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Optimum autonomous photovoltaic solution for the Greek islands on the basis of energy pay-back analysis

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ABSTRACT

Although autonomous photovoltaic (PV) systems are identified as renewable energy technologies able to satisfy the electrification needs of remote consumers, they are strongly accused of their life-cycle energy requirements. To support the specific systems' sustainable character one should be able to ensure minimum period of energy pay-back. In this context, an optimum sizing methodology is developed for stand-alone PV-battery systems in order to obtain configurations of minimum energy content. The proposed methodology is applied to three representative islands across the Greek territory and the results obtained are favourably compared with the up to now – commonly used – diesel-electric generator solution.

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1. Introduction

According to the Amsterdam Treaty, declaration No. 30 [1], "... insular regions suffer from structural handicaps linked to their island status, the permanence of which impairs their economic and social development". In this context, one may encounter serious electrification problems in many island areas [2], where the poor infrastructure of local electricity grids does not allow grid-connection for several remote consumers. To face their electrification needs, remote consumers are obliged to rely on the operation of small diesel engines consuming considerable amounts of oil, requiring frequent maintenance and presenting a short period of service.

Acknowledging that the development of remote communities is strongly dependent on their energy status, the principles of security of supply, competitiveness and environmental sustainability [3] should be conserved. To conserve these principles, the support and promotion of renewable energy technologies is necessary [4]. By exploiting indigenous, renewable energy sources (RES), greater levels of energy autonomy may be achieved at a competitive cost, eliminating also the dependence on oil imports and designating

environmentally sustainable solutions that may allow the local communities' development (contrariwise to those based on oil-based electricity generation, responsible for extremely high production costs and considerable atmospheric pollution).

More specifically, in areas with high local solar potential, the use of photovoltaic (PV) systems introduces a financially attractive electrification solution [5–7] (even at the micro-level [8]), identified by inconsiderable maintenance requirements, minimum environmental pollution during operation, and continuous technological development [9,10]. In this context, PV stand-alone systems, like PV-battery (PV-Bat) configurations, may satisfy the electricity needs of several remote consumers, even providing 100% energy autonomy. On the other hand, PV-based configurations are strongly accused of extreme life-cycle (LC) energy requirements. In this context, although one may encounter several research works with regards to the energy life-cycle assessment (LCA) of grid-connected systems [11–14], no profound research has been carried out for PV stand-alone systems, including also the energy content of the battery component.

For similar systems to be designated as environmentally sustainable as well, one must ensure minimum period of energy pay-back (EPBP), i.e. establish that their LC energy requirements are fairly compensated by the corresponding energy generation. For this purpose, an optimum sizing methodology for stand-alone PV-Bat systems is currently developed in order to obtain configurations

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Symbols N _{max} peak load demand of the remote consumer (kW h) paak load demand of the remote consumer (kW maximum power output of a single PV panel (v maximum power output of the PV array (kV pare) (kV pare) CF capacity factor of the PV generator N _{PV} peak peak power output of the PV array (kV pare) DOD battery system instantaneous depth of discharge battery system maximum depth of discharge energy content of the BOS components (kW h) Q battery system instantaneous capacity (A h) service period of the installation (years) battery system instantaneous capacity (A h) destrey system instantaneous capacity (A h) battery system instantaneous capacity (A h) destrey system instantaneous capacity (A h) battery system one control of the battery system (kW h) battery system one control of the battery system (kW h) battery system one control of the pare criterion (A h) battery system one control of the pare criterion (A h) battery system maximum capacity (A h) battery system minimum permitted capacity (A h) battery system minimum permitted capacity (A h) battery system minimum permitted capacity (A h) bat	tion
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E_{tot} total energy content of the PV-Bat system (kW h) θ ambient temperature (°C)	
$E_{\rm y}$ annual useful energy production of the system (kW h) ξ part of M&O energy needs covered by the PV en	rgy
G solar radiation at horizontal plane (W/m ²) surplus	
I electrical current of the PV module (A)	
k_{cc} energy content coefficient for the charge controller Abbreviations	
(kW h/kW) BOS balance of system	
k_{dies} energy content coefficient for the diesel engine (kW h/ EPBP energy pay-back period	
kW) LC life-cycle	
k _{INV} energy content coefficient for the inverter (kW h/kW) LCA life-cycle assessment	
m _{bat} mass of batteries (kg) M&O maintenance and operation	
n _{bat} service period of batteries (years) mc-Si multi-crystalline silicon N _{CC} rated power of the charge controller (kW) PbA lead-acid	
N _D instantaneous power demand of the remote consumer PV-Bat photovoltaic-battery (kW) PV-ESS photovoltaic-energy storage system	
N _d nominal power of the diesel generator (kW) RES renewable energy sources	
Till Homman power of the dieser generator (KWV) KES Tellewable effergy sources	

of minimum energy content that also ensure 100% energy autonomy for the remote consumer each time examined.

Considering the high solar potential of most Greek territories [15] and the poor electricity network infrastructure met in many islands of the country, an integrated study is conducted for three representative island areas, based on long-term solar potential experimental measurements. The corresponding locations suggest high, medium-high and medium solar potential areas, thus allowing for

the variation of the local solar potential and the production of different results that are favourably compared with the up to now – commonly used – diesel-electric generator solution.

2. Proposed stand-alone energy solution

In order to face the urgent electrification problems of the numerous remote consumers in areas with remarkable solar

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