ELECTRICITY GENERATED FROM LOW-HEAD WATER SOURCES

Shock Wave Engine Technology

Abstract

Shock Wave Engine technology utilizes the Water Hammer Effect powered by low-head water sources to generate clean electricity

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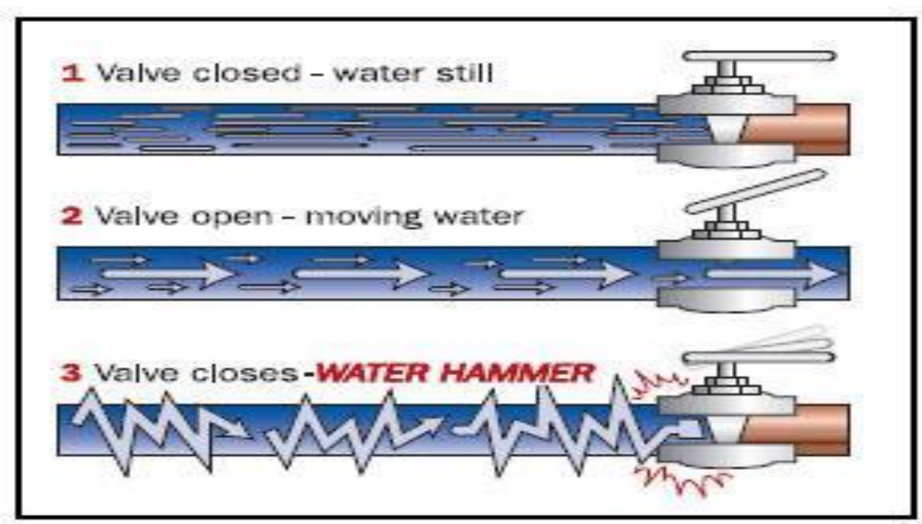
Overview

The Shock Wave Engine (SWE) is a hydroelectric technology specifically designed to generate electricity from very low-head water sources. It is a radical departure from standard hydrokinetic-technologies that rely on continuous flow and high-head water sources. The Shock Wave Engine converts fluid kinetic energy, by creating high amplitude oscillating pressure waves, into mechanical energy and generates clean renewable electricity.

The Water Hammer Effect (WHE):

The Water Hammer Effect (also known as Fluid Hammer) occurs when a fluid flowing inside a rigid pipe is suddenly forced to stop or change direction, for example, by a rapidly closing valve. Since water is *slightly* compressible, the sudden change of flow-momentum inside a pipe creates an oscillating pressure wave. This phenomenon is known as Water Hammer Effect [1, 2]. Figure 1 below shows an illustration of the Water Hammer Effect.



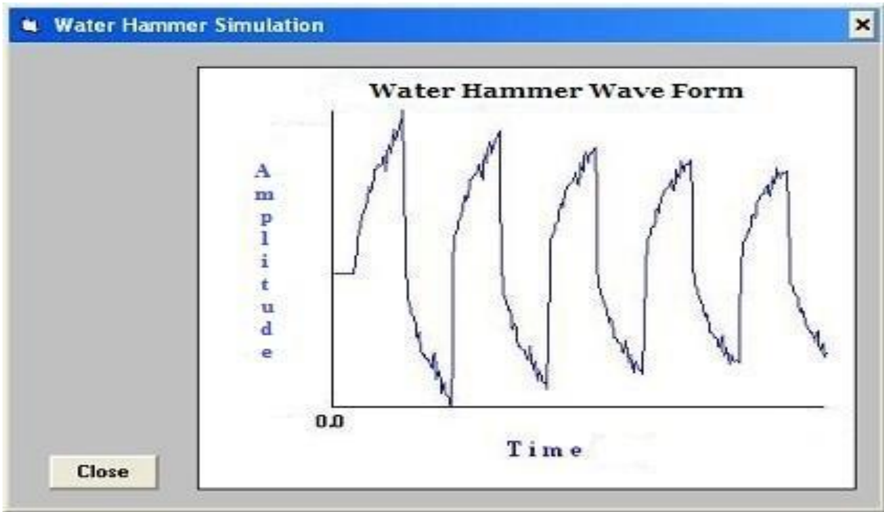


Figure 1 – Water Hammer Effect

Generally speaking, the Water Hammer Effect is an undesirable phenomenon in Industrial Design. Engineers use various features like water towers, surge tanks etc. to reduce its damaging effects. Our proposed technology, the Shock Wave Engine intentionally creates the Water Hammer Effect and exploits the resulting powerful oscillating pressure waves to repeatedly drive a piston/flywheel/generator assembly to produce continuous clean electricity.

