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Wind-Solar Hybrid Electrical Power Generation in Jordan

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Abstract

The paper presents the electrical power generation using solar- and wind-energy for the country of Jordan. Presently with the oil prices are on the rise, the cost of electrical power production is very high. The opportunity of a large wind and solar hybrid power production is being explored. Sights are chosen to produce electricity using, the wind in the Mountains in Northern Jordan and the sun in the Eastern Desert. It is found that the cost of windmill farm to produce 100-150 MW costs $290 million, while the solar power station to produce 100MW costs $560. The electrical power production costs per kWh are 2 cents for the wind and 7.7 cents for the solar. The feasibility for using wind energy is now, solar energy when price of oil reaches $100 per barrel. The paper also discusses different control methods to link with the national grid.

Keywords: Hybrid power production system; wind energy, solar energy; power production cost; Jordan.

1. Introduction

The concept of solar and wind energies dates back to nearly 7,000 years ago [1]. However, in the late 1800s the Danes developed the first wind turbines to produce commercial electricity [1] – [4]. In the early 1900s small-scale wind turbines became more widely used around Europe especially in the rural areas for producing electricity using old car generators and carved rotors. The wind power brought electricity to the rural areas and the electrical power was used to charge batteries to run radios and to draw water from deep wells [2]. Except in Denmark where wind power production and research continued, wind power did not play any major role in the generation of electricity until the late 1900s.

The rapid growth of solar and wind powers is due in part to favorable global political climate towards these energies, efforts to reduce carbon dioxide (CO_2) and greenhouse gases (GHG) and other power plant pollutants, global awareness of climate changes, and the urgency to develop renewable energy sources. Other factors such as lucrative tax incentives and legislation mandating national renewable energy standards have accelerated the march towards solar and wind energies. For example in the US, some states have enacted "renewable portfolio standard (RPS)" law that requires utilities to sell a certain percentage of the energy from sustainable energy sources within reasonable stipulated times. Even though Europe and North America have the largest installed capacity of wind turbine capacity, China, India, and developing world have the biggest potential for wind power [5].

This paper examines the capacity and potential for electricity-generating solar- and wind-turbines installed In the Eastern and Northern part of the country. Wind Solar alternatives are essential for growth, finance, and the political environment. The cost of wind power has reduced from the cost of power production from 9.5 cents per kilowatt-hour to 2 cents for wind energy production and to 7.7 cents for solar power production. This is very significant because developing countries, which depend on external sources to finance major energy projects, may be able to finance small scale solar and wind energies projects from their own resources and faster. In this paper the electrical and power calculations for solar and wind utilization to support the national grid in Jordan will be analyzed. This paper also looks at some of the modern power electronics converters and electrical machines which have improved significantly solar and wind energy technologies to make them acceptable and embraced as cost effective and renewable energy.

2. The Existing Jordan' National Grid

Jordan is interconnected in one national grid. The grid covers most of the populated areas of the country from Aqaba, on the far south to Irbid in the far north. Overhead transmission line link Syria in the north, Palestine in the west, while undersea cable links Egypt in the south. Future countries to be connected to Jordan national grid include Lebanon, Iraq and Turkey.

The major generation centers are the Aqaba Thermal Power Station in the far south, Al-Hussein Thermal Power Station in Zarka near Amman, and Al-Risha near the Iraqi border. The Aqaba Power Station uses gas supplied through pipelines from Egypt. The pipeline extends to Amman. Future expansion of this gas line is expected to go to Syria, and eventually Turkey. Al-Hussein power station uses fuel oil imported from Iraq. Al-Risha power station uses locally produced gas. There are several small

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units scattered in different districts belonging to older utilities. These units are used during peak demands.
The oldest and the highest power production plant in Jordan is the Al-Hussein Thermal Power Station. It is the most expensive because it uses imported oil and also uses air-cooling systems, that consume quite amount of energy, to cool the turbines. A small pilot plant uses biogas produced by sewerage treatment plant. Another pilot plant uses wind energy near the sight proposed in North Jordan.

