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A Methodology for Optimal Selection of a Wind Power Conversation System Based on Economic Analysis

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***Abstract*—Wind energy is one of the most cost-effective and environmentally friendly form energy. One of the main topics that the wind researchers are investigating nowadays is wind power plant (WPP) energy output optimization. In this context, energy output optimization is related to the optimal selection of wind turbines. This paper utilized wind speed data over a period of 34 years between 1981 and 2014 (measured at the Karaburun Peninsula, Albania), in order to assess the energy output and cost-effectiveness for a 12 MW installed capacity WPP. The energy output analysis was completed using three wind energy conversion systems (WECS) of 600, 750 and 2,000 kW rated capacity. The RETScreen Expert model was used to perform the feasibility study of the WPP at the selected location. The study concluded that a wind power plant consisting of 6 wind turbines of 2,000kW rated capacity each is more feasible based on financial viability analysis. Finally, in terms of energy production cost, application of 2,000 kW wind turbine results in 0.058 €/kWh.**

Keywords—feasibility; wind energy; optimal selection; GHG; cost of electricity

I. Introduction

Wind energy offers a great opportunity to support sustainable development in those areas where it is accessible and hence decrease dependence on fossil fuel based energy. Other motivating factors for utilization of wind energy sources include rapid growth in demand for electricity, rising level of carbon emissions as a result of burning of fossil fuels, developing of technology, etc. More importantly, wind energy is believed to be a step on the ways to a healthy global environment in the future. Wind is playing a significant role in meeting the energy challenges that the world is facing nowadays [1]. Cumulative global wind energy capacity reached about 369,597MW at the end of 2014. 2015 was a great year for the wind power industry, with 44% annual market growth and record installations of more than 51 GW [2].

Thirty four years (1981 to 2014) of hourly wind speed records for the Karaburun Peninsula (40.39° N; 19.34° E; altitude 88 m; air density 1.211 kg/m^3) were adopted and analyzed in [3], [4], [5], [6]. The data were recorded continuously at a height of 50 m. Fig. 1 gives the whole data spread across this period considered using continuous measurements and Weibull probability density function. The two parameters of the Weibull were found to lie between $1.56 \leq k \leq 1.77$ and $6.26 \leq c \leq 7.84$ m/s. The annual mean wind speed ranged between 5.58 and 7.02m/s at 50 m height [3]. The monthly mean wind speed ranged between 4.99 and 7.38 m/s at 50 m height.

The technical analysis was carried out using generalized method of capacity factor (CF) proposed by [7]. Based on the generalized method of CF was found that between then different wind turbines, three of them were suitable for application at the selected location.

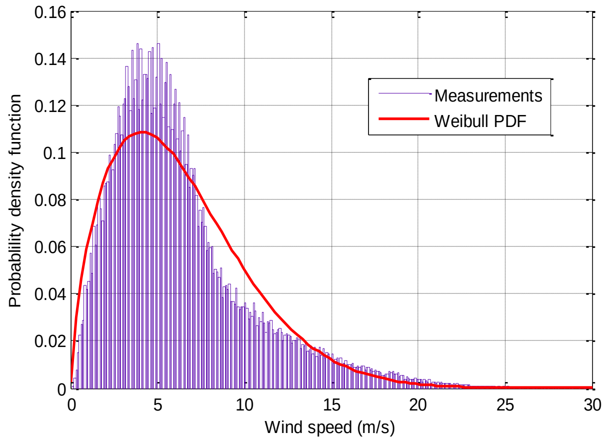

Fig. 1. *Measurements and Weibull PDF.*

The financial analysis is done to check whether or not the WPP is financially available. The financial feasibility study is performed in terms of discount rate (DR), net present value (NPV), annual life cycle saving (ALCS), benefit-cost ratio (B-C), simple payback period (SPP), equity payback period (EPP) and energy production cost/cost of electricity (EPC/COE). With the help of the above financial feasibility indicators, the scenarios are compared with each other. The financial summary worksheet, allows the project decision-maker to consider various financial parameters with relative ease [8], [9], [10], [11], [12].

The aim of this paper is to utilize the long-term wind speed data at a particular location, to investigate the best scenario through economic feasibility of wind power plants of an installed capacity of 12 MW. The energy calculations and economic analysis were performed using RETScreen Expert Software. The details of these calculations as various mathematical equations can be found in [13].

