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Autonomous WPP/HPP power system operating modes study☆

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ABSTRACT

Today, there are centralized and decentralized energy supply areas world-wide. Centralized energy supply is provided by united energy grids which cover most habitable areas; they incorporate several types of power sources with centralized control system. Decentralized energy supply areas cover territories disconnected from power grid, and they incorporate only one type of power source.

Autonomous diesel power plants (DPP) are nowadays used mainly to power decentralized consumers and consumer groups. DPP basic disadvantages are power production high cost, diesel fuel nonregenerability, greenhouse gas emission and environmental pollution. The possibility of power supply by autonomous power systems combining wind power plants (WPP) and hydro power plants (HPP) as alternative to diesel generation due to hydraulic energy storage advantages has been considered.

Autonomous WPP/HPP power system is a combination of WPP, HPP with water-storage reservoir, automatic control system and switchgear, combined by power, infrastructural and data connections. Hydrogen energy storage is considered to be the second energy storage.

HPP water-storage reservoir parametrization procedure considering operating specificity of HPP and WPP as a part of power system with hydraulic and hydrogen energy storage has been suggested. Mathematical models for operating modes of WPP, HPP and storage reservoir have been developed, which consider resources, technical and technological features of their performance in decentralized power supply system. Technique for determining storage reservoir backup volume with allowance for wind conditions parameters, WPP features and storage reservoir configuration have been suggested. Method of day-ahead WPP power calculation in solving problem of operational planning of power system operating modes has been suggested. Simulation of WPP/HPP power system operating modes with seasonal-storage reservoir and hydrogen energy storage have been carried out.

The suggested techniques could be used for solving design problems to substantiate decentralized power supply system parameters in remote and isolated areas, as well as for evaluating energy efficiency of replacing the existent decentralized power supply systems on the basis of DPP using imported diesel fuel by environmentally safe systems on the basis of local energy resource – wind energy and hydraulic energy. The suggested techniques are also focused on solving problem of power system operating modes for operational planning.

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Nomenclature

ACS	Automatic control system
DPP	Diesel power plant
HPP	Hydro power plant
HU	Hydraulic unit
SPP	Solar power plant
SWGR	Switchgear
WPP	Wind power plant

Greek letters

η	Hydraulic unit efficiency
φ	WPP energy loss factor due to wind turbines interaction

Superscripts and subscripts

∇DSL	Dead-storage level
E_{HPP}	HPP output
E_{WPP}	WPP output
$E_{WPP-HPP}$	WPP/HPP power system output
ΔE	Energy excess
G	Water supply path geometry
H	HPP head
H_0	HPP static head
ΔH	Head loss
i	Predicted hour
k	Design day
m	Number of HPP units
n	Number of wind turbines incorporated at WPP
N_{HU}	Hydraulic unit capacity
N_{HPP}	HPP capacity
N_{WPP}	Wind power plant capacity
N_{WT}	Wind turbine capacity
N_{WPP_FIRM}	WPP firm power
∇NPL	Normal pool level
P	Consumer load
Q	River flow
Q_{DW}	Discharge at downstream
Q_{HU}	Hydraulic unit discharge
Q_{ID}	HPP idle discharge
Q_{OD}	Other water discharge at downstream (filtration, lockage, discharges through fish-ladders etc.)
u	Wind speed
V	Storage reservoir volume
V_{ACT}	Active storage capacity
V_{BACKUP}	Backup storage volume
V_{INACT}	Inactive storage capacity
V_{TOT}	Total storage capacity
V_{RES}	Residual storage volume
Z_{DW}	Downstream level
Z_{HW}	Head water level

Introduction

Today, there are centralized and decentralized energy supply areas world-wide. Centralized energy supply is provided by united energy grids which cover most habitable areas; they incorporate several types of power sources with centralized control system. Decentralized energy supply areas cover territories disconnected from power grid, and they incorporate only one type of power source.

Autonomous diesel power plants (DPP) are used mainly to power decentralized consumers and consumer groups nowadays [1–4]. Hybrid power systems combining diesel-gensets and renewable energy systems (wind–diesel power plants (WPP/DPP), solar–diesel power plants (SPP/DPP), combinations of DPP with mini- and micro-hydro power plants (mini- and micro- HPP/DPP)) are also widely used. Decentralized DPP energy supply area map is shown in Fig. 1. More than 65% of Russian territory with population of more than 15 million is considered to be decentralized energy supply areas [3]. Global installed capacity of autonomous generating units with DPP is about 20 GW with annual output of about 110 TW*h [1], while unit capacity of autonomous generating units could vary within the range from 1 to 5 kW up to 15–18 kW in relation to consumer type [3].

DPP basic disadvantages are power production high cost (0.25–2€/kW*h [5]), diesel fuel nonregenerability, greenhouse gas emission and environmental pollution. Hybrid power systems combining WPP with hydrogen and hydraulic energy storage could be considered as alternative to DPP in areas with sufficient wind potential power. Comparative analysis of renewable energy storage systems shows that hydrogen energy storage efficiency could be 23–25% [6,7], while hydraulic energy storage efficiency could be 92–95% [3,6]. Hydrostorage high efficiency is achieved due to the lack of double energy conversion. Problems of hydraulic energy storage in HPP water-storage reservoir are discussed in Refs. [4,8–16]. Problems of hydrogen energy storage are discussed in Refs. [6,17,18]. The possibility of power supply by autonomous power systems combining WPP and HPP as alternative to diesel generation has been considered; water-storage reservoir is the first energy storage and hydrogen energy storage is the second energy storage.

Mathematical model of Wpp/Hpp power system operating modes

Autonomous WPP/HPP power system is a combination of WPP, HPP with water-storage reservoir, automatic control system (ACS) and switchgear (SWGR), combined by power, infrastructural and data connections. Hydrogen energy storage is considered to be the second energy storage. Power system components are arranged close to each other and to power consumer as a matter of serviceability and efficiency upgrading. WPP/HPP combined operation scheme as a part of autonomous power system is shown in Fig. 2.

If annual load curve is supplied only by HPP, then $V_{ACT[1]}$ water-storage reservoir useful volume should be $\nabla NPL_{[1]}$. If second power source operating at $N = const$ during a day is incorporated, then $V_{ACT[2]}$ water-storage reservoir useful volume of $\nabla NPL_{[2]}$ would be sufficient to supply annual load curve. In case WPP is used as a second power source, then wind speed and wind direction fluctuate in space and time stochastically, thus wind turbine operating mode and WPP power generation have probabilistic nature. In order to

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