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A Review for an Effective Approach towards Hydroelectric Power Generation Using In-Pipe Mesoscale Submersible Turbine

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***Abstract:** Turbines are playing a massive role in our day-to-day lives in the back-end portion of lifestyles where they have been efficiently providing us energy through tidal, hydrological, and many such other mediums. A dominant explanation for the need for energy production has been introduced in the 1800s since the requirement for a high consumption of energy in various forms has started taking place. A very common method that has been observed in today's innovative mannerism is the use of turbines in dams, undersea, elsewhere at locations where the flow of fluid induces better outputs. Vertical axis turbines, Francis turbines as well as Kaplan turbines have frequently opted for such purposes but after studying over 65 works done by adepts, professionals, and experts; the purposely implemented input that is required to fulfill the output doesn't have to always be a necessity, it seemed to be the new designing restructured platform for users as well as providers. An overture to install micro versioned turbines of macro hydroelectric power plants within a residential or commercial structure at the main water-supply connections either at their junctions or directly near the overhead water tanks cannot just provide subtle but fortifying and tireless inputs since the flow of water will be anticipated naturally by the implicated outcomes through day-to-day chores performed.*

Hydrokinetic conversion systems may appear suitable in harvesting energy from such renewable resources, despite the fact that they are still in the early stages of development. Contrary to what has been assumed, there are numerous possibilities for the utilization of this energy for common areas/public zones such as signals, street lights, or any such productive amenities to bestow leading-edge facilities without any hitch regarding external contriving inputs.

***Keywords:** Turbine, CFD Simulations, Archimedes screw, Water distribution logistics, Mini-Hydro-Power Plant, In-Pipe electricity generation, Inline hydroelectric generation.*

I. INTRODUCTION

Water resource engineering has a very delicate role in our daily lives wherein energy production through tidal means or hydro is profoundly utilized. It has been observed that these days there is a requirement for a significantly higher amount of energy since energy consumption has become a vital issue on both economic and environmental sides. [24]

A significant evolution in depletion of resources for future as well as environmental damage which is caused by the high rate of fossil fuel consumption has indicated an urgent seek for alternative energy which can be possible through energy coming from sunlight, biomass, geothermal, hydro and wind to replace the non-renewable energy from fossil fuels in order to prevent the loss possible whilst using non-renewable resources.

Currently, alternative energy can be one of the rightful solutions and to place it accordingly in such a manner that every drop of water can be fruitful in the procedure of hydropower energy from home to home, which means producing energy from a clean source since it doesn't create pollution and neither does it arise myriad issues. [1]

After studying about many macro-sized turbines like Kaplan turbine, Francis turbine, and Small Hydropower Plants (SHPs) which are aimed for 10MW, the actual site conditions and hydrological conditions that are influencing the operational parameters if the turbine was to be installed at overhead water tanks or other such sources of distribution wherein adequate amount of flow of water is possible were analyzed.

The Power electronic converter (PEC) can be utilized to provide variable speed operations. [41] Learnings related to the velocity and power generation requirements is directly proportional to the turbine's efficiency.

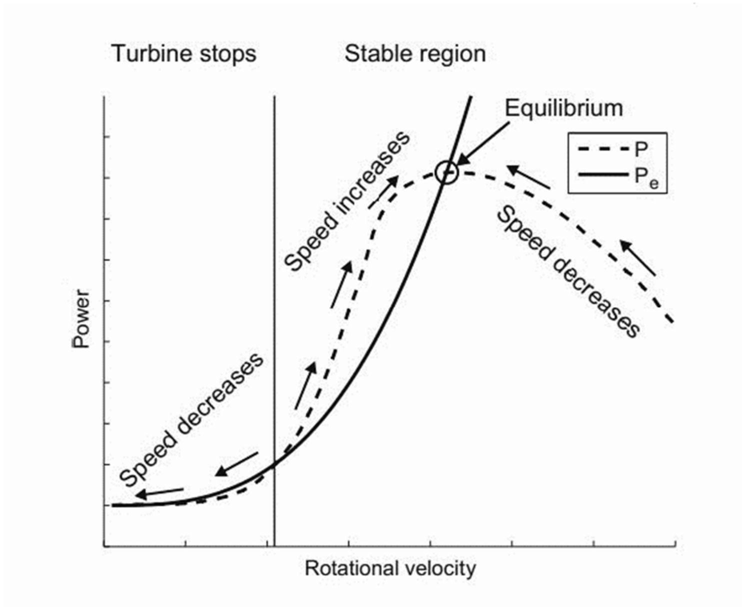

Fig.1 Illustration of a rotational velocity based control scheme [7]

In the above figure, the solid line represents extracted power and the dashed line represents turbine power (at fixed wind speed) and the study of the control system is based on a simulation model for the turbine performance coupled with a model for the electrical system. The control system is embedded into the electrical system. This approach gives full control of the input parameters and makes a study of the performance of the complete system possible. [7]

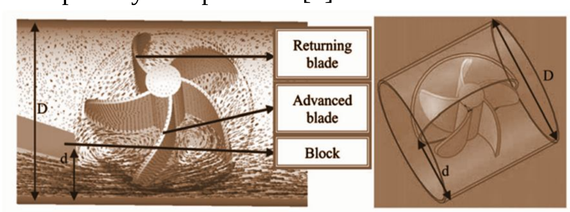

Fig.2 Returning blade formation in a turbine

Whereas the formation of returning blades affects the turbine efficiency in a drastic manner and angular acceleration is the acting force that manipulates the flow as shown in the figure above.

