Back-up powering of a communication educational lab utilizing Photovoltaics

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ABSTRACT

The incident solar radiation in Greece coupled with Photovoltaics (PV) present a possible solution to specific electrical powering issues as well as the supplying of the energy demands in most communication applications. In this paper, we present the sizing details for an end-use application of the PV technology, i.e. supplying the basic electrical power needs of a communication educational laboratory or the powering of an educational laboratory during an electrical black-out. The object is the analysis of a PV system suitable for back-up powering of a communication educational lab. In this frame, we studied the electrical demands of a technological laboratory at the Electronics Department of TEI of Piraeus, and specified the necessary sizing of a PV system, comprising of an inverter, a researchable battery and a PV generator supplied with a maximum power point tracker (MPPT). Further more we tested the calculations in practice supplying the 1kW electrical power demand of the communication educational lab with a PV system using a 12VDC/230VAC inverter, coupled with a 12V/200Ah battery and a PV panel of 50Wp controlled by a MPPT with an efficiency of 93%.

1. INTRODUCTION

A possible application of a PV system may be the buck-up electrical powering of laboratory activities, when the electricity network is unstable with small duration blackouts.

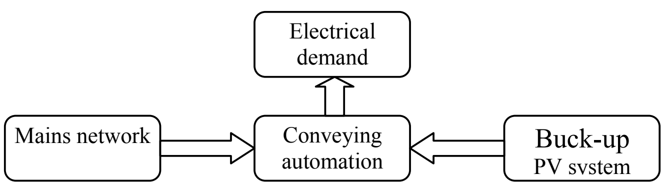

Figure 1. Schematic of a back-up powering system.

As far as the electrical power from a PV fulfils the power needs, a PV system maximizes the quality of services of a communication educational lab, avoiding the use of a combustible electrical generator. Simultaneously it can assist towards the main targets, as are: avoiding the audio noise of a fuel or wind generator, the reduction of the greenhouse gases, the increasing use of renewable energy sources and finally the energy efficiency increasing. A major factor in choosing a PV system instead of a typical electricity buck-up system, is the local sunshine duration as well as the overall cost.

Table 1. Pros and Cons of different electricity producing energy sources

Energy Source	Energy Cost	Energy storage	Supervision	Maintenance	Major disadvantages
Liquid fuels	Significant	Unnecessary	Possibly necessary	scarse simple	Fuel storage safety issues, transport costs and transport safety
Gas fuel	Able	Unnecessary	Scarsely necessary	scarse specialized	Fuel storage safety issues and transport costs and transport safety
Wind	Zero	Necessary	Usually necessary	Frequent specialised	Noise , wind availability
Solar Radiation	Zero	Necessary	Unnecessary	Scarse simple	Batteries needed to ensure autonomy

The table 1 sums up the operational characteristics of major energy sources for communication. This round up implies that a PV generator is advantageous in its own as well as in conjunction with other energy sources, as long as a detailed study for the application and the subsystems is made. Duration of electricity blackouts and the energy demand that the PV system supplies, determine the autonomy (number of cloudy days) for the demanding load; the capacity of the storage media (batteries) and finally the coupling methodology with the mains network. Solar irradiation in Greece is significant, allowing for various comparisons concerning the finances of installation and operation of different electricity production systems. The parameters concerning the technical and financial comparison of the proposed systems constitute a non-standard decision process, making each installation a different case study.

2. SOLAR RADIATION AND PHOTOVOLTAIC GENERATORS

Power density S_l of solar irradiation on earth surface, derives from the solar irradiation at the atmosphere boundary, and depends on air mass [1] etc. During solar noon, in Greece latitudes, S_l has a value of 934W/m^2, accruing to 69,1% of the solar constant So=1353W/m^2 (amount of solar radiation incoming the Earth's atmosphere). The daily solar irradiance Ei delivered at a PV array derives from the direct and the diffuse solar irradiance [2]. Mean values of Ei depend on geographic and climatic factors, thus requiring long term measurements.

