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TECHNICAL-ECONOMIC ANALYSIS OF A AC/DC MICROGRID FOR PUBLIC HEALTH INSTITUTIONS WITH LOW ELECTRICAL DEMAND. CASE STUDY: PERÚ

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Abstract

In this paper, we analyze the implementation of a microgrid with a photovoltaic solar plant in health facilities of the Level I and II according to the categorization of the Ministry of Health of Peru. The study includes both technical (microgrid control and power management) and economic developments under a project investment horizon of 15 years. The mathematical modeling and numerical simulations in Matlab/Simulink are used to demonstrate the feasibility of the project investment. In addition, details of the PV system design and connectivity scheme with external grid are shown. Also, its main characteristic is to allow only the entry of missing energy from external power supply and not have storage systems. The mathematical model has taken into consideration 3-scenarios: pessimistic, average and optimistic. This paper is a contribution to the implementation of microgrids in the society and contribution to places that have not yet taken advantage of the solar resource for electricity generation in health facilities.

KeyWords: Microgrid, Health building, Microgrid control, Power management.

Resumen

En el presente artículo se analiza la implementación de una microred con una planta solar fotovoltaica en establecimientos de salud del tipo I y II de acuerdo a la categorización del Ministerio de Salud del Perú. El estudio evalúa tanto el aspecto técnico (control y gestión de potencia de microredes) y económico bajo un horizonte de proyecto de inversión de 15 años. Modelamiento matemático y simulación numérica en Matlab/Simulink son usadas para demostrar la factibilidad del proyecto. En adición, detalles del diseño del sistema fotovoltaico y esquema de conectividad con la red externa son mostrados. La principal característica de la microred es permitir sólo el ingreso de energía faltante y no tener sistema de almacenamiento. En el modelo matemático tres scenarios han sido considerados: pesimístico, promedio y optimístico. Este artículo es una contribución a la implementación de microredes en la sociedad y en especial en los lugares en que no se ha aprovechado el sol para la autogeneración de electricidad en establecimientos de salud.

Palabras Clave: Microred, Edificación de salud, Control de microred, Gestión de potencia.

INTRODUCTION

The Public Health Institutions (PHI) in Peru are classified according to their level of complexity in three levels: I, II and III. The Level I and II are of low and medium complexity and are located at different latitudes and altitudes covering the entire national territory in three regions which are Coast, Highlands and Jungle respectively. Each PHI needs electricity to operate lighting, biomedical equipment and other loads. For this, the most common solution is the connection to the external power supply provided by a utility. However, for this it has to pay a bill each month.

In Peru, there are places with high values of wind speed and solar radiation (1) which can serve for the self-generation of electricity and/or heat and can be profitable.

In this regard, the Peruvian government through the Ministry of Health (MOH) has been implementing the Program of Support to the Reform of the Health Sector II (PARSALUD II), which is the improvement of the 748 strategic PHI through the development of Public Investment Projects (PIP) with a time horizon of 15 years (2). Each PHI has roof areas potentially useful for the use of radiant energy incident and to implement them with microgrids (MG) with a good impact on the environment and reduction of operational costs.

To analyze this case, a mathematical model was constructed to estimate the feasibility, return time and volumes of production/consumption of electricity.

MG are small-scale, supply networks designed to supply electrical and heat loads for a small community. From a grid point of view, the main advantage of a MG is that it is treated as a controlled entity within the power system. It can be operated as a single aggregated load. This ascertains its easy controllability and compliance with grid rules and regulations without hampering the reliability and security of the power utility. From a customers' point of view, MGs are beneficial for locally meeting their electrical/heat requirements. They can supply uninterruptible power, improve local reliability, reduce feeder losses and provide local voltage support. From a environmental point of view, MGs reduce environmental pollution and global warming through utilization of low-carbon technology (3).

MG concept relates to a system which coordinates locally the demand and supply of energy. MG is essentially an active distribution network because it provides a platform for the integration of various energy sources distributed through a communications system that allows control actions at distribution voltage level (3). There are many possible configurations which may contain generation of renewable and non-renewable electricity, storage and controllable loads with priority categories according to the user (4). Therefore, we want to have: an MG with photovoltaic (PV) plant; control, monitoring and supervision in autonomous real time in PHI's electric system and comply with Peruvian legislation (5).

A MG is not an electrical configuration: (a) without a load, (b) having only electrical charges, without microsources, (c) without monitoring and control despite having microsources, since their operation would not be quantifiable or optimized, (d) a configuration that has all the elements, but insufficient carbon credits (6).

MATERIALS AND METHODS

About the PHI.

