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Feasibility Study and Developing Appropriate Hybrid Energy Systems in Regional Level

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***Abstract*—**Iran has several potential for using renewable energies, so use them could significantly contribute to energy supply. The purpose of this paper is to identify the potential of the country and select the appropriate DG technologies with consideration the potential and primary energy resources in the regions. In this context, hybrid energy systems proportionate with the potential of different regions will be determined based on technical, economic, and environmental aspect. In the following the proposed structure will be optimized in terms of size and cost. DG technologies used in this project include photovoltaic system, wind turbine, diesel generator and battery bank. The HOMER software is applied for choosing the appropriate structure and the optimization of system sizing. The results have been analyzed in terms of technical and economic. The performance and the cost of each project demonstrate the appropriate structure of hybrid energy system in that region.

***Keywords*—**Feasibility, Hybrid Energy System, Iran, Renewable Energy.

I. Introduction

ENERGY is the most important and most essential principle known in economic development. Nowadays, the bulk of energy demand used for economic and social growth is supplied by fossil fuels [1]. On the other hand, the significant increase in energy consumption, non-renewable nature of fossil fuel, high fossil fuel costs, and environmental concerns are major factors in the development of renewable energies. Energy consumption is rapidly increasing in developing countries, which have a significant impact on climate change and global and regional energy management. Mentioned issues lead to many countries planning to reduce dependence on fossil fuels as the primary energy source. Appropriate generation expansion with regard to long-term generation expansion planning can be done with renewable energy sources.

Among the different energy sources, electricity has a key role in achieving political and economic development. Electrical energy consumption is rapidly increasing in Iran as a developing country. Then, the government has the responsibility to plan and build a new plant to increase production capacity in the country. Also it should be noted that the state sector cannot develop the generation for all regions. So, encourage the private sector is necessary to participate in the generation development process. In this regard, from the perspective of the private sector invest in the Distributed Generation (DG) is very important due to lower initial construction investment and lower financial risk [2]. In recent years, the Iranian department of energy has encouraged the private investors and companies to invest in distributed generation units to supply the energy demands. This strategy is for restructuring in power system and moving towards privatization.

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Multiple energy sources including Wind Generator (WG), Photovoltaic panels (PV), Fuel Cells (FC), diesel generators, gas turbines and micro turbines can be combined together to form an hybrid energy system [3]-[10]. Among them, solar and wind are the most important sources of renewable energy. Therefore, the development of energy systems with WG and PV has a significant progress. The solar-wind hybrid system is a new energy source which due to environmental aspect and being renewable, many countries are interested in applying this structure and performing extensive research [11]. But because of the intermittent nature of wind and solar, using the energy storage for use in times of need is necessary. Often the batteries are used for energy storage [5], [11]. Also, the combination of FC and electrolyzer also are used for energy storage [7]-[10], [12]. So with the proper combination of DG technologies and suitable energy management, a high reliability hybrid energy system could be used to meet the load [3]-[10].

National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewable (HOMER) software has been employed to carry out the present study. HOMER performs comparative economic analysis on a distributed generation power systems.

Inputs to HOMER will perform an hourly simulation of every possible combination of components entered and rank the systems according to user-specified criteria, such as cost of energy (COE, US$/kWh) or capital costs. Furthermore, HOMER can perform 'sensitivity analyses' in which the values of certain parameters (e.g., solar radiation or wind speed) are varied to determine their impact on the system configuration [13].

Iran has 17 Regional Electricity Companies (REC), 28 Electrical Power Management Companies and 42 Electrical Power Distribution Companies. The purpose of this paper is identifying the potential of the primary energy resources available in each REC and selecting the DG technology proportional to each region. In this regard, the hybrid energy systems appropriate for different regions based on economic characteristics, performance and environmental features will be analyzed and optimum structures will be suggested.

This paper is organized as follows: In Section II, the renewable energy sources in Iran is reviewed. Section III shows how the optimization problem is simulated, with details of the load profile and weather data. Technical and economic analysis of hybrid energy systems are presented in Section IV. Finally, the conclusion of the paper is described in Section V.