Table 2 presents the daily solar irradiation Ed incoming in the atmosphere, for the wavelengths that the PV generators usually operate, as a function of geographical latitude only (minus all other factors concerning the delivered irradiation). These estimations and our relevant measurements allow us to expect for December in Greece, daily solar irradiation amounts between 2.94 kWh/m^2 up to 4.64 kWh/m^2. The daily solar radiation amount maximizes in June ranging between 11.43 kWh/m^2 to 11.48 kWh/m^2

Table 2. Total daily solar radiation E_d (kWh/m^2) incoming at the atmosphere (mean daily values every month)

Latitude	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
35°	5,01	6,41	8,11	9,86	10,98	11,43	11,19	10,27	8,71	6,89	5,36	4,64
40°	4,18	5,64	7,51	9,53	10,90	11,48	11,19	10,05	8,21	6,18	4,54	3,79
45°	3,33	4,85	6,86	9,13	10,76	11,48	11,13	9,76	7,64	5,43	3,71	2,94

The daily energy balance allows for relevant calculations. The delivered power Pi at the surface A of a PV generator in Greece, at noon on a clear day, is approximated by $Si = P_i/A \cong 934{,}3W/m^2$. Pi is reduced during the remaining hours of the day, due to air mass variations, local diffusion, clouds, etc.

The PV generator elements are semiconductors with a spectral responsivity ranging from 0.1 to 0.3 A/W or performance of a=6-24%. In Si semiconductors, peak value output is 0.7V/element and maximum performance $a=\Phi_r.(0{,}7Volts)=0{,}21$. The electrical power produced, is derived as current I_L and voltage U_L for a given resistance load R_L. The P-V plots (figure 2) [3] shows that with a small resistance load R_L the PV is a current source, whilst with a big resistance load a voltage source.

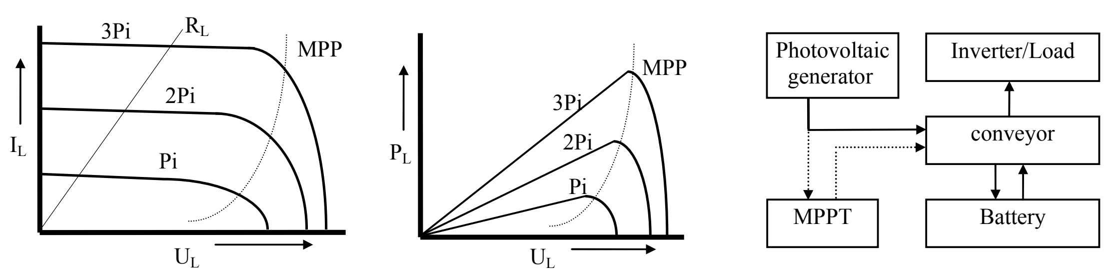

Figure 2. Power as a function of voltage and the schematic of a Photovoltaic system

The corresponding P-V curves show that, during different insolation, the variation of the voltage locus, of the Maximum Power Point (MPP). If Rd is the dynamic resistance of the PV element at the MPP, the following relation applies

$$\left.\frac{dP_L}{dU_L}\right|_{MPP} = 0 \qquad \Rightarrow \qquad R_L = \frac{U_L}{I_L} = \left|\frac{dU_L}{dI_L}\right| \equiv \left.|R_d|\right|_{MPP} \tag{1}$$

The equation is still valid when the PV elements, regardless of their connectivity, constitute a generator. Given that the load is rarely purely ohmic, a MPP sensor (MPP Trucker, MPPT) is useful [5], which can continuously convey the load or/and the battery (figure 2), so that the PV generator will continuously operate at the MPP locus.

3. THE ENERGY EQUILIBRIUM

The electrical power in a communications lab is used to powering of some test equipments, of some computers, of some electromagnetic field meters, of some transmitters, receivers and transceivers and finally of some radiofrequency amplifiers. If all the hardware is powered through batteries and in extreme cases through batteries/inverters, then during the mains black–outs the hardware is powered by its own stored energy and the general buck-up power covering from the PV is minimised. That strategy we apply to the Radio-TV lab in order to keep the general buck-up powering from the PV as low as possible and always under the 0.6KWh for a 2 hours period.