II. APPROACH

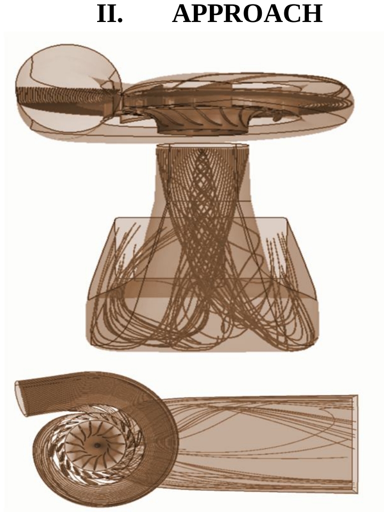

Fig.3 Fluid flow pathlines in the HPP Rijeka turbine, colored by total pressure [29]

The power extracted from a turbine is $P = \frac{1}{2}\, Cp\, \rho A V^3 \infty$, where A is the turbine area, r is the fluid density and CP is the power coefficient. [7]

The computational fluid dynamics (CFD) seems to be optimum for taking qualitative results after surveying a site for the development of such a turbine that works without excessive external intentionally applied force and instead remains operational using the flow of water produced through daily household chores. When it comes to penetration while boring or drilling up of soil, Augers are frequently used to drill holes; similarly, if the multiple teeth of Kaplan turbine are designed such that the helical shaft-like portion of the auger is amalgamated to generate electricity in smaller areas with low head. [29]

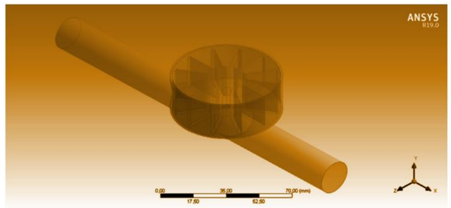

Fig.4 Control volume of pico-hydro turbine model [9]

The Picohydro turbine system can also be opted but it can be an advantageous method only for small waterfalls or streams to generate electricity and henceforth the Archimedes screw can be a booming option for nanomaterials and micro hydropower plants with a maximum power of 5 kW to solve electricity crisis by utilizing the available water potential. [9] The Archimedes screw turbine can be able to work in the range of 1 to 10 meters where low elevations and water flow rate ranging from 0.01 m3/s to 0.10 m3/s is found. [47]

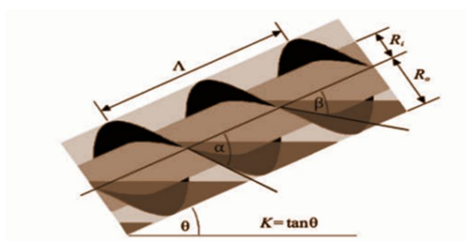

Fig.5 Profile of two-blade screw turbine [47]

These Archimedes screws have been used as a piece of equipment useful for pumping water for ages and recently it is quite involving used as hydroelectric generators known as Archimedes screw generators (ASG) as its observed to be more easy and cost-effective for its maintenance, manufacturer's ease of formation and operation with a lesser amount of environmental impacts. That's one reason why it's a very eco-friendly hydropower option in the energy generation through the water industry especially when it comes to meso-hydropower technology.

III. MULTIPLE DESIGN THEORIES

The previous study developed by Chris Rorres [56] to calculate the main dimensions of the turbine is referred for the current method used to implement this study wherein PEC, Kaplan turbine, Archimedes screw, and multiple teeth like the ones present in augers are used.

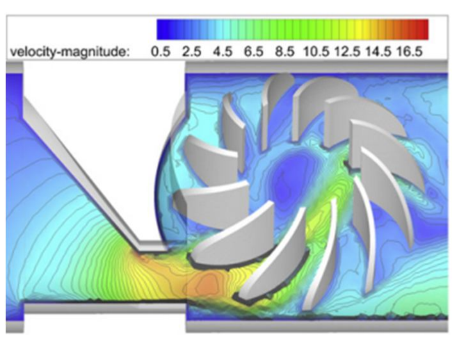

Fig.6 Velocity-Magnitude of the turbine

Effects of blade numbers on pressure and the behavior of turbine using the standard model of turbulence states that turbines with different numbers of blades have different pressure drop at a quarter length distance of the inlet of blades from suction side whereas single-bladed turbine shows a more pressure drop's uniform distribution across all parts of the turbine's blade.

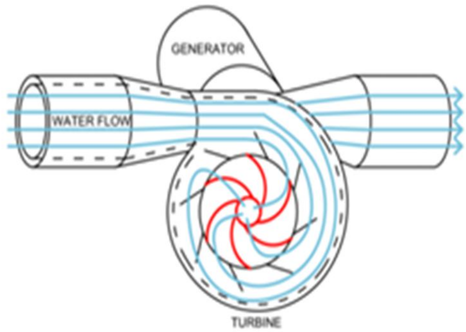

Fig.7 Flow for hydrospin tubular turbine [1]

Fig.8 Sample rotor and stator blade development; (a) rotor, (b) stator. [35]

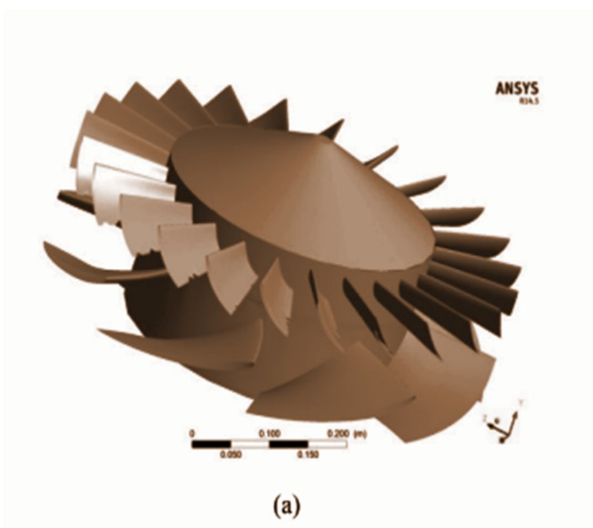

Fig.9 Stator and Rotor turbines development [35]

Rather than opting for a hybrid functionality in designing the turbine, the booming outcomes can be obtained using a tribrid case which means using features that are inspired from three different components/factors of vivid objectification subjectively differing as in different parts of the turbine - Extensional socket which is often found in tap-water filters for volatile diversity, auger type structure and lastly pitching the turbine with casing and PEC generation while keeping the low head discharge in mind with Kaplan turbine's tip [23].