II. Renewable Energy Sources in Iran

In recent years, Iran has increased the use of renewable energy. The investments on solar and wind energy lead to increase generation capacity of wind and solar power plants. For example, 'Yazd' (REC 12) is center of development power generation from solar and 'Khorasan' (REC 15) is center of development power generation from wind in Iran. In addition to these two regions, many other areas around the country have been identified that number of days with direct sunlight or number of days with high wind speed are high [14].

In the past few years with the help of international institutions such as the German Research Institute wind and solar maps have developed for investment in renewable energy. Some of the available potential in the country has described in the following.

A. Wind Energy Potential in Iran

Studies and estimating calculations in the wind energy potential in Iran have shown proper potential of wind energy. Fig. 1 shows the potential sources of wind power in Iran in 20 *m* altitude. As shown in Fig. 1, wind power projects in three provinces of Gilan (REC 3), South Khorasan (REC 15), and Sistan and Baluchestan (REC 16) are economically affordable.

In 2004, from 33,000 MW power production in Iran, only 25 MW were produced by wind power. In 2006, the contribution of power generated by wind power was 45 MW. In 2008, wind power capacity in Manjil (in Gilan province-REC 3) and Binalud (in Khorasan Razavi Province-REC 15), was 82 MW. The wind power capacity in 2009 was 130 MW.

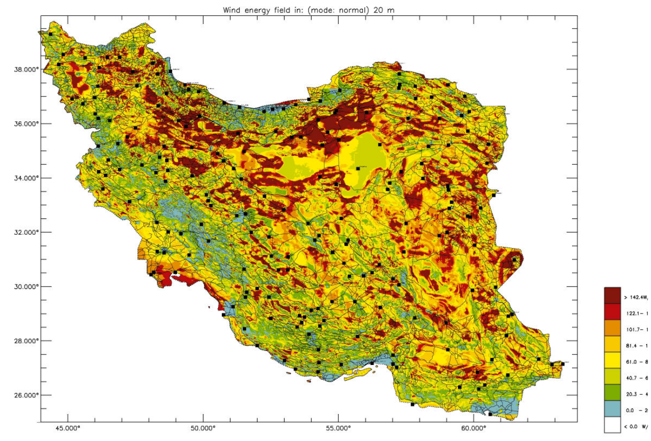

Fig. 1 Potential sources of wind power in Iran in 20 m altitude [14]

B. Solar Energy Potential in Iran

Iran is located in areas of high solar radiation. Studies show that the use of solar energy in Iran is appropriate and can provide part of the energy demands of the country. Iran is a country with 300 sunny days in more than two/thirds of country. The average solar radiation between 4.5-5.5 kWh/m^2 in a day demonstrates that Iran is one of the countries with high solar energy potential. Fig. 2 shows the potential sources of solar irradiation in Iran.

C. Variety of energy in Iran

Iran has a perfect position in terms of various energy resources and has the opportunities for develop them. According to the map shown in Fig. 3, it could be find that different regions have various potential of energy resources. This issue could provide an opportunity to supply the demand with diverse energy sources in the country. Another important point is that these resources are distributed across the country:

- Geothermal resources in the West and Northwest
- High wind speed in the North and East
- Proper solar radiation in Central, South and Southeast
- Oil and gas resources in the West and South
- Coal resources in the East

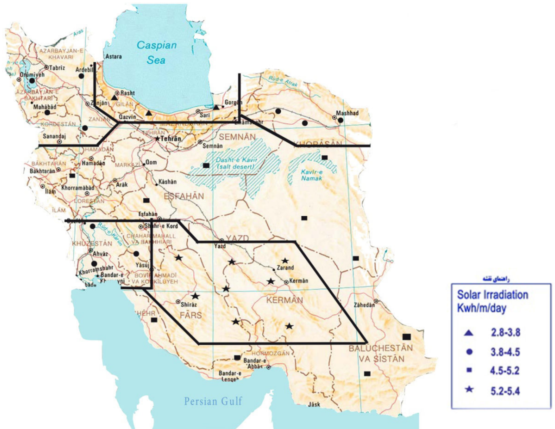

Fig. 2 Potential sources of solar irradiation in Iran [14]

