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Renewable Energy Sustainability With Micro Hydro Systems In Fujairah

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***Abstract*:**
Due to water scarce in Fujairah, several small dams and sand barriers were built to store water, prevent occasional flooding damage as well powering underground water beds. These water reservoirs are oversized 90% of the time. In this paper, a smart grid of multi micro hydro system is proposed to satisfy water and electricity demand for scattered mountainous villages in an optimal manner, by channeling water in needed reservoirs. Sustainability is to be achieved with micro hydro and wind/solar hybrid systems which have been analyzed on aspects, such as environment, solar and wind regimes, existing mountainous reservoirs and dams, seawater desalination, as well as economic feasibility
Keywords*: *micro hydro, hybrid, smart grid, reservoir, feasibility, Fujairah

Background

Renewable water resources in the UAE are very limited. No surface water in the form of rivers or lakes is available. The rainfall is very scarce, random and infrequent. The average rainfall is about 110 mm/year. However, this annual rainfall is mostly encountered in a few events.

Records indicate that the average number of rainfall events per year is five or less. These rainfall events are generally characterized by their short durations and heavy intensities. Such rainfall characteristics are quite consistent with regions classified as drought areas. Fujairah emirate is located in the northern east of the UAE. It is surrounded by small mountainous areas and many valleys, not far from the sea bed. Many sand barriers and concrete dams were built (Fig. 1) to protect mountainous villages from flash floods due to rain water, and to support underground water storage and prevent soil erosion.



Fig. 1, Fujairah dams.

As water is scarce and because of the rapid increase in Fujairah domestic and industrial water demand, many desalination plants were installed. The over-extraction of groundwater resources has led to a lowering of the water table by an average of nearly one meter a decade, and seawater intrusion is increasing in the coastal areas. While about 50 desalination plants were installed, treated wastewater is another source. It is estimated that several billions m^3/year are produced in urban areas, of which more than 10% of it are treated and reused. Desalinated water is withdrawn for domestic and industrial purposes, while the withdrawal of groundwater is mainly for agricultural crops.

Across the region, authorities are undertaking renewables projects to free up hydrocarbon exports and industries, and to diversify energy resources. The UAE is leading the renewables drive in the region, with a target to derive nearly 10% of its energy from renewables by 2020. It is also the home to the International Renewable Energy Agency (Irena), the multilateral organization set up in 2009 to promote renewables. It also set up the green-energy firm Masdar, which is building a low-carbon, zero-waste city with a number of renewable energy projects locally and abroad. Masdar and its partners; the French energy company Total, and the Spanish energy-infrastructure company Abengoa, launched the 100 MW concentrated solar power (CSP) plant, to generate enough electricity for 20000 home. Excess power will be fed the national grid.

Water Resources and Dams of Fujairah

The mean annual rainfall in the UAE is about 100 mm, ranging from less than 40 mm around southern desert to about 160 mm in the northeastern mountains in Fujairah. Almost 90% of rainfall occurs during the winter (October-March) and the wettest month is February. Spring and summer witness only occasional concentrated heavy rainfall. The rainfall distribution is highly variable over space and time. Rainfall tends to be more reliable in the north-eastern mountain region, as depicted in Fig. 2

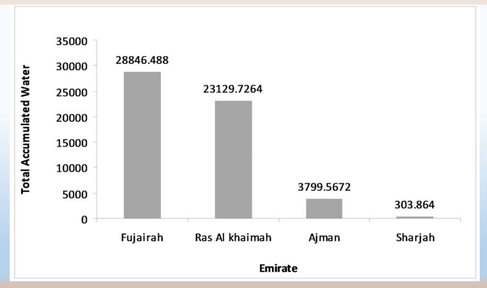


Fig. 2, Distribution of rainfall in the UAE.

As such, the total annual surface runoff produced from rain is about 150 million m^3, but there are no perennial streams. The average annual groundwater recharge is about 120 million m^3, most of which comes from infiltration from river beds. The total groundwater abstraction is around 1500 million m^3. This means that groundwater depletion probably amounts to almost 1500 million m^3/year. However, this figure does not consider the possible annual recharge of groundwater entering from neighboring places. In any case, the over-extraction of groundwater resources has led to a lowering of the water table by more than one meter on average during the last two decades, while seawater intrusion is increasing in the coastal areas.

To increase the groundwater recharge, a number of dams have been built at various locations across the country. There are more than 50 dams and embankments of various dimension having a total storage capacity of over 100 million m^3. While most of these dams are basically built for recharge purposes, they also provide protection against damage caused by flash floods. There are also about 50 desalination plants with a total installed capacity of around 800-1000 million m^3/year, while total actual production is 50-70 % of it. Further, it is estimated that about 1000 million m^3 a year of wastewater were produced in the urban areas, of which 25% of them were treated and reused.