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The water velocity was controlled by opening the control valve under certain conditions.

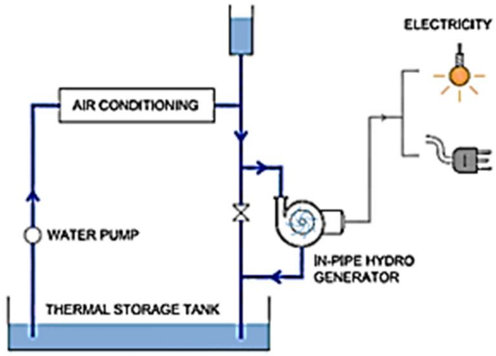

Fig.10 Integration of in-pipe hydro in air conditioning systems [1]

The straight pipes were sufficiently long to provide a uniform flow, and an electromagnetic flow-meter was positioned relatively far away from the water turbine to obtain a more precise value. The water baffles of the turbine transformed the extra water head into mechanical energy. The mechanical energy was subsequently turned into electrical energy by the generator that was mounted on the T-joint.

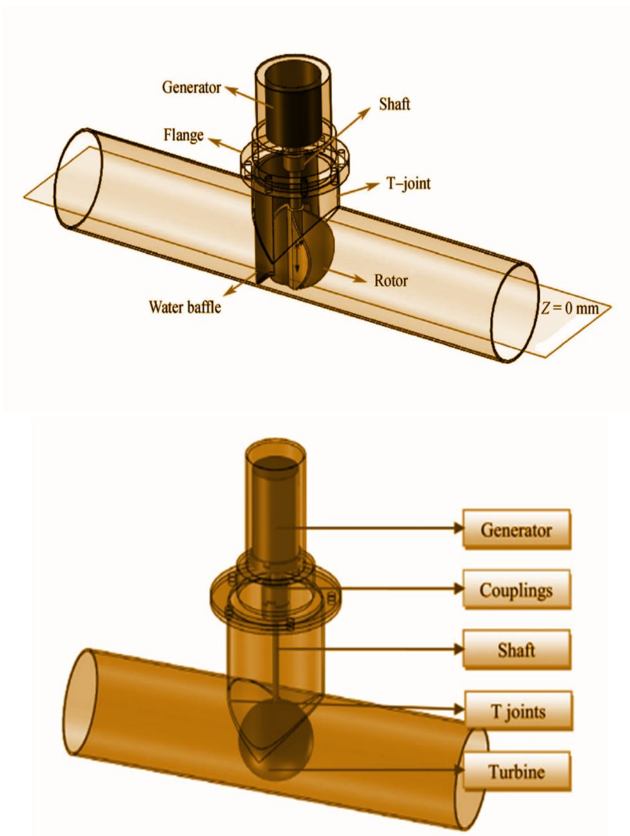

Fig.11 Proposed system for water pipeline [2]

• Faraday's law: He found that when a magnet is moved across a conductor, it causes electricity to flow. In large generators, electromagnets are made by circulating direct current through loops of wire wound around piles of magnetic steel foil. They are called field columns and are installed on the circumference of the rotor. The rotor is connected to the turbine shaft, and it rotates at a constant speed. When the rotor turns, it causes the field electrodes (electromagnets) to move past the conductors installed in the stator. This, in turn, leads to electricity flow and voltage development at the generator output terminals. [27]

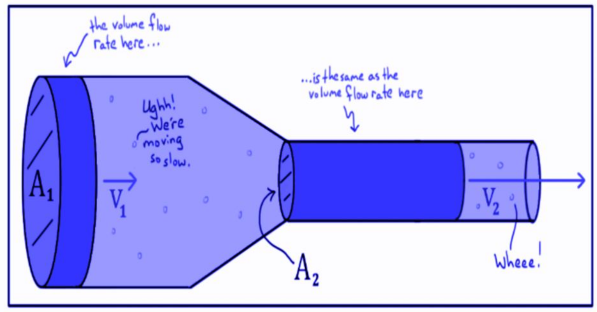

Fig.12 Mass Flow Rate

IV. IN-PIPE FUNCTIONALITY

The load connected to the generator was utilized to manually adjust the water turbine's rotational speed. [6] The embodiments of the hydro turbine are mainly suitable for a tidal basin's application where the flow of water and water current changes the direction over the course but eventually if a dynamic flow occurs in a static pipe that has laminar functionalities but acts turbulent due to pressure and transfer of water from a source to various water mains and distributary pipelines, which leads to rotation of the rotor of water turbine in the same direction regardless of the flow of tide/water. [13]

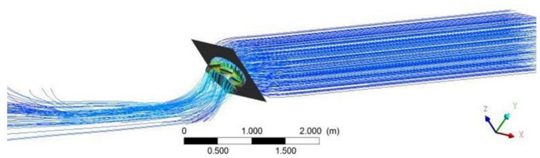

Fig.13 Turbine installation and fluid flow direction [37]