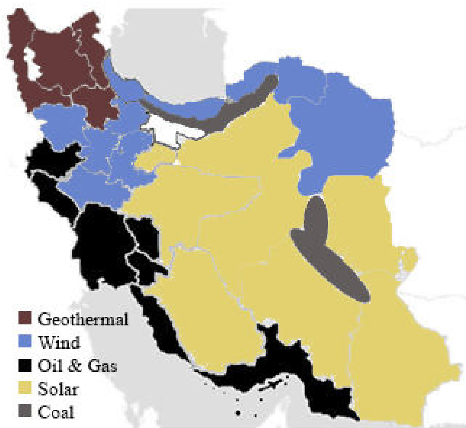

Fig. 3 Potential of energy resources in different regions in Iran

III. Methodology and System Characteristics

In order to analyze and compare the appropriate hybrid energy systems based on the available potential of energy resources in the country, four different regions have been considered. The HOMER software is applied to modeling and performing technical and economic studies of the hybrid energy systems proposed in each region.

A. HOMER Software Simulation Models

In the present work, the selection and sizing of components of hybrid power system has been done using NREL's HOMER software. HOMER is a general purpose hybrid system design software that facilitates design of electric power systems for stand-alone applications [13]. Input information of HOMER includes: electrical loads (one year of load data), renewable resources, component technical details and costs, constraints, controls, type of dispatch strategy, etc. HOMER designs an optimal power system to serve the desired loads.

HOMER is a simplified optimization model, which performs hundreds or thousands of hourly simulations over and over (to ensure best possible matching between supply and demand) in order to design the optimum system. It uses life cycle cost to rank order these systems [13].

In order to verify the system performance under different situation in HOMER software, simulation studies have been carried out using real weather data (solar irradiance and wind speed). The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A decision variable is a variable over which the system designer has control and for which HOMER can consider multiple possible values in its optimization process. In this study, decision variables in HOMER include:

- The size of the PV array
- The number of WG
- The number of Diesel generator
- The capacity of batteries
- The size of the DC/AC converter

B. Renewable Source Availability

In the previous sections, the potential of renewable energy in Iran were described. Table I shows the proposed energy sources to supply depended or independent application in each region. In accordance with Fig. 4, in this paper Iran is divided into four hypothetical "North", "South", "East" and "West" with regard to available energy resources.

C. Load Profile

In this research, the load profile of an imaginary village is considered for all regions. According to load forecast, the annual energy consumption for the proposed area is 623 kWh/d. Fig. 5 shows the load profiles in a sample day and Fig. 6 shows the monthly load variation profile. The peak requirements of the load dictate the system size. In this study 65.1 (kW) has been considered to scale peak load.

TABLE I
AVAILABLE ENERGY RESOURCES ASSUMED FOR EACH REGION

Region	Renewable resources	Non-renewable resources
North	Wind	Electricity grid
South	Solar	Diesel
East	Wind & Solar	---
West	---	Diesel

