DESIGN APPROACH FOR PHOTOVOLTAIC POWER STATIONS FOR DEMAND-SIDE REQUIREMENTS AND COMPETITIVE ENERGY COST

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ABSTRACT

Photovoltaic (PV) plants can be constructed of different sizes capable of delivering the same rated power, however for different operation times. A scoping-factor is being introduced reflecting the peak power the plant is able to supply. The presented design approach allows determining the resulting energy cost on the basis of manufacturing cost of solar cells, solar cell efficiency, other system cost and utilization factor (plant capacity factor). Similarly, due to competitive energy environment this method allows determining required design parameters, such as solar cell efficiency, allowable plant component cost, size of the photovoltaic plant etc. The impact of the scoping factor on the plant capacity factor, the cost of the installed power and on the cost of the produced energy is discussed.

INTRODUCTION

Different literatures have been considering the design of a PV plant from different perspectives, e.g. Ransome, S.J. et. al (2002) had emphasise in a series of publications on the kWh/kWp values and the different aspects influencing plant design. The present work shall provide a methodology to allow determining the required size of a PV plant according to load requirements and competitive energy price. The method is based on the scoping factor SF correlating the peak power of the plant to the rated power. This factor is being introduced in this work as a design parameter, which allows providing flexibility and satisfying demand requirements while sizing total power or capacity of a PV plant. Swift introduction to the methodology is being presented in the following. The total solar cell area in a photovoltaic (PV) system, under same cell conditions and solar radiation determines the total electric power of the plant. However, a rated power of a PV plant could still be achieved at different sizes of solar cell areas. Larger area shall be providing longer operation times at a certain rated power, which in turn leads to a larger utilization factor or plant capacity factor. The cost of the installed power and of the energy produced is determined by the size of the PV plant and the plant capacity factor. The scoping-factor can be determined reflecting a pre-set competitive energy price that the PV plant needs to achieve. This approach provides control and flexibility about decisive factors during projection phase such as the needed time of solar electricity a day. It allows informed design of a PV plant towards a competitive environment and energy prices.

SCOPING FACTOR

The total solar power received at any instant by a PV plant is simply the product of the irradiance and the area of the PV plant. The efficiency of the plant is determining how much electricity is being produced from that particular solar exposure. The power generated by a PV plant follows the intensity of the solar radiation, see **Figure 1a.** The amount of the solar power received on the system surface over the course of a day determine with the system efficiency the quantity of solar electric energy produced. Let it be assumed that the PV system delivers a constant electric power P_r, which represents the rated power of the plant for the operation time t (hour) a day. Energy storage will be provided by a battery system to cater for a constant voltage and constant energy delivery after solar availability. The here introduced scoping factor SF is the ratio of the peak power P_p the PV plant is able to offer at 1000W/m^2 irradiance, to the system rated power P_r, i.e. P_p/P_r, equation (1).

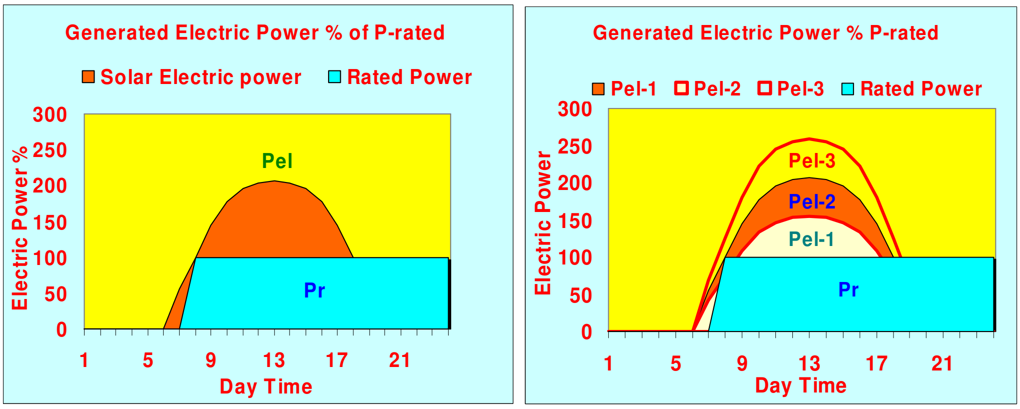


Figure1. Generated power P_{el} and the rated power P_r of a PV plant.

$$SF = P_p/P_r \qquad (1)$$

The electric power P_{el} the system is offering at exposure to solar radiation is implicitly following the solar irradiance and can be calculated as the following:

$$_{t1}\int^{t2} P_{el}(t) = A_{sys}\, \eta_{sys}\, {}_{t1}\int^{t2} I_s(t) \qquad (2)$$

where, A_{sys} the PV total system area (m^2), η_{sys} the total system efficiency, t_1 and t_2 the times encompassing the solar availability on that particular day and $_{t1}\int^{t2} I_s(t)$ representing the accumulated solar irradiation over a day (kWhm^{-2}day) at the location. The maximum or peak electric power P_p is:

$$P_p = A_{sys}\, \eta_{sys}\, I_p \qquad (3)$$

where, I_p the maximal solar radiation intensity corresponding 1000 Wm^{-2}.