The overall design combines the concept behind a swirl turbine draft tube since it involves turbomachinery that suits low heads and large discharges as the head is to be exploited in the draft tube by pressure energy that is recovered by kinetic energy. [37]
Due to kinetic energy transfer from the incoming flow, a water turbine begins to rotate and produce electric energy. This rotational motion is first converted to mechanical energy by a gearing mechanism connected to the rotating shaft, and then to electrical energy via a generator box. [8] The maximum energy available from a water channel [8] is calculated as follows:

$$Pmax = {}^{1}/_{2}\, \rho m v^{3}$$

The power coefficient Cp is the ratio between the maximum available power and the power output. [18,45] The rotor solidity ratio and Tip speed ratio, which are determined by the following relationships to determine the ideal working conditions of a wind turbine:

$$\text{Solidity ratio: } \sigma = \frac{Nc}{R}$$

$$\text{Tip Speed Ratio: } \lambda = \frac{R_w}{v}$$

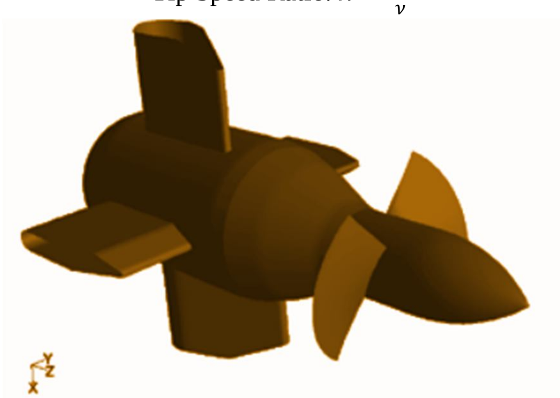

Fig.14 Swirl type turbine model [37]

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The shape of a draft tube is optimized to increase pressure recovery, which results in stronger velocity gradients and shear layers.

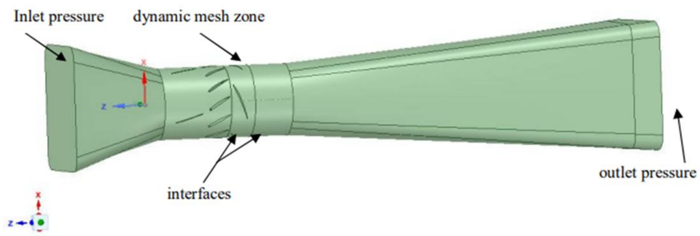

Fig.15 Boundary Condition Schemes [23]

Euler scheme was used for time discretization while Gradient and Laplacian discretization was accomplished with central schemes in the second order. [19] The simulations proved that the modeling methodology in the ANSYS FLUENT software ought to have higher successive rates in simulation and can successfully be used in the designing process and optimizing rotating machines, and in particular the facilities for which the prototyping is done. This mainly applies to prototype objects, to which practically every new hydropower plant can be calculated. [23]
Other loss modes are predicted to be affected by altering frictional loss. Water clinging to the screw blades causes a friction leakage flow, which has been discussed in the literature [55, 56], although modeling of this phenomenon appears to be lacking. This frictional leakage is thought to be a dynamic form of overflow leakage, dubbed "dynamic overflow leakage" by the authors. Surface roughness has an impact on this loss.
The geometric quality of the mesh is essential in a simulation, independently of the shape functions used. [9]
The pressure drop through the turbine is to be calculated using the equation $\Delta p = p_{0\cup t} - p_{in}$. Then, the hydraulic power yielded by the water was calculated from the equation P = γ QH; in which γ is the specific weight of the water, Q is the flow rate at the point of operation and H is the pressure difference expressed in meters. [9]
The fluid flow velocity inside the turbine will be inversely proportional to the pressure, which then changes into the momentum that will drive the turbine. Understand the pressure patterns that occur in the turbine blades, it can be seen the difference in performance on each turbine that is suitable for use. The greater the pressure is the greater result in shaft rotation. However, keep in mind that the pressure will decrease as it changes into the momentum that produces a spin on the turbine shaft. In a single-blade turbine, the pressure is still high enough at the end of the turbine output, especially when the pitch distance is small. [51]

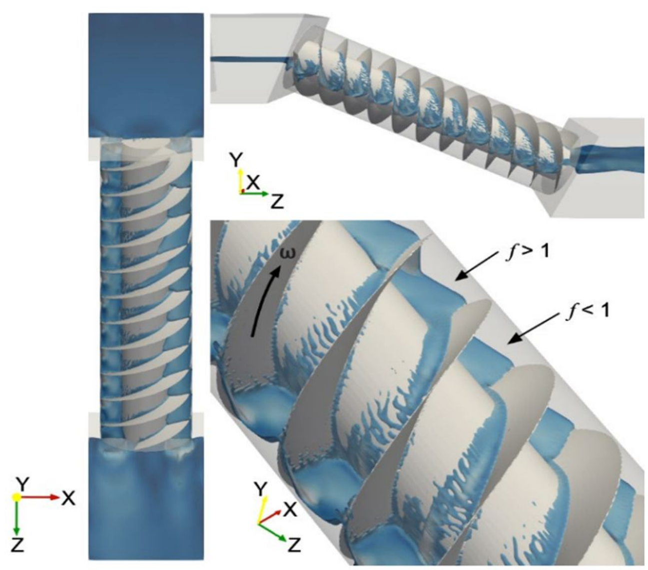

Fig.16 CFD model domain highlighting the main boundary conditions [54]

The observations state that the hydrodynamic behavior of the Archimedes turbine was examined and results in aiming to harness the technical/hydraulic potential of tidal currents.