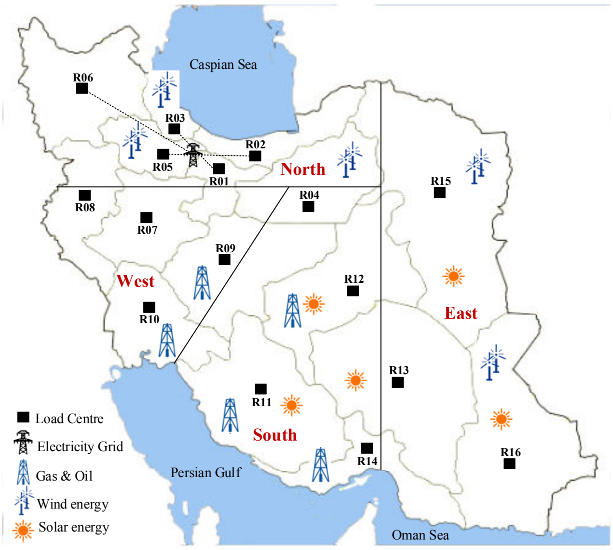

Fig. 4 Regional boundaries assumed for energy resources for Iran

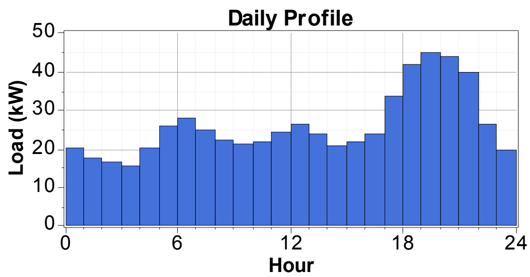

Fig. 5 Load profiles in a sample day

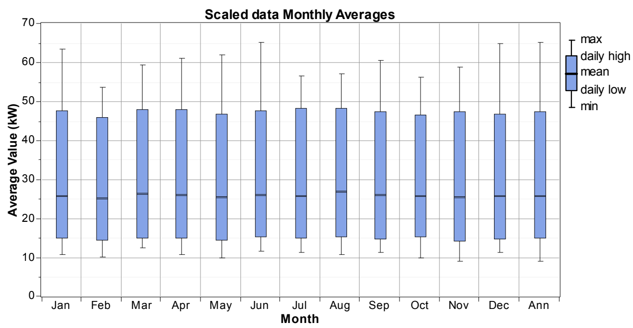

Fig. 6 Monthly load variation profile

D. Weather Data

A monthly average of 20 years of wind speed and solar radiation data for the geographic centre of each region is given according to Table II [15]. The information of solar radiation and wind speed can be used for analysis of hybrid energy system consisting of photovoltaic panels and wind turbines.

Figs. 7 and 8 show the monthly average daily wind speed for North and East. Figs. 9 and 10 illustrate the monthly average daily solar radiation for South and East.

TABLE II
MONTHLY AVERAGE WIND SPEED AND SOLAR IRRADIATION FOR PROPOSED REGIONS

Region	North	South	East	
Weather Data	Wind speed (m/s)	Solar irradiation ($kWh/m^2/d$)	Wind speed (m/s)	Solar irradiation ($kWh/m^2/d$)
January	5.63	3.34	5.42	3.47
February	6.04	4.45	5.80	4.34
March	6.95	5.24	5.99	5.01
April	7.47	6.02	5.61	5.96
May	7.11	6.97	6.44	7.04
Jun	8.08	7.45	7.32	7.06
July	9.61	7.02	8.28	7.40
August	9.48	6.62	8.07	7.14
September	7.34	5.99	7.01	6.28
October	6.03	4.93	5.70	4.93
November	5.05	3.83	5.03	3.76
December	5.31	3.24	5.43	3.15