An autonomous PV generator, which daily accepts Ed (Wh/m^2), must ensure that the demand consumes an equivalent amount of energy. Thus, mean power of P_{av} for H_L hours per day, should be consumed, or $W_L = H_L \cdot Pav$. Supposing the PV array has an area factor coverage equipped with PV elements of b=60~100% and performance a, then the electrical loss coefficient is c=5~15%, and the necessary area A of the generator, to supply the energy demand calculates:

$$A \geq \frac{1}{ab.E_d}.(1+c)W_L = \frac{1+c}{ab}.\frac{H_L.P_{av}}{E_d} \tag{2}$$

The array should face south and incline β degrees from the horizon, similar to the geographical latitude φ. The proper inclination depends on time of year, and ranges as we tested in the area of φ-15°<β<φ+15° (figure 3).

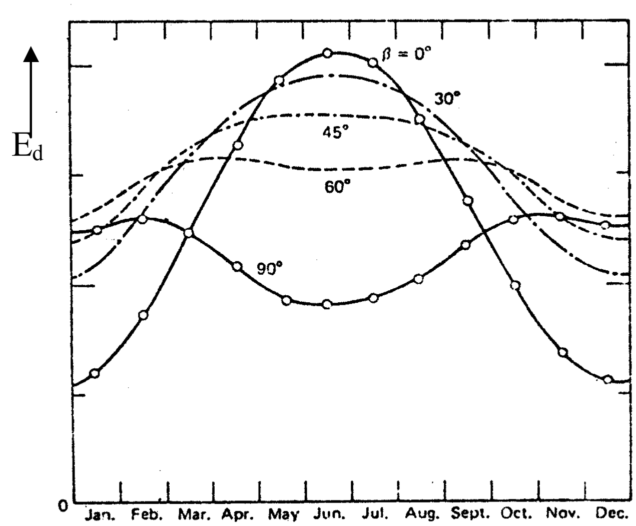

Figure 3. Energy received per square meter, for various inclinations, per month.

The values of the necessary surface A can be reduced up to 50%, by the use of a heliostat targeting the sun. If there is some concentration medium providing irradiation concentration Cv with a performance n, then A is reduced more to A=A/n·Cv.

Finally if an auxiliary energy source can provide the mean power Ps for Hs hours daily then A is calculated to:

$$A \geq \frac{1}{ab.E_d}.\left[(1+c).H_L.P_{av} - (1-c).P_s.H_s\right] \tag{3}$$

If the P_{mpp} value, of the Si, for a nominal radiation value of $1kW/m^2$ is the only given information for the PV generator, then the generators' energy is approximated with a general factor f, depending on the matching of the load to the Maximum Power Point curve, on the local irradiation variations from the calculated mean valued of Ed and on the inclination β of the PV array.

$$P_{MPP} = f.\frac{H_L}{24h}P_{av} \qquad 7 \leq f \leq 15 \tag{4}$$

4. ENERGY MANAGEMENT

Communications provides a broad area for PV applications, allowing not only the supply of its own demands but also the supply of energy in cases of mains power cuts. Thus it allows population to get in touch with the various alternative energy solutions the technology allows, as well as its application characteristics and to realize its advantages.

There are PV applications needless of energy storage, e.g. desalination, direct usage from an electric motor, etc., and applications where the electrical energy is converted to mechanical (compressor, pumping station, etc). When the load is a DC motor, then the PV should be chosen to comply with the impedance of the load. In communication applications an active approach comprising of a MPTT and a DC/DC converter should be utilised, to enhance performance. Alternatively a DC/AC inverter is used in the buck-up powering of a communications lab.

In the majority of the PV applications a battery is utilised to store electrical energy during production and supply the energy demand during buck-up powering. Connecting a battery parallel to the PV generator and the demanding load, constitutes a PV system of Si that supplies a voltage different than that in MPP, for irradiations other than the noon.

When the battery's nominal capacity C is reached, it should be detached from the PV source. Similarly the demand load should be detached from the battery, when the latter has less than 10-30% of its capacity left. Thus some automation is necessary. Given the demand load and the automation is provided with I_{rms} and consumes P_{av}, then capacity C for the battery under voltage, is calculated upon the number of repeated buck-up 2 hours periods D (with) which the demanding load will be supplied solely from the capacitor:

$$C \geq 1{,}25.H_L.D.I_{rms} = 1{,}25.H_L.D.\frac{P_{av}}{U_\sigma} \qquad (Ah) \tag{5}$$

Autonomy of the PV generator, its power storage, cooperation with auxiliary systems and the method of the DC/AC conversion in order to comply the powering with the mains, depend on the period of power outage; the autonomy period for cloudy weather; the type of the application, the power of the demanding load.