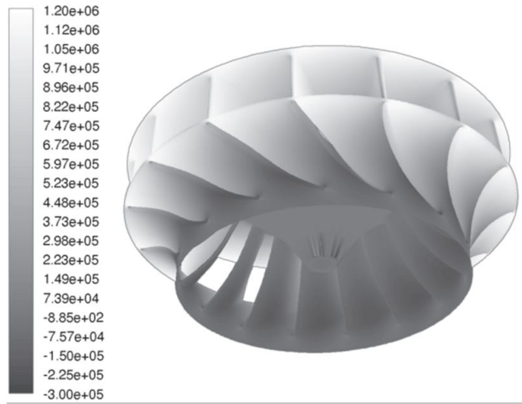

Fig.17 Contours of static pressure on runner surfaces [29]

The static pressure contours depict the pressure differential between the pressure and suction sides of the runner blades. The force that causes torque is created by the pressure difference. The static pressure contours clearly indicate the stagnation sites (or 3D stagnation curves) when the fluid's total energy is turned into pressure energy. [29]

The pathlines follow a fairly stable fluid flow in the spiral distributor and between the stay ring blades, which then transforms into an extremely complex turbulent flow in the diffuser due to improper operation. [30] As a result, the fluid flow's kinetic energy is partially transmitted to the diffuser. CFD models provide a full understanding of the complicated structure of Francis turbine fluid flow in addition to computing hydraulic properties. [29, 32]

The flow pattern has resulted in indicating the highest streamline velocity to be enacted at the surface of the helical blade's suction when compared with the surface discharge. [33] The flow field as in the turbulent structures has a computed process with various mesh designs and mixed fluctuations in order to get variable equations. [2]

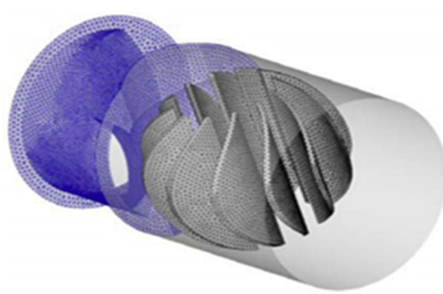

Fig.18 Mesh Design [2]

The sliding mesh approach was used to simulate the unstable flow field. Internal and external components of the computational domain were separated. 1.5 million unstructured tetrahedral meshes were used to decompose the entire computational domain. The finished design's mesh is displayed. Although the mesh number is still a contentious topic, the degree of mesh number was deemed sufficient for such a small computing domain to eliminate the need for a grid-dependence analysis. [2]

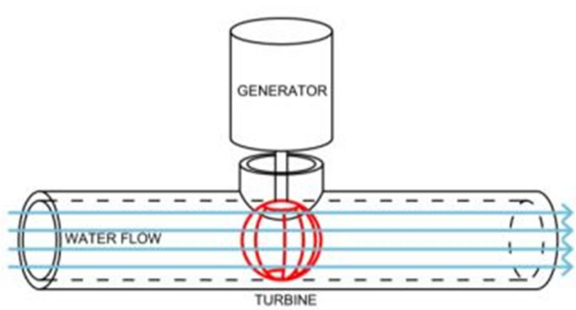

Fig.19 Internal system of an in-pipe turbine [1]

Navier-Stokes Equation is used for the flow of water in pipe too along with airflow in the aircraft wing productions or weather modeling or even ocean currents analysis, and hence the complex and simplified formation of the equation helps to design turbines and power plants in the water resource engineering domain. [17] The turbulent structure has been observed to occur at different timescales with various lengths, henceforth creating a model that can analyze all these possibilities isn't practicably easy.

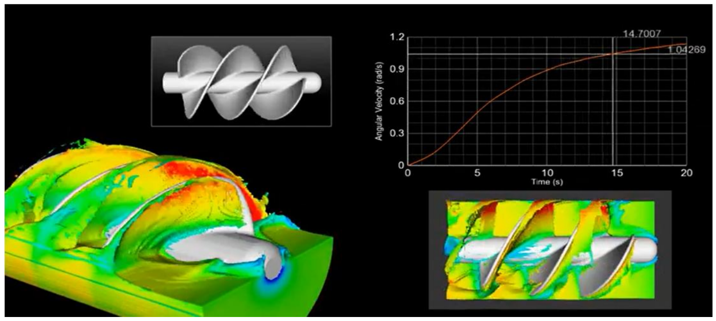

Fig.20 Graph results from turbine

Leakage and slope decrease causes a difference in heads as the rate of leak flow amount reduces when driven by differential pressures. The Archimedes screw generator's (ASG) efficiency is inversely proportional to the slope's height i.e. Screw efficiency increases when slope decreases. [62]

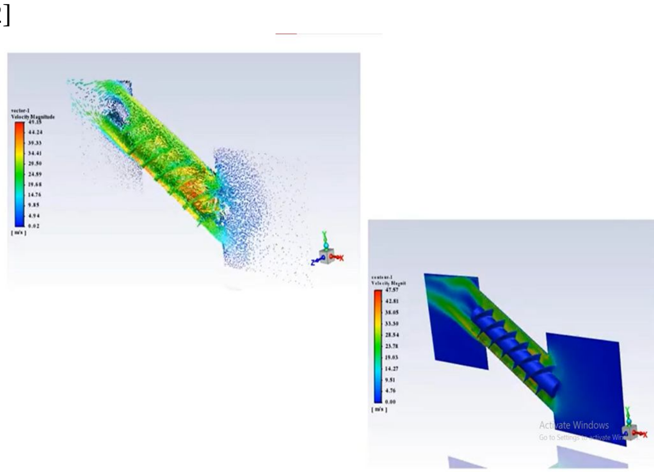

Fig.21 CFD simulations of ASG

Another such factor that affects the efficiency is the optimization of blades in the turbine which increases efficiency since the optimized designs opted for blades that will be able to absorb a maximized amount of energy.