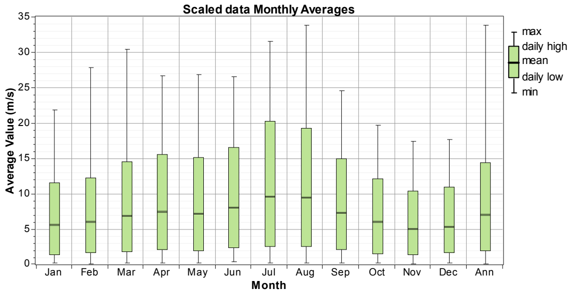

Fig. 7 Monthly average daily wind speed for North

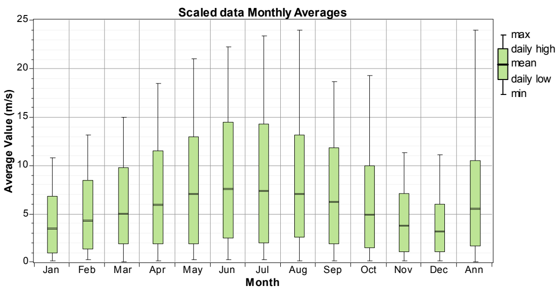

Fig. 8 Monthly average daily wind speed for East

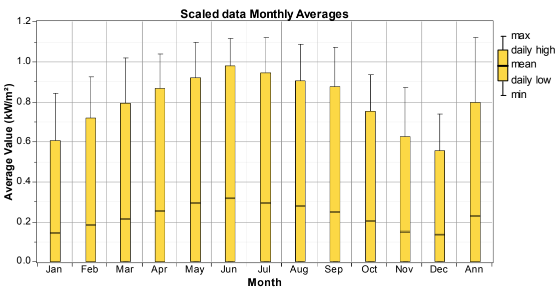

Fig. 9 Monthly average daily solar radiation for South

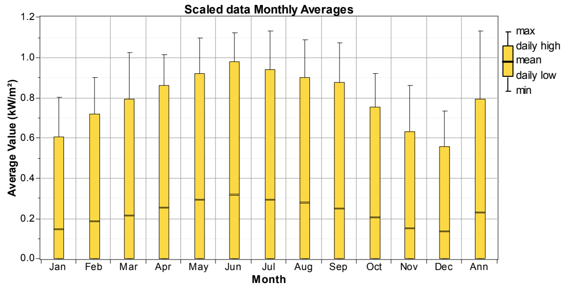

Fig. 10 Monthly average daily solar radiation for East

IV. TECHNICAL AND ECONOMIC ANALYSIS OF HYBRID ENERGY SYSTEMS

On the design point of view, the optimization of the size of hybrid plants is very important, and leads to a good ratio between cost and performances [16]-[19]. Figs. 11-14 show the structure of the hybrid energy systems studied in different regions. The hybrid energy system used in the North is WG/battery and is applied in stand-alone applications. Similarly, the hybrid energy system in the South is PV/diesel generator/ battery. The hybrid energy system used in the East is WG/PV/battery and the hybrid energy system used in the West is diesel generator/battery. Technical data of the components used in the system are shown in Table III.

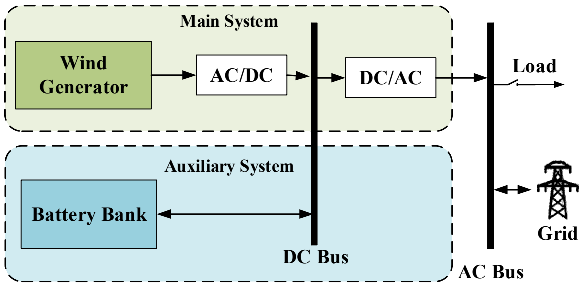

Fig. 11 Proposed hybrid energy system configuration in North

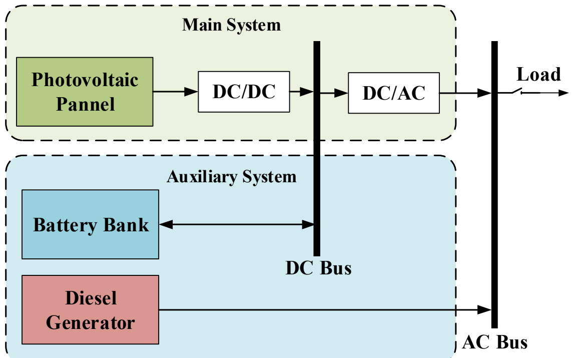

Fig. 12 Proposed hybrid energy system configuration in South

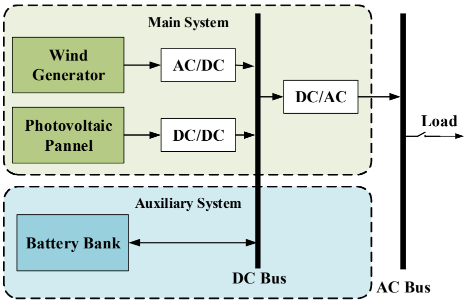

Fig. 13 Proposed hybrid energy system configuration in East

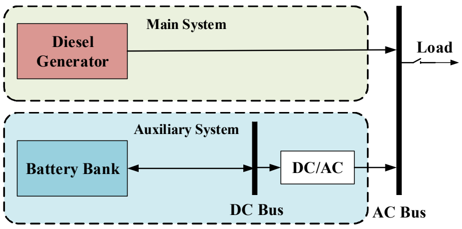

Fig. 14 Proposed hybrid energy system configuration in West

A. Technical Analysis

According to the explanations given in the previous sections, the proposed hybrid energy systems are modelled and analysed by HOMER software. A schematic of the hybrid energy systems in different regions are shown in Figs. 15-18.

