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Exploitation of temporary water flow by hybrid PV-hydroelectric plant

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ABSTRACT

The paper presents a new type of Renewable Energy Sources (RES) suitable for exploitation watercourse with periodical-temporary water flow. This innovative solution consist of Hydroelectric Plant (HEP) and solar Photovoltaic (PV) generator working together as one hybrid power plant, producing green energy with the same characteristics as classical hydroelectric plants. The main objective of this hybrid solution is achievement of optimal renewable energy production in order to increase the share of RES in an Electricity Power System (EPS). As a paradigm of such exploitation of RES, the example of HEP Zavrelje/Dubrovnik in Croatia was used, where it was ascertained that the proposed solution of hybrid PV-HEP system is natural, realistic and very acceptable, which enhances the characteristics of both energy sources. The application of such hybrid systems would increase the share of high quality RES in energy systems.

1. Introduction

In order to reduce air pollution due to CO_2 emission from energy sector, European Union (EU) foresees up to 20% of Renewable Energy Sources (RES) in covering total energy consumption by the year 2020 [1]. The predicted share of RES in production of electric energy only is 33.8%. On the other hand, the AIP scenario of EREC forecast of Renewable Energy Scenario by 2040 [2], foresees 82% of RES in total production of electric energy. The construction of large energy capacities based on renewable energy sources will be required in order to achieve these objectives. However, the problem of exploitation of RES lies in the fact that, unlike the conventional sources and hydro energy, renewable energy sources cannot guarantee safe and continuous electric energy supply to consumers. Inherent characteristics of major renewable energy based electricity generation systems based on wind and solar energy are intermittency and non-controllability [3]. Therefore, although the annual energy balance can contain sufficient energy from RES for full covering of energy consumption, RES cannot continuously provide electric power to consumers with sufficient reliability [4].

Obviously, considerable effort will be required to achieve EU objectives with conventional and innovative solutions of RES. One of the promising innovative solutions presented in this paper is exploitation of periodical water flows, i.e. hydro energy potentials combined with Solar Energy (SE). SE has no possibilities of continuous production, as it depends exclusively on daily solar radiation. That is why solar energy has to be stored in order to be available constantly. On the other hand, hydro energy can be produced continuously if there are suitable water resources. Water can be stored easily, thus providing continuous production of energy. That is why the promising solution of the problem is the use of pump storages as Electric Energy Storage (EES) for SE production. Pump storage is a mature technology with large volume, long storage period, high efficiency and reliability, while capital cost per unit of energy is low [5–7].

Climate and hydrological conditions in the Mediterranean part of Croatia, as well as in areas with similar climate, create watercourses which have high flow in rainy winter periods and dry out or have significantly lower flow in dry periods, Fig. 1(a) [8]. Evidently, exploitation of water flow for energy production only in winter period is generally possible, but there is the question of its cost effectiveness and acceptability of seasonal energy production for an Electric Power System (EPS). On the other hand, in Fig. 1(b) it can be seen that the distribution of solar energy (measurement from 2004 to 2008; Pyranometer, Kipp & Zonen, CM 11, [9]) at the same location is fully compatible and replenished with energy from seasonal watercourse.

The exploitation of such hydro energy resources has traditionally been exploited by constructing seasonal reservoirs [10]. Unfortunately, on pronouncedly karstic hydro geological terrain, as in Croatian Mediterranean river basin, as well as many other locations, the construction of large reservoirs is generally very difficult and an

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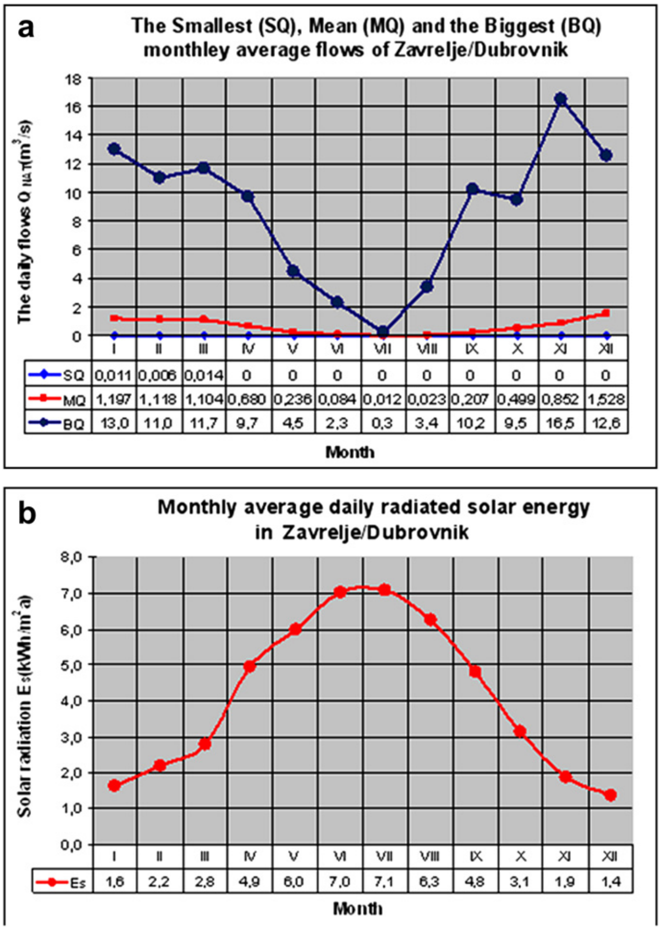

Fig. 1. Hybrid concept with main input resources: (a) Monthly average daily flows (m^3/s) of the Zavrelje spring [5] and (b) solar radiation at location Zavrelje/Dubrovnik, Croatia [6].

ecologically sensitive issue. Unlike large reservoirs, the smaller ones are more frequently built, mostly for irrigation purposes.