From equations (2) and (3) we get:

$$_{t1}\int^{t2} P_{el}(t) = P_p \, _{t1}\int^{t2} I_s(t) \ / \ I_p \qquad (4)$$

Substituting P_p with SF x P_r from equation (1):

$$\therefore \quad _{t1}\int^{t2} P_{el}(t) = SF \, P_r \, _{t1}\int^{t2} I_s(t) \ / \ I_p \qquad (5)$$

That is, the electrical power generated is a product of the Scoping factor SF, the rated power P_r and the ratio of the solar irradiation to the peak solar irradiance 1000W/m^2. At given solar irradiation for a certain location and time, the generated electrical power is a direct linear function of the scoping factor. **Figure 1b** shows three different projected cases following different scoping-factors i.e. different plant sizes. The three cases are generating respectively different electrical power at equal rated power but different operation time t a day. Making the assumption that the arising operation time a day t remains within the 24h a day, i.e.:

$$P_r \times t = \, _{t1}\int^{t2} P_{el}(t) \qquad (6)$$

we can reform equation (5) to be :

$$SF \, _{t1}\int^{t2} I_s(t) \ / \ I_p \ = \ t \qquad (7)$$

That is :

$$SF = t \, I_p \ / \ _0\int^{24} I_s(t) \, dt \qquad (8)$$

where, t is the proposed operation time for that particular day at given solar irradiation $_0\int^{24} I_s(t)$ dt. At projecting PV plants the service time t to be fulfilled at a particular day of the year along with the solar irradiation at that location are explicitly determining the scoping factor, i.e. the size of the PV system.

DESIGNING A PV STATION

Data for solar irradiation used in this research are extracted from the Australian Solar Radiation Data Handbook, for Brisbane reference, published by the Renewable energy Centre, Brisbane Institute of TAFE (2000) and adjusted to Toowoomba using methodology published by Angus (1980). Solar data has been used to demonstrate different projections using the presented technique. **Figure 2** shows the solar irradiation data used for Toowoomba, Queensland, Australia latitude 27˚36′.

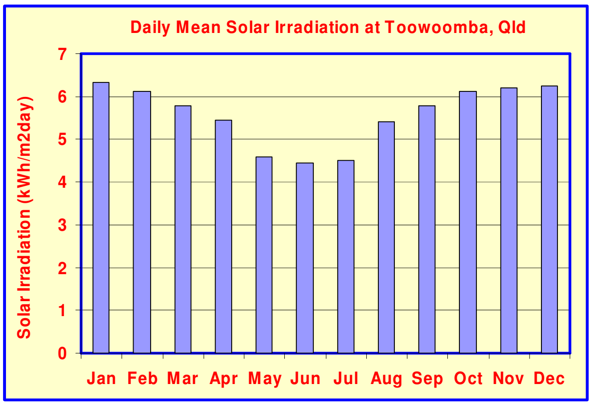
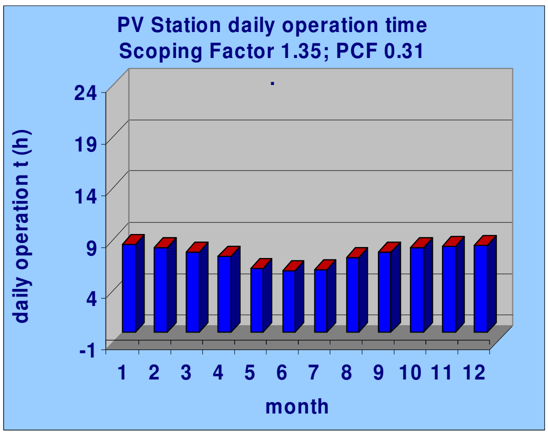
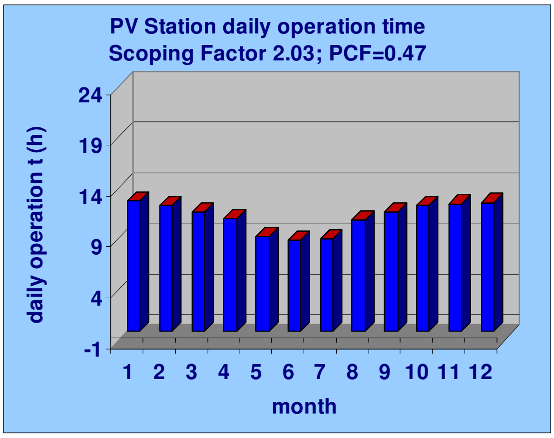


Figure 2. Daily mean solar irradiation at Toowoomba, Qld.