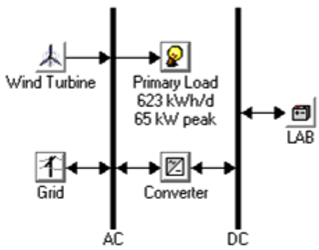

Fig. 15 Proposed system configuration in HOMER in North

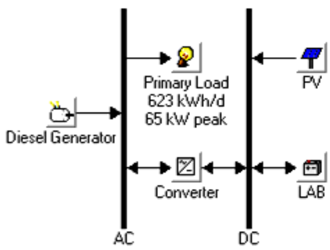

Fig. 16 Proposed system configuration in HOMER in South

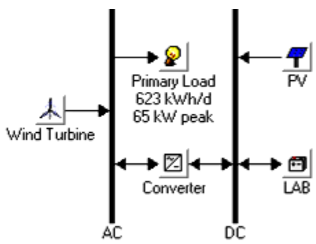

Fig. 17 Proposed system configuration in HOMER in East

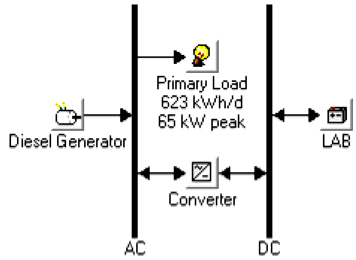

Fig. 18 Proposed system configuration in HOMER in West

TABLE III
TECHNICAL DATA OF THE COMPONENTS USED IN THE SYSTEM

Photovoltaic Panel	
Technology	Poly Crystalline
Capital Cost	4850 US$/kW$_{pk}$
O & M Cost	0
Efficiency	15 %
Lifetime	25 year
Tracking system	No Tracking
Wind Generator	
Technology	Fahrlander 100
Power	100 kW
Capital Cost	320000 US$
O & M Cost	300 US$/year
Lifetime	25 year
Diesel Generator	
Technology	VOLVO-GSW
Rated Power	50 kW
Voltage and Frequency	400 v , 50 Hz
Capital cost	10000 US$
Lifetime	25 year
Battery	
Technology	Lead-acid
Capital cost	8000 US$
Replacement cost	6000 US$
Charging Efficiency	80 %
Lifetime	5000 hour
Converter	
Capacity	25 kW
Capital cost	15000 US$
Replacement cost	15000 US$
Efficiency	95 %
Lifetime	20 year
Project Data	
Project Life Time	25 year
operating strategy	Load following
Spinning reserve	10 % of the load
Max. Annual Capacity Shortage	1 %

Several simulations have been made by considering different PV capacities, the number of WG, the number of diesel generator and etc. The COE of hybrid grid-connected WG/Battery system was 0.796 (US$/kWh) in North as shown in Table IV. The Summary of optimum simulation results for each region are presented in Table IV.

Figs. 19-22 show the monthly average electrical production in the regions in Iran.

