Issues in the Technology Selection for a Wind Farm in Iran

AMIN ERFANI[1], **ROGHAYEH GHASEMPOUR**[2], **AND HASHEM ORAEE**[3]

[1,2] *Faculty of New Sciences and Technologies, University of Tehran, Iran.*
[3] *3Department of Electrical Engineering, Sharif University of Technology, Iran.*
[*] *Corresponding author:ghasempour.r@ut.ac.ir*

Manuscript received May 1, 2017; revised june 11: accepted July 3, 2017. Paper no. JEMT-1706-1024

Wind energy is the most economic and clean energy, which has considerably developed in recent years.Wind turbines can be classified by different indicators. One of the main classifications is based on the drive train and generator technologies. This study is based on a multi-parameter survey to develop an optimal decision-making algorithm for the technology selection. Two key technologies, including Permanent Magnet Generator (PMG) turbines and geared Doubly Fed Induction Generator (DFIG) turbines, are considered to be suitable options according to turbine and sites' technical, economic and geographical parameters. Economic indices, such as IRR and NPV of a wind farm, are reported for each technology used in the model.

A 50MW wind farm in Iran has been modeled in this article as a case study. Results show that according to Iran's financial and economic fluctuations, a DFIG turbine, with 43% IRR and 52 M€ NPV is the most efficient technology for Iran. Specifically, its low initial investment and high efficiency and 48% capacity factor make this turbine as the most suitable technology for Iran. Results show that 3.9 and 4.2 years payback period for DFIG and PMG wind turbines respectively, therefore the PMG turbines require a longer payback period for the wind farm.

keywords: *Renewable Energy, Wind Energy, Turbine Technologies, Wind farm Modelling, Financial Analysis*

http://dx.doi.org/10.22109/JEMT.2017.49435

1. INTRODUCTION

Different technologies are employed to convert wind energy to electrical power [1, 2]. Wind turbine technology is well developed and widely used. There are various commercial wind turbines. Turbine drive trains and their technical parameters have been widely studied [3,4]. The principle of wind turbine operation consists of two well-known processes. First, it involves the conversion of kinetic energy of moving air into mechanical energy. This is accomplished by using aerodynamic rotor blades and a variety of methodologies used to control the mechanical power. The second process includes electro-mechanical energy conversion through a generator that is transmitted to the electrical grid [5].

It is important to identify an optimum selection of wind turbine based on various economic and technical factors. Most of the studies on the optimum selection of wind turbine have largely focused on a single parameter [6,7], and only a few studies have incorporated more than one parameter simultaneously into their model [2–8]. A number of variables are important in the performance of a turbine. Among them, technical parameters of turbines, wind farm location, existing infrastructures, wind conditions and cost calculations, are the most relevant factors in determining the efficiency of a wind farm. In fact, it is crucial to select the most appropriate technology for a particular wind site, based on its location, wind potential, economic parameters and existing infrastructures. Previous studies have investigated and compared different technologies and parameters individually. Most of them have studied on turbine without considering wind farm parameters. M. G. Khalfallah and A.M. Koliub show the effect of dust on an individual wind turbine performance [9]. It indicates that the dust particles size is effective issue that wind turbine height and rotor diameter may change dust effect on turbines performance. However Khalfallah studied that wind farm specifications matter too, but not study on wind farm parameters. Therefore, a dynamic and comprehensive model should include multiple variables relevant to the performance of wind farms, namely its location, wind regime and economic parameters.

Sathyajith Mathew et al have investigated wind regime parameters effect on the performance of wind turbines [10]. This study shows that apart of cut-in and rated speed of wind turbines, wind farm site parameters have to be considered for final analyses and evaluation. They didn't specified different technologies and wind regime effect on different turbines technical parameters. Other researches like [11–13], have investigated technical parameters of turbines like output generated power. These studies are regardless of site, geotechnical parameters and turbines generator technology.

This study proposed a dynamic model based on technical and economic factors in order to find an optimum solution for a wind farm.

This study analyzed two leading and advanced wind turbine technologies, namely Doubly Fed Induction Generator (DFIG) and Permanent Magnet Generator (PMG), focusing on the technical and economic factors of a wind farm located in Khaf, Iran. From the analysis, a dynamic model has been derived that includes technical parameters of the wind turbines, site location, economic factors and wind potentials. The results are based on a financial analysis and a comparison of the two turbine technologies.

2. METHODOLOGY

A. Site and Wind Regime Characteristics

Case study wind farm of this article is located in Khaf, Khorasan Razavi province in Iran. Khaf region is in the northeast of Iran and has a great wind energy potential. Three anemometer sensors (80m, 60m and 40m) and two wind vane sensors (80m and 60m) have been installed on this met mast. 80m met mast wind data [14] has been used in this study which, is shown in "Technical Results".