II. Materials and Methods

A. *Wind speed data*

Thirty four years of hourly wind speed measurements for the Karaburun Peninsula were adopted from Balkan Wind Atlas. The data were recorded continuously at a height of 50 m [3].

B. *Energy model*

The energy yield from a proposed wind power plant of 12 MW installed capacity is calculated by RETScreen Expert software using the monthly average wind speed at hub height and the energy production curve of the wind turbines. The RETScreen Expert software, an environment for investigating the technical and economic feasibility of potential different Renewable Energy projects is now being used by thousands of people around the world [9].

The estimation of wind energy is obtained by taking into consideration the effect of several losses like array (1.5 %), airfoil soiling (1%), miscellaneous losses (3%) and availability (97%). The coefficient of losses resulted 0.9175. The pressure and temperature adjustment coefficients which affect the energy yield were also considered, and are assumed as standard values 1 (101.3 kPa and 15ºC), respectively. A value of 0.143 for the wind shear exponent was used in this study [4], [9].

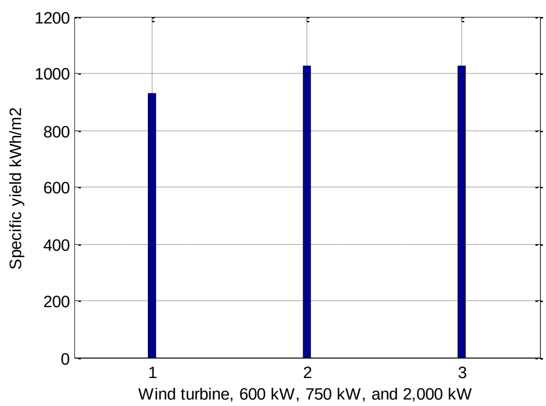

Fig. 2. Comparison of specific yield.

The gross energy production and wind energy delivered using wind turbines of rated capacity of 600, 750 and 2,000 kW are estimated. It is observed that the gross energy yield, without losses from WPP proposed, was found to 33,653.07, 29,738.06 and 35,400.28 MWh respectively. Wind energy delivered also follows the same trends including losses 8.25%.

The values of the specific yield at Karaburun Peninsula for 600, 750 and 2000 kW wind turbines are obtained 928.98 kWh/m^2, 1,026.13 kWh/m^2 and 1,025.07 kWh/m^2, respectively as seen in Fig. 2.

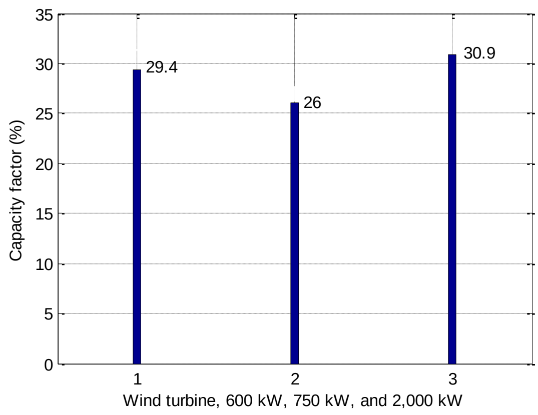

Fig. 3. Capacity factor.

The plant capacity factors obtained for all WECSs are shown in Fig. 3. A higher capacity factor of 30.9% is obtained from a power plant with 2,000 kW wind turbine.

C. *Emission analysis*

The RETScreen model also calculated the reduction of GHG as a result of using the wind as a source of energy to generate electricity [10]. The resulting values of GHG per year from all WECSs are presented in Fig. 4.

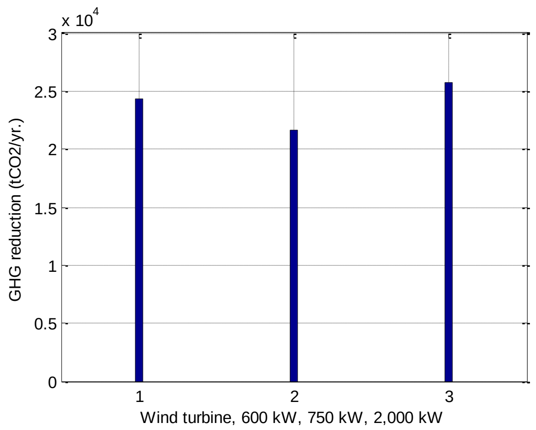

Fig. 4. Comparison of reduction in GHG/year.

