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Assessment of Small-Scale Hydro Power Energy Potentiality for Selected Locations in Egypt.

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Assessment of Small-Scale Hydro Power Energy Potentiality for Selected Locations in Egypt

تقييم امكانات الطاقة الكهرومائية صغيرة الحجم لمواقع مختارة فى مصر

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KEYWORDS:
Mini hydro turbine, Hydro turbine efficiency, Design steps, Hydro energy assessment.

الملخص العربي:- **أحد أكبر التحديات التي تواجه العالم اليوم هو توفير إمكانية الوصول إلى انتاج الكهرباء باستمرار بطريقة آمنة وبأسعار مقبوله. تعتبر محطات الطاقة الكهرومائية الصغيرة واحدة من أكثر مصادر الطاقة المتجددة نظافه واقلها تكلفه واكثرها اعتماديه. وتتميز مصر بأن لديها نهر طويل وهو مصدر جيد للطاقة الكهرومائية. حيث يمكن تركيب العديد من محطات الطاقة الكهرومائية الصغيرة في مجرى النهر. يجب على مصر أن تستفيد من موارد الطاقة الكهرومائية ، ليس فقط لتلبية الطلب المتزايد للطاقه، ولكن أيضا للحد من التلوث البيئى لاستخدام للوقود الحفرى.**

يقدم هذا البحث دراسة عن قدرات الطاقة المائية الصغيرة في مواقع مختلفة في دلتا مصر. تم استخدام بيانات معدل تدفق ومنسوب المياه خلال السنوات الخمس الماضية لمعرفة قدرات الطاقة المائية التى يمكن الحصول عليها. تم حساب الطاقة الكهربيه المتولده سنويا لثلاثة انواع مختلفة من التوربينات التى يمكن استخدامهم فى محطات الطاقة الكهرمائية الصغيرة في ثماني مناطق مختارة في دلتا مصر, ويتضمن التحليل مقارنة بين الطاقة المتولدة من الثلاث أنواع من التوربينات المائية. علاوة على ذلك، تم تصميم برنامج MATLAB لحساب كفاءة التوربينات في كل موقع بمعدلات مختلفة من تدفق ومنسوب المياه. وقد وجد أن استخدام التوربينات من النوع Cross flow and Kaplan, بأحجام مختلفة يقدم افضل إنتاج من الطاقة الكهربائية في المواقع المختارة.

Abstract— **One of the biggest challenges facing the world today is to provide access to sustainable, safe and affordable electricity supply. Small-hydro or micro-hydropower is considered as one of the most cost-effective, reliable and clean sources of renewable energy. Egypt has a long river which is a very good energy source. Many small and micro-hydropower plants can be installed in run-of-river schemes or implemented in existing river infrastructure. Egypt has to make use of its hydro power resources, not only to meet increasing demand, but also for reducing fossil fuels causing environmental pollution.**

This paper investigates the small hydro energy potentiality at different locations in Delta-Egypt. The head and water flow rates for the past five years are used to find out the hydro energy potential. The annual energy of three different mini-hydro turbines are calculated for eight selected regions in Delta Egypt. The analysis includes a comparison between energy outputs from the three types of hydro turbines.

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I. INTRODUCTION

NOWADAYS, the high emissions of greenhouse gases have prompted to severe changes in the atmosphere. So, it is important to move toward the use of sustainable energy sources. These sources include, for example solar power, wind power, and hydropower. Hydropower systems use the kinetic energy in running water to generate electrical or mechanical energy. The water run through the hydro-turbine and go back to the river to use it for other purposes. There are many benefits of hydropower systems such as: its renewable nature as electrical energy source, low operating and maintenance costs, no pollution nor greenhouse gas emissions, high efficiency (about 60～80%) and long-life equipment [1, 2]. On other hands, there are some drawbacks of hydropower systems; variation of water flow rates throughout the year, their effects on the availability of the water in certain seasons, their long construction period and higher initial investment, and lack of ability to construct them near load centers in most cases.

According to the installed power of the plant, hydropower plant systems are classified as large-scale hydropower plants: over 100 MW capacity, medium scale hydro plants: 10 - 100 MW, small hydro plants less than10 MW, Mini hydro plants: 1000 - 100 kW, Micro hydro plants: 5 - 100 kW and Pico hydro plants: less than 5 kW [3, 4].

Mini-hydro is considered best appropriate method of generating renewable energy from low head and flow rivers. It is designed to be a run of river type as it requires low head and flow to drive the hydro-turbine. Many papers were published on utilization and assessment of low head hydropower energy [5-10]. Ref. [5] presented a numerical method to achieve the optimal size of a small-scale hydropower plant composed of two units, with different size and type, operating in parallel. Ref. [6] developed an excel software program to compute the annual energy, and to propose economic indices for a small-hydro power plant by applying a sensitivity analysis method. Refs. [7-10] evaluated small scale hydropower (SHP) development in some countries such as (Nigeria, Turkey, and India) with respect to the government policy and economical aspects.