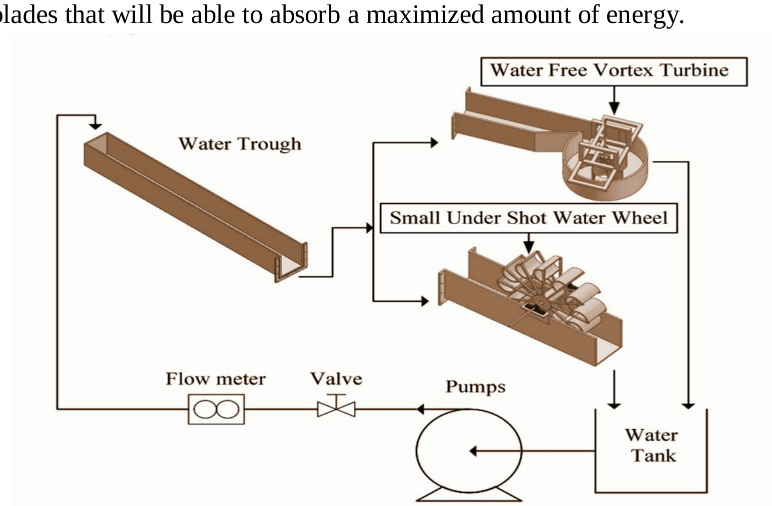

Fig.22 Water Free Vortex Turbine Diagram [65]

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V. PICO-HYDRO RECOMMENDATIONS

Usually, very low head turbines are designed as a compact turbine using one guiding vane's row and rotor blade whilst the bloc of the turbine can be opted to be placed such that the position inside the canal is about 30-60 degrees from the vertical axis in order to construct a suitable turbine that utilizes very low head flow with higher amount of efficiency without any complexion or expensive regulator flows. [49]

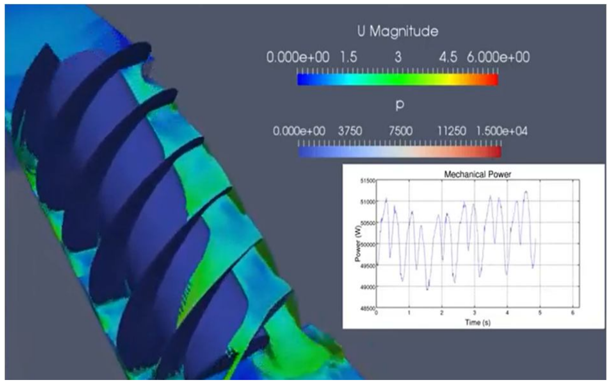


Fig.23 Graph showing mechanical power produced

There are mainly two reasons due to which the angle of attack on lades varies at every azimuthal location during the rotation of the turbine and that is the blade pitch angle with a constant incoming flow which varies because of the tangential orientation maintained while placing blades to the turbine circumferential portion whereas the second reason is the direction of relative water velocity that changes constantly as the interaction between blade tangential velocity and incoming water velocity takes place.

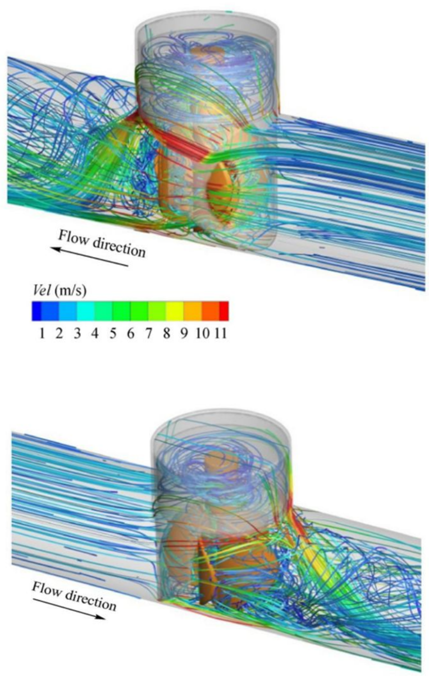


Fig.25 Pico-Hydro variation in results due to directional changes

The basic necessity behind the production and growth of pico-hydro electricity in today's date is that it gives allowance to a simple generation of electricity at 0% fuel cost in its generation which creates the goring demand as the design is not just small but has compact elements that could be easily installed or put into action at small areas. The cost per kilowatt in the generation of electric power through these meso-hydro-turbines is lower than that of the cost per kilowatt through solar power generation or wind power generation. [5,9]

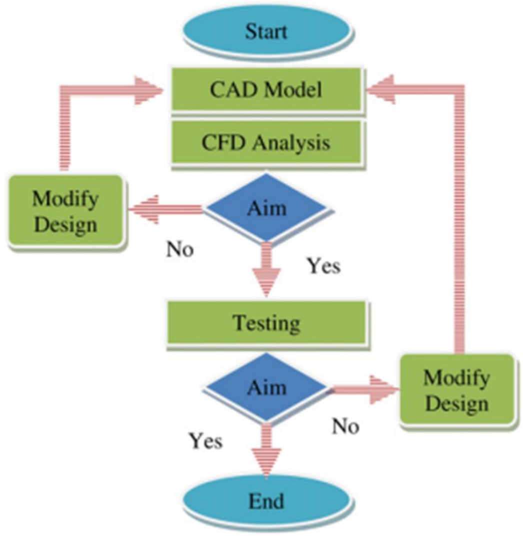


Fig.26 Design Methodology [2]

Modern fluid mechanical design has shifted from pure experimental design to simulation-based design complemented by experimental tests as a result of the introduction of CFD. [2]

There are possibilities to place multiple turbines at distances as per the requirement of energy, usage of water, and the flow availability in a multistoried building. [49] There is an observation of frequent usage of nozzles as a convergent to provide a high amount of pressure jet but that is not a necessity now that the tribrid model can take advantage of its optimum design to modulate as per the flow and the turbine can be attached to different size of pipes through its extensional socket provided at one of its ends.

