CALCULATION OF DISPERSED GENERATION SHARE IN POWER AND ENERGY BALANCE OF POWER SYSTEM

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SUMMARY

Electrical power and energy balance is equality between total electrical power and energy input and output in/from power system. Electrical energy input in power system is consisted of several categories: generation of thermal, hydro and wind power plants, generation of power plants on distribution network (dispersed generation (DG)) and input of electrical energy from neighboring power systems. Power balance is developed for the hour of maximum load appearance in power system during year of consideration. Power balance categories in the considered moment of time are: total power of all thermal power plants connected on transmission network, total power of all hydro power plants connected on transmission network, total power of all wind power plants connected on transmission network, power exchange with neighboring power systems (import/export). Maximum load on transmission network level is equal to maximum load on power system level reduced for hourly generation of power plants connected on distribution network in the hour of maximum load appearance.
The goal of this paper is to show how DG share can be calculated and forecasted in the described power and energy balances. Namely, two basic quantities are used for calculation of DG share in power and energy balance. Equivalent number of working hours with maximum power is used for energy balance, while for power balance availability of generation is used for each power plant in DG category. The calculation procedure and typical values of these two quantities are presented in the paper for each power plant in DG category.

Keywords: Dispersed generation, power and energy balance, power system.

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INTRODUCTION

Advancements of technology, remote control and management of power plants which belong to DG category have enlarged there integration in power system. Increased integration of DG is also a result of achievements in technology with combination of restructuring of wholesale and retail electricity markets. Dispersed generation of electricity by definition is: not centrally planned, out of central control of power system, in most cases connected on distribution networks and with rated power from 50 kW to 100 MW Jenkins et al. (1). The fact that DG is not centrally planned and controlled means that DG commitment in active and reactive power generation is out of control of power system operators. DG rated power has most important role in obtaining the network voltage level for DG connection. Usually DG is connected on typical distribution network voltage levels from 400 V up to 110 kV.
The goal of this paper is to show how DG share can be calculated in the described energy and power balances. Balance of electrical power and energy is equality between total electrical power and energy input and output in/from power system. Electrical energy input in power system is consisted of several categories: production of thermal, hydro and wind power plants, production of generators on distribution network (DG) and input of electrical energy from neighboring power systems. Power balance is developed for the hour of maximum load appearance in power system during year of consideration. Power balance categories in the considered moment of time are: total power of all thermal power plants connected on transmission network, total power of all hydro power plants connected on transmission network, total power of all wind power plants connected on transmission network, power exchange with neighboring power systems (import/export). Maximum load on transmission network level is equal to maximum load on power system level reduced for hourly production of power plants connected on distribution network in the hour of maximum load appearance. Namely, two basic quantities are used for calculation of DG share in power and energy balance. Equivalent number of working hours with maximum power is used for energy balance, while for power balance availability of generation is

used for each power plant in DG category. The calculation procedure and typical values of these two quantities are presented in the paper for each power plant in DG category, Bajs and Atanasovski (2).

DISPERSED GENERATION SHARE IN ELECTRICAL ENERGY BALANCE

Each year electrical energy balance is equality between total input of electrical energy in power system and total output of electrical energy from power system:

$$W_{\mathrm{input}}(t) = W_{\mathrm{output}}(t)\ . \quad (1)$$

$$W_{\mathrm{input}}(t) = W_{TPP}(t) + W_{\mathrm{HPP}}(t) + W_{\mathrm{WPP}}(t) + W_{\mathrm{distribution}}(t) + W_{\mathrm{import}}(t) \quad (2)$$

$$W_{\mathrm{output}}(t) = C_{\mathrm{distribution}}(t) + C_{\mathrm{losses\_D}}(t) + C_{\mathrm{transmission}}(t) + C_{\mathrm{losses\_T}}(t) + W_{\mathrm{export}}(t)\ . \quad (3)$$

where: W_{input}, W_{output} – are total input/output of electrical energy in/from power system, W_{TPP}, W_{HPP}, W_{WPP} – are generated electrical energy of thermal, hydro and wind power plants, respectively, $W_{\mathrm{distribution}}$ - is electrical energy generation of DG on distribution network, W_{import}, W_{export} – are import/export from/to neighboring power systems, $C_{\mathrm{distribution}}$ - is electrical energy consumption on distribution network, $C_{\mathrm{losses\_D}}$ – are electrical energy losses in distribution network, $C_{\mathrm{transmission}}$ - is electrical energy consumption of loads connected directly on transmission network, $C_{\mathrm{losses\_T}}$ – are electrical energy losses in transmission network.