The proposed operation time t per day is predetermined to secure energy delivery on a representative day of the least solar month of the year, here June. The scoping factor is calculated using the June irradiation and the necessary operation time in June in order to determine the capacity of the PV plant. The operation times in other solar rich months will be significantly longer. **Figure 3** shows three different projections of PV plants at different predetermined operation times/day in June. These times are 6, 9 and 12 hours with corresponding scoping factors 1.35, 2.03 and 2.7 respectively. The columns in the figures represent operation times on representative day of the months/year. These values correspond to plant capacity factors PCF of 0.31, 0.47 and 0.63. The plant capacity factor or the also called utilization factor of a power station is, by definition, the relation between the yearly electrical energy generated by the station and the electrical energy generated in case the station operates at its rated power for a full year's time, Brinkmann (1980).





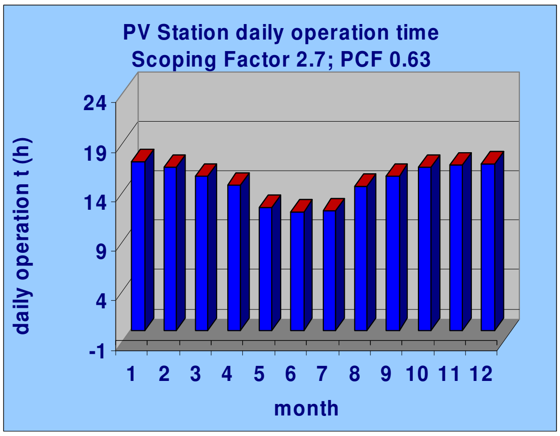


Fig. 3 Operation time per day of a PV plant for three different scoping factors.

IMPACT OF SCOPING FACTOR ON THE COST OF INSTALLED POWER

The composition of the total cost of a PV plant has been described in several literatures. Reference is made here to the National Photovoltaic Program, DOE 1981 and previous work of the author Kamel et al. (1984) describing the PV plant cost consisting of fixed cost and area-related system cost. The fixed cost depends on the rated power and on the energy requirement of the plant, while the area-related cost depends on the technology and efficiency of the used PV cells, module, arrays etc. The cost of the rated power can be expressed as:

$$c_{tr} = c_{sysr} + c_{fr} \qquad (9)$$

where c_{tr} the total cost per rated power (Watt rated W_r), c_{sysr} the area-related system cost and c_{fr} the fixed cost.

The area-related system cost can be calculated as the following:

$$c_{sysr} = SF \times c_{sysp} \qquad (10)$$

where c_{sysp} is the area related system cost referred to the peak power of the plant at $1000 Wm^{-2}$ and SF the scoping factor. **Figure 4** shows the impact of the scoping factor on plant power unit cost for a range of market oriented plant cost.

