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Utilization of Hydropower from Dams in Jordan - Wadi Al - Arab Case Study

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Abstract: ***Micro - hydropower plant is the most effective method and environmentally friendly method to supply rural villages by the required electricity. Power plants operated by Fossil fuels, in Jordan are barely able to meet all electricity needs, in addition to the high cost of grid electricity. The rural villages have low load demand, but the electricity supply has been characterized by high transmission and distributed costs. This paper is mainly a feasibility study, of utilizing the dams in Jordan, by their potential of hydropower, and design a small hydropower plant at Wadi Al - Arab dam. It is estimated that installing small hydropower plants on the most promising existing dams in Jordan would generate mechanical power output of 45.5 GW, and 40.5 GW of electrical energy output. A small hydropower plant has been designed on Wadi Al - Arab dam, can produce 3.4 MW. This involves the selection of the most efficient components of the plant, including type of the turbine, specific speed, speed of the turbine, and the diameter of penstock pipe.***

Keywords: Dams, electricity, Hydropower, Jordan

Nomenclature

D_p	Diameter of penstock pipe (m)
E	Electric energy (W)
g	Acceleration of gravity (m/s^2)
H	Water falls height (m)
IEA	International Energy Agency
m	Mass flow rate (kg/s)
N	Speed (r. p. m)
MCM	Million cubic meter
N_s	Specific speed
P	Mechanical power output (W)
Q	Volumetric flow (m^3/s)
TEAS	Turkey's Electricity Generator and Transmission Corporation
ρ	Density of water (kg/s)
η_g	Generator efficiency
η_m	Transmission efficiency
η_o	Global efficiency
η_t	Turbine efficiency

1. Introduction

Energy is a critical parameter in developing countries for economic growth, in addition to economic growth and social development and human luxury. Power plants operated by fossil fuels in Jordan, are barely able to meet electricity needs. Hydropower is one of the significant sources of renewable energy, non - polluting, and reliable. The hydraulic fundamentals in hydropower plants, addresses the conversion of potential energy, to kinetic energy, to mechanical, and finally to electric energy.

International Energy Agency (IEA), suggests that the world would need 2600 GW of hydropower capacity by mid - century to have a chance by keeping global temperature rises below 1.5 ºC. This means that we need to build the same amount of capacity in the next thirty years as in the previous 100 years. As recognized by the International Energy Agency, hydropower will become the dominant source of flexible electricity by 2050, so it is essential that investment in this field should grow up quickly, to ensure low carbon security over the coming decades [1]. Hydropower is one of the oldest energy sources, that have been utilized all over the world, to generate electricity, especially in rural areas [2]. Hydro energy is one of the richest and most useful renewable energy sources in the world. It contributes 16 - 20% of the extent of total electricity generated in the world [3]. The extent of hydropower development will depend on several risk factors, including: the cost of alternative energy sources, the environmental sustainability of hydropower, and social issues of equitable development [4].

Nowadays micro hydro systems could capitalize head range starting of 1 m, and efficiency of hydro systems range between 65 - 75% in micro and small applications, climbing up to 95% in macro design [5]. The hydro power stations are more of the most significant sources of renewable energy. Small scale hydropower can potentially be quite important in the future of renewable energy systems, that may have a limited regulatory capacity in energy storage and transmission capacity [6].

In Turkey, domestic energy consumption accounts for 37% of total energy consumption. For this reason, renewable sources are very important for Turkey's energy sector. Projection by Turkey's Electricity Generation and Transmission Corporation (TEGTC). A public company in Turkey owns and operates 15 thermal and 30 hydroelectric plants generating 91% of electricity, indicate that rapid (as high as 10% annual) growth in electricity consumption will continue over the next 15 years. Turkey has a total gross hydropower of potential of 433 GW, but only 125 GW of the total hydroelectric potential can be economically used [7].