Ref. [11] presented a probabilistic approach for the generation reliability evaluation of municipal waste water based micro-hydro power plant. The optimal installation location of water capture within a hydropower plant was obtained in [12] using mixed-integer nonlinear programming method. Thirteen hydro-turbine system architectures were used to select the most appropriate turbine architecture for a low-head small scale hydro specification in [13]. Ref. [14] analyzed the significant factors affecting the performance and operation of the hydro-power turbines. It coved their various categories, performance, operation, and cost. Ref. [15] presented a feasibility study of two potential locations in India and it concluded that the irrigation project is a prospective location for small scale hydro-power plant. Ref. [16] presented the analysis of technical and economic feasibility of a small-scale hydropower plant for domestic use in Italy. Different solutions and combination of pipes and turbine and storage tanks have been analyzed in order to identify the most convenient. For each solution, the yearly energy production was evaluated.

Egypt is a well electrified country, with 99 percent of households connected to the electricity system. Egyptian electricity demand has grown significantly in recent years due to the country’s socio-economic development. Electricity in Egypt is generated mainly from thermal electrical power plants. Fossil fuel is the corner stone of the electric production system. Burning these fuels results in the production of carbon dioxide (CO_2)—the primary heat-trapping, “greenhouse gas” responsible for global warming. Applying renewable energy alternatives can potentially reduce CO_2 emissions. One of these alternatives is the mini and micro hydro technology. Egypt has a long river which is a very good hydraulic energy source. Many small and micro-hydropower plants can be installed in run-of-river schemes or implemented in existing river infrastructure. Egypt has to make use of its hydro power resources, not only to meet increasing demand, but also for reduction the fossil fuels causing environmental pollution.

This paper presents an analyzing study to assess hydro energy potentiality for selected locations in Delta-Egypt. The study is based on real date for five years ago. The analysis examines different types of mini-hydro turbines and different types of generators for eight sites in delta Egypt. According to the head and water flow rate of the site, the most efficient configuration for each location is recommended.

The rest of the paper is organized as follows: section 2 discusses the criteria required for selecting the turbine type, section 3 presents a comparison between different generator types that can be used with mini hydro turbines, section 4 presents the mathematical equations used to compute the hydro turbine output power and energy, section 5 describes the selected sites, section 6 discusses the procedure used for evaluating mini-hydro energy in Egypt and section 7 presents the simulation and results. Finally, section 8 concludes the paper.

II. CRITERIA FOR SELECTING APPROPRIATE MINI-HYDRO TURBINE

Selecting the best type of turbine type for a particular situation often depends on the amount of available head and water flow rate in the location and whether it is at the side of a river or stream, or the water is to be channeled or piped directly to your location. Specific speed of a turbine is one of the important indices for designing water turbine. This section discusses the important issues required for the selection of a hydraulic turbine, and the essential equations required to compute specific speed and dimensions of different water turbine types.

A. Hydropower Turbines Type

The selection of the specific turbine depends upon the flow rate and the head of the selected site to get the highest efficiency [17]. Hydropower turbines are mainly categorized as impulse and reaction types. In impulse turbines, the water pressure is turned into kinetic energy before entering the runner, but in reaction turbines the water pressure applies a force on the face of the runner blades. Impulse turbines have a better performance in high and medium heads, while reaction turbines are better in low head and high flow rate sites [18]. There are various types of impulse turbines such as Pelton, Turgo and Cross flow turbines. Whereas, the reaction turbines types are: Francis, Propeller and Kaplan turbines. Table 1 shows the operating head classification of each hydro-turbine type. Figure 1 explains different types of hydro-turbines [19], whereas Fig. 2 shows the operating range of different hydro-turbines for a given head and flow [14].

TABLE 1
OPERATING HEAD CLASSIFICATION OF DIFFERENT HYDRO-TURBINE

Turbine Type	Head Classification		
	High (> 50 m)	Medium (10-50 m)	Low (< 10 m)
Impulse	- Pelton - Turgo - Multi-jet - Pelton	- Cross-flow - Turgo - Multi-jet Pelton	- Cross-flow
Reaction		- Francis (spiral case)	- Francis (open flume) - Propeller - Kaplan

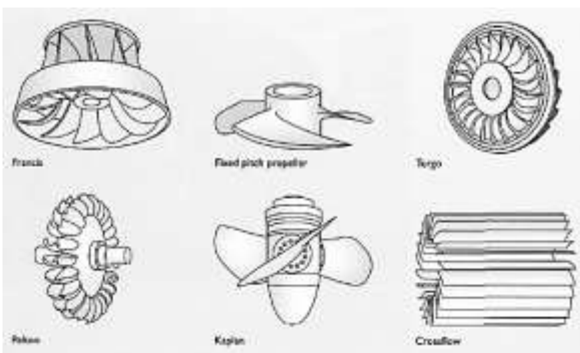


Fig. 1: Different types of water turbines [19].