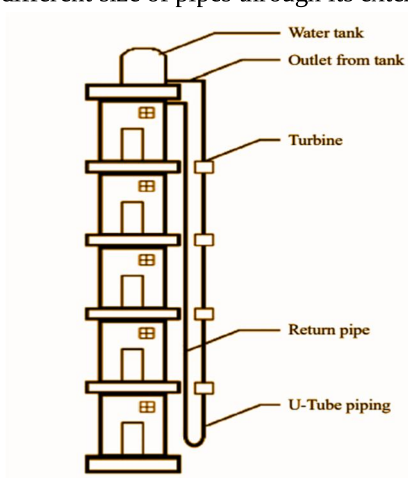


Fig.27 Residential pico-hydroelectricity [62]

The pico hydro system makes advantage of the energy stored in the water reservoir, which is used to power the system. The water in a residential building's water tank with a minimum 3m head can be used to generate pico power. [64]

We deploy many turbines at a distance in multi-storied buildings based on flow availability and water use. The water exits the tank via pipes, one of which is convergent with a nozzle, allowing for a high-pressure jet. The pipe is shaped into an oval nozzle with a very tiny mouth that pushes water out in a line to a large region for better electricity production efficiency. [63]

The time of generation taken up by a normal pico-hydro electric generator is observed to be 05.00 am to 10.00 am as the maximum usage of water will be high during this period of time as one or more than one source of water for various purposes such as bathing, cooking, laundry, etc are used and henceforth the maximum flow rate due to continuous water consumption occurs at this period of time. [62] Similar results for the time taken in generating electricity are observed for the newer models of turbine too because usage of water in the morning is higher as compared to the other phases of the day. [49,58]

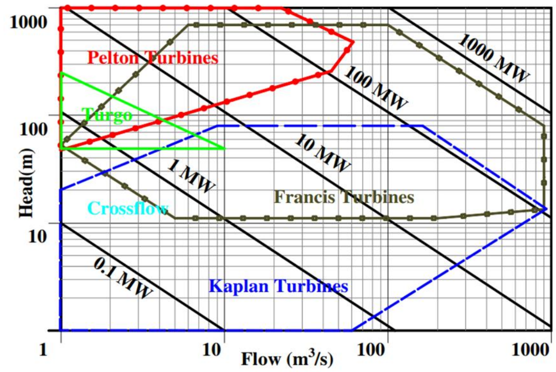


Fig.28 Turbine Application Chart [5,67]

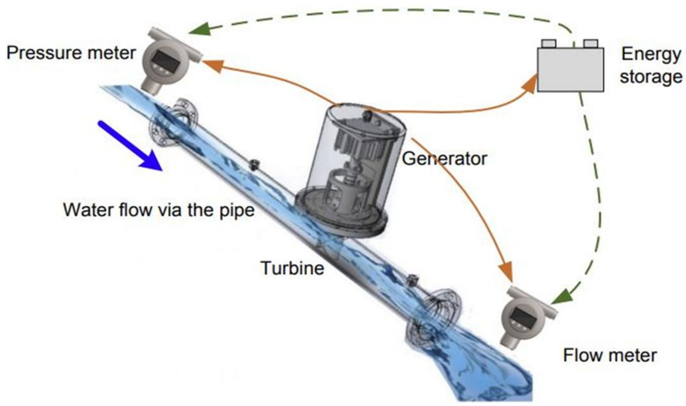
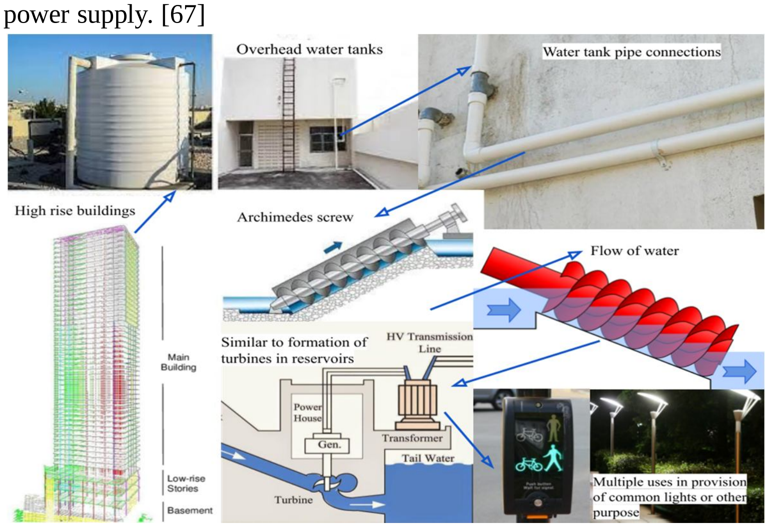


Fig.29 Scheme diagram of the inline hydroelectric generation system (IHGS) [67]

The inline hydroelectric generation system (IHGS) captures the essential little power inside the water pipelines and generates electricity for the monitoring system, as shown in Fig.29. This IHGS is made up of an exterior hydropower generator, as well as a high-efficiency hydro turbine that reclaims leftover pressure by dipping it into flowing water. The turbine drives a central spinning shaft when water passes through. To generate electricity, a shaft and a tiny generator are used. After satisfying the load, excess electricity can be used to charge the energy storage system for later usage. The IHGS uses a remote monitoring system to manage power output and stabilize the power supply. [67]



a) High rise building, b) Water tank, c) Pipe connections, d) archimedes screw, e) flow of water, f) Similar to formation of turbines in reservoirs, g) electricity provisions for pedestrians or public use.