Using 20 wind turbines of 600, 16 of 750 and 6 of 2,000 kW rated capacity at this location will result in a reduction in CO2 of 24,361, 21,588 and 25,693 tons each year respectively from entering into the local atmosphere thus creating a clean and healthy atmosphere for local inhabitants.

III. Results and Discussions

A. *Financial analysis*

The RETScreen Expert model is able of executing a detailed economics analysis of the wind energy yield using some financial parameters such as discount and inflation rates, GHG emission reduction credit, project life, energy cost escalation rate, etc. The inflation and discount rates of 3% and 9%, used in the present study, accompanied by other cost parameters are given in Table 1 [9].

TABLE I. Financial Parameters

Inflation rate	3 %
Discount rate	9 %
Project life	25 yr.
Debt ratio	50 %
Debt interest rate	5.8 %
Debt term	15 yr.

The initial costs, annual costs and debt payments, and annual savings and revenue (costs, savings, and revenue) including feasibility study development, engineering, power system balance of system & miscellaneous, O&M, debt payments, electricity export revenue and GHG reduction revenue – 25 years for the best scenario (2,000 kW wind turbine) are given in Table 2 [10], [12].

TABLE II. Initial and Annual Costs, and Savings

Costs	2,000 kW	
	Cost [€]	%
Feasibility study	42,300	0.2808
Development	338,500	2.2469
Engineering	117,500	0.7799
Power system	12,673,000	84.121
Balance of system & miscellaneous	1,893,832	12.571
Total Initial cost	**15,065,132**	**100**
Annual costs	1,139,948	
Annual savings and revenue	2,914,994	

As seen in Table 2, the major cost of €12,637,000 correspond to a WECS of 2,000 kW wind turbines and is about 84.12% of the total project initial cost.

The feasibility study is performed in terms of the internal rate of return (IRR), simple payback period (SPP), equity payback period (EPP), net present value (NPV), annual life cycle saving (ALCS), benefit-cost ratio (B–C), debt service coverage (DSC) and energy production cost (EPC), which are evaluated and displayed in Fig. 6, 7, and 8.

The IRR (including pre-tax IRR – equity and including pre-tax IRR – assets) for all scenarios using three different types of WECS is shown in Fig. 5, which indicates that the project of 12 MW installed capacity for all types of wind turbines is feasible for all scenarios at the selected location.

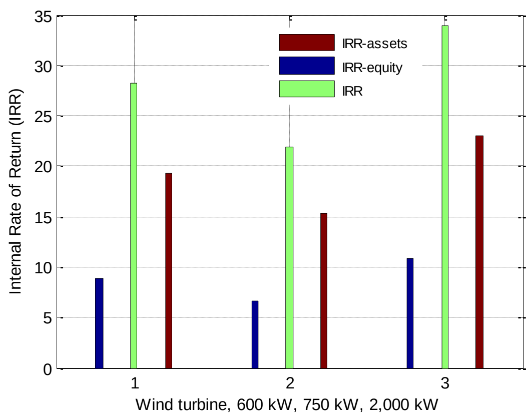

Fig. 5. Comparison of Internal Rate of Return (IRR).

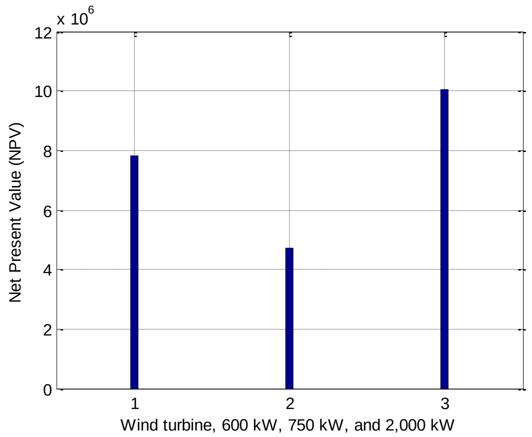

Fig. 6. Comparison of Net Present Value (NPV).

For 600, 750 and 2,000 kW rated power wind turbines the internal rate of return (IRR) was found to be 28.2%, 21.9%, and 33.9%, respectively. The after-tax values were also found to be the same as pre-tax values of IRR.