B. Doubly Fed Induction Generators (DFIG) with gearbox

DFIG turbine is the most common technology in the wind energy sector. The main components of the drive train are gearbox system, doubly fed induction generator and a partially rated convertor [4]. The stator is connected to the grid directly, whereas the rotor is connected to the grid through a power electronic converter. The power converter controls the rotor frequency and speed [15]. This concept supports a wide speed range of operation, depending on the size of the frequency converter. Typically, the variable speed range is 30% around the synchronous speed [16].

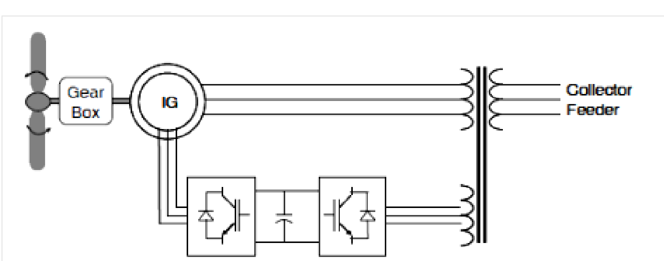

Fig. 1. DFIG drive train [5]

Table 1. Wind turbines characteristics

Turbine	DFIG-3G	PMG-DD
Weight (Ton) [23–25]	60.3	94.5
Availability factor [26]	96.5%	98%
V_c [27–29]	4	3
V_r [27–29]	11	10
V_{off} [27–29]	24	25
Investment cost (K€)	1412	1561
Operation cost (K€) [30,31]	72	76

The most important advantage of DFIG turbine is its low cost, acceptable efficiency and reduced electrical losses due to partially rated convertor [5].

C. Gearless Permanent Magnet Generators (PMG)

PMG turbines are commonly used as direct drive variable speed wind turbines. The advantage of these turbines is their low operating and maintenance (O&M) costs, which are even lower in the gearless PMG turbines since the gearbox is eliminated. The gearbox is the most significant mechanical part of a wind turbine, which usually has high maintenance costs [17]. Wind turbines can be connected to a generator directly, the so-called direct-drive, or through a gearbox. In the direct-drive connection, the gearbox is omitted which reduces the maintenance cost and increases the reliability [18].

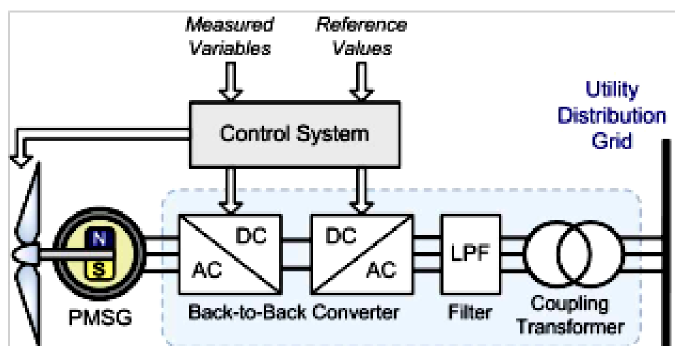

Fig. 2. PMG drive train [19]

However, PMG turbines require a higher capital investment, though they provide a higher operational efficiency. Many large wind turbine manufacturers, such as Enercon, Goldwind and turbines are now using these technologies [20–22]. Furthermore, PMG turbines have a smoother output power [18] and are the most appropriate candidate for some grid codes.

D. DFIG and PMG turbines characteristics

The main characteristics and economic performance of DFIG and PMG turbines are presented in Table 1.

In both technologies, the costs related to construction, engineering and management are identical. Also, the costs of blades, tower and transformers are identical for both technologies. The highest cost differentials are due to their generator, gearbox, converter and transportation. Transportation costs are a function

Table 2. Drivetrain costs of turbines

Type	DFIG – 3G	PMG – DD
Generator (K€)	23	170
Gearbox [24] (K€)	96	0
Converter (K€)	17	50

of component weight, which is calculated using the following equations [16,23,24,32]:

$$C_{DFIG} = 1.1 \times Weight_{DFIG} \quad (1)$$

$$C_{PMG} = (157 \times ratedtorque_{PMG} + 20)/5 \quad (2)$$

$$T = \frac{\rho}{\omega}$$

$$\omega = R/(\lambda.v) = (2\pi N)/60$$

Where T, P,ω, R and λ are the rated torque, Power, Rotor speed $(1/s)$, Rotor diameter and speed ratio respectively.

$$C_{conv} = S \times \delta \times turbinerating \quad (3)$$

Where $\delta = 50$, C_{Conv} and S are Cost and Size ratio respectively.