Pb batteries are characterised for considerable depths of discharge, significant electrolyte volume and big weight, and insignificant cost, pairing reasonably with the requirements of usual PV generators, as can be seen in Table 3.

Table 3. Batteries Characteristics	
Specific energy	25~35 Wh/Kg
Specific power	80~100 W/Kg
Energy density	70 Wh/L approximately
Depth of discharge	50~80 % της C
Imax(A) during charging-discharging	0,1~0,4 of capacitance C (Ah)
Self-discharging rate at normal temperature	3~4% monthly
Life expectancy	600~1200 cycles
Capacitance decrease due to aging	15~20% in a 5-year period max 50% in a 8 year period

Frequently nevertheless low cost batteries (such as the used at vehicles or boats costing approximately 100 €/kWh), with a nominal operational voltage of 12,6V and similar features are used.

5. RESULTS.

In table 4 results of our parametric calculations for an autonomous PV station in Greece, sized to supply a load such as a telemetry system in December, when the solar irradiation is lesser.

Table 4. Autonomous Photovoltaic supplies a demanding load of P_{av} for H_L hours in December ($0,08 \leq a \leq 0,12$, $0,7 \leq b \leq 0,9$, $0,05 \leq c \leq 0,1$, $7 \leq f \leq 15$, $\beta = \varphi + 15°$, 3times≤D≤14times)

Amount of mean power demand for powering the lab P_{av} (W)	Minimum PV array surface of hourly supply of P_{av} A/H_L (m^2/h)	Peak power supply for for hourly supply of P_{av} P_{MPP}/H_L (W_p/h)	Minimum capacity of a 12,6V capacitor for hourly supply C/H_L (Ah/h)
25	0,07~0,20	7,3~15,6	7,4~34,7
50	0,15~0,40	14,6~31,3	14,9~69,4
75	0,22~0,60	21,9~46,9	22,3~104,2
100	0,29~0,80	29,2~62,5	29,8~138,9
125	0,37~1,01	36,5~78,1	37,2~173,6
150	0,44~1,21	43,8~93,8	44,6~208,3
175	0,51~1,41	51,0~109,4	52,1~243,1
200	0,59~1,61	58,3~125,0	59,5~277,8

Thus, providing adequate energy amounts throughout the year. The significant deviations between the parametric results indicate that the PV system should be chosen after a special study, which demands exact knowledge of the load's mean power demand; of solar irradiation at the specific installation area; of the characteristics of the PV generator and the battery; and finally of the cost in comparison with other viable energy systems. In a case that some of the aforementioned parameters are unknown, then the decision includes a significant amount of uncertainty and more than one solution

The battery is necessary in all communication applications, to store energy during sunshine and provide the load during buck-up. The use of an auxiliary electrical generator reduces capacitance significantly as well as cost. Diesel oil with an energy capacitance of 12kWh/kg, used in a usual electrical generator, compared with a Pb battery which stores only 25~35Wh/kg, favours financially the use of the auxiliary system.

According to our practical experience of early successful applications [4,5] and using the table 4 results, two autonomous PV stations were installed and tested in powering of the Radio-TV Lab of TEI of Piraeus. Operational data confirmed the full coverage of the energy demands during winter, for up to three buck-ups autonomy of 2 hours periods.

6. CONCLUSIONS AND COMMENTS

An algorithm was developed for usage of PVs in Greece where solar irradiation is high. Results indicate that solar irradiation can be reasonably utilised via PV generators; they will provide annually an energy supply of 180-240kWh/m^2 and will cover the energy demands of a Radio-TV Lab for a cost of 6~10€/W_{MPP}. Except the winter, in cases of non frequent buck-ups a second battery (equal to the dominant) may be added to the PV system for lighting purposes of the lab or night-lighting the outside area.

Further more the results show that table 4 parametrical calculations can supply the buck-up energy demand in cases such as

-Unavailability or extreme connection costs with the mains network, in powering of the Radio-TV repeaters and radio-links

-Unavailability of fuel or storage difficulties in cases where fire safety is a priority (e.g. forest or agricultural area), in powering of the Radio-TV repeaters and radio-links

-In powering of various applications of base transceivers or fixed cordless communication or telemetry systems.

7. SOURCES.

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