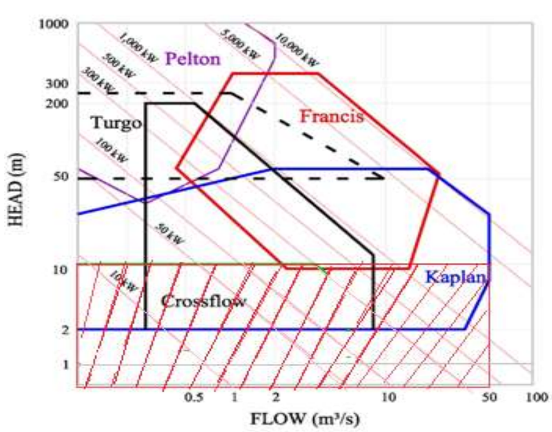


Fig. 2. Hydro-turbines characteristics in terms of water head and flow rate [14]

According to Fig. 2, the range of small scale hydro is less than 10 MW size and less than 10 m height. So, the turbines which can be used in this rang (as illustrated by Fig. 2) are Cross-flow, Francis (open flume) and Kaplan. In the following subsection, the three turbines will be defined and their specific speed and dimensions will be illustrated in detail.

- Cross-flow turbine

The cross-flow turbine is used for a wider scale of heads. It can operate with heads between 0.5 and 200 m. Water enters the turbine, directed by one or more guide-vanes located upstream of the runner and crosses it two times before leaving the turbine [20]. Although, Kaplan and Francis turbines have higher peak efficiency than Cross flow turbine; the cross-flow turbine has a flat efficiency curve under varying load more than those of Kaplan and Francis turbines.

The main advantages of the cross-flow turbine include its low price, good regulation, and easy maintenance due to its simple construction. There is another advantage, where it has a flat efficiency curve and its performance is better than other turbine systems. This type is mainly used in mini and micro hydropower units for small run-of-the-river schemes, as flow rate in small rivers varies seasonally [21]. Due to its better performance, even at partial loads, the cross-flow turbine is well-suited to stand-alone electricity generation.

- Francis turbines

This turbine is called ‘mixed flow turbine’, as the water enters through the outer periphery of the runner in the radial direction and leaves it in the axial direction [22]. Francis turbine has mainly two types: open flume type and closed type. In open flume type, the turbine is immersed under water of the headrace in a concrete chamber and discharge into the tailrace through the draft tube. The disadvantage of this type is that the runner and guide-vane mechanism is under the water and they are not open either for inspection or repair without draining the chamber [23]. In closed type, the water is led to the turbine through the penstock whose end is connected to the spiral casing of the turbine. The open flume type is used for the plants of 10 meters head whereas; closed type is preferred above 30 meters head.

- Kaplan turbines

These turbines are axial-flow type. The inlet guide-vanes can control the amount of flow passing through the turbine by opening or closing it. When it is fully closed, the water will stop completely and bring the turbine to rest [20, 22]. Kaplan turbines can be used across a wide range of flow rates and heads, but it is preferred in low head sites with high flow rates, as it is more effective in lower heads than other turbine types, while, other turbines are more effective on higher heads. The disadvantage of Kaplan turbine is that it is expensive. Typically, it can be used on sites with rang of net heads from 1.5 to 20 meters and peak flow rates from 3 m3/s to 30 m3/s. Such systems would have power outputs ranging from 75 kW up to 1 MW.

There are three types of Kaplan turbines, which are vertical axis turbine, horizontal axis (also called S-turbines) and bulb turbines. Vertical-axis Kaplan turbines are preferred in sites with small footprint, but horizontal axis or ‘S-turbines’ require a larger system footprint. Vertical turbines for the installation in open flume are designed for the water energy utilization at relatively low heads. These turbines are usually provided with a gear drive connecting them to the generator. Bulb Kaplan turbines sites within the main flow. Horizontal axis and bulb turbines are technically slightly more efficient than vertical axis because the inlet flow does not have to change direction and, so should have lower hydraulic losses. The application heads are from 1.5 m to 25 m and output is up to 50 MW [24]. In reality, the difference between the three types is not significant and, so the decision of choice is dependent on supplier and price.

B. Specific speed of turbines

Specific speed is the main numerical classification of a hydro turbine. This number characterizes the speed of the turbine at its maximum efficiency with respect to its flow rate and power. Specific speed can be determined independently of turbine size. Given the fluid flow conditions and the desired shaft output speed, the specific speed can be calculated and consequently the appropriate turbine design is selected. Hence, the specific speed can be used to reliably scale an existing design of known performance to a new size with corresponding performance. The specific speed can be calculated as a function of maximum power and net head using Eq. (1) or as a function of the flow rate discharge and net head using Eq. (2) [20, 25] as follows:

Specific speed Ns is the turbine rotation speed (r.p.m) working under a fall of 1 m and delivering a power of 1 kW.

$$N_s = \frac{N*\sqrt{Pt}}{H_n^{5/4}} \tag{1}$$

where N is the turbine speed in (r.p.m), H_n is the net head in (meter) and P_t is the turbine power in (kW).