The Office of Investment Projects (IPO) of the General Office of Planning and Budget of the MOH by RD No. 010-2012 / EF-68 approved the Minimum Contents Specific 012 (MCS 012), a technical guidethat authorizes the use of renewable energy in PHI [2] but it does not say how nor mentions modern trends as MG. MOH by means of PARSALUD makes the evaluation of PHI called "strategic" to improve their operational capacity (7), This work is a contribution for the evaluation and installation of MG in PHI of low electricity demand. The PHI of Category I and II have usually a roof from 2,000 m^2 to 13,000 m^2.

Solar Map of Peru.

Peru is politically constituted by 24 regions. A solar map of Peru is available at (1). The largest PHI are located in the capital of each region, therefore the solar radiation in the capital of each regionis considered as a reference. From (7) three values are assumed: Maximum (R_{max}): 6.08 kWh/m^2day; Average (Rave) 5.17 kWh/m^2day, and Minimum radiation (R_{min}) 4.42 kWh/m^2day.

Wind energy was not considered because installation of wind turbines depends largely on the location; wind speed varies during the year, depending on the season, changes daily and have changes in short term (seconds to minutes) both speed and direction (8). Currently there exists a wind map of Peru (9) with only general information; one needs to installation of measuring equipment in PHI and needs real time records for an adequate technical and economic evaluation of the wind resource (10).

PV Solar Panel Technology

There is a continuous improvement in materials and construction processes in solar panels (11). For this study, a standard panel has been selected: Model E20-327-COM (12) from SunPower Company with nominal power of 327 Wp, average panel efficiency of 20.4 %, panel area of 1.63 m2, weighing 18.6 kg and 1046 x 1558 mm of dimensions. (12). It cost in the Peruvian market is US $ 1/W including installation. The lifetime of solar panel selected exceeds the duration of PIP in 10 years.

Proposal connection between external electrical network and MG of PHI

The proposed configuration is shown below in Fig.1.

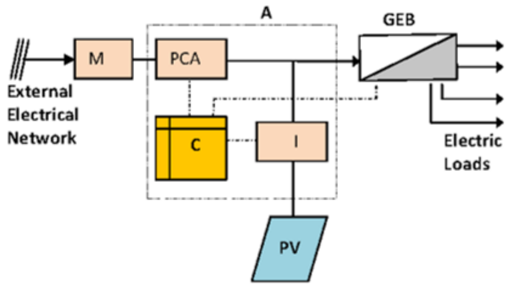


Figure 1: Proposal of microgrid in electric network

where: "PV" are the PV solar panels; "M" is a electricity meter that measures the energy coming from the external power grid; "I" is a microsource controller (3,6); DC/AC converter of energy from the solar panels, can synchronize the phase, can let flow from the external power supply the amount of missing energy to complete the need of electricity of IHP; "PCA" is the Point of Common Coupling that connects/disconnects the MG of the utility network (13); "C" is MG central controller (3,6) that communicates bidirectional with General Electric Board (GEB). Both "I" and "PCA" management makes the power of the MG under the rule of admitting only missing input power from the external power supply, too "C" has the adequate human-machine interface (HMI) (3,6); "A" brings together the control, management and monitoring equipments of MG proposal; it is of according at the state of art actual in MG with good reliability, low unavailability and little interruptions (6).. "A" could be in the future a single assembled element. The cost of the electricity that companies sell has also been considered. In this there are two scenarios, buy in low voltage (LV) and/or medium voltage (MV). PHI Level I usually feed on 220V (single phase) or 380/220 V (three phase). The PHI level II, usually purchased in MV with nominal voltage of 10 kV or 22.9 kV. The price of electricity in both low voltage "PrBT" and MV "PrMT" are [14]: PrBT = 0.38115 US$/kWh and PrMT = 0.05705 US$/kWh. In all cases the cost assumed of "A" is C (C_C) equal to US $ 3,500.00

General Considerations

The growth rate of the maximum power demand to future isassumed as the same value as the percentage growth rate of the population (15) of the region to study. The equations for calculating the growth in electricity demand will be according with (5):

$$X_{(t_2)} = X_{(t_1)} e^{PRG(t_2 - t_1)}$$

where: PRG is percentage growth rate, t2 is time at the end of the study period, t1 is the initial time of the study phase, X*(t1)* is the variable to deduce their behavior when baseline and X*(t2)* is the variable at the end point of the study period. Something similar is done with the prices in LV and MV where the percentage of annual growth in electricity prices (PRG) will be equal to 3.9% (16) to calculate the evolution of prices during the PIP.