3. Conventional Electrical Production Cost

The Kingdom of Jordan is considered an emerging country in the Middle East; it has almost no natural resources. The country imports most of its oil needs from neighboring countries at market prices. Oil and gas imports are huge burden on the country's national economy. Electricity is generated by burning imported gas and oil, limited generation from hydro, wind mills, and biogas. When oil prices rose to extremely high levels last summer, Jordanians experienced continuous increases in electricity prices. It is now urgent and essential to deploy other alternatives for electrical generation, which is the use of solar and wind energy for electrical generation.
As shown in Table 1 Jordan in 2007 produced a total of 13,001 GWh of electrical energy and consumed 10,553 GWh. The average per capita electricity consumption in Jordan in 2007 was 2277 kWh as compared to 2075 KWh in 2006[18], resulting in annual growth rate of 9.7%. Table 1 shows generating capacity and electrical energy production by type of generation for 2007.

Table 1 .Energy Production In 2007 By Generation Type [18]

Fuel Type	Generating Plants Capacity (MW)	Electrical Production (GWh)
Steam Units	1013	6,904
Gas Turbines/Diesel	193	45
Gas Turbines/Natural Gas	310	916
Diesel Engines	43	1
Hydro Units	12	61
Windmills	1.4	3
Biogas	4	10
Combined Cycle	600	5,061
Total Generation	2176.4	13,001

Almost all electricity production in Jordan currently is carried out by the state-owned utility National Electric Power Company (NEPCO). Al-Hussein Power Plant (with capacity of 400 MW) and the Aqaba Power Plant (with capacity of 650 MW) are the country's two main power generation facilities. Jordan has modest reserves of natural gas, of 230 billion cubic feet, and has developed one gas field at Al-Risha in the eastern desert near the Iraqi border. The current output of this field is around 30 million cubic feet per day. Al-Risha field is used to fuel one nearby power plant, which generates about 10% of Jordan's electricity. For several years, Jordan has been exploring the option of importing natural gas from Egypt. In 1999, a decision was made to delay imports until a more thorough evaluation of reserves at Al-Risha field was completed. When this review showed that quantities available were not sufficient to meet the country's needs, Jordan decided to reopen talks on imports from Egypt. A pipeline was constructed and completed in 2006. Aqaba thermal power station, a major generating center, currently uses Egyptian gas. Jordan imports about 150,000 barrels of oil per day mostly from Iraq and Saudi Arabia. The Zarka refinery near Amman, the only refinery in the country, refines the imported oil. Table 2 shows electrical generation fuel consumption in 2007. Gas and oil imports pose a huge burden on the national economy.

TABLE 2 FUEL CONSUMPTION IN 2007 FOR ELECTRICAL GENERATION [18]

Fuel Type	Consumption in Thousands Tons Oil Equivalent
Heavy Fuel	621
Natural Gas	2,396
Diesel	9
Total	3,026

According to 2007 data supplied by NEPCO[18], electrical production cost is USr$0.073 per KWh; out of which fuel cost is US$0.0386 per KWh. This figure is considered expensive as compared to production cost in other countries. As the oil prices surged to more than double in the summer of 2008, accordingly the production cost increased to US$ 0.11 per KWh. If it is assumed that the true value of oil price is $100 per barrel, the production cost would be about US$0.095 per KWh. This figure will be used in cost comparison.

4. Assesment Of Wind And Solar Energies

In Jordan electricity demand grew around 9.7% in 2007. The Jordanian government has been seeking ways to attract foreign capital to fund additional capacity. Wind and solar energies as main source of electricity generation are currently set as government priorities. The government implemented the following actions [19]:

- Developing new wind and solar maps for Jordan.
- Developing a legal framework for renewable energy.
- Developing incentives for renewable energy projects.
- Securing an appropriate fund to implement the 1st commercial wind energy project in Jordan.
- Secure an appropriate fund to implement the feasibility
- Study of the hybrid solar power plant.

Because of the government enthusiasm to promote renewable energy, a thorough investigation has been conducted to study the possibility for a hybrid system of windmills and solar arrays for electricity generation. Data collected over many years by the Jordan Meteorological Department [20] has helped in locating the sights for both windmills and solar arrays.