Specific speed n_q is the turbine rotation speed (r.p.m) working under a fall of 1 m and a flow of $1m^3$ /s

$$n_q = \frac{N*\sqrt{Q}}{H_n^{3/4}} \tag{2}$$

where Q is the discharge (m^3/s)

The relationship between Ns and nq is:

$$Ns \approx 3*nq \tag{3}$$

C. Hydropower Turbines Dimensions:

Once the turbine type, specific speed and net head are known, the fundamental dimensions of the turbine can be estimated. Each type has its own shape and construction as explained before in Fig. 1. So, there will be different dimensionality equation according to the turbine shape and operation [20, 26]:

- Cross-flow turbine:

The main dimensions of this type are the runner diameter, runner length and the jet thickness or nozzle width and they can be formulated as functions of net head, water flow and rated turbine speed as:

$$D_r = \frac{40*\sqrt{Hn}}{N} \tag{4}$$

$$L_r = \frac{0.81*Q}{Dr*\sqrt{Hn}} \tag{5}$$

$$t_j = \frac{0.233*Q}{Lr*\sqrt{Hn}} \tag{6}$$

where D_r is the runner diameter in meters, L_r is the runner length in meters and t_j is the jet thickness or nozzle width in meters.

- Francis turbine:

In this type, the main dimensions are: outlet diameter and inlet diameter. They are formulated as functions of net head, rated turbine speed, and specific speed.

$$D_3 = 84.5(0.31 + 2.488\frac{Ns}{995}) * \frac{\sqrt{Hn}}{N} \tag{7}$$

$$D_1 = \left(0.4 + \frac{94.5}{Ns}\right) * D3 \tag{8}$$

$$D_2 = \frac{D3}{0.96+3.8*10^{-4}*Ns} \tag{9}$$

where:
D_3 : outlet diameter in meters
D_1 : inlet diameter in meters.
D_2 : inlet diameter in meters for Ns > 163
If $N_s < 163$ then $D_1 = D_2$

This type covers a wide range of specific speeds, going from 30 to 400 corresponding to high head and low head.

- Kaplan turbine:

The main dimensions of this type are: runner outer diameter and runner inlet diameter. They are formulated as functions of net head, rated turbine speed, and specific speed.

$$De = 84.5(0.79 + 1.60 * 10^{-3}\ Ns) * \frac{\sqrt{Hn}}{N} \tag{10}$$

$$Di = \left(0.25 + \frac{94.5}{Ns}\right) * De \tag{11}$$

where De is the runner outer diameter in meters and Di is the runner hub (inlet) diameter in meters. The Kaplan turbines exhibit much higher specific speeds than Francis.

D. Efficiency of Hydro-Turbines

The available head and flow conditions are the criteria of selection for the previous three types of turbines. The calculated efficiency curves of turbine depend on rated head, runner diameter, turbine specific speed and the turbine manufacture/design coefficient. The efficiency equations can be deduced from a large number of manufacture efficiency curves for different turbine types and head and flow conditions [27]. The calculation of hydro turbines efficiency differs according to the turbine's configuration. These equations depend on many factors such the specific speed, runner size, rate of discharge …etc. Following are the efficiency equations for the three low head turbine types.

- Cross-Flow Turbines

The turbine efficiency (η_q) can be computed using the following equation:

$$\eta_q = 0.79 - 0.15\left(\frac{Q_p - Q}{Q_p}\right) - 1.37\left(\frac{Q_p - Q}{Q_p}\right)^{14} \tag{12}$$

where Q_p is the peak efficiency flow which can be computed as: $Q_p = Q_d$ and Q_d is the design flow (flow at rated head and full gate opening in m^3/s)

- Francis Turbines

A significant factor in the comparison of different turbine types is their relative efficiencies both at design point (peak efficiency, $\hat{\eta}_p$ and at reduced flows, η_q).

The peak efficiency can be computed using the following equation:

$$\hat{\eta}_p = \left(0.919 - \hat{\eta}_{nq} + \hat{\eta}_d\right) - 0.0305 + 0.005R_m \quad (13)$$

where:

$\hat{\eta}_{nq}$: specific speed adjusted to peak efficiency:

$$\hat{\eta}_{nq} = ((n_q - 56)/256)^2 \quad (14)$$

$\hat{\eta}_d$: runner size adjusted to peak efficiency:

$$\hat{\eta}_d = (0.081 + \hat{\eta}_{nq})(1 - 0.789d^{-0.2}) \quad (15)$$

D: runner size of Francis turbine

Rm: turbine manufacture/design coefficient (2.8 to 6.1; default = 4.5) Refer to online manual [27].

