A METHODOLOGY TO SELECT BEST SIZE PV PANEL FOR SOLAR PHOTOVOLTAIC POWERED STREET LIGHTING SYSTEMS

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ABSTRACT

Renewable energy is considered as a solution for mitigating climate change and environmental pollution. One of the most common renewable energy systems is solar PV. This research proposed a methodology for selecting best PV panel size which is used for powering street light system. A case study is conduct for demonstrating how the methodology is working.

Keywords:
Renewable energy, PV panel selection, street lighting

1. INTRODUCTION

In the last few years, due to soaring fuel prices and gas emissions, renewable energy technologies have been suggested as the power source for infrastructures. The interest in solar photovoltaic (PV) assisted street lighting systems stems from the fact that they are sustainable and environmentally friendly compared to conventional energy powered systems. The feasibility study of PV system based on energy saving analysis and economic feasibility have been highlighted in a number of research projects [1]. In roads infrastructures, the creation of photovoltaic powered street lighting systems has become an important objective of a responsible energy management policy. This policy framework is based upon the experience gained over recent years from carrying out several feasibility studies for large-scale projects in Europe and US [2]. Whilst conducting these studies, a methodology was developed which selected the most suitable and feasible PV for the establishment of solar photovoltaic powered street lighting systems, with a view to achieving the highest chance of successful implementation. This methodology is a step-by-step multi criteria approach with three stages: (1) the excluding stage, which uses excluding criteria leading to a number of PV sizes potentially suitable for street lighting. These are called “potential PVs”; (2) the suitability stage, which tests the potential PVs on their suitability, leading to the selection of a limited number of (theoretically) “most suitable PVs”: Three groups of criteria are used for this selection, related to the potential for (a) annual electricity produced by the system, (b) sustainability analysis, and (c)LCC analysis. This is followed by (3) the feasibility stage, where the most suitable sizes are then tested for their feasibility. Initially, these PVs are analysed for possible conflicts with other types of PV use; the two main criteria used for this selection being (a) the government pays money for produced electricity (PE) and reduced tax for equipment, and (b) the government don’t pays money for produced electricity. Where several “most suitable PVs” have a similar acceptability score, the final choice of the PV of the street light project is determined by opportunity criteria – defined primarily by the potential for the immediate realization of the street lighting project.

2. PROPOSED METHODOLOGY

In order to select the most appropriate PV for solar photovoltaic powered street lighting systems, a step-by-step approach, Fig (1)

demonstrates the proposed methodology for selection of the best PV for streetlight projects. The must available PVs are considered as selectable PV for the street light system. The selection of the best PV(s) took place in three stages: the excluding stage, the suitability stage and the feasibility stage. The excluding stage, through the use of excluding criteria, leads to the initial identification of a number of PVs that are potentially suitable for street lighting projects, called potential PVs. The suitable remaining PVs are considered as potential PVs for the street lighting system.
In the next step, the suitability stage, the potential PVs are assessed on their suitability for the desired street light system. This process leads to the most suitable PVs for the establishment of the desired system. The PVs are selected based on annual electricity production, LCC, sustainability criteria's. In the event that several PVs yield an almost identical score, the final choice for the PV can be determined by so-called 'opportunity criteria'. This category of criteria is related to the chances for 'immediate realization' of the street light project. The final result is the selection of the most suitable and feasible PV(s) for the street light project. In this way, the methodology is tested using Homer software, with collected weather data and economic data as inputs. It is a micro power optimization model developed by the National Renewable Energy Laboratory [3] and widely used by many countries for the simulation and optimization of renewable energy system or/and hybrid systems. This program is able to simulate the economical performance of the system, and to supply the optimization system configuration and components sizing. The assessment criterion of HOMER is the LCOE, which presents the life cycle cost of the system.