The wind farm location was set in the area of Ras-Munif where the annual wind speed average is 10.6 knots which is equivalent to 5.5 meters/second according to data collected by the Meteorological Department in Jordan. With the exception of the months of September and October, where the wind speed is low, the other 10 months the speed is 6-6.5 m/s. Remembering that this speed represents the village ground level speed. If the windmills are sighted at higher elevation and in the valley curvature between mountains running west to east where wind tunnel effect exists, the average wind speed might rise to comfortable levels where windmills run near full capacity. The windmill tower height of 100 meters also increases wind speed to levels close to the 7-9 m/s [22] which might bring the wind turbine power output to 1 Mw or more for ten months of the year. Experience indicates that wind speed tend to be higher during the night time. Therefore, during the day time the deficiency in windmills' power output can be augmented by solar cells electrical production.

5. The Wind-Solar Hybrid System

A. Proposed Windmill-Solar Hybrid

The proposed non-conventional electrical generation will supply 100-150 Mw. As it was pointed out earlier, the sight is chosen in a high valley curvature in the mountainous range where wind tunnel effect exists where continuous high speed wind prevails all year round. An array of 100 windmills was chosen for this work. Each unit has a capacity 1.5 Mw. Several windmill suppliers were investigated and the choice was set on SAIP Electric Group [21]. Figure 1 shows the windmill chosen for this project. Since the average annual wind speed characteristics at location is 6 m/sec and might average about 7-9 m/sec as was pointed out in section 4 above. The cut in wind speed for the units is 3 m/sec, which is way above the annual average wind speed at the chosen sight guaranteeing continuous power output. The cutout speed is 25 m/sec where this average is over 10 minutes span average. In that location wind never reach that high. Consequently the chosen units are suited for the proposed sight. Figure 2 indicates that with the wind speed average at sight, the windmill average power output would be about 1 Mw for year round. This power may increase up to 1.5 Mw, which is the maximum power output of the generator. Therefore the proposed windmills farm may produce a continuous power output between 100-150 Mw. The blade length is 37.5 m, making the windmill side clearance 75 m, and at a height of 100 m. Leaving additional side clearance of 100 m so that windmills do not form wind obstacles between each other. Therefore the wind farm array should be about 2 Km long. Land appropriation for this sight would be about 200,000 m2. This is easily accommodated in the proposed sight.

Figure 1. The 1.5 MW Windmill.

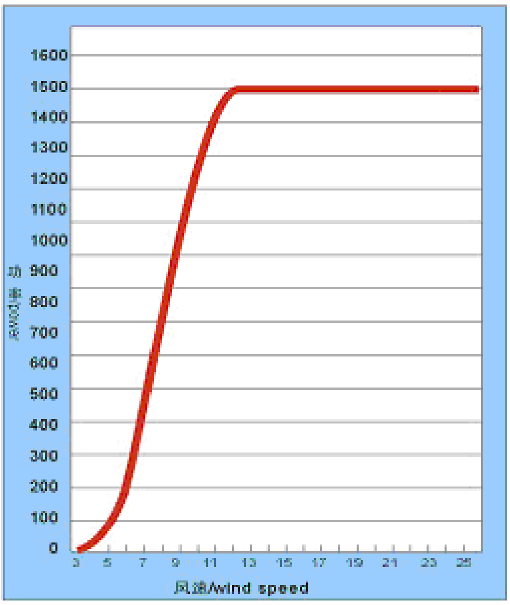

Figure 2 The Power-Wind Speed Characteristics

In case the windmills' output is reduced a solar cells array may be an alternative for additional support and reliability. Experience had told us that whenever the wind speed drops means a fair weather where sun shine is a maximum. For a reliable renewable energy power supply, the windmills farm is supported by solar cells array. Table 3 shows the solar array type specifications to be used. The decision was to install solar array to produce 100Mw to support the windmill farm. A total of 500,000 arrays are needed to supply this required power.

Since Ras Munif, the location of the windmills is mountainous area, is unsuitable location for the solar arrays, because they are used for agricultural plantations. A better location is in the Easter Jordanian Desert. In desert land is readily available and the yearly average daily sunshine is 9.3 hours[20]. By installing east-west sun tracing system, a full 8 hours daily average maximum power output can be obtained. Accounting for the modules

Table *3*. Solar Module Speifications.

Maximum power (Wp)	*200W*
Maximum power voltage (V)	42
Maximum power current (A)	5.24
Open circuit voltage (V)	50
Short circuit current (A)	5.7
Number of cells (Pcs)	91(7x13)
Size of module (mm)	1702x945x45
Weight per piece (kg)	19

surface area and spaces between modules, the solar installation requires land appropriation of 1 km2.