The efficiency at reduced flow can be computed using the following equation:

$$\eta_q = \left\{1 - \left[1.25\left(\frac{Qp-Q}{Qp}\right)^{(3.94-0.0195nq)}\right]\right\}\hat{\eta}_p \quad (16)$$

where

Q_p: peak efficiency flow which can be computed as:

$$Q_p = 0.65\, Q_d {n_q}^{0.05} \quad (17)$$

Q_d : the design flow (flow at rated head and full gate opening in m^3/s)

- Kaplan Turbines

The peak turbine efficiency can be computed using the following equation:

$$\hat{\eta}_p = \left(0.905 - \hat{\eta}_{nq} + \hat{\eta}_d\right) - 0.0305 + 0.005R_m \quad (18)$$

where:

$\hat{\eta}_{nq}$: Specific speed adjusted to peak efficiency:

$$\hat{\eta}_{nq} = ((n_q - 170)/700)^2 \quad (19)$$

$\hat{\eta}_d$: runner size adjusted to peak efficiency:

$$\hat{\eta}_d = (0.095 + \hat{\eta}_{nq})(1 - 0.789d^{-0.2}) \quad (20)$$

d: the runner size of Kaplan turbine

The efficiency at reduced flow can be computed using the following equation:

$$\eta_q = \left\{\left[1 - 3.5\left(\frac{Q_p-Q}{Q_p}\right)^6\right]\right\}\eta_p \quad (21)$$

Q_p: peak efficiency flow which can be computed as: $Q_p = 0.75\, Q_d$ (22)

III. SELECTION OF GENERATOR

Selection of a suitable generator is the next step after selecting the turbine type and size. Both synchronous and asynchronous generators can be used for small scale-hydro applications. Generator selection depends on a number of factors including the generators available, cost, amount of power, type of electrical output (i.e. AC/DC, frequency, and voltage). Generally, hydroelectric generators are rated on a continuous-duty basis to deliver net kVA output at a rated speed, frequency, voltage, and power factor and under specified service conditions. Following is a brief description of the three available generator types.

A. *Synchronous generator*

Synchronous generators (SG) are usually equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They can supply the reactive energy required by the power system they are connected to. The main advantages of synchronous generators are that they can operate on an isolated system and they can provide any amount of reactive power. But most grid connected small hydro schemes do not need to operate on isolated mode [28]. SG is preferred for large hydropower stations, where the water flow via the dam is nearly constant, but not preferred in small or mini hydro, as it is more expensive than induction generators and permanent magnet synchronous generators and has larger size [20].

B. *Induction generators*

In induction generators, there is no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive power by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive power. They cannot generate any power when they are disconnected from the grid because they are incapable of providing their own excitation current [20, 28]. Their construction is simpler, lighter and cheaper than synchronous generators and they do not require synchronization or voltage controls. But the induction generator operates at lagging power factor because the machine is magnetized from the stator. This means that less power is available with a given current than permanent magnet synchronous machines.

C. *Permanent Magnet Synchronous generators (PMSG)*

In a permanent magnet synchronous generator, the magnetic field of the rotor is produced by permanent magnets. Permanent magnets generators do not require a DC supply for the excitation circuit, nor have slip rings and contact brushes. The advantages of PMSG include their high efficiency and energy, where they do not require additional power supply for the excitation. They have high reliability due to the absence of mechanical components such as slip rings, and they are lighter and therefore they possess higher power to weight ratio. Due to the mentioned advantages, the PMSG are becoming an interesting solution for small scale hydro turbine applications [29, 30].

IV. TURBINES OUTPUT POWER AND ENERGY

Hydro-electric generation depends on two factors: the amount of water falling and the head of falling water. Regardless of the water path through an open channel or penstock, the power generated in a turbine can be given by [20, 31]:

$$P_t=\rho*g*H_n*Q*\eta_t \quad (23)$$

where P_t is the power in Watt generated in the turbine shaft, ρ is the water density (1000 kg/m^3), H_n is the net head (m), Q is the water flow rate (m^3/s), g is the gravity acceleration constant (9.8 m/s^2) and η_t is the turbine efficiency (normally 80-90%).

A turbine converts water pressure energy into the mechanical energy of the turbine shaft, which drives a generator to produce electrical energy.

V. Sites Description

In this study, eight different places are chosen to install small scale hydro plants. These places are located along the Delta of the Nile River in Egypt. The chosen sites have low head, low flow rate and spacious areas away from urban, which make them excellent positions for the establishment of hydropower station. The elevation map in Fig. 3, indicates these locations. The locations are chosen to cover eight sites (El-Reah El-Towfiqy (TW) – Zefta (ZE) – Rashed (RA) – Damita (DA) – El-Mansouria (MA) – El-Reah El-Beheary (RB) – El-Reah El-Menofy (RM) – El-Reah El-Nasery (RN)).

In this study, the head and water flow rates for the past five years (2011-2016) collected by the Egyptian ministry of water resources and irrigation are used to find out the hydro energy potential. Tables A1 and A2 in appendix A, show the average monthly net head and annual flow rate of the selected sites for the last year (2016).