Mathematical Model

The radiant energy incident on the area where the solar panels will be arranged is calculated based on average values recorded incident of solar radiation, according to:

$$E_{max,ave,min}\ [\text{kWh/day}] = A \times R_{max,ave,min}$$

where: maximum energy radiated for a day is "Emax", "Eave" is average value, and "Emin" is minimum daily radiation energy. It is considered that "A" has three scenarios:

$$A_{min}=3{,}000\ m^2;\ A_{ave} = 7{,}000\ m^2 \text{ and } A_{max}=11{,}000\ m^2 \qquad \text{[Eq. 3]}$$

Given that Peru is located close to the equator, the amount of daily hours of sun is approximately 12 hours, the daily energy available can supply an electric charge to daily power average electric "Pp", for which, a given amount of solar panels "Upv" is needed, therefore:

$$Pp\ [\text{kW}] = fa \times Emes$$

where: "fa" is an adjustment factor that indicates the amount of energy consumed during daylight hours and we considered fa = 0.70; "Emes" is the monthly electric energy consumed by the

PHI in kWh and is considered under the following three scenarios:

$Emes_{min}$= 5,000 kWh; $Emes_{ave}$= 10,000 kWh and $Emes_{max}$= 15,000 kWh

The amount of solar panels required is calculated by the following equation:

$$Upv = (Pp \times 1000)/(Pnom)$$

The initial cost [US$] of the MG "C_in" is:

$$C\_in_{max,ave,min} = Upv_{max,ave,min} \times C \times 327 + C\_C$$

Fifteen years of PIP involves 5475 days. This represents a payment in purchased energy "Pec" therefore low voltage "Pec_BT" and MV "Pec_MT" of:

$$Pec\_BT_{max,ave,min(t)} = PrBT(t) \times Days(t) \times Pp_{max,ave,min(t)}$$
$$Pec\_MT_{max,ave,min(t)} = PrMT(t)\ Days(t)\ Pp_{max,ave,min(t)}$$

where "Pp_{max}", "Pp_{ave}" y"Pp_{min}" are the average powers: maximum, average and minimum deducted from the scenarios: "$Emes_{min}$", "$Emes_{ave}$" y "$Emes_{max}$". During PIP's lifespan, the price of MG is amortized progressively considering the following calculation of real value (VR) (5) for both tariff LV (VR_BT) and tariff MV (VR_MT):

$$Pec\_MT_{max,ave,min(t)} = PrMT(t) \times Days(t) \times Pp_{max,ave,min(t)}$$

$$VR\_BT_{max,ave,min(t)} = C\_in_{max,ave,min} - Pec\_BT_{max,ave,min(t)}$$

Similarly, the incident radiant energy converted into electrical energy for one day, quantified as "E_{max}", "E_{ave}", "E_{min}"; is primarily affected by the efficiency of the solar panel "η", then the electrical energy from solar panels for a day "EEsol" is:

$$EEsol_{max,ave,min} = E_{max,ave,min} \times \eta$$

The electricity generated, for this case, will make the price of energy at low voltage "PrBT" because it resembles the voltage level and the form of equipment that is supplied through the distribution network. The price at the time is calculated using equation 4. Therefore, during PIP, sales price of energy produced from solar panels "CEEsol" is valued according:

$$CEEsol_{max,ave,min(t)} = EEsol_{max,ave,min} \times Days \times PrBT(t)$$

In short, installation of MG in PHI consists of an initial cost which is amortized by the cost of energy to stop buying in LV or MV, likewise, the energy produced represents a value that gradually increases in the time. In any time, both values of MG and production are equalized to represent return time of investment, the MG pays for itself. Fig. 2 shows the trend where "TIR" is the return time investment, and; "VR" is real value of MG. Three curves of scenarios is shown: optimistic (suffix "max" in variables), average (suffix "ave") and minimum (suffix "min").

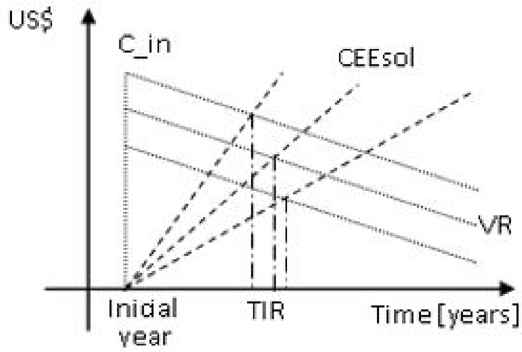


Figure 2: Evolution of the actual value of the facility and the value of the energy produced.

RESULTS AND DISCUSSION

The first scenario simulated is the power estimated using 20 % of the available area of PHI. For this we considered the efficiency of solar panels, a solar radiation assumed in Eq. 8 divided by 10 hours of sunshine. Fig. 3 shows the results, which allow us to verify that the PV plant will occupy a portion of the available area of PHI.