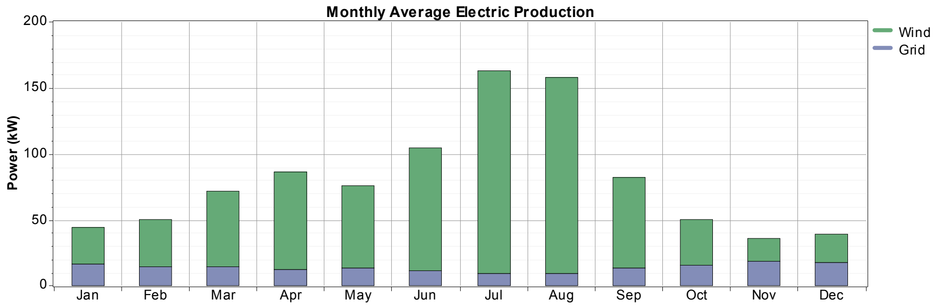

Fig. 19 Monthly average electrical production in North

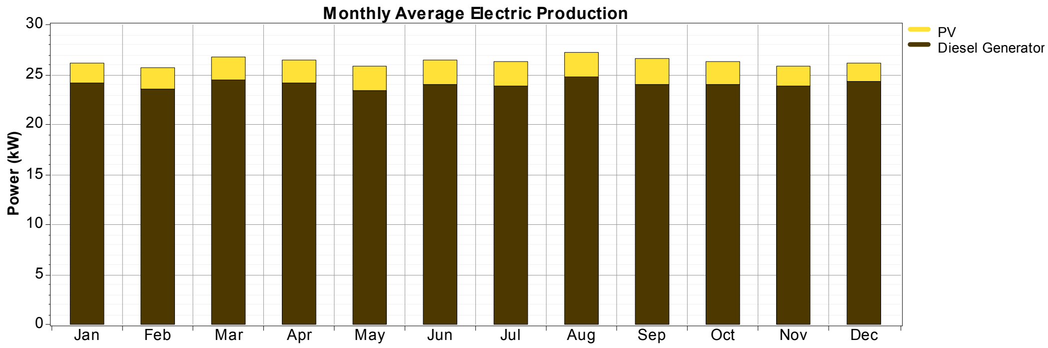

Fig. 20 Monthly average electrical production in South

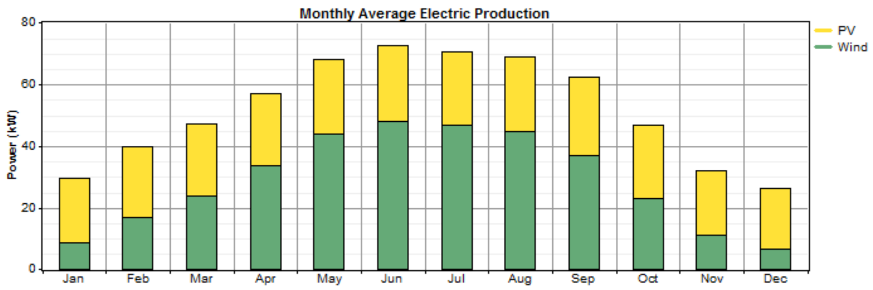

Fig. 21 Monthly average electrical production in East

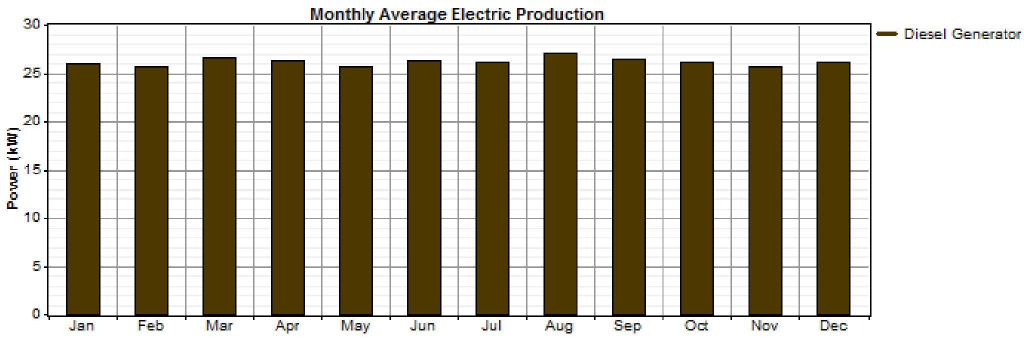

Fig. 22 Monthly average electrical production in West

B. Economic Analysis

The aim of this study is to achieve a stand-alone and grid connected hybrid generation system, which should be appropriately designed in terms of economic, reliability, and environmental measures subject to physical and operational strategies.