Location of the solar power station is chosen to be near Al-Risha Power Station currently in operation in the Eastern Jordanian Desert. This sight is chosen for easier link to the national grid. Al-Risha is located on 32˚ latitude. This requires the modules to be installed inclined toward the South at 32˚ with the horizontal, facing southward. Modules inclination adjustments of ±15˚ are needed to track the sun's seasonal variations. East-West tracking motors may be used to increase full capacity power production to 8 hours per day.

The proposed hybrid wind-solar installation is needed to supply Jordan with low cost renewable electric power. The two installations are capable to supply 10% of the country's electricity peak demand needs for the year 2009.

B. Cost Estimation

The cost of one windmill is US$ 1.85[21]; additional 20% of the price may cover shipping and installation. In addition and US$200,000.00 per unit for controllers and other supporting equipment needed for grid link. Result is a total cost per unit ready to supply the grid may be set around US$2.4 million. Another 10% for maintenance, 6% for capital investment, and another 5% Administration may be added to the 2.4 million; the result is a net cost of US$2.9 million per unit. A total of US$290 million are needed for the wind farm installation to produce 100 – 150MW of electrical power. The average life-time of the windmill is 20 years. Simple calculations, after the assumption that the full wind power out is for 20 hours per day, result in electrical production cost US$0.02/kWh. This figure is much lower less than the current conventional electrical production cost of US$0.095/kWh.

As for the solar power station, the cost of 500,000 modules needed to produce 100 MW is US$370 million. This cost includes the controllers for grid link. In addition to the 370 million solar modules cost, 20% for installation, 10% for the sun tracking system, 10% maintenance, 6% capital investment and 5% administration may bring the total cost of the solar power station to $560 million. The high percentage for installation is to cover the cost of frames upon which the modules will be installed. Remembering that the power production is for 8 hours per day and the life time of the solar cells is 25 years; then the production cost will be US$0.077/kWh. This production cost is almost the same as the present conventional production cost., but lower than the projected production cost of US cents 9.5, for when the price of oil reaches $100 per barrel.

Comparing the wind and solar power production costs, it seems that wind power production cost is much lower than the solar power production. Therefore wind energy production is feasible now even with the oil prices at $40 per barrel. In the future when oil prices rise, even with the high cost of solar energy, solar power is important for power flow reliability.

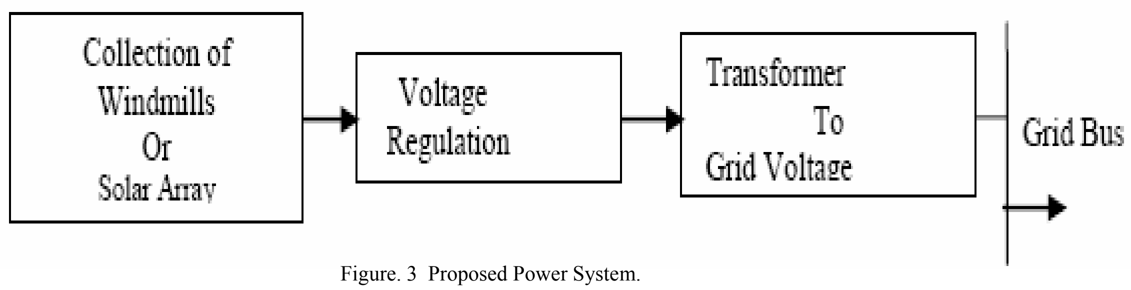

Figure. 3 Proposed Power System.

6. Conclusion

Jordan have high electric production cost that is directly linked with the oil prices. An alternative is renewable wind and solar electric power production. The possibility was thoroughly investigated. The result is to install windmill farm in the mountainous area in the north, where wind speed proved to be viable, while the eastern desert is suitable to install solar power station. The cost for the windmill farm to produce 100-150MW for 20 hours per day is US$290 million. The cost of the solar power station to produce 100MW for 8 hours per day is US$560 million. The production cost per kWh (in US cents) is 2 cents for the windmill and 7.7 cents for the solar. The conventional production cost 9.5 cents projected when the price of oil is $100 per barrel. For reliable energy system, hybrid power production is essential.

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