Figure 2 – Damaged Pipes from Water Hammer Effect

The Shock Wave Engine

The Shock Wave Engine can be described as a mechanical resonating oscillator that uses the kinetic energy of water momentum flowing through a pipe, interrupted at specific intervals, to create powerful oscillating pressure waves inside the pipe. Figure 3 below illustrates the mechanism of the Shock Wave Engine.

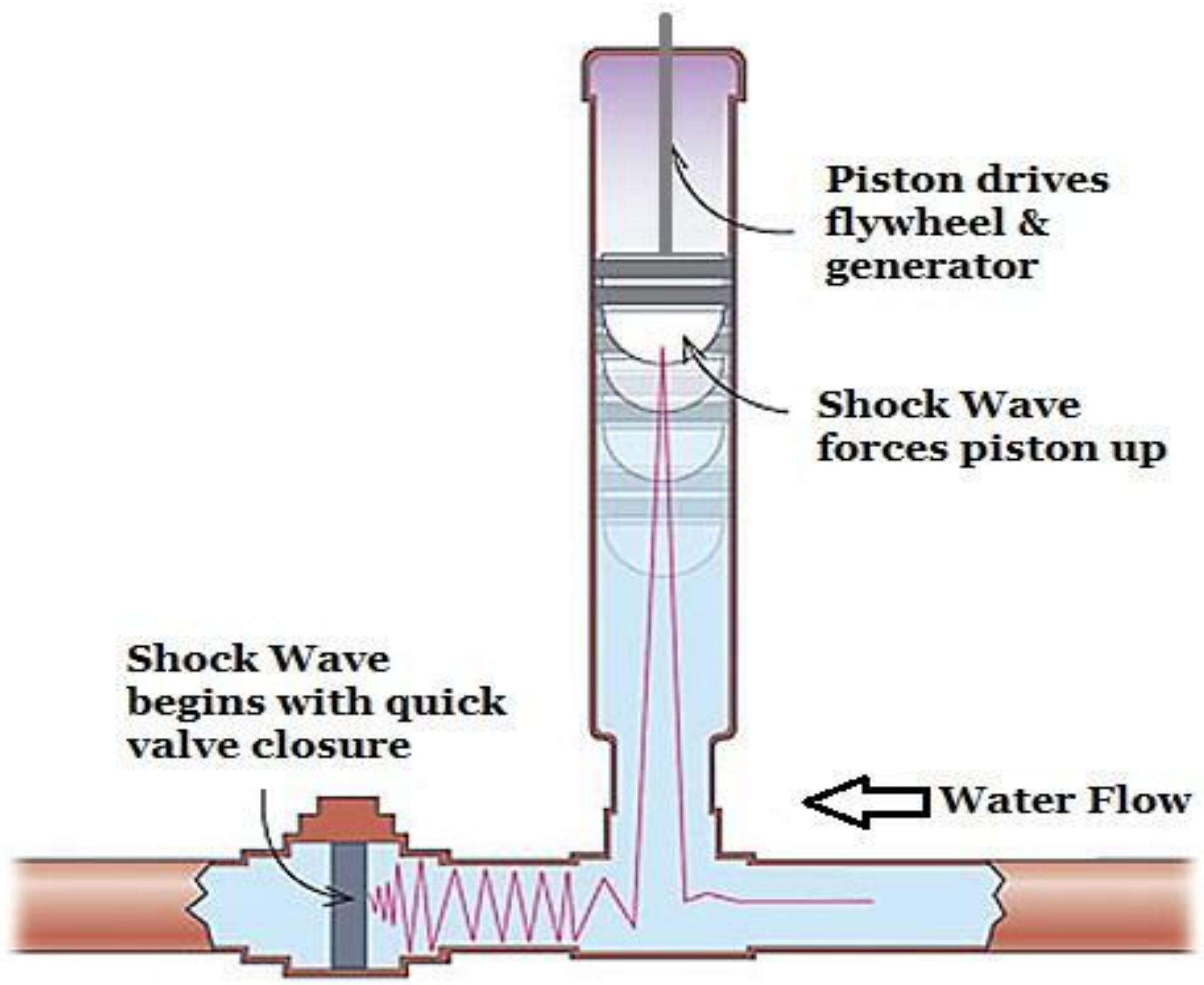


Figure 3 – Shock Wave Engine Technology

The Shock Wave Engine may be located in the flow of water or on the shore provided that the input pipe is positioned to receive proper water flow. An optional radio transmitter and display gauges on production units would permit remote monitoring of the Shock Wave Engine.

