

# Optimum Implementation Renewable Energy Systems in Remote Areas

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## Abstract

*The growth in energy consumption and the lack of access to the electricity network in remote areas, rising fossil fuel prices, the importance of using renewable energy in these areas is increasing. The integration of these resources to provide local loads has introduced a concept called microgrid. Optimal utilization of renewable energy systems is one of their most important issues. Due to the high price of equipment such as wind turbine, solar panels and batteries, capacity sizing of the equipment is vital. In this paper, presents an algorithm based on techno-economic for assessment optimum design of a renewable energy system including photovoltaic system, batteries and wind turbine is presented.*

**KEYWORDS:** renewable energy systems, photovoltaic, wind turbine, batteries, techno-economic.

## I. INTRODUCTION

The pollution caused by fossil fuels and their scarcity has led to focus on utilization of renewable resources in recent years. Historically, renewable energy sources as sources of electricity supply in power systems has been taking human's attention. renewable energy systems consist of loads, distributed generators, and energy storage systems that operates as a single-controllable load or generator and can provide power and heat to a local area [1]. Most of the people having no access to electricity live in remote areas. So, one of the best alternatives is to build an independent electricity production unit at such sites consisting of locally available renewable energy resources such as wind, solar and batteries. Various ways and solutions has been presented in order to reduce the cost of solar and wind power plants. In article [2], these resources are used as a power supply in hybrid and islanded grids, and in others, they are used in the grid connected to the upstream network to supply and sell. An off-grid hybrid system includes a wind, solar, fuel cell source in which the fuel cell, along with an electrolyzer and a hydrogen tank, has been considered as a storage facility for improving the performance of wind and solar resources. In [3], the authors used nonlinear programming to select the optimal location and capacity of grid-connected wind power plants to optimize energy density and minimize costs. In order to encourage consumers towards smart energy consumption and use of smart equipment, there is another important

parameter to reducing the cost of consumption, which is called cost risk. This cost is in the form of anticipated cost deviation in the presence of uncertainty such as uncertainty in forecasting energy production and consumption. Now, studies show that the lower the cost and risk of a predicted cost, the faster the penetration of smart grids will increase among consumers [4]. In [5], energy management techniques for commercial consumers of a renewable energy systems have been discussed. This reference proposes an energy management system for micro-networks including solar cells, energy storage units, and gas micro turbines. This system consists of two parts: the first part is based on central energy management and the second part is based on local energy management on the consumer side. Local and central management systems transmit their information through a communication network. In [6], most use of RESs by grid-connected vehicles has been proposed to reduce the pollution and cost of power generation networks and the electric transportation industry. The PSO optimization method has been used to develop a successful vehicle control program. Also, a fuzzy-PSO algorithm has been presented for load propagation in a specific renewable energy systems considering economic and environmental issues. The results show that with the high penetration of renewable energy resources, pollution reduction and renewable energy systems costs are serious, and the energy exchange between the renewable energy systems and the upstream grid connected to it has a lot of advantages. In [7] a multi-agent system for



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smart energy demand-side of renewable energy systems has been proposed that includes predictive algorithms to improve system management. The simulation results show that the intelligent demand-side management system fulfills all the design objectives and also results in effective utilization of the microgrid boundary conditions.

In the continuation of this article, the problem expression section is presented, then the mathematical modeling of components for renewable energy systems is examined. In the third section, the objective function and the problem of minimization are discussed. Finally, the optimization results of the combined renewable energy system are presented with practical data and compared with the diesel system.

## II. PROBLEM STATEMENT

Providing the required load at any time by power generation and storage resources at the lowest annual cost is an issue that is addressed in this study.

### A. Objective Function Problem Statement

This section presents some of the important details about each component of the renewable energy systems. The goal of assessment techno-economic is to optimum design of a renewable energy system consisting of wind, batteries and solar as primary energy sources and minimize the total operating cost. The objective function of this problem is expressed by Equation (1).

$$f(x) = \sum_{t=1}^{NT} \left\{ \sum_{i=1}^{Ngpv} A_{Gi}(P_{PVGi}^t) + \sum_{i=1}^{Ngwt} B_{Gi}(P_{WTGi}^t) + \sum_{i=1}^{Ngbt} C_{Gi}(P_{BTGi}^t) \right\} \quad (1)$$

Where, NT the total number of hours, Ngpv the total number of solar panels generation resources,  $P_{PVGi}^t$  power solar panels output of the source i, Ngwt the total number of wind turbine generation resources,  $P_{WTGi}^t$  power wind turbine output of the source i, Ngbt the total number of batteries generation resources,  $P_{BTGi}^t$  power batteries output of the source i. Also  $A_{Gi}$ ,  $B_{Gi}$  and  $C_{Gi}$  cost of the power generation ever unit i.