Based on (1) and (2) and also PMG and DFIG generator data sheets [28–33], cost per megawatt of generators are presented in Table 2:

Other parts of the initial capital expenditure (CAPEX) are obtained from a wind farm analysis report as the percentage of total cost (Figure 3).

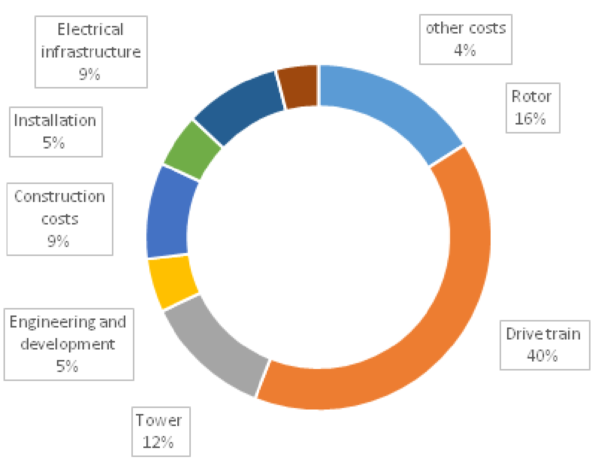

Fig. 3. Wind farm investment cost breakdown [34]

3. TURBINE SELECTION MODEL

A dynamic model for selecting the most appropriate drive train technology for the site is selected and used. The related parameters can be classified into three main categories: technical, economic and power generation potential parameters.

A. Technical parameters

Electrical output power is mostly affected by mechanical parameters of turbines. Three critical turbine speeds (cut in, cut off and rated speed), which are very important for calculating turbines' output power, are obtained from the turbines' power curves [27,28,35].

The overall efficiency of a turbine depends on the efficiency and loss of its parts. In order to model turbines' actual generated power, availability factor has to be considered as a critical parameter that indicates the total number of hours which a turbine is available for power generation. This factor is determined by historical data on maintenance schedules, using the following relation [30].

$$A.F. = \frac{(8760 - T_off)}{8760} \quad (4)$$

$$T_{off} = \sum T_i$$

where A.F. is the availability factor and T_i is the total turn off duration of the turbine.

B. Power generation potential parameters

The generated electrical power is calculated and used in modeling a wind farm and its performance. The most significant parameters in calculating wind farm energy generation are wind data, Weibull curve of the wind, wake effect and critical speeds of the wind turbine power curve. These parameters, coupled with various technical parameters, are very important in calculating the turbine and wind farm capacity.

C. Economic parameters

To compare the performance of different wind turbine technologies in terms of economic criteria, some of the most important economic parameters are considered in the model. Some of turbine and wind farm costs, such as the costs associated with design, roads and site construction, are alike. Furthermore, some component costs, such as blades, tower and electrical equipment, are identical (Figure 4).

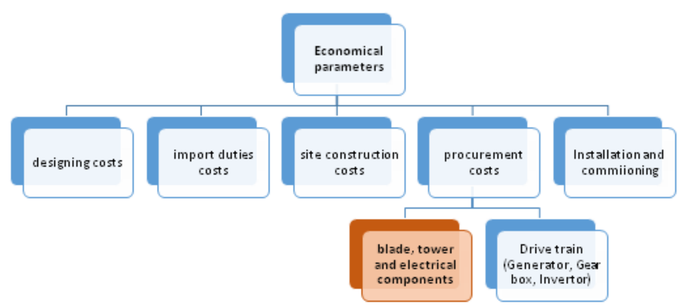

Fig. 4. Wind farm costs breakdown

The most significant costs are the investment costs of drive trains, which vary between different technologies, transportation costs, are related to the size, weight, and import duties. Also in this model, the annual maintenance costs of different technologies have been included.

Economic parameters and the annual generated energy will be applied in the analysis. In this model, the economics of a wind farm is analyzed. Assumptions such as discount rate, interest rate, the purchase price of electricity, and inflation rate are included in the model.

The output of the model is presented through three main economic indices, based on the technical and economic analysis of a wind farm and its location, which assists an investor in identifying the optimum technology. The three main indices are NPV (Net Present Value), IRR (Internal Rate of Return) and payback period of the project.