Total water withdrawal was estimated at 10 billion m^3 a year. Over 75% of the total water withdrawal was groundwater. Agricultural water withdrawal for crops was 5 billion m^3 a year (all from groundwater), while landscape irrigation used 10% of it (all treated wastewater). Total water withdrawal for domestic and industrial purposes was estimated at 1 billion m^3 (25% and 10% of total water withdrawal, respectively), of which 500 million m^3 or 60% consisted of desalinated water and the remaining part of groundwater.

Renewable Projects Model for Water Sources

Whereas solar energy in Fujairah is highly available with up to 100% rate, the wind regime is unpredictable. In general steady wind energy is unavailable, yet occasional galls and gusty high speed winds blow for days. Fujairah gets both north western winds in winter and tropical winds in summer. There has been no detailed study on the wind energy in Fujairah, which has long open sea sides, as well as many mountainous areas with winds channeled through valleys. There is an opportunity to measure and test wind energy with pilot wind turbine systems, whilst utilizing renewable projects for water resources.

Around 50 small dams were built to establish water reservoirs for irrigation and drinking purposes. In order to accumulate larger water reservoirs in the mountainous areas, it is suggested to connect them with channels of water pipelines, with reversible compressors electrified by both solar and wind renewable energy systems. These compressors can operate as micro hydro systems for generating electricity when water heads were available.

A model is proposed here with the assumption that an average water storage capacity of reservoir of 10 million m^3. One can estimate the size of solar and wind energy systems required for one reservoir to pump water to a higher one. It is required to install one wind turbine at the top of mountainous reservoir for each pipeline channel connecting to a lower one, the capacity of which is related to the header and storage capacity of the lower reservoir according to:

$$P=\xi\rho Q\ g\ h \qquad (1)$$

Where P is output power in watts, ζ is the efficiency, ρ is water density in Kg/m^3, Q is flow rate in m^3/s, g is *gravity*$=9.81\ m/s^2$ and h is water head in meters

and
$$Q=VA \qquad (2)$$

where V is flow velocity in m/s, and A pipe cross section area in m^2, with

$$V^2=2g\ h \qquad (3)$$

Typical examples for a typical Fujairah dams, are: $h=50m$, $\rho=1000\ kg/m^3$, $Q=1\ m^3/s$ *for* $A=1\ m^2$, which would require around 500 kW for 50% hydro turbine efficiency. This would be equivalent to 5000 m^2 of photovoltaic (PV) solar panels. A 100-200 kW wind turbine with 2500 m^2 solar panels per site can be an approximate installation size. Also with this head value, flow rate would be 30 m/s. Therefore, a 100 KW power would be enough to empty a reservoir of 2.5 million m^3 of water in 24 hours. PV solar panels of similar capacity are also installed nearer to the bottom reservoir.

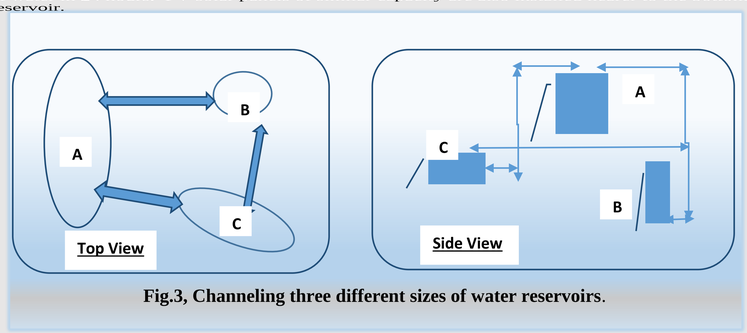


Fig.3, Channeling three different sizes of water reservoirs.

With this scheme, a network of $N(N-1)/2$ pipeline channels connecting N reservoirs to higher ones, and powered by both wind and solar energy systems are obtained, as depicted in Fig. 3, for three reservoirs. With this system, it is hoped to build a larger water capacity storage with large header, as well as accumulating water resources as required by nearby villages. It is intended that both fresh and seawater can be used, with freshwater for drinking and irrigation, while seawater for the micro hydro turbines installed wherever required. It is to be mentioned that Fujairah low salinity seawater, PPN, desalination process can also be implemented.

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Renewables systems in Enhancing Electric Grid

The above proposed model can further be utilized to generate electricity to enhance the national grid. The normal wind regime is highest at nights, whereas solar during day hours, which both may contribute towards charging all water reservoirs to be discharged during the day. As a result, extra electric power can be added to the grid, both to overcome short peak s as well long time steady-state demands.

The added electric power is a twofold supply option; either local power demand can be supplied by the individual smaller-size micro hydro system due to header variations, or through one larger hydro system discharging to sea by gravity. In the later case, it is estimated that for N micro hydro systems of P_i power generation capacity, a maximum of ΣP_i, $i=1\rightarrow N$ is added.