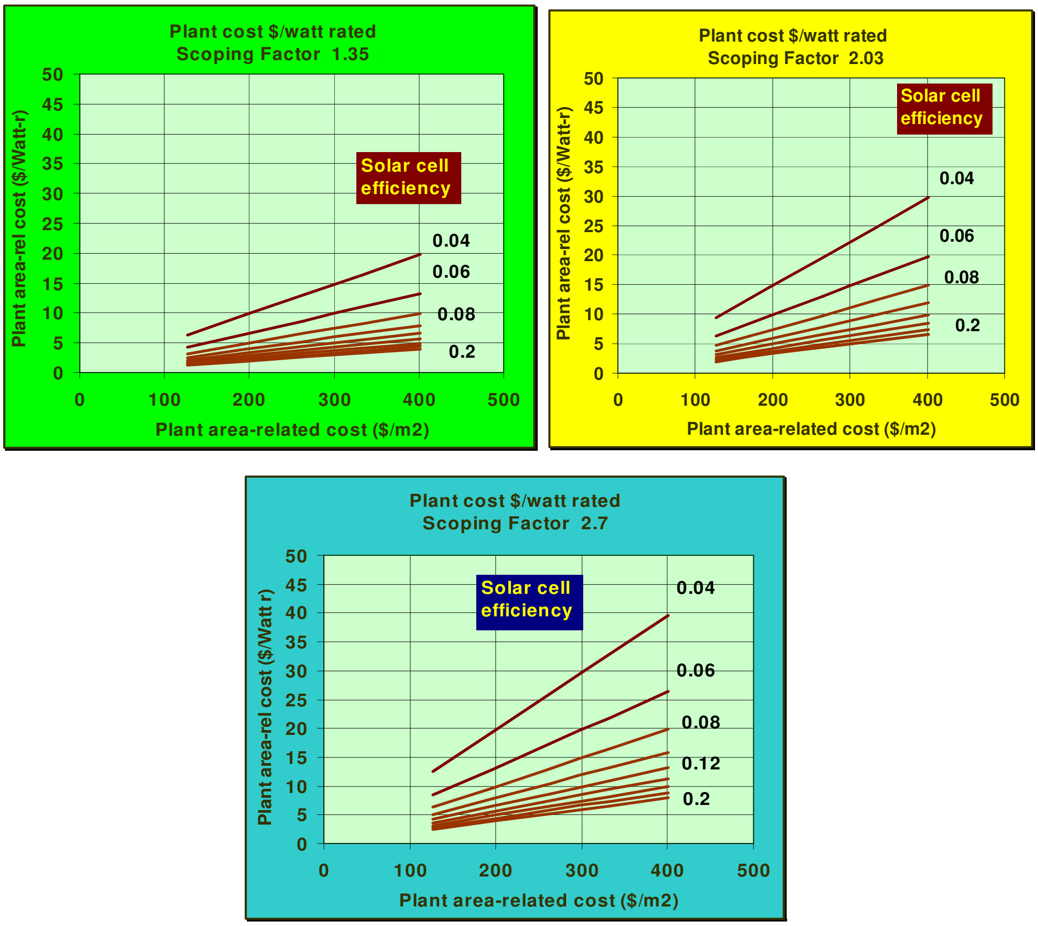


Figure 4 Impact of the scoping factor on total cost of plant power unit for PV.

Adding power-related cost to the area-related cost is presenting the final plant cost per unit rated power, **Figure 5**.

INFLUENCE OF THE SCOPING FACTOR ON THE COST OF ENERGY GENERATION

For the calculation of energy generation cost the fixed charge method is used according to De-Meo & Bos 1978, Leonard et al. 1977, Chobotov & Siegel 1978 and Clorefeine 1980. That is:

$$c_E = c_{tr}\,FCR / (T_o\,PCF) + c_{op} \qquad (11)$$

where c_E is the cost of energy generation, c_{tr} the cost of the installed power including taxes during the installation period, FCR fixed charge rate of the capital, normally 15…18% year according to Leonard et al. 1977 and 1978. T_o =8760 are the hours per year, PCF plant capacity factor and c_{op} the operation and maintenance cost of the plant. **Figure 6** presents in a) the impact of the scoping factor on the plant capacity factor and in b) the impact on the cost of generated energy of a photovoltaic plant.

