Integrating photovoltaics into energy systems by using a run-off-river power plant with pondage to smooth energy exchange with the power grid

Jakub Jurasz a,⇑, Bartłomiej Ciapała b

a AGH University of Science and Technology, Faculty of Management, ul. Gramatyka 10, 30-067 Kraków, Poland
b AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Al. Mickiewicza 30, 30-059 Kraków, Poland

HIGHLIGHTS

• A novel MINLP model was developed for PV–ROR hybrid optimization & optimization.
• A ROR power plant with pondage eases integration of PV sources to the grid.
• The PV-ROR smooths energy exchange with power grid and increases RES share.
• Appropriate operation of ROR increases PV based energy source reliability.

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ABSTRACT

In order to slow climate change, economies need to quickly move away from finite energy sources and towards using low-carbon energy systems. However, the integration of non-dispatchable wind and solar sources comes with additional costs and can make the energy market unusual and unpredictable. Specifically, the presence of variable renewable energy sources makes it harder to accurately forecast energy demand. This paper is a first step in presenting a novel approach to overcoming the inherent variability of photovoltaics (PV) by combining them with a run-off-river (ROR) power plant. A mixed integer mathematical model has been developed and applied to simulate the operation of a PV–ROR hybrid energy source coupled with the national power system. Simulations demonstrate various configurations of parameters and their impact on the objective function which was to maximize the volume of energy from PV and hydropower used to cover energy demand, while ensuring that neither energy deficits nor energy surpluses exceed 5% of energy demand. Our analysis indicates that an ROR power plant with relatively small pondage is capable of subsidizing the varying energy output of the PV system. Besides conducting a simulation and optimization, this paper suggests an approach to smoothing the energy exchange with the grid based on fixed volumes of energy which should be delivered during daylight and nighttime hours.

1. Introduction

The world is heading towards a period of changes on a hitherto incomparable scale, most likely including a transition from fossil-based and non-renewable fuels to renewable, sustainable energy [1,2]. Renewability is quite a clear and strict criterion, while, conversely, sustainability is wide in scope, especially in energetics. On the one hand, sustainability requires that all stakeholders be treated fairly, that a reliable energy supply [3] be provided for society, and that reasonable use be made of non-renewable natural resources. On the other hand, renewable energy sources (RES) also have significant potential to decrease emissions and improve air quality [4]. As already mentioned, reliability is a very important criterion in energy systems, being the ability to provide both the required amount of power and the ability to ensure that the power conforms to a certain set of parameters, such as proper frequency and voltage, a safe level of reactive power, and so on [5], in the face of inconstant (but predictable) demand [6]. Additionally, it is impossible to control the abundant primary sources of renewable energy (such as wind, solar radiation, or wave power) [7], while only limited power is available from those which are easily...
The energy demand curve (e.g. demand-side management [10]) is difficult; demand varies not only within a single day, but also on a weekly and annual basis. The most commonly proposed way to modify the demand curve is by applying smart grids with modern controllers which automatically initiate certain household activities when energy demand decreases (e.g. switching on laundry machines or dishwashers overnight). Although it may seem simple, the efficient use of smart grid networks requires significant investment, both on the provider and the customer side, making it a difficult solution to apply in practice.

Since the potential to smooth the demand curve is extremely limited, power generation may be limited by having potentially to be shut down when the grid cannot accommodate increased power generation. This leads to the conclusion that RES needs be integrated into the grid in such a way as to provide stable energy generation.

There are a handful of solutions that might limit fluctuations in power generation. The first, energy storage, is already widespread. Because the most abundant [8] and widely-usable RES generate significantly variable power, connecting too many such energy sources to the grid may make it difficult to maintain proper energy quality, and this cannot be ignored [9]. So far, energy systems have been simple to maintain and organize because the power generation of conventional energy sources is easily controlled and predictable, and energy demand is also predictable. The problem of adapting to a system in which there are floating levels not only of demand, but also of energy generation, is very complex, especially assuming that power quality must be maintained. The problem is multi-faceted, with ecological, economical and production engineering aspects in particular. A rapid transition from traditional energetics to an RES-based power system is therefore practically impossible, so the current scientific literature focuses on easing the integration of RES into the power system.

Smoothing the energy demand curve is extremely limited, power generation must be made more predictable and controllable. However, international and state strategies which often involve increasing the amount of power generated by RES only make power generation less stable. These RESs include non-dispatchable sources of electricity whose power generation may be limited by having potentially to be shut down when the grid cannot accommodate increased power generation. This leads to the conclusion that RES needs be integrated into the grid in such a way as to provide stable energy generation.

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