Based on available data, it is believed that there are at least 6 candidate sites in the north and middle of Jordan, and3 locations in the southern part, which could be developed as small hydropower plants, with a combined potential of more than 33 MW. At present, only king Talal dam has been developed to be operationalfrom 1980. It is estimated that installing small hydropower plants on the most promising existing dams will generate more than 200 GW h/year of electric energy without affecting the natural environment [8]. Saadoun et al. [9], investigate the effect of the primary production of phytoplankton on water quality of Wadi Al - Arab dam in northern Jordan. Species successive change and composition, in addition to increased rain seems to be the major factor behind fluctuation of total chlorophyl.

Wadi Al - Arab dam in the northern part of Jordan was investigated. It was constructed in (1987). The designed total reservoir storage capacity was scheduled to be 20 million cubic meters. The actual storage capacity was calculated using echo - sounding transverses [10].

Micro (small) hydro electric power is both an efficient and reliable form of clean source of renewable energy. It can be an excellent method of harnessing renewable energy from small rivers and streams. The micro - hydro project designed to be run - of - river type, because it requires very little or no reservoir in order to produce power in turbine. The water will run straight through the turbine and back into the river or stream to use it for the other purposes. This has a minimal environmental impact in the local ecosystem [11]. Global climate change, related to the greenhouse gases emission, impact hydroelectric power generation mainly due to the increase in air temperature and change in the precipitation patterns. Consequently, it affects basin evapotranspiration process, runoff, sediment transport as well as evaporation of reservoirs or dams [12].

This paper is mainly a feasibility study, of utilizing the dams in Jordan, by their potential of hydropower, and design a small hydropower plant capable of generating 3.4 MW at Wadi Al - Arab dam. This involves the selection of the most efficient components of the plant.

2. DAMS

Jordan is among the ten most water stressed countries in the world. Dams construction was the top priority of Jordan development plans. Six dams were constructed in the north and middle Jordan valley, with a total storage capacity of 160 MCM. These dams include (Wadi Al - Arab, Ziglab, king Talal, Karameh, Shuaib, and kafrein). Three other dams (Wala, Mujib, and Tannur), were constructed in the southern regain, with total live storage of 30 MCM.

Inorder to calculate the power output and energy, and to design the power plant rating chart, which shows relation ship between the flow rate and its level is necessary, then the total power generated from water in hydropower plant is given by:

$P = m \times H \times g$

Where P is the mechanical power produced in W

m is the mass flow rate of the water in kg/s

H is the height of water in m

For Wadi Al - Arab dam:

$P = \rho \times Q \times H \times g$ (1)

$P = 1000 \times 4.66 \times 83.5 \times 9.8 = 3813$ kW

The formula clearly shows that the total power that can be generated from the hydroelectric power plants depends on two major factors: the volumetric flowrate of the water, and the height or head of water [13].

To calculate the theoretical electric power output, the following equation is used:

$E = Q \times \rho \times g \times H \times \eta_o$ (2)

Where:

E electric power (kW)

Q volumetric flowrate (m^3/s)

ρ density (kg/m^3)

g acceleration of gravity (m/s^2)

H waters fall height (m)

η_0 global efficiency (0.89)

For Wadi Al - Arab dam:

$E = 1000 \times 4.66 \times 9.81 \times 83.5 \times 0.89 = 3394$kW

Table I: The hydropower potential at existing dams in Jordan

Name	Start of operation	Height (m)	Volumetric flowrate (m^3/s)	Hydropower utilization	Total power produced (kW)	Theoretical electric power output (kW)
King Talal	1977	108	6.56	yes	6943	6179
Wadi Al - Arab	1986	83.5	4.66	No	3813	3394
kafrein	1967	37	21.64	No	7847	6984
Shuaib	1969	32	13.95	No	4374	3893
Ziglab	1967	48	0.52	No	2446	2177
karameh	1997	45	0.8	No	353	250
Tunnur	2001	60	1.54	No	905	805
Mujib	2003	62	19.28	No	11714	10425
Wala	2003	52	13.96	No	7114	6331

3. Design Analysis

The hydropower potential at existing dams in Jordan, is shown in Table 1. From the nine dams found in Jordan, Wadi Al - Arab dam was chosen for this study, since the main water supply is from king Talal dam (the largest dam in Jordan), which is reliable source of water.