4. MODELING

A. Technical formulation

In order to model the annual generated energy of the turbine or the wind farm, the capacity of the turbine or wind farm is calculated based on the wind data and the turbine's technical parameters. Wind flow characteristics are usually defined by the Weibull distribution function. The wind distribution can be described by two main parameters: shape factor and scale factor [36]. The probability function for a given duration of wind flow is expressed by (5) [37].

$$f(V) = \frac{K}{C}(\frac{V}{C})^{(k-1)}.exp(-(\frac{V}{C})^{k}) \quad (5)$$

where K, C and V are shape factor, scale factor and wind speed respectively. The Capacity factor is defined as:

$$C.F. = (E.P_{nominal})/T \quad (6)$$

Where

$$E = T[\int_{V_c}^{V_off} P(v).f(v)dv] \quad (7)$$

T is the total duration of production in hour and P is the generator power in the particular wind speed (v).

The output power of the turbine is a function of wind speed within the range of V_c and V_{off}, which is usually expressed as an exponential function.

Combining (2) and (3) and using the standard turbine power curve, the capacity factor is calculated as follows [37]:

$$\begin{aligned} C.F. = &-G(V_{off}) + 1/8[(1-\alpha).G(V_c) + (1+\alpha).G(V_r) \\ &+(3+\alpha).G(\tfrac{(V_c+2V_r)}{3}) + (3-\alpha).G(\tfrac{(2V_c+V_r)}{3}) \end{aligned} \quad (8)$$

$$G(v) = exp(-(\frac{V}{C})^{k}) \quad (9)$$

$$\alpha = \frac{(V_r+2V_c)V_r}{(-0.08V_c - 0.05V_{rc} + \beta)(V_r^2 - V_c^2)} \quad (10)$$

$$2 < \beta < 4$$

The actual annual energy generation of the wind turbine or wind farm is then calculated based on the capacity factor, availability factor (A.F) and wake effect (W.E) of the wind farm using the following relation:

$$E_{an} = C.F \times A.F \times W.E \times 8760 \times Cap.(MW) \quad (11)$$

B. Cost calculations

• NPV

Net Present Value is the difference between the present value of cash inflows and outflows. NPV is used in capital budgeting to analyze the profitability of a projected investment or a project. It also determines the size of the project [38]

$$NPV = \{AnnualCashflow\} \times \{((1+d)^{-t})\} \quad (12)$$

• IRR

Internal Rate of Return (IRR) is a metric, used in capital budgeting, which measures the profitability of potential investments. The IRR is a discount rate that makes the NPV of all cash flows in a particular project equal to zero. The internal rate of return also indicates the economic efficiency of a project [39]. This variable is important in the economic analysis of a project.

$$\sum_{0}^{T} AnnualCashflow \times ((1+i)^{-t}) = 0 \quad (13)$$

i: Internal Rate of Return

• Power Purchase Agreement

Various methods are used in different countries to purchase green energy from renewable power plants, including tendering, Power Purchase Agreement (PPA), and free market. Tendering system and Feed-in Tariffs (FiT) are the most important power purchase methods.

In this study, a wind farm in Khaf, located in the northeast of Iran, was selected for the analysis. In Iran, FiT and PPA are in operation. The duration of guaranteed contract is 20 years. The purchase price for a 50MW wind farm is obtained as follows.

$$R = 8760 \times C_F \times P_N \times I \quad (14)$$

R: Annual Income

CF: Capacity Factor

PN: Rated power

I: Power purchase price

The base part of FiT is adjusted by the following index:

$$H = (CPI_i/CPI_F)^{\alpha} \times (EUR_i/EUR_F)^{1-\alpha} \quad (15)$$

$$\begin{aligned} CPI_n &= CPI_{n-1} \times (1+i) \\ CPI_{2016} &= 250 \end{aligned} \quad (16)$$

- H : the adjustment factor
- CPI_i : Retail price index in the first payment year
- CPI_F: Retail price index in the first contract year
- EUR_i: Average of Euro/Iranian Rial in the interval of 365 days before the payment
- EUR_F: Average of Euro/Iranian Rial in the interval of 365 days before the contract
- α: A parameter which is specified by the owner of the wind farm based in the interval of 0.15 to 0.30

C. Economic Analysis Assumptions

As a case study, a 50MW wind farm in Khaf, Iran was modeled. Tables 3 and 4 show the assumptions according to the economic situation and power purchase agreement that are currently in operation.