Fig.29 Pictorial presentation of the concept behind the tentative results

VI. CONCLUSIONS

An amalgamation of pico-hydro generation systems along with Archimedes screw generators and alternatively applying convergence if required is recommended to be designed as an alternative energy resource by consuming hydropower through the flow of water from a water tank in buildings where frequent usage of water is observed on a daily basis. The flow rate can be normal in order to achieve persistence in its efficiency as one of the reviewed papers has even stated that flow conditions must be maintained at the highest conditions to obtain maximum torque and power which requires very good flow control and the highest efficiency isn't achieved through higher flow rates but instead in the condition of moderate (medium) flow rate. PEC and Kaplan can further be implemented after certain modifications if required to improvise the efficiency if it doesn't remain as reluctant as proven above. [62] The water-free vortex turbine's turbine produced the most power (14.5 watts) with a turbine efficiency of 35.92 percent, while the small undershot water wheel's turbine produced the most power (7.51 watts) with a turbine efficiency of 13.96 percent. [36] This is a highly adaptable power source that can generate AC electricity even in remote locations around the world. The tribrid model is under testing as its prototype is yet to be generated but after the collection of sufficient data, there is an observation lastly which summarizes the significant necessity of such models in residential, institutional, and commercial building platforms for nominal electricity generation.

VII. ACKNOWLEDGEMENT

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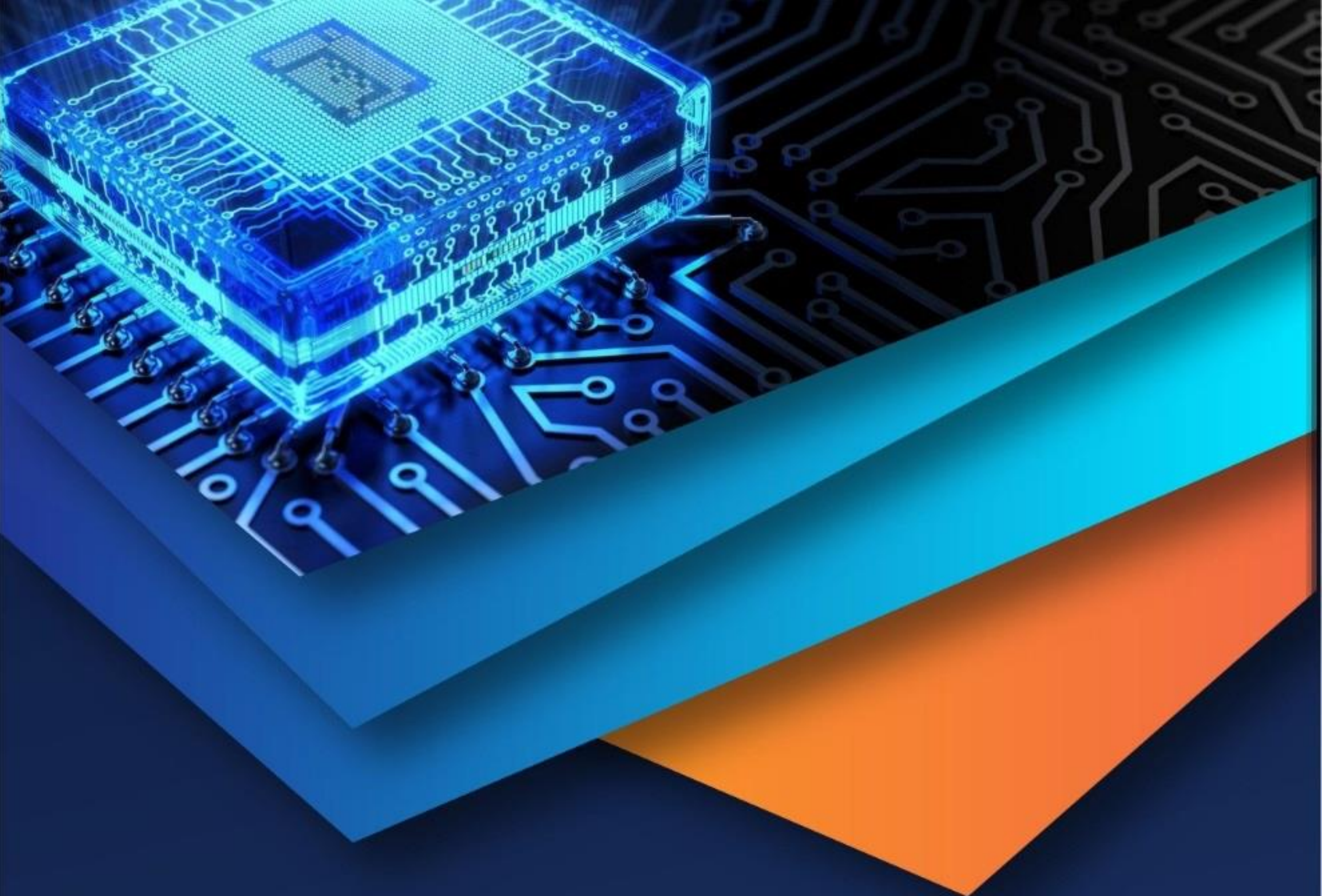

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