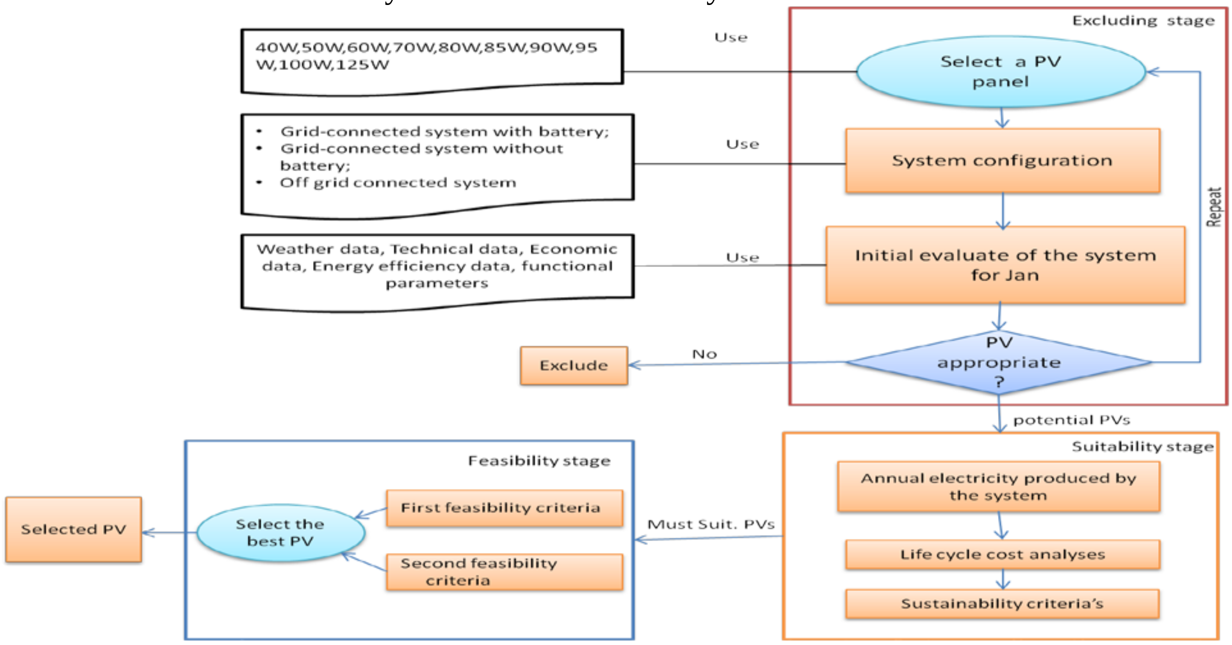

Fig. 1. Proposed methodology

2.1. The excluding stage

The main goal of this stage is to delineate potential PVs appropriate enough to use in a street light system. At this stage, four tasks are necessary for the delineation of the potential PVs.

First task: indication of the available PVs panels at the market. PV panels are pre-constructed units ready to be installed and are composed of several PV solar cells.

Second task: system configuration and component layout, the delineation of the total search is mainly based on the system configuration and component layout of the street light system. In many cases of PV systems, there is a need to store the produced energy, in order to use it afterwards (e.g. during rainy days or during nights). The storage of the produced energy is implemented by using appropriate batteries, which along with their control unit comprise the energy storage system. It should be mentioned that in several occasions of PV systems, there might be a need for using a conventional energy production system (e.g. diesel generators, natural gas, gasoline, etc) along with the PV system, in order to cover the energy demands of the plant. These kind systems are known as hybrid PV systems. The exits system configuration and component layout for PV project are categorize

a) grid-connected street light system with battery

b) Grid-connected street light system without battery

c) Off grid connected street light system

Third task: In this task using initial data (i.e. Weather data, Technical data, Economic data, Energy efficiency data, functional parameters) as input for each of the selected system configuration and layout a monthly electricity production by the system must be done.

Task four: in this task a decision must be took. Using information which comes from the previous tasks the methodology stockholders can decide whether the desired PV panel appropriate to the selected configuration or not. If it is appropriate the panel is named as potential PV panel and is employed in next stages.