Table 3. Financial assumptions

Financial Assumptions	Amount
Local Inflation rate	14%
Exchange Inflation rate	10%
Discount rate	20%
Euro / Rial [40]	35,349

Table 4. Power Purchase Agreement [41]

Power Purchasing Parameters	Amount
Power purchase agreement period	20 years
First year Price [42]	4200 Rial
Adjustment Regulation	Adjustment Factor
First year retail sale index [40]	250

Table 5. Wind analysis results

Characteristics	Amount
Mean wind speed	10.3 m/s
shape factor	1.727
Scale factor	11.664

5. RESULTS AND DISCUSSIONS

A. Technical results

The results indicate wind behavior and annual energy generation, according to turbine and wind characteristics. Table 5 shows the wind characteristics of Khaf wind corridor within a year, at an elevation of 80 meters for every ten minutes.

Figs. 5 and 6 illustrate the wind data analysis and Weibull curve for Khaf respectively.

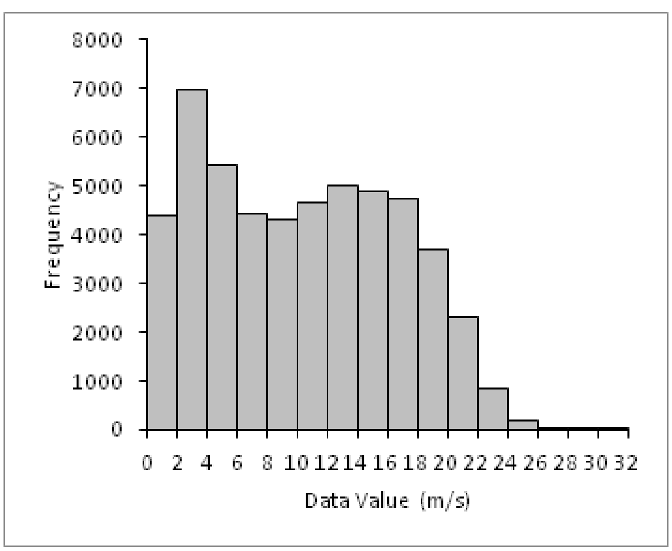

Fig. 5. Khaf wind data

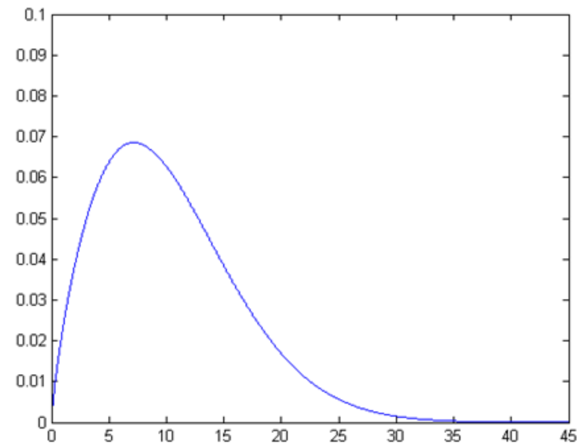

Fig. 6. Weibull curve of Khaf wind data

Table 6. Wind turbines characteristics

Characteristics	Vestas 2MW,V90 wind turbine	Goldwind 2.5MW PMDD
Capacity	2MW	2.5MW
Hub height	90m	90m
IEC Class	IIA	IIA
Rotor Diameter	90m	109m
Gearbox	two helical stages and one planetary stage	-

Table 7. Technical results

Technology	DFIG-3G	PMG-DD
Wind farm capacity (MW)	50	50
Capacity Factor (%)	48%	50%
Availability factor (%)	96%	98%
Yearly production (MWh)	212,786	220,261

Table 6 shows two different types of wind turbine, which are used in this study. Vestas 2MW, V90 turbine [43] is picked as DFIG turbine and Goldwind 2.5 MW turbine [29] is picked as a variable speed turbine. Both turbines are selected from pioneer brands and almost same class.

Table 7 shows the technical results of the model for a 50MW wind farm n Khaf at an elevation of 80 meters in every ten minutes.

As shown in Table 7, PMG turbine gives a higher capacity factor due to the higher availability factor, lower turbine losses and the suitable power curve. The annual production of the PMG turbine is about 4% higher than that of the DFIG, which translates to higher annual revenue for the wind farm (Figure 7).