### B. Constraints

The sum of the output power of the distributed generation units and the grid injection power must cover the total demand load at each time interval t. Equation (2) shows this power equation [9]:

$$\sum_{i=1}^{Ns} P_{Gi}^t + P_{Grid}^t = \sum_{d=1}^{ND} P_{LD}^t \quad (2)$$

For stabilized operation, the actual output power of the distributed generation units along with the main grid is in the range indicated by inequalities (4) [11]:

$$\begin{aligned} P_{Gi,min}^t &\leq P_{Gi}^t \leq P_{Gi,max}^t \\ P_{Grid,min}^t &\leq P_{Grid}^t \leq P_{Grid,max}^t \end{aligned} \quad (3)$$

## III. MATHEMATICAL MODELING

In the MILP method, all mathematical relations, including constraints and head functions, must be programmed linearly. In the continuation of this section, the mathematical model of the equipment along with their technical and economic specifications and geographical data are explained [10].

### A. SOLAR PANEL

Power output of a PV array is based on solar irradiance and ambient temperature. The power output in this model is calculated as:

$$P_{PV} = \eta_{PVg} \cdot A_{PVg} \cdot G_t \quad (4)$$

Where  $\eta_{PVg}$  is PV generation efficiency,  $A_{PVg}$  is PV generator area (m<sup>2</sup>), and  $G_t$  is solar irradiation in tilted module plane (W/m<sup>2</sup>).

Fig. 1 shows the license plate module plate installed in the case study and Table (I) shows their technical and economic specifications.



Fig. 1: Solar panel plate studied.

TABLE I  
TECHNICAL AND ECONOMIC SPECIFICATIONS OF THE SOLAR  
PANEL

|                                          |           |
|------------------------------------------|-----------|
| Rated power                              | 200 watts |
| Module efficiency                        | % 15.4    |
| Temperature coefficient of maximum power | % -0.42   |
| Open circuit voltage                     | 23.7 volt |
| Voltage at maximum power                 | 30.3 volt |
| Current at a maximum power               | 8.59 amps |

#### B. WIND TURBINE

The fundamental equation governing the mechanical power of the wind turbine is given by:

$$P_w = \frac{1}{2} \cdot C_p(\lambda, \beta) \cdot \rho \cdot A \cdot v^3 \quad (5)$$

Where  $\rho$  is air density (kg/m<sup>3</sup>),  $C_p$  is power coefficient,  $A$  is intercepting area of the rotor blades (m<sup>2</sup>),  $V$  is average wind speed (m/s),  $\lambda$  is tip speed ratio. The theoretical maximum value of the power coefficient  $C_p$  is 0.593, also known as Betz's coefficient [12].

Fig. 2 shows the license wind turbine plate installed in the case study and Table (II) shows their technical and economic specifications.



| Model         | MAX 1200W            |
|---------------|----------------------|
| Rated power   | 1200W                |
| Max power     | 1300W                |
| Rated voltage | 48VDC/110VDC         |
| Rated current | 25A/10.9A            |
| Rated Rpm     | 650                  |
| Blades        | 5Pcs NylonFiberglass |

Fig. 2: Wind turbine plate studied.

#### C) BATTERIES

The maximum and minimum charge and discharge energy of the batteries are as follows:

$$Ch(t) \leq E_{ch, rated} \times S_{B1}(t) \quad (6)$$

$$Disch(t) \leq E_{disch, rated} \times S_{B2}(t)$$

Where  $E_{ch, rated}$  maximum charge power (kwh),  $E_{disch, rated}$  maximum discharge power (kwh),  $Ch(t)$  charge variable with limit  $0 \leq Ch(t) \leq E_{ch, rated}$ ,  $Disch(t)$  discharge variable with limit  $0 \leq Disch(t) \leq E_{disch, rated}$ .

Considering that only charging or discharging takes place at any moment, it is mathematically mentioned in Equation (7) [14].

$$S_{B1}(t) + S_{B2}(t) \leq 1 \quad (7)$$

The battery charge has a minimum and maximum limit and is as follows.

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (8)$$

$$SOC_{min} = N_{bt} \times (V_{bt} \cdot M_{Ah} \cdot (1 - dod))/1000$$

$$SOC_{max} = N_{bt} \times (V_{bt} \cdot M_{Ah})/1000$$

Where  $SOC_{min}$  the minimum charge of the battery pack (kW),  $SOC_{max}$  the maximum charge of the battery pack (kW),  $V_{bt}$  the nominal voltage of the battery (V),  $M_{Ah}$  the subtlety of each battery (Ah), dod the depth of discharge of the battery (in this study dod = 0.5).