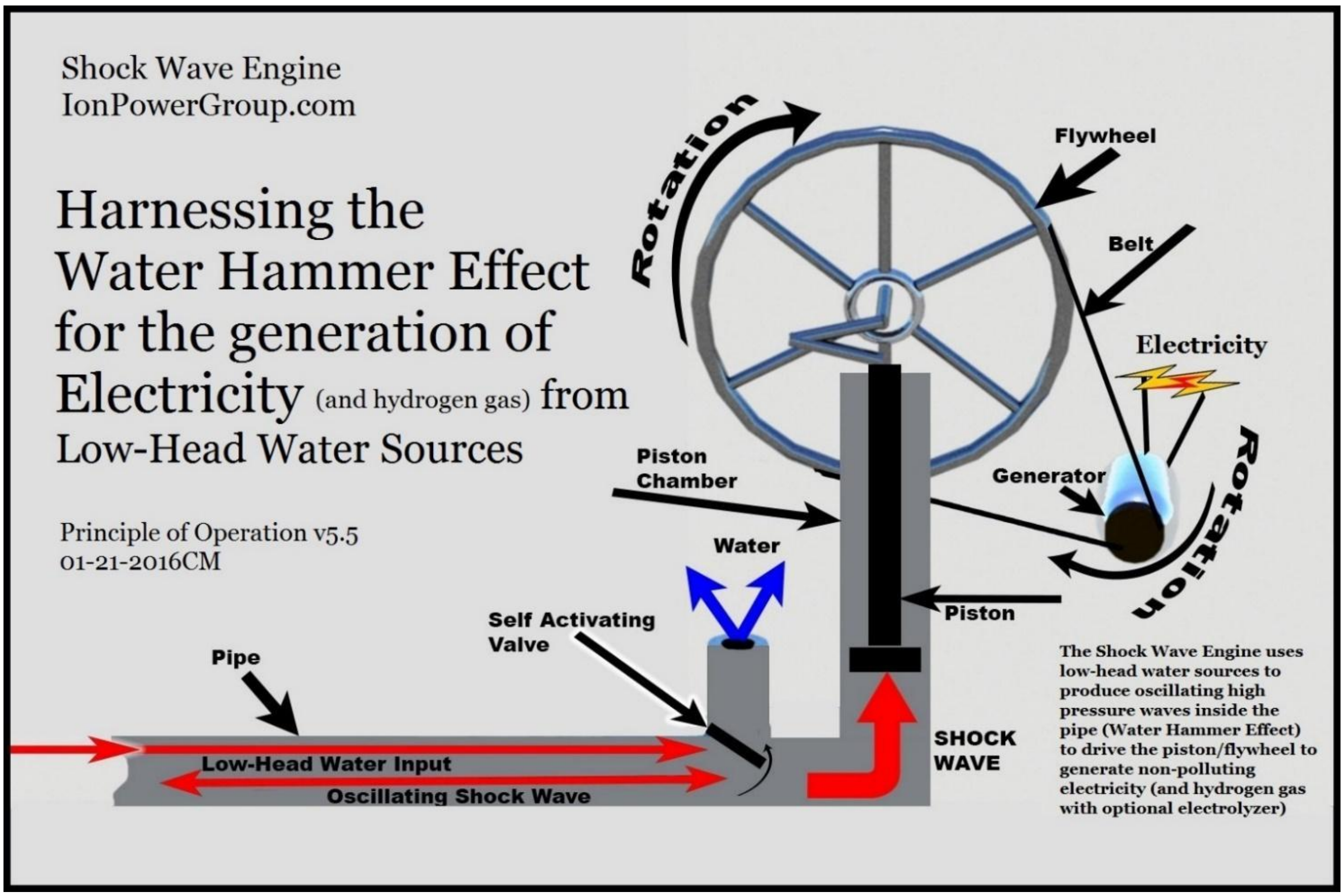


Figure 4 – Conceptual Depiction of the Shock Wave Engine in a Production Housing

Proof-Of-Concept Analysis and Test:

When a valve is closed rapidly in a pipe network it creates an oscillating pressure wave - known as a Water Hammer. To demonstrate understanding of Water Hammer Effect, we quantified overpressures in a simple model consisting of a reservoir, a pipe, and a valve [2]. In this model, the valve is closed instantaneously. The model is sketched in the figure below.