The following model is formulated for the above system:

For N reservoir systems sorted according to their vertical levels, sorted from $i=1$ the lowest to $i=N$ the highest, with Q_i *and* D_i being the individual power capacity and individual power demand respectively:

$$Q_T = \Sigma Q_i - \Sigma Di \qquad (4)$$

with
$$Q_i = H_{N-I} \qquad (5)$$

The generation-demand curves for both water and electricity in each site installation being exclusively probabilistic as shown in the following figure (Fig. 4)

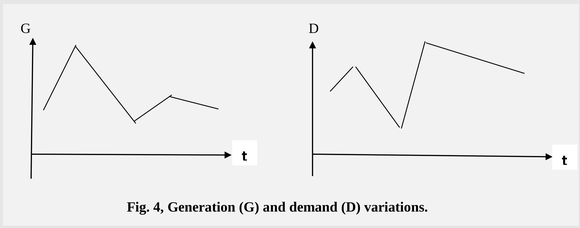


Fig. 4, Generation (G) and demand (D) variations.

A controller based on queueing theory can be implemented for optimum site installation capacity and location:

Next forecast= previous forecast + soothing constant X forecast error
with a soothing constant $0 \le \alpha \le 1$

$$\hat{u}_t = \hat{u}_{t-1} + \alpha\,(u_{t-1} - \hat{u}_{t-1}) = \alpha\, u_{t-1} + (1-\alpha)\,\hat{u}_{t-1} \qquad (6)$$

Renewables in Remote Places

With the above model in use, remote mountainous villages can be supplied by part or whole electric power generated by wind and solar hybrid systems already installed for the individual micro hydro systems, depending on load demand. As such, it acts as a smart grid arrangement, by either supplying the main hydro system of bulk reservoir storage and header, or channeling water compressors, or supplying local load demand. The individual micro hydro systems can also supply local demands, depending on availability.

With this isolated arrangement, demands of either electricity or water can be met with both hybrid systems as well as the micro hydro system. Supplying water and electricity demands locally has the advantage to avoid losses, both electrically and mechanically, as well as avoiding extra electrifying installations in harsh environments.

Several scenarios arise with this dynamic arrangement that requires optimization control system. For example, locating a micro hydro system at a particular site involves both fixed and variable costs. The following model yields the optimum, location and size of plant.

Assuming m the number of demand, n number of supplies, k_i fixed cost, x_{ij} percent of demand i satisfied y supplier j, y_j =1 if plant installed, else *0*, and c_{ij} cost of supplying total demand for site i plant j, then,

Minimize total cost for all demands

$$= \Sigma_{\ i=1\rightarrow m}\ \Sigma_{\ j=1\rightarrow n}\ c_{ij}\ x_{ij} + \Sigma_{j=1\rightarrow N}\ k_j\ y_j \qquad (7)$$

against the following constraints:

$$\Sigma_{i=1\rightarrow m}\ x_{ij} \le m y_j \quad j=1\rightarrow n \qquad (8)$$

$$\Sigma_{j=1\rightarrow n}\ x_{ij} = 1, \quad i=1\rightarrow nm \qquad (9)$$

$$Y_j = (0,1) \quad j=1\rightarrow n \quad or \quad V_j \qquad (10)$$

$$X_{ij} \ge 0, \quad i=1\rightarrow m \ and \ j=1\rightarrow n \quad or \quad V_{i,j} \qquad (11)$$

Renewables in Desalination

Sea water can be desalinated from the main input intake using the main reversible hydro system, next to sea. These waters can be channeled to destinations where water demands are in need. In this arrangement, water transportation to remote villages is more efficient and reliable. It could also help in enhancing crop cultivation is some areas.

If we assume that total water desalinated from main sea intake as WS and individual fresh water source and demand as WS_i *and* WD_i, then for N installations,

$$WS=\Sigma_{i=0\rightarrow N}\ (WS_i - WD_i) \qquad (12)$$

This condition is to be verified at all times, for the required renewable energy systems installations needed for water desalination plant.

Conclusion

A smart micro hydro model is proposed for Fujairah that utilizes several adjacent mountainous water reservoirs for supplying local water and electricity loads, as well enhancing the electric grid. Solar-wind hybrid systems of relatively smaller capacities (100-200 kW) are to be installed for the individual water reservoirs of typically 1-5 million m^3 sizes. A controller for scheduling renewable energy generation against water and electricity demands, is suggested but not implemented.

With a grid of renewable hybrid systems with the suggested multi micro-hydro arrangement, scenarios are listed. Further work is needed to convert this grid into a smart probabilistic one.

This model can be beneficial for the local villagers in getting their water and electricity demands at much lower costs. The proposed model can also enhance the national electric grid in reducing the peak load demand. Further benefit is to improve environment since Fujairah is expanding as a main petrochemical center in the region.

This case study is open for dialogues such as design, investment and project planning. Fujairah city is surrounded by many small mountainous dams used as fresh water storage reservoirs, which are rarely utilized throughout the year. With this study, it would be advantageous to achieve renewable energy sustainability as well as clean power generation.