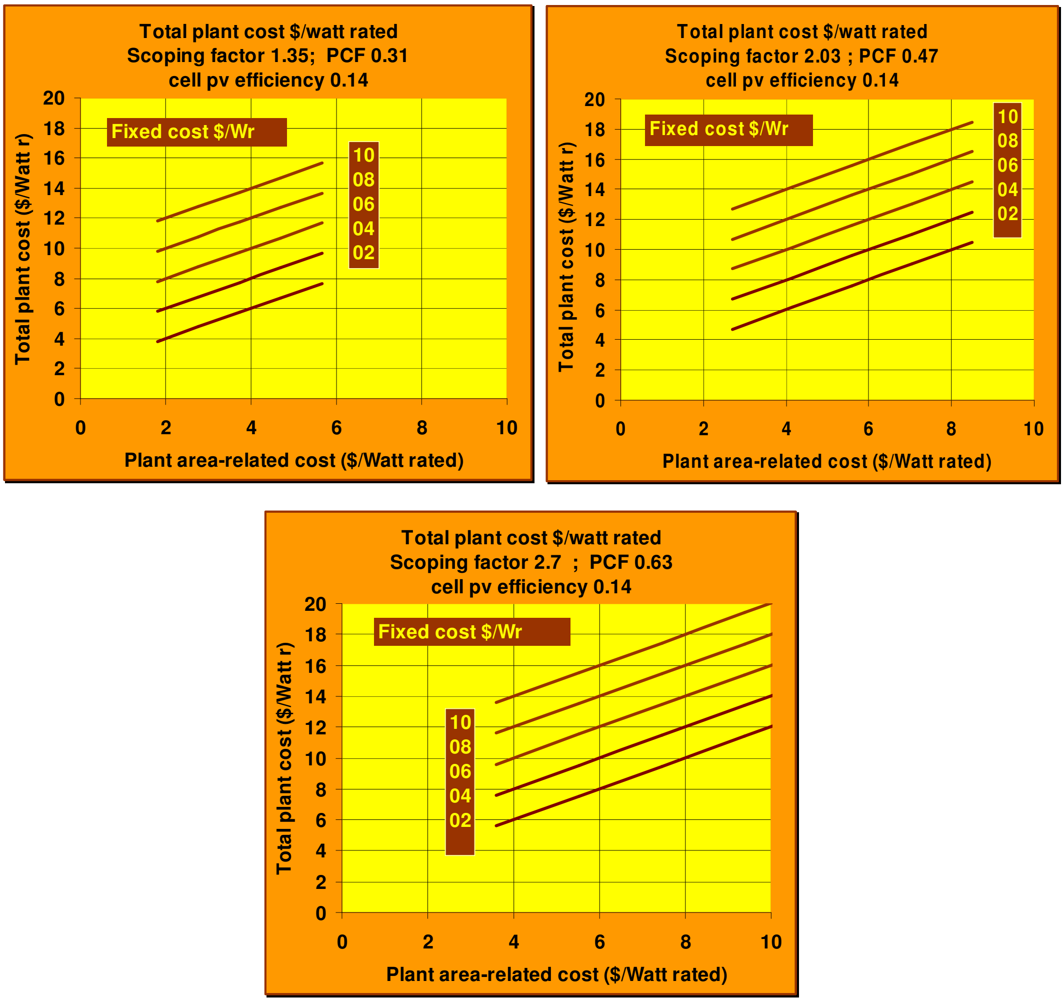
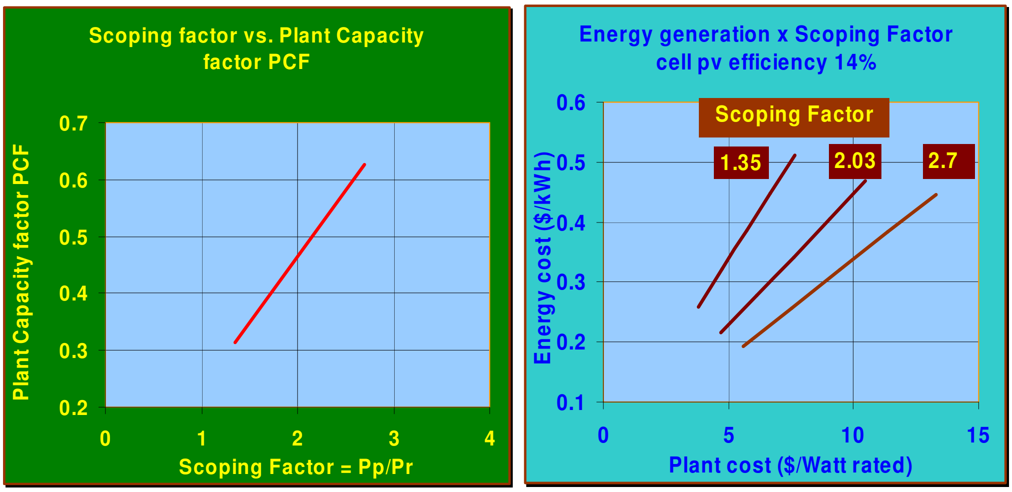


Figure 5 Total cost of a PV plant per rated power unit.

In Figure 6 (b), PV plant cost of 5$ per rated Watt can achieve an energy cost of 0.23 $/kWh at a scoping factor SF of 2.03 while an SF of 1.35 leads to and energy cost of $0.35/kWh. That is a design targeting a larger plant size, i.e. larger scoping factor leads to a reduction of the cost of the generated energy.. This can be referred to the increased energy larger plants are providing, despite the fact they are demanding higher investment.



(a) (b)

Fig.6. Impact of the scoping factor on a) the plant capacity factor and on b) the cost of generated energy for a PV plant.

CONCLUSION

Photovoltaic electrical generating plants can be projected at different peak power capacities (plant sizes), targeting the same rated power, however for different operation times. The method is based on the scoping factor SF correlating the peak power of the plant to the rated power. The factor, which is determining the size of the PV plant, can be decided reflecting a pre-set competitive energy price that the PV plant needs to achieve.

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