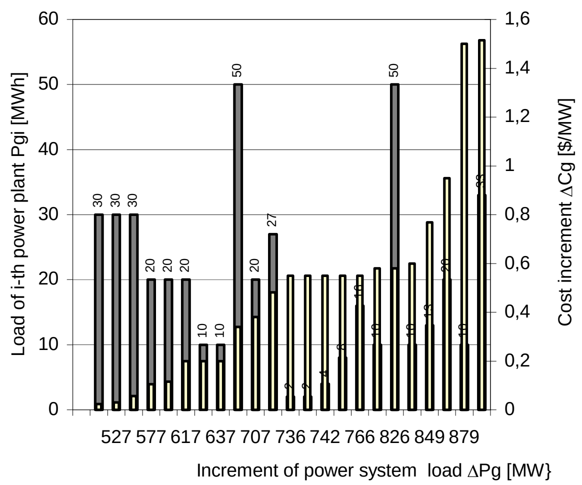


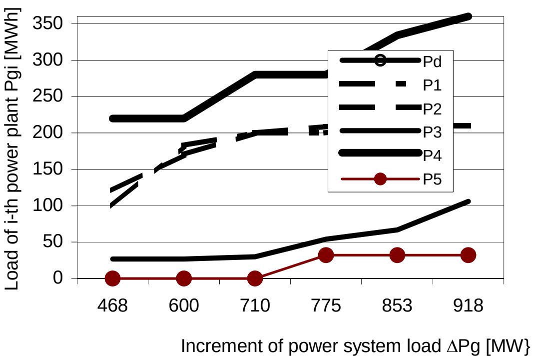
Figure 7: Simulated Load Characteristics for Given Set of Power Plants – CHPP, HPP, WPP; γ= 0,2 [$/m^3] and κ= 0,0223 [$/MW]

The third class of units (HC-CG) is generating power and heat in co-generation mode. Delivery costs are taken into account in the form of the simulated losses for the given network configuration. Transmission and distribution networks' topology must to be taken considered by using penalty factors (Chowdhury at al. 1990, Sroczan 1999, Baltierra at al. 1998). The losses are comparable because of small power variation.



Figures 8: Results of Calculation the Incremental Costs for the Set of CHPP, HPP, WPP; γ= 1,5 [$/m^3] and κ= 0,0223 [$/MW]; ΔCg = {0, 1,5} [$/MW] – increment of generation costs which is balancing the power demand $\Delta P_{g\lambda} \in$ {468, 918}

As it is shown in the figures 3., 7. and 9., the load of CHPP varies within the necessary range to cover the load in case of shut down the WPP set and discharge of HPP or WPP units, as the result of the manager's decision. It is assumed that the units of WPP should be shut-down without additional cost of operation.



Figures 9: Simulated Load Characteristics for Given Set of Power Plants – CHPP, HPP, WPP; γ= 0,2 [\$/m^3] and κ= 0,0223 [\$/MW]

CONCLUSIONS

To solve the problem of LEEM operating there are some procedures developed within the field of simulation the expected costs of energy supply for the given wholesale providers and power plants.

The range of manager's decision is described by acceptable values of λ, γ and κ coefficients, balancing the load of committing units with regard to ecologic sources of energy. Due to varied weather constraints the energy from this kinds of sources is more expensive than energy from conventional power plants.

The optimal operating the LEEM is possible with respect to market rules by using the proposed simulation procedures.

The described system simulates routines of the manager of power system dedicated for checking the broker's decisions in case of buying and selling with rational level of risk

The problem of validation the manager's decision takes into account both terms of analysis: the technical and economic effects. Considering the ecologic – renewable sources of energy supplying the local markets it is possible to formalize the impact of manager's decision on natural environment.

Distributed generation allocated in the hydropower and wind plants effect the flow of energy in the power network, especially in weather disturbances. To preserve the set of thermal units the commitment of hydropower and wind farms is necessary.

Using the described process of simulation it is possible to obtain the minimal costs of energy and optimal allocation of the given energy resources with respect to environment protection rules and PS demand.

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