B. Financial Results

The financial results of the 50MW wind farm in Khaf can be obtained by the proposed model. Table 8 and Figs. 8-10 show the overall financial results of the case study. Table 8 and Figs. 8 - 10 show that although the annual production of PMG turbine is higher than that of DFIG turbine, because of the higher CAPEX of PMG turbines, DFIG turbines provide better financial results

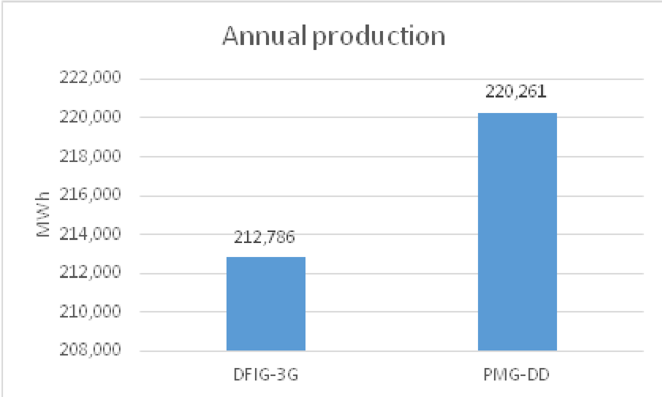

Fig. 7. Annual production comparison

Table 8. Financial results

Turbine	IRR (%)	NPV (M)
DFIG	43	52.4
PMG	41	49.9

for this project.

Given the high inflation rate in Iran, CAPEX is the most important factor in the project analysis, and even with a 4% lower revenue, DFIG gives us better financial results. Also, the payback period is 3 months shorter.

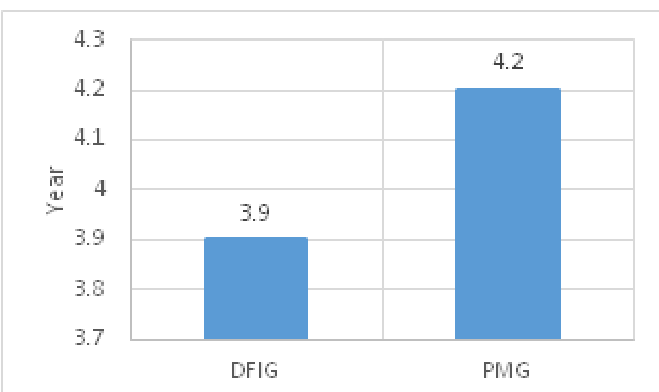

Fig. 8. Payback period comparison

6. CONCLUSIONS

The pros and cons of a technology optimize it for a specific circumstance, location and wind regime. In this study, the two main technologies of wind turbines were studied and modeled for a 50MW wind farm in Khaf, Iran. These technologies are the geared Doubly Fed Induction Generator (DFIG) wind turbine and the direct drive Permanent Magnet Generator (PMG) turbine, which both are the most commonly used wind turbines worldwide.

Results from the proposed model show that direct drive PMG turbine has better efficiency and higher annual generation. The predicted capacity factor for the PMG turbine is 50%, while the corresponding figure for the DFIG turbine is 48%. The annual

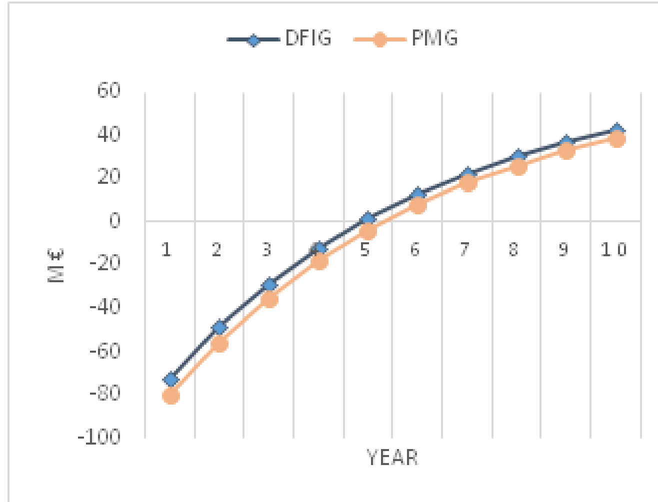

Fig. 9. Cumulative present value

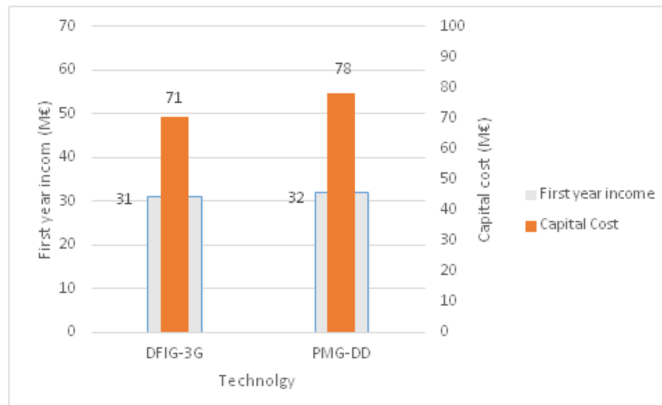

Fig. 10. Costs and income of technologies

revenue of the PMG turbine is 4% higher than that of DFIG wind turbine.