Fig. 3 Locations of the Main Nile River Bridges

VI. Procedure for Evaluating Mini-Hydro Energy in Egypt

The following procedure is used to evaluate the selected sites for installing small hydro turbines:

1. Collect the required data for the selected site (water flow rate and head),
2. Determine the construction dimensions and speed of different turbines type and consequently design the proper small hydro turbine for that site
3. Select the generator type and rating appropriate for that site
4. Determine the output power and energy for the site
5. Repeat the above steps for each site
6. Analyze and discuss the results.

The procedure is illustrated in the flowchart shown in Fig. 4.

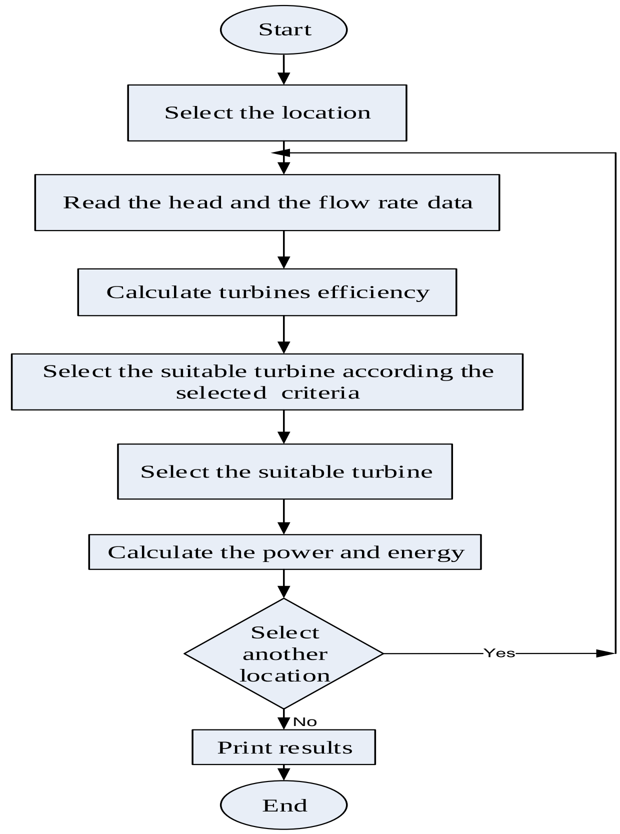


Fig. 4. Procedure of evaluating mini-hydro energy

VII. Simulation and Results

The selected sites for this study identify several areas with different average water head and rate. Simulation is performed for the three hydropower turbines at each location. Firstly, the flow rate of water head data is measured, then the geometry dimensions parameters of the selected mini hydro turbine are calculated. The mini-hydro turbine efficiency, output power and energy for all sites are then computed. These steps will be explained in details in the following subsections.

A. Water flow-rate and water head data

The flow rate of water is determined by measuring the river's water flow velocity and cross-section areas in the selected locations. The Nile river flow and water head change throughout the seasons and, so it is important to measure water flow-rate at various intervals of the year. In this study, Monthly Flow Duration Curves (MFDC) have been obtained for the development and installation of the small-scale power plant by recording water flows and heads from maximum to minimum values. The MFDC are used to assess the expected availability of head and flow variations to select the suitable type of the turbine and generator. Figure 5 shows the net head for the eight selected sites through the year. From that figure, it can be observed that RASHID (RA) site has the highest net head around the year. El-Reah El-Beheary (RB) and El-Reah El-Nasery (RN) sites have the lowest net head around the year. Figure 6 shows the flow rate for the selected sites. It can be observed that the El-Reah El-Beheary (RB) site has the highest water flow rate through the year and Zefta (ZE) site has the lowest water flow rate.

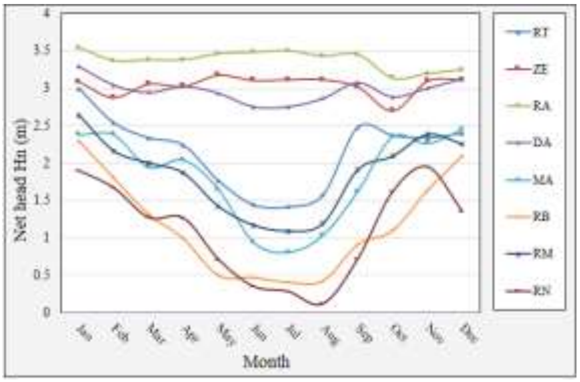


Fig. 5. The net head for the selected sites

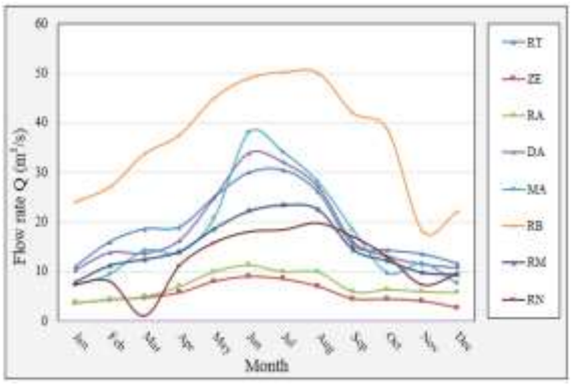


Fig. 6. The flow rate for the selected sites

B. Design of mini hydro turbine

Depending on the available water flow-rate and net head at the selected sites, the suitable hydro turbine is suggested. Then the geometry dimensions parameters are determined according to (4) to (11). According to Fig. 2, the net heads of all selected sites are less than 5 meters. Francis turbine is not suitable for net head less than 9 m. The net head of the selected sites is lesser than 5m and, so Francis turbine type is not suitable to use in these sites. Tables 2 and 3 present the geometry dimensions parameters of the Kaplan and Cross flow hydro-turbine, respectively for each site.