3. SUITABILITY STAGE

Suitability stage assesses the technical feasibility of the renewable energy system by calculating the electrical load that the power system is unable to serve (unmet load) and life cycle cost analysis, moreover sustainability analysis of the system .for each system configuration, suitability stage calculates the total unmet load that occurs over the year and the total bring back of the system to ecosystem and sustainability criteria's.

3.1. Annual electricity produced by the system

Solar-based street light systems generally included two PV panels. The PV panels receive solar irradiation and convert it into DC (Direct Current) electricity. Eq (1) which is given by the PV derating factor [4]calculates the electricity generation of PV panel

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_t}{G_{t,stc}}\right) \left[1 + \theta_p \left(T_C - T_{C,stc}\right)\right] \quad (1)$$

If temperature on the PV array is not considered, it is possible to assumes that the temperature coefficient of power is zero, so that the above equation simplifies to Eq (2) [4]:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_t}{G_{t,stc}}\right) \quad (2)$$

Although a battery increases systems' investment cost, it is needed because of the following benefits: smoothing the fluctuations of both load and electricity production; improving the efficiency of operation of the system; reducing grid electricity usage; and providing security of energy supply [5]. life time of the battery is one of important indicter to increasing of investment cost [6]. The battery bank life time is calculated by Eq(3).

$$L_{batt} = \min\left(\frac{N_{batt} \cdot Q_{lt}}{Q_{th}} R_{batt,f}\right) \quad (3)$$

3.2. Life cycle cost analysis

A simplified systematic economic feasibility approach is adopted in this present research study to assess the potentials of the proposed hypothetical PV street light system. The following equations are adopted for the economic parameter estimations [7];

$$NPV = \sum PV_{AS} - \sum PV_{LCI} \quad (4)$$

$$SIR = \frac{\sum PV_{AS}}{\sum PV_{LCI}} \quad (5)$$

$$SPP = \frac{\text{Initial investment}}{\text{Annual saving}} \quad (5)$$

$$COE = \frac{C_{ann,tot}}{E_{prime,AC} + E_{grid,sales}} \quad (6)$$

IRR is the discounted rate obtained when SIR =1, or NPV=0

Measure of the feasibility, the project is said to be economically feasible if the NPV>0, SIP>1 and IRR>discounted rate. If otherwise, the project is not feasible. In this research, the economic performances of all size of PVs are compared.

3.3. Sustainability criteria's

A wide range of indicators is used to characterize the environmental dimensions of the potential PVs. Firstly; the same weight is given to all indicators in order to evaluate a global sustainability index from an equality point of view. Then, indicators are used separately to assess sustainability. For this evaluation, the weighting factor of a selected indicator is higher than the others. Finally, the weighting factors of indicators assumed as more relevant, are higher compared to the weighting factors of the remainder indicators.

4. FEASIBILITY STAGE

The most suitable PV panels are used as input to feasibility stage. In this stage, depend on feasibility criteria's one or group of the PV panels is selected as best PV panel for the desired system. Nowadays the exits feasibility criteria's are as follows:

(a) the government pays money for produced electricity (PE) and reduced tax for equipment,

(b) the government don't pays money for produced electricity

Initially, these PVs are analysed for possible conflicts with other types of PV. Where several "most suitable PVs" have a similar acceptability score, the final choice of the PV of the street light project is determined by opportunity criteria – defined primarily by the potential for the immediate realization of the street lighting project. Because of the three stages of the multi-criteria analysis, the most suitable and feasible PV(s) are selected for further political scrutiny prior to implementation.

5. CASE STUDY

Based on the two kind of policy for this case study, first one government policy "don't pay money" to extra produced electricity, second one government "pay money" to extra produced electricity. First step of proposed methodology is system configuration, we selected grid-connected system with battery because the streetlights in city exist and we are just focused to retrofitting system. Fig (2) shows the HOMER codes for the system configuration. According to market availability and some previous knowledge the 40w, 50w, 60w, 70w, 80w, 85w, 90w, 95w, 100w, 125w are selected for this case study.