On the other hand, compared to the PMG turbine, DFIG wind turbine needs a lower investment, which makes it economically more attractive. Results show that in countries like Iran, with an unstable economic situation, high inflation rate, and a shorter payback period, the lower initial investment is more important than a long-term benefit plan. As a result, a DFIG geared turbine is, in fact, a better choice for such a context. The DFIG turbine with 3.9 years payback period and 43% IRR is the optimum choice for this case study in Khaf.

As the economic situation becomes more stable, PMG can be a good choice due to the fact that it gives 4% higher generation and annual income, compared to DFIG turbine. The long-run analysis over a 10-year period in Figure 9 shows that PMG turbine is as well as DFIG. This suggests that in an economic situation with lower inflation and discount rates, or with a long-term finance facility, PMG turbines have better results.

REFERENCES

1. H. Gorginpour, H. Oraee, and R. A. McMahon, "A novel modeling approach for design studies of brushless doubly fed induction generator based on magnetic equivalent cir-

cuit," *IEEE Transactions on Energy Conversion*, vol. 28, no. 4, pp. 902–912, 2013.

2. E. Abdi, M. Tatlow, R. McMahon, and P. Tavner, "Design and performance analysis of a 6 mw medium-speed brushless dfig," in *Renewable Power Generation Conference (RPG 2013), 2nd IET*, pp. 1–4, IET, 2013.
3. E. Rareshide, A. Tindal, C. Johnson, A. Graves, E. Simpson, J. Bleeg, T. Harris, and D. Schoborg, "Effects of complex wind regimes on turbine performance," in *Proceedings American Wind Energy Association WINDPOWER Conference (Chicago, IL)*, 2009.
4. W. Cao, Y. Xie, and Z. Tan, "Wind turbine generator technologies," in *Advances in Wind Power*, InTech, 2012.
5. E. Camm, M. Behnke, O. Bolado, M. Bollen, M. Bradt, C. Brooks, W. Dilling, M. Edds, W. Hejdak, D. Houseman, *et al.*, "Characteristics of wind turbine generators for wind power plants," in *Power & Energy Society General Meeting, 2009. PES'09. IEEE*, pp. 1–5, IEEE, 2009.
6. H. Arabian-Hoseynabadi, P. Tavner, and H. Oraee, "Reliability comparison of direct-drive and geared-drive wind turbine concepts," *Wind energy*, vol. 13, no. 1, pp. 62–73, 2010.
7. T. Einervoll, "Impact on wind turbine systems from transient fluctuations in offshore utility grids," Master's thesis, Institutt for elkraftteknikk, 2009.
8. T. Ackermann and L. Söder, "Wind energy technology and current status: a review," *Renewable and sustainable energy reviews*, vol. 4, no. 4, pp. 315–374, 2000.
9. M. G. Khalfallah and A. M. Koliub, "Effect of dust on the performance of wind turbines," *Desalination*, vol. 209, no. 1-3, pp. 209–220, 2007.
10. S. Mathew, G. S. Philip, and C. M. Lim, "Analysis of wind regimes and performance of wind turbines," in *Advances in Wind Energy Conversion Technology*, pp. 71–83, Springer, 2011.
11. B. Ernst, Y.-H. Wan, and B. Kirby, "Short-term power fluctuation of wind turbines: Analyzing data from the german 250-mw measurement program from the ancillary services viewpoint," tech. rep., National Renewable Energy Lab., Golden, CO (US), 1999.
12. T. Einervoll, "Impact on wind turbine systems from transient fluctuations in offshore utility grids," Master's thesis, Institutt for elkraftteknikk, 2009.
13. K. Toshimitsu, H. Kikugawa, K. Sato, and T. Sato, "Experimental investigation of performance of the wind turbine with the flanged-diffuser shroud in sinusoidally oscillating and fluctuating velocity flows," *Open Journal of Fluid Dynamics*, vol. 2, no. 04, p. 215, 2012.
14. B. Co., "Production report and 80m met mast data.," tech. rep., http://beheen.com/Projects.aspx?C-ID=110, 2015.
15. J. Fletcher and J. Yang, "Introduction to the doubly-fed induction generator for wind power applications," in *Paths to Sustainable Energy*, InTech, 2010.
16. H. Li and Z. Chen, "Overview of different wind generator systems and their comparisons," *IET Renewable Power Generation*, vol. 2, no. 2, pp. 123–138, 2008.
17. S. Alshibani, V. G. Agelidis, and R. Dutta, "Lifetime cost assessment of permanent magnet synchronous generators for mw level wind turbines," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 1, pp. 10–17, 2014.
18. A. H. Isfahani, A. H.-S. Boroujerdi, and S. Hasanzadeh, "Multi-objective design optimization of a large-scale direct-drive permanent magnet generator for wind energy conversion systems," *Frontiers in Energy*, vol. 8, no. 2, p. 182, 2014.
19. M. Molina, A. Sanchez, and A. R. Lede, "Dynamic modeling of wind farms with variable-speed direct-driven pmsg wind turbines," in *Transmission and Distribution Conference and Exposition: Latin America (T&D-LA), 2010 IEEE/PES*, pp. 816–823, IEEE, 2010.
20. T. Switch, "M.-s.p.m.g., pmg 1650-6400 kw", datasheet," tech. rep., Finland,, January 2013.
21. Enercon, "Available from," tech. rep., http://www.enercon.de/en/products/., 2016.
22. Goldwind., "Available from," tech. rep., http://www.goldwindglobal.com/web/solutions.do?action=technolo 2016.
23. L. Fingersh, M. Hand, and A. Laxson, "Wind turbine design cost and scaling model," tech. rep., National Renewable Energy Laboratory (NREL), Golden, CO., 2006.
24. E. Aydin, "Determination of best drive train technology for future onshore wind turbines as a function of the output power," 2013.
25. H. Li and Z. Chen, "Design optimization and evaluation of different wind generator systems," in *Electrical Machines and Systems, 2008. ICEMS 2008. International Conference on*, pp. 2396–2401, IEEE, 2008.
26. J. M. P. Pérez, F. P. G. Márquez, A. Tobias, and M. Papaelias, "Wind turbine reliability analysis," *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 463–472, 2013.
27. Siemence, "Available from," tech. rep., http://www.energy.siemens.com/nl/en/renewable-energy/wind-power/platforms/.
28. "Available from," tech. rep., https://www.vestas.com/en/products$_{a}nd_{s}ervices/turbines$.
29. Goldwind, "Goldwind pmg wind turbine," tech. rep., http://www.goldwindamericas.com/sites/default/files/Goldwind2016.
30. A. Albers, "O&m cost modelling, technical losses and associated uncertainties," in *Proceedings of the 2009 European Wind Energy Conference, Marseilles, France, March*, 2009.
31. Y.-S. Xue, L. Han, H. Li, and L.-D. Xie, "Optimal design and comparison of different pm synchronous generator systems for wind turbines," in *Electrical Machines and Systems, 2008. ICEMS 2008. International Conference on*, pp. 2448–2453, IEEE, 2008.