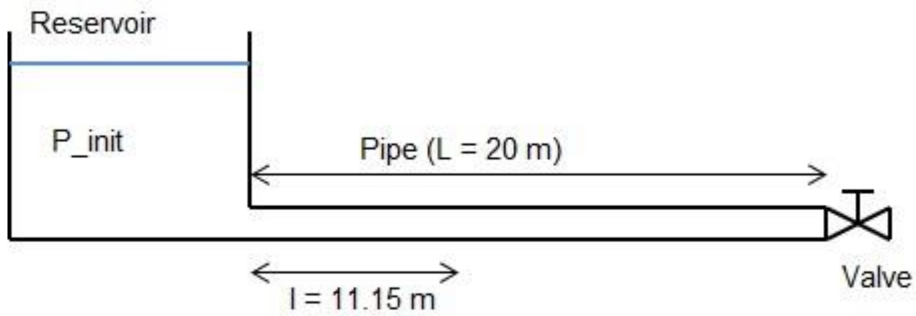


Figure 5: Pipe system with reservoir and valve.

Pipe length, L	20 m
Wetted Pipe Radius, R	398.5 mm
Pipe Material	Steel
Young's Modulus, E	210 GPa
Wall Thickness of Pipe, w	8 mm
Pressure in reservoir, p_init or p_0	1 atm
Initial Flow Rate, Q_init or Q_0	0.5 m^3/s
Pressure Measurement point, l	11.15 m

At time t = 0 s the valve is closed instantaneously, thereby initiating the Water Hammer. As a result of the compressibility of the water and the elastic behavior of the pipe a sharp pressure pulse is generated traveling upstream of the valve. The Water Hammer wave speed c is given by the expression

$$\frac{1}{\square} = \frac{1}{\square_{\square}^{2}} + \square\square_{\square}$$

where c_s is the isentropic speed of sound in the bulk fluid (1481 m/s for water), while the second term is caused by the elasticity of the pipe walls. The water density is ρ, and β_A is the pipe cross sectional compressibility, and the resulting effective wave speed is 1037 m/s. The instantaneous closure of the valve results in a Water Hammer pulse of amplitude P given by Joukowsky's fundamental equation [3]

$$\square = \square\square\square$$

where V is the average fluid velocity before valve closure.

The solved dynamic equations are:

$$\frac{\partial\square}{\square\square} + \frac{1}{\square}\frac{\square\square}{\square\square} = 0$$

$$\frac{\partial\square}{\square\square} + \frac{1}{\square}\frac{\square\square}{\square\square} + \frac{\square}{2\square}\square|\square| = 0$$

Where, $\square$is the friction factor; D is the pipe diameter; B is bulk modulus.

The excess pressure , p − p0, as measured at the pressure sensor located at L=11.15 m is shown in Figure 6. The curves correspond very well to the results obtained in the verification model of Tijessling et al.[3], Figure 10 and thus verify the water hammer model. The verification model is benchmarked against Delft Hydraulics Benchmark Problem A.

The plot shown in Figure 7 illustrates the pressure distribution along the pipe at time t = 0.24 s.

It is clear from Figure 7 that even for small flow rates significant overpressures are created ranging in several orders of magnitude. These can be effectively converted to mechanical energy which, in turn, can be converted to electrical energy.