TABLE 2
THE GEOMETRY DIMENSIONS PARAMETERS FOR KAPLAN TURBINES

Location	H_n	D_e	D_i
RT	3	1.6904	0.59076
ZE	3.18	1.4391	0.55403
RA	3.54	1.5565	0.59061
DA	3.29	1.8316	0.63098
MA	2.452	1.5812	0.54472
RB	2.3	1.5314	0.52757
RM	2.64	1.4869	0.53512
RN	1.95	1.41007	0.48577

TABLE 3
THE GEOMETRY DIMENSIONS PARAMETERS FOR CROSS FLOW TURBINES

Location	H_n	D_r
TR	3	0.34641
ZE	3.18	0.35665
RA	3.54	0.37629
DA	3.29	0.36277
MA	2.452	0.31318
RB	2.3	0.30332
RM	2.64	0.32496
RN	1.95	0.27929

C. Selection of generator type and rating

Generally, synchronous generators are more expensive and have larger size than other generators' types for small ratings (below 1 MW). For these reasons, synchronous generators are not preferred in small or mini hydro. The two suitable generators types for small ratings are the induction generators and the permanent magnet synchronous generators. However, for power ratings from 300 to 1000 kW, PMSGs are lighter in weight, smaller in size and higher in efficiency compared to induction generators. So, we recommend to use PMSGs with the small hydro turbines used in the selected sites.

D. Mini-hydro turbine efficiency, output power and energy

The efficiencies of the two suitable turbines (Kaplan and Cross flow hydro-turbine) are calculated from the efficiency equations of each turbine according to (12) to (22). Figure 7 shows the efficiency of the Kaplan and Cross flow hydro-turbine at each location.

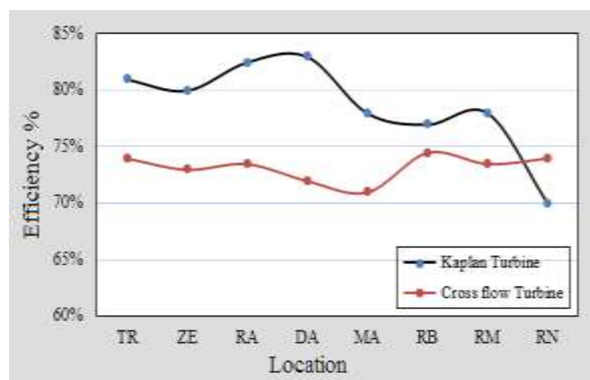
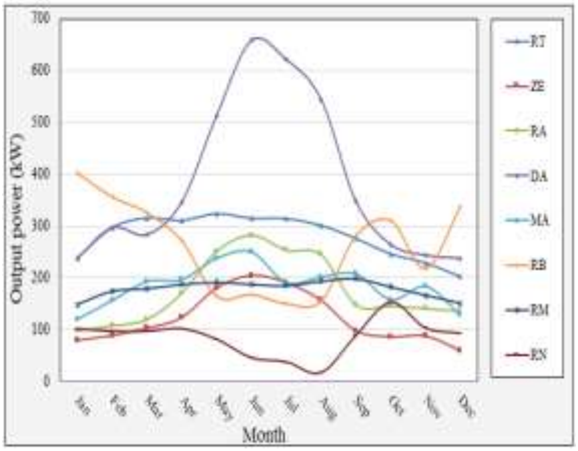


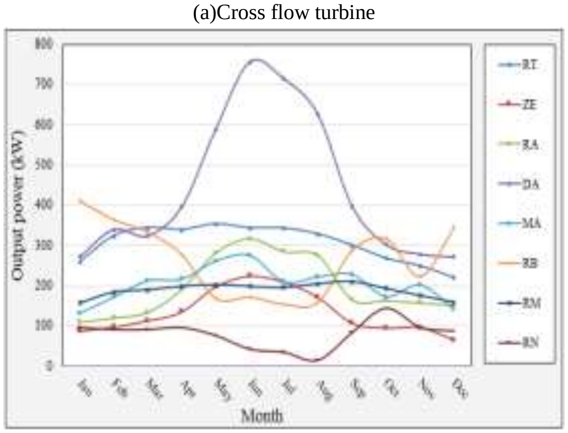
Fig. 7 Efficiency of the Kaplan and Cross flow hydro-turbine at each location

The output power of both Kaplan and Cross-flow turbines for each site is shown in Fig. 8. The Kaplan turbine is more efficient than Cross-Flow turbine at all the selected sites, but for net head is less than 2 m and flow rate is less than 20 m3/s. Conversely, Cross-Flow is more efficient (at RN site).