Positive values of NPV make evident that the proposed project is feasible. The NPVs calculated using the discount rate at 9%. Fig. 6 shows that the project is feasible for all scenarios and for all types of

WECS considered. For 600, 750 and 2,000 kW rated capacity wind turbines the net present values were found to be €7,833,381, €4,736,656, and €10,062,366, respectively.

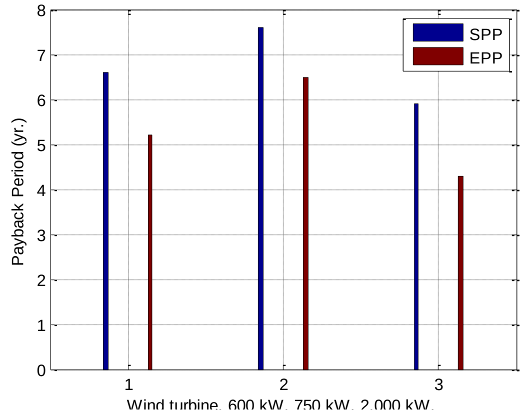

Fig. 7. Comparison of Simple Payback Period (SPP) and Equity Payback Period (EPP).

A wind power project with a shorter payback period is considered to be the winner. In other cases would be an evidence that the annual costs incurred are higher than the annual savings generated. Fig. 7 shows the SPPs estimated by the RETScreen Expert model for the proposed wind power plant using three wind turbines. Shorter SPPs are found for wind power plant developed using 2000 kW wind turbines.

The minimum payback period of 5.9 years is found for WPP corresponding to 2000 kW wind turbine. For 600 kW and 750 kW wind turbines, the SPP is 6.6 and 7.6 years, respectively. It is the same tendency for the EPP as seen in Fig. 7, and Fig. 8. The ALCS were found to be 797,487, 482,221 and 1,024,412 €/yr., respectively. The ratio of the net benefits to costs of the project is named benefit-cost ratio (B–C). B-C ratios greater than 1 are indicative of profitable projects. The B–C values are found to be 2, 1.6 and 2.3, respectively.

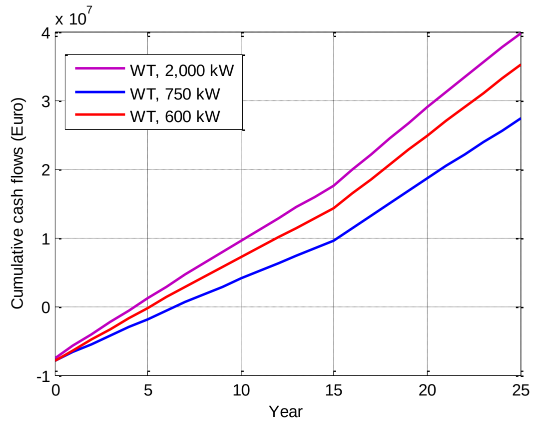

Fig. 8. Comparison of Simple Payback Period (SPP) based on cumulative cash flows.

The model estimates the energy production cost per kWh or MWh. The EPC is calculated assuming that all financial parameters including the avoided cost of energy are kept constant. The EPC of the 600, 750, and 2,000 kW wind turbine was found to be 0.064, 0.072, and 0.058 €/kWh, respectively.

IV. CONCLUSIONS

This paper presented a methodology for selecting the optimal WECS. The methodology was applied to a case study and an economic analysis of wind generation was carried out. The optimal selection based on economic analysis developed in this paper shows that the wind farm consisting of 6 wind turbines of 2,000 kW rated capacity each is more feasible compared to the other wind turbines. The main conclusions arising out of the economic analysis are presented here.

A. WPP of 12 MW installed capacity at the Karaburun Peninsula, if developed, could produce 32,480,422 kWh of electricity annually taking into consideration the standard values of temperature and pressure coefficients and all other losses of about 8.25%.

B. It was noted such a development at these sites could result in avoidance of 25,693 tons of GHG from entering into the local atmosphere of Vlora region each year and about 642,328 tons of GHG over the lifetime of the WPP.

C. The capacity factor of 6 *x* 2,000 kW WPP was found to be 30.9%. The economics feasibility study based on the assumed financial parameters exposed that a positive cash flow could be obtained in 5.9 year with a corresponding benefit-cost ratio of 2.3. Finally, in terms of energy production cost, application of 2 MW wind turbine results in 0.058 €/kWh.

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