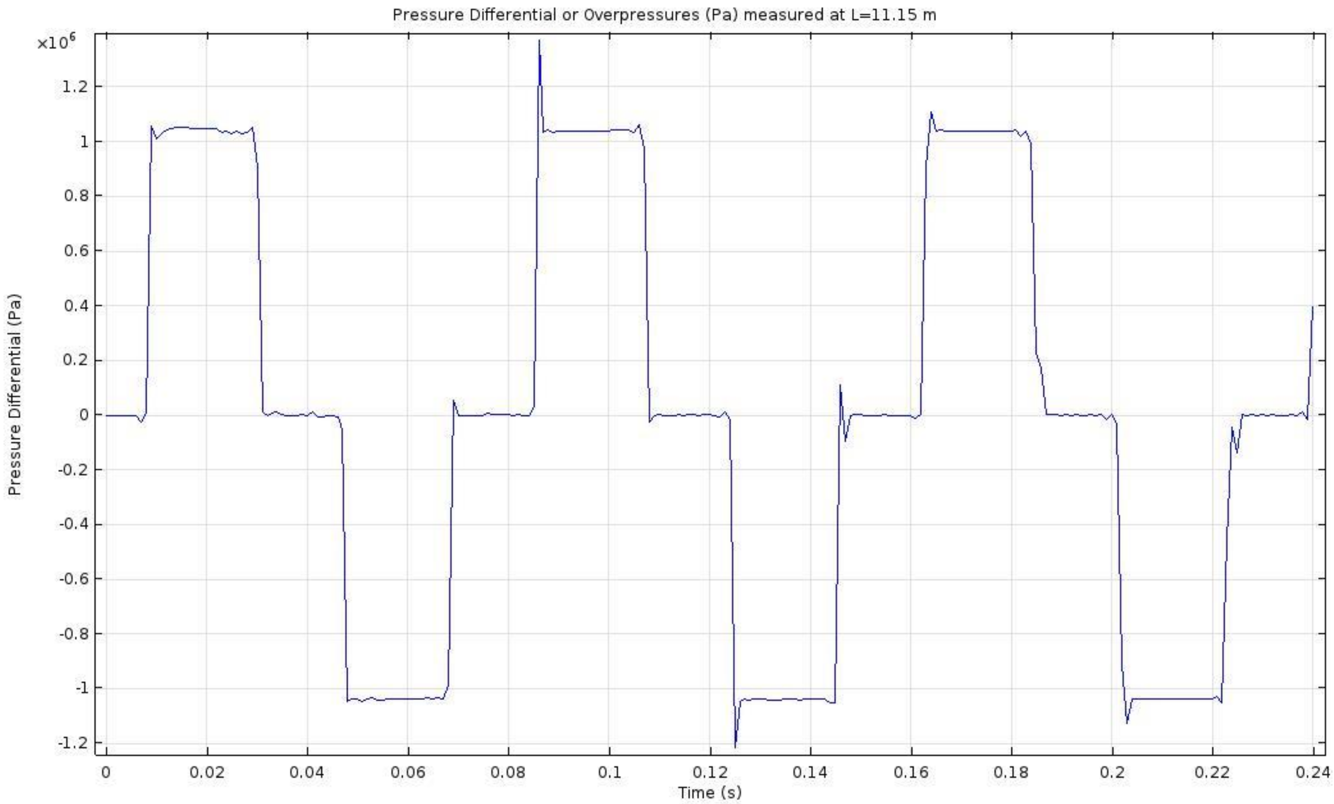


Figure 6: Excess pressure history measured at L = 11.15 m.

A Bench-Unit test performed by Ion Power Group (IPG) confirmed that the Water Hammer Effect can be produced from a low-head water source and converted to electrical energy. A pipe, with a valve attached at the end, is supplied with steady flow of water. The valve is timed to close and reopen at regular intervals, thus creating hydraulic transients. The excess pressure thus produced is directed towards a cylinder housing piston-crank mechanism that in turn produces continuous rotary motion of the output shaft. This shaft is connected to electric generator. As seen in the video, evidence of electrical production is demonstrated by the powering of two different electric loads, in this case a LED lamp and a water electrolyzer to produce hydrogen gas.

https://www.youtube.com/watch?v=iZNXLf_XrUc&feature=youtu.be

The Bench-Unit test provided strong support for the concept that a piston-crank mechanism can be used to effectively harness the repetitive and oscillatory motion of the pressure waves in order to generate electricity. Encouraged by the Bench-Unit test, Ion Power Group team members are confident of our ability to research, develop and refine Shock Wave Engine technology. A US patent application was filed January 28th, 2016.