Yearly electricity production of DG has to be expressed by one of the following types of power plants: small hydro, photovoltaic, biomass, biogas, cogeneration, and for each type equivalent number of working hours with maximum power in a year, has to be calculated:

$$T_{\mathrm{ekv\_small\_HPP}} = \frac{W_{\mathrm{small\_HPP}} * 1000\ [GWh]}{P_{\mathrm{small\_HPP}}\ [MW]}\ . \quad (4)$$

$$T_{\mathrm{ekv\_PV}} = \frac{W_{\mathrm{PV}} * 1000\ [GWh]}{P_{\mathrm{PV}}\ [MW]}\ . \quad (5)$$

$$T_{\mathrm{ekv\_biogas}} = \frac{W_{\mathrm{biogas}} * 1000\ [GWh]}{P_{\mathrm{biogas}}\ [MW]}\ . \quad (6)$$

$$T_{\mathrm{ekv\_biomass}} = \frac{W_{\mathrm{biomass}} * 1000\ [GWh]}{P_{\mathrm{biomass}}\ [MW]}\ . \quad (7)$$

$$T_{\mathrm{ekv\_CHP}} = \frac{W_{\mathrm{CHP}} * 1000\ [GWh]}{P_{\mathrm{CHP}}\ [MW]}\ . \quad (8)$$

Where: $W_{\mathrm{small\_HPP}}$, W_{PV}, W_{biogas}, W_{biomass} and W_{CHP} are yearly electrical energy generated by following types of DG: small hydro (HPP), photovoltaic (PV), biomass, biogas, cogeneration (CHP), respectively, and $P_{\mathrm{small\_HPP}}$, P_{PV}, P_{biogas}, P_{biomass} and P_{CHP} are installed (rated) power of each type of DG, respectively.

Forecast of yearly electricity generation of each type of DG connected on distribution network can be performed by average equivalent number of working hours with maximum power in a specific past period (for example five years period), as it follows:

$$\overline{T_{\mathrm{ekv\_small\_HPP}}} = \frac{\sum_{j=1}^{\mathrm{N}} T_{\mathrm{ekv\_small\_HPP}}(t-j)}{\mathrm{N}}\ . \quad (9)$$

$$\overline{T_{\mathrm{ekv\_PV}}} = \frac{\sum_{j=1}^{N} T_{\mathrm{ekv\_PV}}(t-j)}{\mathrm{N}}\ . \quad (10)$$

$$\overline{T_{\mathrm{ekv\_biogas}}} = \frac{\sum_{j=1}^{N} T_{\mathrm{ekv\_biogas}}(t-j)}{\mathrm{N}}\ . \quad (11)$$

$$\overline{T_{\mathrm{ekv\_biomass}}} = \frac{\sum_{j=1}^{N} T_{\mathrm{ekv\_biomass}}(t-j)}{\mathrm{N}}\ . \quad (12)$$

$$\overline{T_{\mathrm{ekv\_CHP}}} = \frac{\sum_{j=1}^{\mathrm{N}} T_{\mathrm{ekv\_CHP}}(t-j)}{\mathrm{N}}\ . \quad (13)$$

Where: $T_{\mathrm{ekv\_small\_HPP}}(t-j), T_{\mathrm{ekv\_PV}}(t-j), T_{\mathrm{ekv\_biogas}}(t-j), T_{\mathrm{ekv\_biomass}}(t-j)$ and $T_{\mathrm{ekv\_CHP}}(t-j)$ are equivalent number of working hours with maximum power of one of the following types of power plants: small hydro (HPP), photovoltaic (PV), biomass, biogas, cogeneration (CHP), respectively, in a year (*t-j*), and N is the number of years in the analyzed past period (N=5).