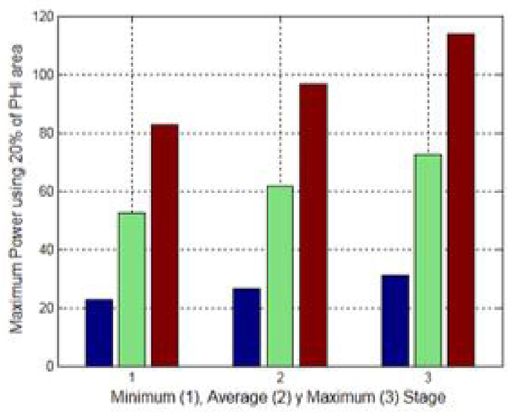
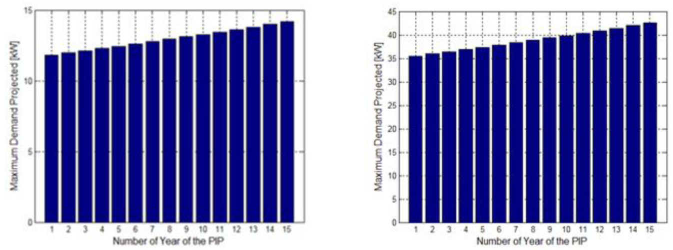


Figure 3: Estimated production considering the three scenarios of "A" and "R".

In the case of R_{min} and A_{min} has 36 PV panels which occupy 60 m2; in the case of R_{max} and A_{max} are needed 108

PV panels which occupy 180 m^2.

A second simulation scenario is to calculate the maximum demand (MD) during the years of PIP considering the growth rate of the population, given that as the population increases, so does the health care and therefore the amount of energy that is required for PHI. For this, two scenarios have been considered: with A_{min}, R_{min} (see Fig.4a) and A_{max}, R_{max} (see Fig. 4b). In this aspect the environmental conditions have been assumed constant over the years.



(a) with A_{min} and R_{min} (b) with A_{max} and R_{max}

Figure 4: Projection of MD during PIP time.

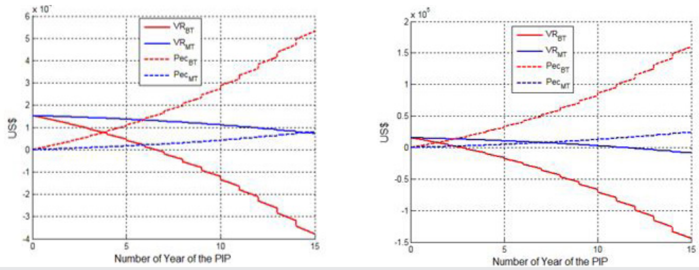


Figure 5: Evolution of the VR and Pec in BT and MT for calculate of TIR

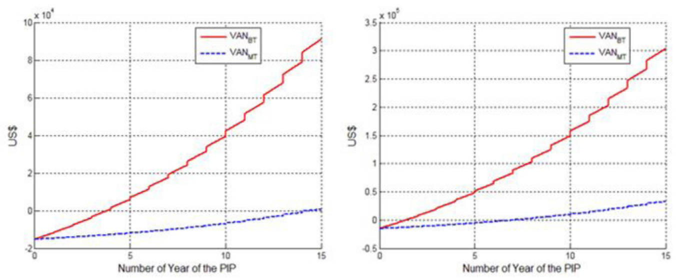


Figure 6: Evolution of VAN into BT and MT for calculate of TIR.

Figure 5 indicates that the return time of the investment is shorter if there is a higher energy demand. Fig. 6 indicates that it is more beneficial for the PHI to buy at LV instead of buying at MV, but in both cases the return time is within PIP. It has to be studied at what energy demand in order to change from LV to MV.

CONCLUSIONS

It has been shown that a PIP horizon of 15 years is viable, reaching a payback (a) in worst case scenario (Amin, Rmin and electric demand) within approximately 4 years for users who buy at low voltage and 14 years for users who buy at medium voltage; and (b) in best scenario (Amax, Rmax and electric demand) is about 2.5 years for users who buy atlow voltage and 6.5 years for users who purchase atmedium voltage.

At the end of PIP (15 years) are still 10 years more of optimal performance inPV solar panels, which entails that if is necessary, PHI may increase the capacity of PV solar power.

Moreover, there is area available for installation of solar thermal equipment for production of hot water. Both cases lead to an improvement in PHI economy, quality of care and working environment and increase the efficiency contributing to a green image.

The calculation described considers the PV solar power as a source of electrical power of the base type, that is to provide important part of consumption and the remaining (which may be continuous, intermittent or changing) will be supplied from the public grid.

Not considered is electrical storage, because it has a high cost in operation and maintenance, which will increase the cost and extend the return time of investment. The electricity produced by a PV solar plant in a MG pays itself.

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