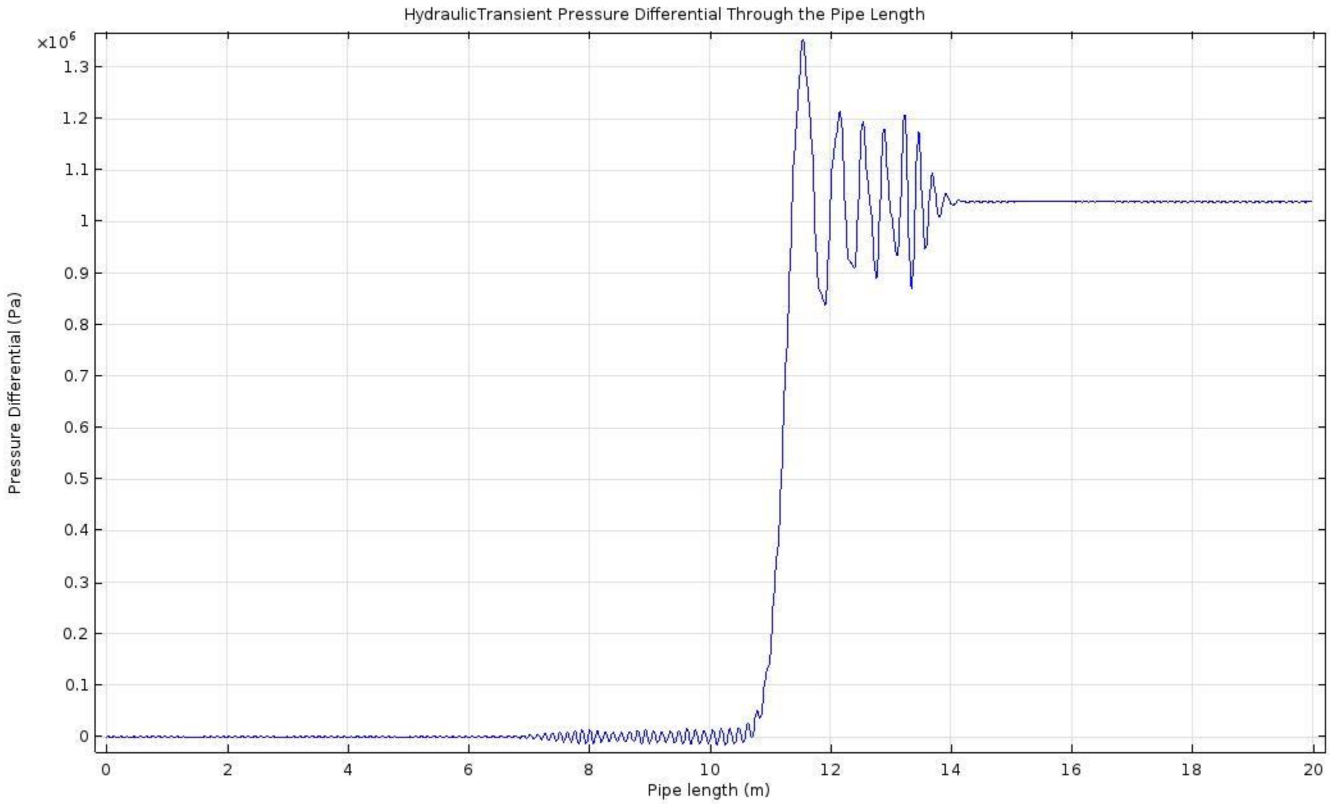


Figure 7: Excess pressure distribution along the pipe for t = 0.24 s.

Significance of the Problem and the Solution

At a time in history when alternative clean energy sources are sought like never before and most of the developing world is deficient in terms of basic electricity, it is quite notable that the low-head water resources in the form of shallow streams, channels, canals and small-to-medium-sized rivers are untapped for energy generation.

High-head water sources such as waterfalls or dammed rivers are historically the choice of preference for hydroelectric power generating systems using standard turbines [4]. However, ideal high-head water sources such as waterfalls are few in number compared to numerous low-head water sources throughout the world. In the US, the top 100 Non-Powered dams with potential to produce 8 GW lie around major rivers in Eastern and Central time zone [4]. They are also capital intensive and significantly impact environment and social issues (danger to freshwater life forms, displacement of population for dam construction etc).

Problem #1: High-head water sources are geographically few in number and do not exist in abundance in many parts of the world.

Problem #2: Although Low-Head water sources are abundant in number and exist in many parts of the world, current turbine technology cannot readily harness low-head water sources for useful electrical production.

In the US, new stream-reach development potential of more than 3 million streams is estimated to be 65.5 GW [5]. A new approach must be developed, specially designed to generate electricity from low-head water sources [5].