Forecast of electricity generation in year *t* for each type of DG connected on distribution network is calculated as follows:

$$W_{\mathrm{small\_HPP}}(t) = P_{\mathrm{small\_HPP}}(t) * \overline{T_{\mathrm{ekv\_small\_HPP}}}\ . \quad (14)$$

$$W_{\mathrm{PV}}(t) = P_{\mathrm{PV}}(t) * \overline{T_{\mathrm{ekv\_PV}}}\ . \quad (15)$$

$$W_{\mathrm{biogas}}(t) = P_{\mathrm{biogas}}(t) * \overline{T_{\mathrm{ekv\_biogas}}}\ . \quad (16)$$

$$W_{\mathrm{biomass}}(t) = P_{\mathrm{biomass}}(t) * \overline{T_{\mathrm{ekv\_biomass}}}\ . \quad (17)$$

$$W_{\mathrm{CHP}}(t) = P_{\mathrm{CHP}}(t) * \overline{T_{\mathrm{ekv\_}CHP}}\ . \quad (18)$$

Total electricity generation of DG connected on distribution network in year *t* is:

$$W_{\text{distribution}}(t) = W_{\text{small\_HPP}}(t) + W_{\text{PV}}(t) + W_{\text{biogas}}(t) + W_{\text{biomass}}(t) + W_{\text{CHP}}(t) \;. \quad (19)$$

Table 1 summarizes typical values of equivalent number of working hours with maximum power for each type of DG connected on distribution network according to literature (2).

TABLE 1 - TYPICAL VALUES OF EQUIVALENT NUMBER OF WORKING HOURS WITH MAXIMUM POWER FOR EACH TYPE OF DG

Type	Equivalent number of working hours with maximum power
Small HPP	3.000
PV	1.200
Biogas	5.000
Biomass	4.000
CHP	1.000

DISPERSED GENERATION SHARE IN ELECTRICAL POWER BALANCE

Electrical power balance is usually developed for the hour of power system maximum load (P_{max}) appearance in one year period. However, balances can be also developed for some other specific days and hours for specific analysis (third Wednesday in the month at 7.00 PM, summer maximum, minimum load of power system etc.).
For the process of developing power balance at specific analyzed moment, it is necessary to collect following data:

- Power output of each thermal, hydro and wind power plant connected on transmission network at specific analyzed moment ($P_{\text{TPP},i}$), ($P_{\text{HPP},i}$) и ($P_{\text{WPP},i}$)
- Power exchange with neighbouring power systems (import/export) (P_{exchange}),
- Net power of each power substation 110/x kV that supplies distribution network at analyzed moment, without power output of DG conneted on distribution network at analyzed moment (P_i),
- Power of each power substation 110/x kV that supplies consumers connected directly on transmission network at analyzed moment ($P_{\text{D}i}$),
- Power losses in transmission network ($P_{\text{losses\_T}}$).

According to the fact that maximum load on transmission network level is equal to maximum load on power system level reduced for hourly generation of DG connected on distribution network in the hour of maximum load appearance, new magnitude is introduced, which is called availability of generation.
Availability of generation in % is expressed as average ratio between total hourly generation of all power plants of one type (small hydro, photovoltaic, biogas, biomass and cogeneration) at analyzed hour of maximum load appearance and total installed capacity of that type of power plants at analyzed year.

$$\text{availability\_generation}_{\text{small\_HPP},j}(t) = \frac{P_{\text{small\_HPP},j}(t)[MWh/h]}{P_{\text{small\_HPP}}(t)[MW]} * 100\% \;. \quad (20)$$

$$\text{availability\_generation}_{\text{PV},j}(t) = \frac{P_{\text{PV},j}(t)[MWh/h]}{P_{\text{PV}}(t)[MW]} * 100\% \;. \quad (21)$$

$$\text{availability\_generation}_{\text{biogas},j}(t) = \frac{P_{\text{biogas},j}(t)[MWh/h]}{P_{\text{biogas}}(t)[MW]} * 100\% \;. \quad (22)$$

$$\text{availability\_generation}_{\text{biomass},j}(t) = \frac{P_{\text{biomass},j}(t)[MWh/h]}{P_{\text{biomass}}(t)[MW]} * 100\% \;. \quad (23)$$

$$\text{availability\_generation}_{\text{CHP},j}(t) = \frac{P_{\text{CHP},j}(t)[MWh/h]}{P_{\text{CHP}}(t)[MW]} * 100\% \;. \quad (24)$$