32. D.-j. Bang and H. Under, "Promising direct-drive generator system for large wind turbines," *in 2008 Wind Power to the Grid-EPE Wind Energy Chapter 1st Seminar*, 2008.

33. Enercon, "Enercon wind energy converters,technology service," tech. rep., http://www.enercon.de/en/downloads/., 2016.

34. e. a. Moné, C., "2013 cost of wind energy," tech. rep., http://www.enercon.de/en/downloads/., 2015.

35. Suzlon, "2available from:," tech. rep., http://www.suzlon.com/products/.

36. D. Indhumathy, C. Seshaiah, and K. Sukkiramathi, "Estimation of weibull parameters for wind speed calculation at kanyakumari in india," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 3, no. 1, pp. 8340–8345, 2014.

37. M. Bencherif, B. Brahmi, and A. Chikhaoui, "Optimal selection of wind turbine generators," *International Journal of Computer Applications*, vol. 92, no. 10, 2014.

38. M. Hovey, *Spreadsheet modelling for finance*. Pearson Education Australia, 2005.

39. J. M. Moten Jr and C. Thron, "Improvements on secant method for estimating internal rate of return (irr)," *International Journal of Applied Mathematics and Statistics™*, vol. 42, no. 12, pp. 84–93, 2013.

40. C. Iran, "Central bank of iran2016;," tech. rep., Available from: Central Bank of Iran, 2016.

41. r. Iran, "Renewable energy guaranteed power purchase agreement.," tech. rep., Available from: http://www.suna.org.ir/fa/purchase/purchase2., 2016.

42. I. Organization, "Iran new feed in tariff.," tech. rep., Available from: http://www.suna.org.ir/fa/guidance/guidance/guidance1., 2015.

43. Vestas, "Vestas 2mw v90 wind turbine," tech. rep., Available from: https://www.vestas.com/en/products/turbines/v90-2$_{0m}w!technical - specifications$, 2016.