The promising solution is implementation of Solar Hydroelectric Plant (SHE) in dry periods [11,12], and conventional hydroelectric plants in winter period. This is a hybrid concept where HEP and PV generator continuously operate together as a unique energy production unit-system, Fig. 2. Storage volume depends on the period of flow balancing and production of hydro energy. Therefore, the hybrid system will have minimum volume of storage for the case of daily balancing. Any longer period of balancing (per week, seasonally, annually) provides a safer and better power supply but requires a greater storage volume.

The SHE concept is similar to pump storage hydroelectric plant with two pipes between lower and upper storage. Such concept of SHE with two pipes provides continuous energy production regardless the natural water flow into the headwater pool.

The main objective of building this hybrid energy system (SHE = PV + HEP) should be maximization of reliable renewable energy production and therefore satisfying the European Union (EU) requirements [1]. Equal objectives are sought through various combinations of RES and hydro power plant operation [13,14].

The price of energy of the proposed hybrid system would be competitive in relation to other RES (wind, solar, geothermal, etc.). The bigger the flow and the longer the duration of flow of seasonal watercourse into upper pool, the more cost effective is the system.

This paper explains and analyses this new concept of exploitation of solar and hydro energy based on periodical water flow.

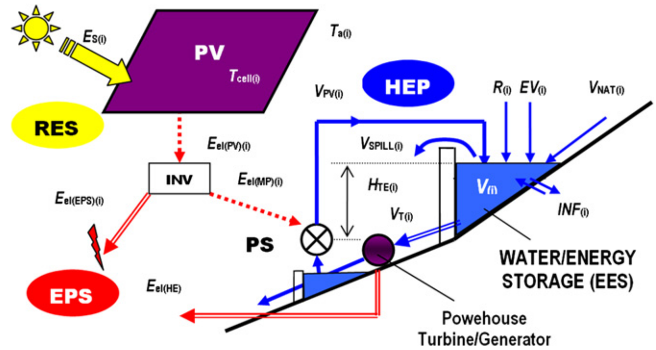

Fig. 2. Operation concept of hybrid solar hydroelectric plant (PV-HEP).

2. Hybrid operation PV-HEP on the rivers with extreme seasonal flow

2.1. Basic settings and relations

The basis of the hybrid solar hydroelectric plant (PV-HEP) operation lies in transformation of solar energy SE (Wh) into hydro energy, i.e. water volume V (m^3) serving as new inflow V_{HE} (m^3) for production of hydro energy E_{HE} (Wh) in the hydroelectric plant, Fig. 2:

$$SE(\mathrm{Wh}) \rightarrow V_{PV}(\mathrm{m}^3) \rightarrow V_{HE}(\mathrm{m}^3) \rightarrow E_{HE}(\mathrm{Wh}) = f(V_{HE}, H_n) \tag{1}$$

Upper storage is the main functional element of the hybrid system. Therefore, the cognition of the state and its processes is necessary for problem solution. State equation of HEP upper storage is:

$$V_{(i)} = V_{(i-1)} + V_{PV(i)} + V_{NAT(i)} + R_{(i)} - EV_{(i)} - V_{T(i)} \pm INF_{(i)} - V_{SPILL(i)} \tag{2}$$

Subject to:

$$V_{\mathrm{MIN}} \le V_{(i)} \le V_{\mathrm{MAX}} \tag{3}$$

where increment i assumes the values $i = 1$ to N (N is the total number of time stages, e.g. days or hours); V_{MAx} and V_{MIN} constraint of storage filling-level at a certain period during the year, which is the result of requirements related to the planned operation of HEP (flood protection, environmental constrains etc.); $V_{(i-1)}$ and $V_{(i)}$ are reservoir volumes in (i-1) and i period respectively; $V_{PV(i)}$ is water pumped by the PV generator in i period; $R_{(i)}$ is total precipitation coming into the reservoir in i period; $V_{NAT(i)}$ is natural flow from the adjacent watershed in i period; $EV_{(i)}$ is water from reservoir consumed by evaporation in i period (m^3); $V_{T(i)}$ is water discharged from the HEP in i period; $INF_{(i)}$ is infiltration or seepage in i period; $V_{SPILL(i)}$ is water discharge from bottom orifice or spill in i period, H_n is net available drop.

Transformation of SE into $V_{PV(i)}$, $V_{PV(i)}$ into V_{HE}, and V_{HE} into E_{HE} is realized in a number of stages-processes where one part of initial solar energy is lost, Fig. 2. In the PV generator SE is first transformed into electrical energy, required for motor/pump operation which pumps water V_{PV} into storage of HEP. Pump volume $V_{PV(i)}$ (m^3) in a certain period (in stage i) of PV generator operation creates new water flow in the storage, i.e. water volume V_{el} in total period T used for production of energy in the HEP:

$$V_{el} = \sum_{i=1}^{T} V_{PV(i)} \tag{4}$$