Where: $P_{\text{small\_HPP},j}(t), P_{\text{PV},j}(t), P_{\text{biogas},j}(t), P_{\text{biomass},j}(t)$ and $P_{\text{CHP},j}(t)$ are hourly generation (MWh/h) of all small hydro, photovoltaic, biogas, biomass and cogeneration power plants connected on distribution network at the hour j of power system maximum load appearance at analyzed year t, respectively.
Because hourly commitment of each type of DG connected on distribution network at analyzed hours can be significantly different in the analyzed years, it is necessary to calculate the average value of availability of generation in the past period (for example 5-years period). This average value of availability of generation is used as a base for estimation of each type of DG commitment at the analyzed hour j of maximum load appearance.

$$\overline{\text{availability\_generation}_{\text{small\_HPP},j}} = \frac{\sum_{j=1}^{N} \text{availability\_generation}_{\text{small\_HPP},j}(t-j)}{N}. \quad (25)$$

$$\overline{\text{availability\_generation}_{\text{PV},j}} = \frac{\sum_{j=1}^{N} \text{availability\_generation}_{\text{PV},j}(t-j)}{N}. \quad (26)$$

$$\overline{\text{availability\_generation}_{\text{biogas},j}} = \frac{\sum_{j=1}^{N} \text{availability\_generation}_{\text{biogas},j}(t-j)}{N}. \quad (27)$$

$$\overline{\text{availability\_generation}_{\text{biomass},j}} = \frac{\sum_{j=1}^{N} \text{availability\_generation}_{\text{biomass},j}(t-j)}{N}. \quad (28)$$

$$\overline{\text{availability\_generation}_{\text{CHP},j}} = \frac{\sum_{j=1}^{N} \text{availability\_generation}_{\text{CHP},j}(t-j)}{N}. \quad (29)$$

Total hourly commitment (generation) of all types of DG connected on distribution networks at the hour j of maximum load appearance at year t, is equal to:

$$P_{\text{distribution},j}(t) = \overline{\text{availability\_generation}_{\text{small\_HPP},j}} * P_{\text{small\_HPP}}(t) + \\ + \overline{\text{availability\_generation}_{\text{PV},j}} * P_{\text{PV}}(t) + \overline{\text{availability\_generation}_{\text{biogas},j}} * P_{\text{biogas}}(t) + \\ \overline{\text{availability\_generation}_{\text{biomass},j}} * P_{\text{biomass}}(t) + \overline{\text{availability\_generation}_{\text{CHP},j}} * P_{\text{CHP}}(t) \quad (30)$$

Table 2 summirizes typical values of availability of generation for each type of DG connected on distribution network. However this values should be exactly calculated for each type of DG by continous following the generation of DG at the hour of power system maximum load appearance.

TABLE 2 - TYPICAL VALUES OF AVAILABILITY OF GENERATION FOR DG TYPES AT THE HOUR OF POWER SYSTEM MAXIMUM LOAD APPEARANCE

Type	Availability of generation
Small HPP	10%
PV	0%
Biogas	50%
Biomass	50%
CHP	20%

CONCLUSION

This paper has presented one algorithm for calculation of DG share in electrical power and energy balance in power system. Namely, presented algorithm is one deterministic way of yearly electricity generation forecast of each type of DG. Two basic quantities were used for calculation of DG share in power and energy balance. Equivalent number of working hours with maximum power is used for energy balance, while for power balance availability of generation is used for each power plant in DG category. The calculation procedure and typical values of these two quantities were presented in the paper for each power plant in DG category.
Electrical power balance is usually developed for the hour of power system maximum load appearance in a system in one year period. According to the fact that maximum load on transmission network level is equal to maximum load on power system level reduced for hourly generation of DG connected on distribution network in the hour of maximum load appearance, new magnitude is introduced in the paper, called availability of generation. Availability of generation has a substantial role in calculation of DG electricity production on distribution network level at analyzed hour.

LITERATURE

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