Francis turbine was selected using the net head versus volumetric flow rate chart. It produces the appropriate energy compared with the height of the dam and is characterized by the higher efficiency among the other types.

Turbine efficiency for francis turbine $\eta_t = 0.94$

Transmission efficiency (Belt type) $\eta_m = 0.98$

Generator efficiency (Synchronous generator) $\eta_g = 0.97$

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The power obtainable from hydropower plants, considering an equal flowrate and heads, depends on the global efficiency of energy conversion of the hydropower plant, which is the product of three partial efficiencies: the hydraulic efficiency, the volumetric efficiency of the turbine, the mechanical efficiency of the turbine - generator, and electrical efficiency of the generator.

The global efficiency of the system is:

$\eta_o = \eta_t . \eta_m . \eta_g$

$\eta_o = 0.94 \times 0.98 \times 0.97 = 0.89$

The power developed by the generator is:

$P = 1000 \times 4.66 \times 83.5 \times 0.89 \times 9.8 = 3397 \text{ kW} = 3.4 \text{ MW}$

After the analysis, the Frances turbine was selected using the net head, flow rate, rotational speed, specific speed, and power output. The selection was arrived, using tables as shown below:

Table 2: Typical efficiencies of small turbines

Turbine Type	Best Efficiency
Kaplan single regulated	0.91
Kaplan double regulated	0.93
Frances	0.94
Pelton n nozzles	0.90
Pelton 1 nozzle	0.89
Turgo	0.85

Table III: Range of Heads

Turbine Type	Head range in (m)
Kaplan and Propeller	$2 < H_n < 40$
Frances	$25 < H_n < 350$
Pelton	$50 < H_n < 1300$
Cross flow	$5 < H_n < 200$
Pelton 1 nozzle	$24 < H_n < 69$
Turgo	$50 < H_n < 250$

The specific speed N_s is given by:

$N_s = 1.924 / H_n^{0.512} = 0.2$ (3)

For Francis turbine the range of specific speeds is:

$0.05 \leq N_s \geq 0.33$ (4)

Hence the specific speed is within the range, thus applicable.

$N = 0.2484 (g \times H_n)^{0.75} / Q^{0.5}$ (5)

$N = 0.2484 \times (9.8 \times 83.5)^{0.75} / (10)^{0.5} = 12$ rev. /s = 720 r. p. m.

The diameter of penstock pipe (D_p) is:

$D_p = 0.72 \times Q^{0.5} = 0.72 \times (4.66)^{0.5} = 1.55$ m (6)

4. Results and Conclusions

There are mainly nine dams in Jordan, with total capacity of 220 million m^3. The estimated total mechanical power output from the nine dams is 45.5 GW, electrical energy output of 40.5 GW. with a total volumetric flow rate of 82 m^3/s. Among the nine dams exists in Jordan, only king Talal dam has been utilized by hydropower plant. This opens the door widely to utilize hydropower plants on the rest of dams, which would enhance the electrical supply in Jordan.

A small hydropower plant is designed at Wadi Al - Arab dam, that can generate3.4 MW. Francis turbine was selected using the net head versus volumetric flowrate chart, this turbine produces appropriate energy compared with the height of the dam and is characterized by the highest efficiency by the highest efficiency among the other types. The design includes calculating the overall efficiency of 0.89, specific speed, the power developed by the electric generator. The speed of the turbine is estimated to be 720r. p. m., and the diameter of penstock pipe of 1.55 m.

5. Conclusions

1) Among the nine dams exists in Jordan only one (king Talal) dam is furnished by hydropower plant.
2) It is estimated that installing small hydropower plants on the most promising existing dams in Jordan would generate mechanical power output of 45.5 GW, and 40.5 GW of electrical energy.
3) A small hydropower plant has been designed on Wadi Al - Arab dam, can produce 3.4 MW. This involves the selection of the most efficient components of the plant, including type of the turbine, specific speed, speed of the turbine, and the diameter of penstock pipe.

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