The annual energy generated from each turbine at the selected sites are shown in Table 4. Although the water flow rate and net head are not the highest at DA site, the annual energy generated at this site is the largest energy of all the selected sites as the output energy depends on both the net head and flow rate. This means that an economic optimization analysis is required to detect the best site to install mini hydro in Egypt.



(a)Cross flow turbine



(b)Kaplan turbine

Fig.8 Output Power of both Kaplan and Cross-flow turbines at the selected sites

TABLE 4:
ANNUAL ENERGY OUTPUT

No.	Locations	Annual turbine electrical energy generation(kWh)	
		Kaplan	**Cross flow**
1	DA	3804785	3300537
2	RT	2646949	2418200
3	RB	2336340	2260485
4	MA	1755313	1597785
5	RA	1691449	1506927
6	RM	1634950	1540626
7	ZE	1146397	1046087
8	RN	633389	669582

VIII. Conclusion

This paper presented a preliminary assessment of small hydro energy potential in Egypt. The paper investigated the small hydro energy potentiality at eight sites in Delta-Egypt. The study was based on real date for five years ago and examined different types of mini-hydro turbines and different types of generators for the selected sites. A MATLAB program was built to compute the turbines efficiencies for each site at different head and water flow rate. According to the annual energy generated, the most efficient configuration for each location is recommended. Out of this study, it can be concluded that: the most suitable mini-hydro turbines used for heads less than 5 m are Kaplan and Cross flow. In most sites, Kaplan turbine is more efficient than Cross flow turbine. The expected total energy that can be produced from the eight sites is 15.6 GWh. The most suitable Egyptian sites for mini-hydro power generation was assessed and the following conclusions was observed:

1. El-Reah El-Beheary (RB) and El-Reah El-Nasery (RN) sites have the lower net head around the year.
2. El-Reah El-Beheary (RB) site has the most amount of water flow rate around the year.
3. Damita (DA) site has the highest values of electric power and annual energy.
4. Reah El-Nasery (RN) site has the lowest values of electric power and annual energy

The study proved that the mini-hydroelectric projects can be created in many sites in Egypt, so that it can be considered as a good alternative for solving a part of Egyptian energy crisis. An economic optimization analysis is required to detect the best site to install mini hydro in Egypt.

Appendix A

TABLE A1:
AVERAGE MONTHLY NET HEADS (METER) OF THE SELECTED SITES AT YEAR 2016

	RN	RM	RB	MA	DA	RA	ZE	TW
Jan	1.9	2.64	2.3	2.38	3.29	3.54	3.09	3
Feb	1.67	2.16	1.8	2.381	3.04	3.37	2.88	2.54
Mar	1.27	2	1.32	1.946	2.94	3.38	3.06	2.34
Apr	1.265	1.864	0.99	2.045	3.02	3.38	3.03	2.24
May	0.711	1.42	0.5	1.651	2.93	3.46	3.18	1.77
Jun	0.35	1.17	0.47	0.945	2.75	3.48	3.11	1.45
Jul	0.28	1.09	0.41	0.804	2.75	3.5	3.12	1.42
Aug	0.116	1.19	0.426	1.036	2.86	3.43	3.12	1.58
Sep	0.72	1.91	0.915	1.623	3.07	3.45	3.02	2.48
Oct	1.62	2.09	1.1	2.356	2.88	3.14	2.7	2.37
Nov	1.95	2.38	1.64	2.264	3	3.2	3.1	2.34
Dec	1.35	2.25	2.1	2.452	3.12	3.25	3.12	2.4

TABLE A2:
AVERAGE MONTHLY FLOW RATE (m^3/s) OF THE SELECTED SITES

	RN	RM	RB	MA	DA	RA	ZE	TW
Jan	7.43	7.8	24	7.2	10.2	3.8	3.6	11
Feb	8	11.15	27.1	9.4	13.8	4.4	4.3	16
Mar	1.05	12.4	33.76	14.2	13.6	5	4.7	18.6
Apr	11.14	14	37.5	13.8	16.2	7	5.7	19
May	15.8	18.6	45	20.7	24.8	10	8	25
Jun	18	22.2	49	38	33.9	11.3	9	30
Jul	18.4	23.42	50.2	34	32	10	8.5	30.5
Aug	19.73	22.5	50	28	27	9.9	7	26
Sep	17	14.4	42	18.4	16	6	4.5	15.3
Oct	13	12.1	38.6	9.6	13	6.4	4.4	14.3
Nov	7.3	9.7	18.2	11.6	11.4	6	4	13.5
Dec	9.5	9.3	22	7.5	10.7	5.8	2.65	11.6

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