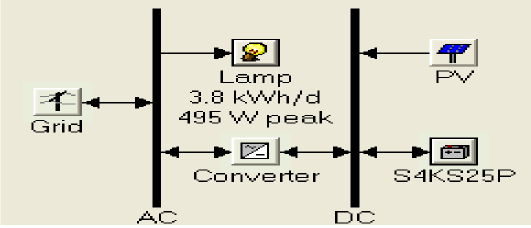

Fig.2 Homer codes for the system configuration

Table1-2 and 3 demonstrates the initial input data for the tool using information of the case location.

Table 1:Weather Data

Latitude and longitude	33°55E and 35°7N
Altitude	25m
Time Zone	GMT+02:00

Table 2: Technical Data

Output PV and size	DC&40w,50w,60w, 70w,80w,85w,90w,95w, 100w,125
Derating Factor (%)	70
Slope degree	33°
Azimuth	0°
Ground reflection (%)	35
Efficiency of converter (%)	90
Tracking system	No
load	30w

Table 3: Economic Data

Replacement($/kw)	0
Tariff(TL/kw)	0.4
Life time	20
Discount rate (%)	10
Residual value (%)	10% of purchase price
O&M($/year/kw)	5

6. RESULTS AND DISCUSSION

Electricity produced by each PV panel for each month was estimated by Homer software Fig.3 show the electricity produced by each PV ,the horizontal axis was arranged by minimum daily radiation (2.66 in the December) to maximum daily radiation (8.063 in the July) according to data from Fig.4

Vertical axis of this Figure is electricity produced (w) by PVs systems.

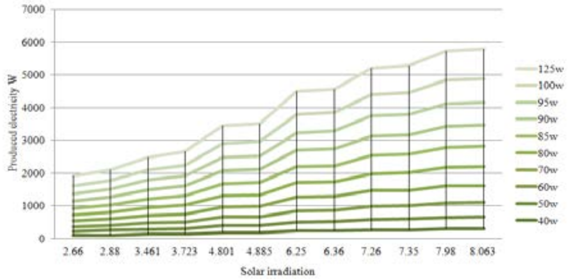

Fig.3 Electricity produced by PV systems

In order to design the optimum system to serve the desired loads and helping to decision maker to take correct decision according the energy policy. We proposed cost of energy (COE) and saving investment ration (SIR) and NPV graphs to help decision maker. Fig(5) shows the NPV graph horizontal axis is PVs size and vertical axis is dollar. For each size of PVs consist of three column first one total present value of all annual savings (PVs) and second is total present value of all life cycle investment(PVc) and the third is net present value (NPV), NPV shows the total potential earning of project. If NPV>0, a project is profitable at this case the 40watt system was not profit because NPV=-218<0. Except 40-watt system, all systems are feasible. Fig (6) shows the SIR graph of this study the horizontal axis is PVs size and vertical axis is ration of present value of saving and present value of investments. If SIR>1, a project is profitable .this graph shows that the 40watt system is not feasible but others systems are feasible. Minimum point it means that present saving value is equal present investment value. Maximum point of this curve was 1.9 shows the maximum profit of selected size.