Fig. 3 shows the license batteries plate installed in the case study and Table (III) shows their technical and economic specifications.

TABLE II  
TECHNICAL AND ECONOMIC SPECIFICATIONS OF THE WIND  
TURBINE

|                     |        |
|---------------------|--------|
| Rated power         | 1200W  |
| Rated voltage       | 12V    |
| Number of blades    | 5      |
| Rated wind speed    | 13m/s  |
| Survival wind speed | 50m/s  |
| Start-up wind speed | 2.0m/s |
| Wheel diameter      | 1.3m   |
| Blade length        | 58cm   |



Fig. 3: Batteries plate studied.

TABLE III  
TECHNICAL AND ECONOMIC SPECIFICATIONS OF THE  
BATTERIES

|                                     |             |
|-------------------------------------|-------------|
| Type                                | sealed acid |
| Capacity                            | 133 Ah      |
| Nominal voltage                     | 12 V        |
| Maximum charging current            | 33 A        |
| Life time at discharge of depth 50% | 653 cycles  |
| Purchase cost                       | \$ 112      |
| Replacement cost                    | \$ 112      |
| maintenance cost                    | 0           |

#### IV. SIMULATION AND RESULTS

In this research, planning and determining the optimal capacity of hybrid renewable energy systems in remote areas has been formulated, during which the optimal capacity of solar panels, wind turbines and batteries is determined and the optimal planning is done over a period of one year. The project life period is 15 years and the inflation interest rate is 10%. For convenience, planning the use of renewable energy has been formulated in two scenarios for a period of one year. Table (IV) shows results of the simulated scenarios.

TABLE IV  
THE RESULTS OF THE SIMULATED SCENARIOS

| Title                  | unit   | Scenario1 | Scenario2 |
|------------------------|--------|-----------|-----------|
| Solar module - 200 w   | Number | 16        | 0         |
| wind turbine - 1200 w  | Number | 1         | 0         |
| Converter              | Kw     | 4         | 0         |
| Battery - 100 amp-hour | Number | 25        | 0         |
| Net costs life cycle   | \$     | 16395     | 25262     |
| maintenance cost       | \$     | 1533      | 17762     |
| Energy prices          | \$     | 0.276     | 0.426     |
| Total renewable energy | Kwh/y  | 8993      | 0         |
| Total diesel function  | h/y    | 112       | 8760      |
| Total energy load      | Kwh/y  | 7801      | 7801      |

As shown in Table 4, Scenario 1 includes a combined solar panel / wind turbine / battery / diesel system. Net life cycle costs are much lower than in Scenario 2. The energy price in the first scenario is COE = \$ 0.276 / kWh and the energy price in the second scenario is COE = \$ 0.426 / kWh. This is due to the lower life cycle cost in scenario 1.

#### V. PRACTICAL IMPLEMENTATION OF THE PROJECT

The practical implementation of the renewable energy system faces limitations. Due to the operating voltage of the 42V converter, it is necessary for the batteries to be sealed as

a 48V bus. It is also necessary that the input voltage of the solar modules is always within the allowable range of the converter. Therefore, for the practical implementation of the renewable energy system, the required equipment is considered according to Table (V).

TABLE V  
THE RESULTS OF THE PRACTICAL SCENARIOS

| Title                  | unit   | Practical Scenario |
|------------------------|--------|--------------------|
| Solar module - 200 w   | Number | 20                 |
| wind turbine - 1200 w  | Number | 1                  |
| Converter              | Kw     | 4                  |
| Battery - 100 amp-hour | Number | 28                 |

Fig. 4 shows the exterior space and Fig. 5 and 6 the interior space of the combined renewable energy system under study.



Fig. 4: Overview of the system under study.



Fig. 5: Converter and controller charger of the studied system.



Fig. 6: Battery collection of the studied system.

## VI. CONCLUSIONS

Given the lack of access to the electricity distribution network in remote areas, rising fossil fuel prices and transportation costs, the importance of using renewable energy in these areas is increasing. Due to the high price of equipment such as wind turbine, solar panels and batteries, capacity sizing of the equipment is vital. In this research, the optimal design of practical implementation of renewable energy systems and mathematical modeling of various system equipment's were done. The system was implemented in practice by 4 kW solar panel, 28 sealed acid batteries with 4 kW converter and 1.2 kW wind turbine. Economic analysis shows that renewable energy systems will be utilized by a 35% reduction in costs relative to energy from diesel generators

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## CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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