The Shock Wave Engine technology successfully addresses these problems by producing significant motive force from low-head water sources, thereby creating wide-spread opportunities for electrical power generation from untapped resources. It can be used by the military, industry, governments, towns, cities, developing countries and villages across the planet.

Hydropower generation from the Shock Wave Engine has significant inherent advantages. Less capital investment; scalable and modularity provide for easy customization; localized control; easy maintenance; environmental and socially responsible; positive impact on public health through water purification; remote offgrid power supply; reduction in use of diesel/kerosene generators; creating a new localized semi-to-skilled job market.

Potential Applications:

Many cities have municipal water storage supplies, currently untapped for electrical generation, but capable of powering multiple Shock Wave Engines for the production of clean renewable electricity for use by the city, citizens and business through "Green Pricing Programs" [6]. These consumers form the "voluntary" or "green power" market in which consumers and institutions voluntarily purchase renewable energy to match all or part of their electricity needs. Voluntary action provides a revenue stream for renewable energy projects and raises consumer awareness of the benefits of renewable energy [6]. It is notable that the Shock Wave Engine design is scalable to fit different environments, small, medium, large and industrial size. Multiple Shock Wave Engines can be 'daisy-chained' to produce additional electricity in suitable locations. Non-obvious sources of low-head fluid flow, such as the liquid portion of a city's sewage plant, may be used to power Shock Wave Engines to produce clean electricity. The Shock Wave Engine design will allow City, State and Federal government(s) to transform many low-head lakes and retaining ponds into electricity producing assets. Villages and towns in developing countries with access to suitable low-head water sources can use the Shock Wave Engine to help power their communities and refrigerate medicines without the need for batteries or other electrical storage devices. Public or communal water supplies can also be utilized to produce electricity by routing the water flow through the Shock Wave Engine on its way to the final destination for consumption.

Equipped with the optional water electrolyzer, the Shock Wave Engine can also output any combination of these products:

a) electricity

b) hydrogen gas

c) oxygen gas

Hydrogen gas produced by the Shock Wave Engine is suitable for powering the new generation of hydrogen powered fuel cell vehicles now emerging in the United States, the U.S. Military and foreign countries. Hydrogen gas can also be used as a clean substitute for highly toxic and polluting Kerosene for cooking in developing countries. The optional electrolyzer can also produce oxygen gas useful to medical facilities and hospitals.

Considering the recent national and international push towards "green" and "clean" economy as a source of economic renewal and potential job creation [7], Shock Wave Engine technology can contribute and provide a significant step in moving towards low-carbon economy.

Approximate Costs:

It is expected that the Shock Wave Engine design will be mass produced in a range of sizes to accommodate a broad global market: portable, home, business, industrial1, industrial2 and industrial3 subject to verification by future market research.

The unit size/weight and the degree of installation effort associated with each location greatly influence the installation costs. The portable Shock Wave Engine unit (small-size and lightweight) is expected to be easily transportable by car, truck, or even peddle bike by two or more people and require minimal installation time/effort and therefore negligible installation cost, possibly <US$100. However, a 300kW Shock Wave Engine, many times larger and heavier, will require a large truck, a crane or forklift and notable manpower thereby having a much greater installation cost, possibly >US$2,000.

Subject to modification as the variables become better defined, it is presently estimated that parts for a 50kW Shock Wave Engine power plant are likely to range between US$1000-US$3000 (+/-30%) in mass production quantity dependent on country of manufacture. These estimates are based on data obtained from retail sources. Mass produced units tend to have cheaper costs and accessories, hence the wide variance in cost.

Routine maintenance is expected to include replacement of the piston 0-ring (~$70 per set), the waste water valve hinge-pin or closure-ball (~$12-22), lubrication upkeep as well as inspections for rust on the unit (variable cost based on region). As an example, for a 50kW unit, annual maintenance parts cost for a properly maintained unit is estimated to be US$100. (+/- 40%). Over a 20 year life cycle US$2,000 (+/- 40%). The assumed useful life is twenty years (20) for production units that receive routine maintenance.

Conclusion

In conclusion, it can be reported with confidence, that Ion Power Group has the capability to quantify the Water Hammer effect for power generation and/or production of energy carriers as required. Also, the multiplicity of applications show that Shock Wave Engine potentially has very high benefit-to-cost ratio.

With appropriate funding and necessary technical and business resources from a world-class technology incubator like CRI, Shock Wave Engine technology has the potential to become an important and significant part of the global “clean” and “renewable” energy economy.

References

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