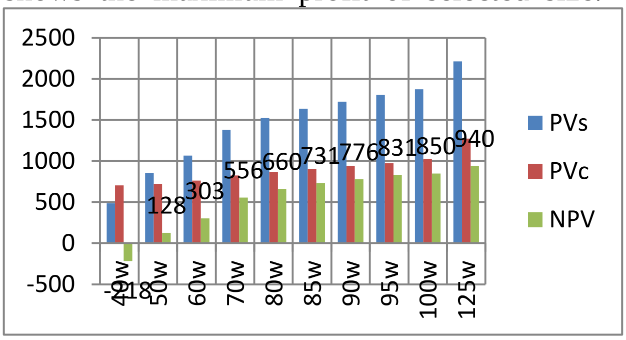

Fig. 4 NPV graph

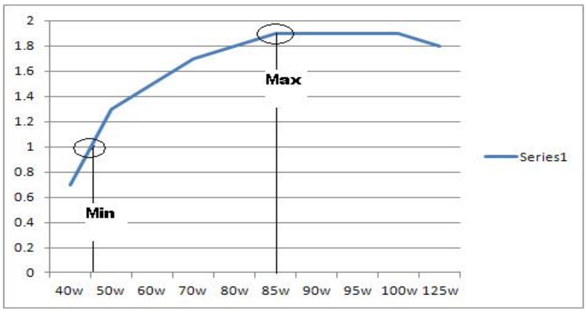

Fig. 5 SIR graph

Annual carbon dioxide emission, as the most important indicator of environmental assessment of energy system [9], is discussed for the environmental performances of the PV systems. The carbon dioxide emission (as shown in Fig) has relationship with PV size. This relationship between size of PV system and annual carbon dioxide emission (kg\year) can be writing by liner algebra equation. Horizontal axis was PV size and vertical axis was annual carbon dioxide emission for traditional streetlight (grid) system with load 30w the total emission gas was equal 2104 (kg/year).

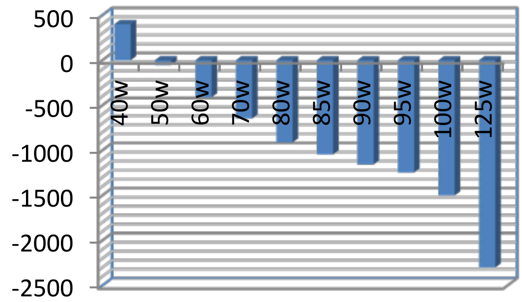

Fig. 6 relations between carbon dioxide emission and PV size

7. CONCLUSIONS

A methodology for selecting best PV panel for powered street lighting systems has been successfully developed for the feasibility and suitability analysis. The model is capable of performing a long term simulation of the system's economic, technical and environmental feasibility. The major findings of case study using the proposed methodology are outlined below:

- For 40watts PV based street lighting systems the Life cycle investment(PVs) is more than the annual saving(PVs) and the SIR is equal 0.7 therefore this system wasn't feasible for this condition.

- The 85watts PV based street lighting system was selected because according the SIR graph the maximum SIR for 85w,90w,95w but the investment cost of the 85w was less than other one so the 85w is selected for university.
- The 50W PV based street lighting system was selected for the city because the SIR of this system was approximately equal one.

References

[1] Wu, M. S., et al. (2009) "Economic feasibility of solar-powered led roadway lighting." Renewable energy 34.8: 1934-1938.

[2] Nieuwenhout, F. D. J., et al. (2001) "Experience with solar home systems in developing countries: a review." Progress in Photovoltaics: Research and Applications 9.6: 455-474.

[3] Razak, Juhari Ab, Kamaruzzaman Sopian, and Yusoff Ali.(2007) "Optimization of renewable energy hybrid system by minimizing excess capacity." International Journal of Energy1.3: 77-81.

[4] Farret, Felix A., and M. Godoy Simoes. Integration of alternative sources of energy. John Wiley & Sons, 2006.

[5] Ter-Gazarian, Andrei G. Energy storage for power systems. No. 6. Iet, 1994.

[6] Liu, Gang, et al.(2012)"Techno-economic simulation and optimization of residential grid-connected PV system for the Queensland climate." Renewable Energy 45: 146-155.

[7] Okoye, Chiemeka Onyeka, and Uğur Atikol. (2014)"A parametric study on the feasibility of solar chimney power plants in North Cyprus conditions." Energy Conversion and Management 80: 178-187.

[8] Evans, Annette, Vladimir Strezov, and Tim J. Evans. (2009) "Assessment of sustainability indicators for renewable energy technologies." Renewable and sustainable energy reviews13.5: 1082-1088

[9] Farret, Felix A., and M. Godoy Simoes. Integration of alternative sources of energy. John Wiley & Sons, 2006.