The system cost is defined as sum of PV cost (C_{PV}), WG cost (C_{WG}), battery cost (C_{BAT}), diesel generator cost (C_{DSL}), convertor cost (C_{CONV}), and electricity cost purchase from the grid (C_{Grid}) [20].

$$C_{SYSTEM} = C_{PV} + C_{WG} + C_{BAT} + C_{DSL} + C_{CONV} + C_{Grid} \quad (1)$$

The cost for each element should be deducted:

$$C_i = N_i * [CCost_i + RCost_i * K_i + OMCost_i] \quad (2)$$
$$i = PV,\ WG,\ Battery,\ Diesel\ generator,\ Converter$$

where N_i is the number/size of the system component, C_{Costi} is the capital cost, R_{Costi} is the replacement cost, K_i is the number of replacement, and OM_{Costi} is operation and maintenance cost through the system operation. Figs. 23-26 show the System component cost in in the regions in Iran.

TABLE IV
SUMMARY OF OPTIMUM SIMULATION RESULTS FOR EACH REGION

Region	North	South	East	West
System Components				
PV (kW)	---	10	100	---
WG	10	---	1	---
Diesel (kW)	---	10	---	40
Battery	1000	10	400	10
Convertor (kW)	300	50	100	10
Grid (kW)	1000	---	---	---
Total NPC (US$)	4523921	441177	1720833	377831
COE (US$/kWh)	0.796	0.078	0.305	0.067
Capacity Shortage	0.00	0.01	0.01	0.01

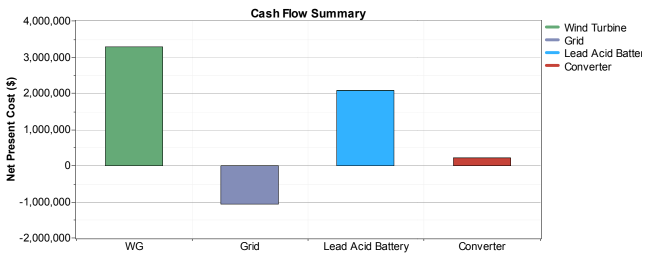

Fig. 23 System component cost in North

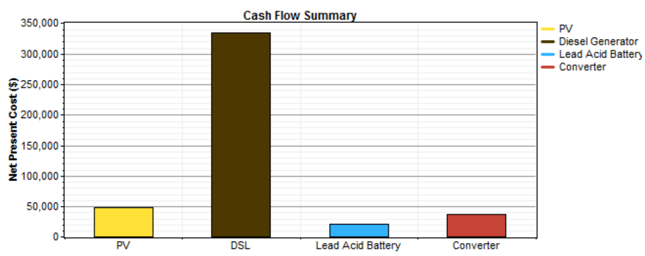

Fig. 24 System component cost in South

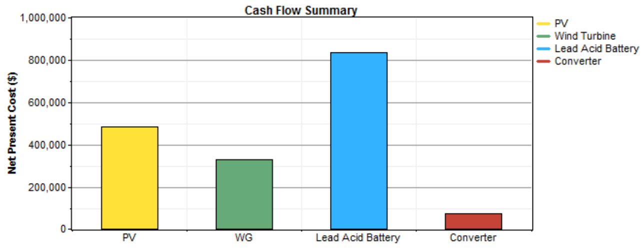

Fig. 25 System component cost in East

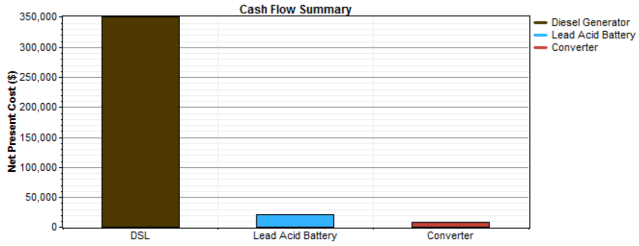

Fig. 26 System component cost in West

V. CONCLUSION

Iran is geographically located in a very rich and full of various energy sources. Wind energy potential in the North and East, solar energy potential in the center and south and vast fossil resources in the South are an excellent opportunity for the development of energy sources. Hybrid energy systems with renewable energies if established based on technical and economic studies could obtain substantial economic benefits. In this paper, technical and economic studies and optimum sizing of hybrid energy systems in different regions of Iran were performed using the HOMER software. The results show the good performance of the proposed hybrid energy system proportional to the potential of the regions.

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